ORGANOCHLORINE CONTAMINANTS IN SEABIRD EGGS FROM THE PACIFIC COAST OF CANADA, 1971-1986

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Abstract. Eggs were collected from seven seabird species at colonies on the British Columbia coast from 1983 to 1986 and analyzed for organochlorine contaminants. Total PCB levels (wet weight) were highest in double-crested cormorants (*Phalacrocorax auritus*) from the Fraser estuary (2.91 mg kg^{-1}) and the Strait of Georgia (3.79 mg kg^{-1}). Highest DDE levels were in fork-tailed storm-petrels (*Oceanodroma furcata*) from the Queen Charlotte Islands (1.68 mg kg^{-1}). Organochlorine levels were generally lower in eggs from the mid 1980s than in those collected in the early 1970s. Organochlorine levels in Pacific alcids and hydrobatids foraging in offshore locations were compared to those in the same or ecologically similar species from the Canadian Atlantic coast. DDT- and HCH-related compounds were higher in Pacific populations while levels of dieldrin, oxychlordane, and HCB were generally lower. With the exception of β-HCH, levels of all measured organochlorines were lower in cormorants breeding in the Fraser River estuary than in cormorants from the St. Lawrence River estuary on the Atlantic coast.

1. Introduction

The seabirds of the Pacific coast of Canada constitute a rich and diverse natural resource. Vermeer and Sealy (1984) estimated that several million birds of more than 40 species breed or winter along this coast. Little is known of the impact of toxic chemicals on the health of those populations, especially relative to other human impacts such as logging, oil transportation and introduction of mammalian predators.

Ohlendorf *et al.* (1978) reported PCB and DDE levels in pooled samples of Canadian Pacific seabird eggs in 1970. More recently, Henny *et al.* (1982) reported organochlorine levels in Oregon seabirds to the south and Ohlendorf *et al.* (1982) reported residues in Alaskan seabirds to the north. The present study was undertaken to determine current organochlorine levels in representative seabird species from the Pacific coast of Canada to assess possible effects on health of the populations, and provide a general indication of temporal trends in contaminant levels. As seabirds are useful indicators of marine pollution (Boersma, 1986; Gilbertson *et al.*, 1987), a second objective was to assess the organochlorine contamination of the northeast Pacific Ocean marine environment relative to that in the northwest Atlantic Ocean

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(Pearce *et al.*, 1989). This was accomplished by choosing the same or similar indicator species as in the Atlantic coast study.

2. Methods

Criteria for selecting seabird species for monitoring were outlined in Gilbertson *et al.* (1987). The Leach's storm-petrel (*Oceanodroma leucorhoa*) and the fork-tailed storm-petrel (*Oceanodroma furcata*) are offshore planctivores. The Leach's is more a bird of the open ocean while the forktail is more of the continental shelf (Vermeer and Rankin, 1984). The diet of both storm-petrels on the west coast of the Queen Charlotte Islands is similar, consisting mainly of amphipods and myctophid fishes; Leach's also feed on more pelagic species including jellyfish (Vermeer and Devito, 1987). The rhinoceros auklet (*Cerorhinca monocerata*) is a piscivore inhabiting the continental shelf. This alcid feeds on schooling pelagic fish, mostly herring, sandlance, sauries and rockfishes on the British Columbia coast (Vermeer and Westrheim, 1984). In winter it disperses southward (Vermeer, 1979). The double crested cormorant (*Phalacrocorax auritus*) and the pelagic cormorant (*Phalacrocorax pelagicus*) feed on benthic and mid-water schooling fish and are resident along the British Columbia coasts. The glaucous-winged gull (*Larus glaucescens*) is an inshore omnivore. Vermeer (1982) reported that adult gulls in May and June ate mostly human refuse in the Strait of Georgia and gooseneck barnacles (*Polliceps polymerus*) on the west coast, although the chicks in all locations were mainly fed fish. The ancient murrelet (*Synthliboramphus antiquus*) is a planktivore feeding mainly on euphausiids and larval and juvenile fishes on the west coast of the Queen Charlotte Islands (Vermeer *et al.*, 1985), while it in turn is a main item in the diet of the coastal peregrine falcon (*Falco peregrinus*) population.

Seabird eggs were collected in June and July of the years indicated in Table I from locations on the coast of British Columbia shown in Figure 1. With the exception of the eggs of ancient murrelets from 1986 and of pelagic cormorants from 1973, which were salvaged late in the season, fresh eggs were taken from randomly selected nests early in the nesting season. For cormorants and gulls, a single egg was taken from the first clutch, where possible. Eggs were collected by hand and refrigerated temporarily. Egg contents were then removed and placed into chemically cleaned (acetone and hexane) glass jars with a foil-lined lid. Egg contents were then frozen at $-25\,^{\circ}C$ until analyzed.

Samples from 1971 to 1983 were analyzed by the Ontario Research Foundation following procedures described by Reynolds and Cooper (1975). Samples from 1985 and samples of pelagic cormorants collected in 1973 and stored in the CWS National Specimen Bank (Elliott, 1985) were analyzed at the National Wildlife Research Centre using methods described in Peakall *et al.*, (1986). PCBs were estimated as a 1:1 mixture of Aroclors 1254:1260, which was dictated by the procedures employed in earlier analyses. This number is an overestimate of the true sum of PCB congeners, but it is a 'stable' value for comparison of older packed column and newer capillary

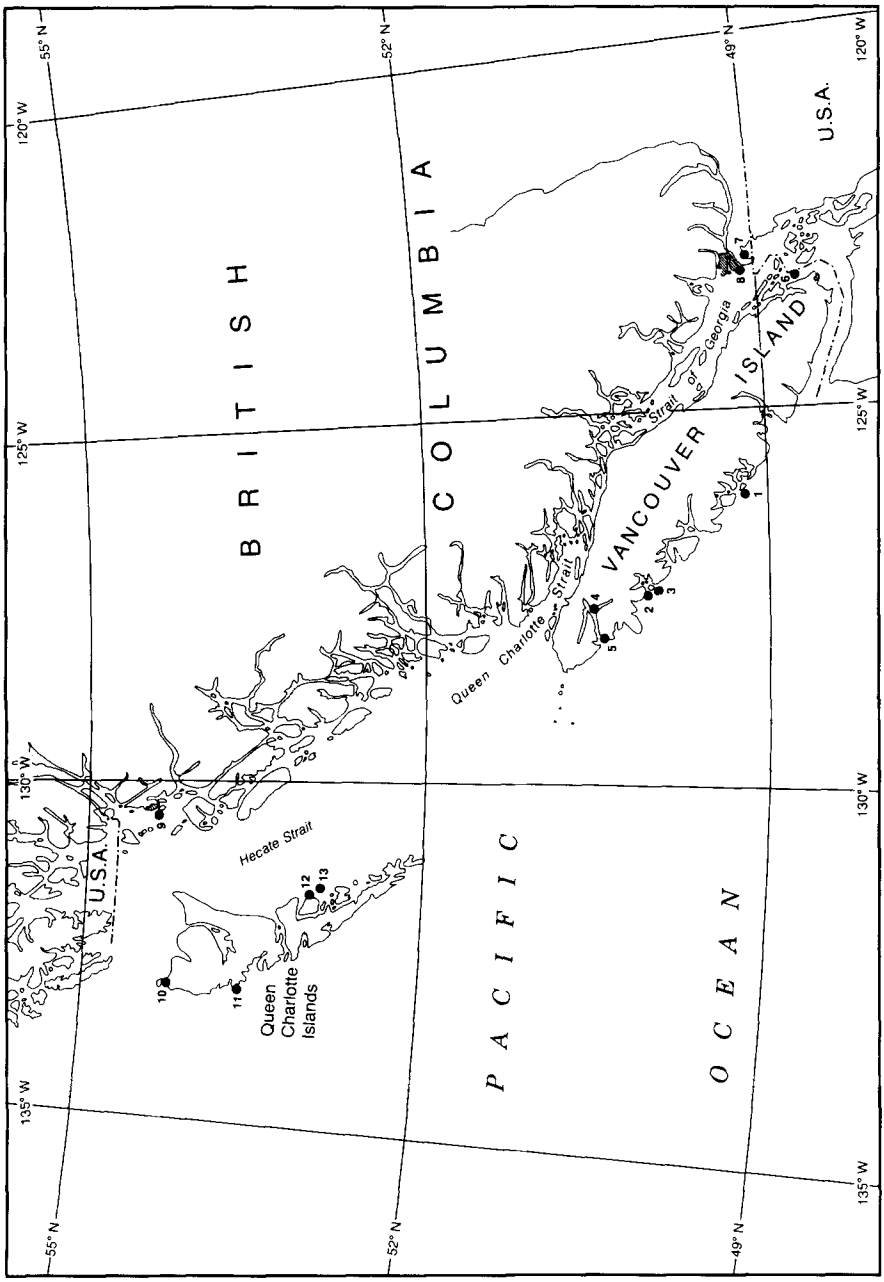

Fig. 1. Geographical locations of seabird egg collections

Map No.	*Site*	*Map No.*	*Site*
1.	Cleland Island	7.	Tsawwassen
2.	Nipple Rocks, Kuyguot	8.	Fraser River estuary
3.	Thornton Island	9.	Lucy Island
4.	Thomas Island	10.	Graham Island
5.	Guillam's Island	11.	Hippa Island
6.	Mandarte Island	12.	Skedans Island
		13.	Reef Island

TABLE I

Organochlorine residue concentrations (mg /kg^{-1} wet weight, geometric mean, 95% confidence interval) in eggs of seabirds collected from Pacific coastal areas of Canada, 1970-1985

Species	Site (Map No.)	N	Year	% H_2O	% Lipid	DDE	Dieldrin	Heptachlor-epoxide	Oxy-chlordane	Mirex	HCB	α-HCH	β-HCH	PCBs**	PCB/DDE
Leach's Storm-petrel	Cleland I. (1)	1	1970[1]	73.4	12.7	2.16	0.045	—	—	—	—	—	—	1.09	0.505
	Graham I. (10)	5	1971	64.8	14.1	1.89 (0.186-19.2)	0.013 (0.006-0.032)	0.010 (0.010-0.010)	—	—	0.053 (0.022-0.128)	—	—	1.71 (0.034-8.78)	0.905
	Hippa I. (11)	6	1983	72.2	12.3	0.647 (0.308-1.36)	0.013 (0.009-0.018)	0.030 (0.012-0.073)	0.018 (0.013-0.024)	0.011 (0.008-0.015)	0.019 (0.018-0.021)	0.017 (0.011-0.027)	0.021 (0.013-0.035)	0.791 (0.561-1.15)	1.22
	Thornton I. (3)	6	1985	82.6	10.9	0.725 (0.372-1.41)	0.008 (0.006-0.012)	0.004 (0.004-0.005)	0.015 (0.011-0.019)	0.014 (0.011-0.018)	0.026 (0.024-0.029)	0.006 (0.004-0.008)	0.014 (0.012-0.017)	0.739 (0.558-0.980)	1.02
	Thomas I. (11)	3	1985	73.1	10.7	0.601 (0.313-1.54)	0.019 (0.001-0.563)	0.004 (0.002-0.007)	0.019 (0.013-0.027)	0.018 (0.007-0.046)	0.029 (0.021-0.040)	0.005 (0.002-0.015)	0.014 (0.007-0.028)	0.860 (0.446-1.66)	1.43
Fork -tailed Storm-petrel	Skedans I. (12)	2*	1970[1]	74.0	19.0	2.62	0.009	—	—	—	0.714	—	—	9.78	3.78
	Hippa I. (11)	3*	1983	70.6	11.3	1.68	0.04	0.03	0.15	0.05	0.064	0.01	0.04	3.89	2.320
Double-crested Cormorant	Mandarte I. (6)	3*	1970[1]	81.4	6.9	4.07	0.040	—	—	—	0.304	—	—	14.0	3.44
		10*	1979	82.7	5.6	0.640	0.050	0.040	0.010	ND	0.030	0.030	ND	5.34	13.8
		5	1985	83.4	4.40	0.501 (0.252-0.998)	0.006 (0.003-0.013)	0.004 (0.003-0.008)	0.014 (0.005-0.037)	ND	0.030 (0.020-0.045)	0.004 (0.002-0.008)	0.008 (0.004-0.016)	3.79 (1.19-12.1)	7.56
	Fraser River Estuary (8)	5	1985	83.7	3.90	0.464 (0.362-0.595)	0.004 (0.003-0.006)	0.003 (0.002-0.003)	0.012 (0.009-0.016)	0.008 (0.005-0.014)	0.014 (0.011-0.018)	0.004 (0.003-0.006)	0.006 (0.005-0.009)	2.92 (1.86-4.59)	6.29
Pelagic Cormorant	Mandarte I. (6)	10*	1970[1]	83.7	5.3	0.819	0.061	—	—	—	0.009	—	—	2.64	3.22
		6	1973	75.2	8.5	1.49 (1.18-1.89)	0.08 (0.060-0.108)	0.021 (0.012-0.038)	0.040 (0.030-0.057)	0.01 (0.01-0.01)	0.031 (0.025-0.038)	0.006 (0.004-0.008)	0.01 (0.009-0.018)	7.83 (6.06-10.1)	5.26
		5	1985	83.7	4.03	0.274 (0.192-0.393)	0.027 (0.022-0.033)	0.008 (0.007-0.010)	0.018 (0.014-0.023)	ND	0.014 (0.010-0.020)	0.006 (0.004-0.008)	0.021 (0.016-0.027)	1.84 (1.25-2.71)	6.71

TABLE I

(continued)

Species	Site (Map No.)	N	Year	% H_2O	% Lipid	DDE	Dieldrin	Heptachlor-epoxide	Oxy-chlordane	Mirex	HCB	α-HCH	β-HCH	PCBs**	PCB/DDE
	Nipple Rocks (6)	6	1985	83.9	4.23	0.270 (0.145-0.501)	0.023 (0.013-0.040)	0.009 (0.006-0.015)	0.014 (0.009-0.023)	ND	0.018 (0.010-0.033)	0.010 (0.009-0.011)	0.020 (0.012-0.032)	0.605 (0.428-0.854)	2.52
Glaucous-winged Gull	Cleland I. (1)	10*	1970[1]	77.0	8.6	1.59	0.014	ND	—	—	0.037	—	—	2.58	1.62
	Thornton I. (3)	8	1983	76.2	8.01	0.570 (0.388-0.838)	0.014 (0.010-0.019)	0.033 (0.021-0.051)	0.03 (0.02-0.04)	0.01 (0.001-0.098)	0.011 (0.008-0.014)	0.002 (0.001-0.004)	0.01 (0.01-0.01)	0.986 (0.693-1.40)	1.73
	Guillam's I. (5)	8	1983	76.3	9.15	0.52	0.01	0.03	0.02	0.005	0.015	ND	0.005	0.78	1.50
	Mandarte I. (6)	10*	1970[1]	83.7	6.0	0.75	0.046	0.021	—	—	0.009	—	—	2.49	3.32
	Tsawwassen (7)	10	1977	75.6	9.4	0.483 (0.367-0.635)	0.009 (0.007-0.011)	0.014 (0.011-0.018)	0.001 (0.001-0.001)	ND	0.023 (0.018-0.030)	ND	0.007 (0.005-0.009)	1.78 (1.32-2.41)	3.69
Rhinoceros Auklet	Lucy I. (9)	10*	1970[1]	71.7	15.0	2.84					0.029			2.01	0.708
		6	1985	67.1	14.0	0.631 (0.281-1.42)	0.012 (0.008-0.017)	0.009 (0.007-0.011)	0.023 (0.016-0.033)	0.003 (0.002-0.004)	0.034 (0.026-0.046)	0.002 (0.002-0.003)	0.016 (0.013-0.022)	0.607 (0.373-0.986)	0.96
Ancient Murrelet	Graham I. (10)	3	1968	65.2	15.3	0.871 (0.377-2.01)	0.008 (0.004-0.014)	0.031 (0.003-0.350)	—	—	—	—	—	—	
	Reef I. (13)	6	1986	57.9	23.5	0.685 (0.315-1.49)	0.0043 (0.003-0.006)	0.0085 (0.005-0.013)	0.013 (0.008-0.021)	0.005	0.057 (0.036-0.088)	0.005 (0.004-0.006)	0.179 (0.063-0.514)	1.11 (0.739-1.68)	1.62

* Pooled sample.

** PCBs as a |:| mixture of Aroclor 1254 to 1260 - see Methods

(—) not analyzed

(ND) not detected

[1] From Ohlendorf *et al.* (1978).

column analytical methods (Turle *et al.*, 1988). As egg moisture content varies less than lipid content during development (Peakall and Gilman, 1979), we expressed residue values on a wet weight basis. We compared organochlorine levels in Mandarte Island pelagic cormorant eggs in 1985 to levels in eggs collected in 1973 at the same location by analysis of 1973 eggs stored in the Canadian Wildlife Service specimen bank. Organochlorine residues in bird eggs remain stable when stored at $< -20\,°C$ (Elliott, 1985; Norstrom and Won, 1985). However, the pelagic cormorant eggs from 1973 contained significantly less moisture and more lipid than the eggs collected in 1985 (Table I), possibly due to dehydration during storage and/or because those eggs were collected late in the breeding season. Therefore, for statistical analysis of changes in residue levels with time, we adjusted the organochlorine levels to the same mean wet weight as the 1985 fresh eggs.

Ohlendorf *et al.* (1982) has shown that organochlorine residues generally exhibit a log normal distribution; therefore, we transformed our date to common logarithms for statistical determinations. The significance of differences in residue levels between samples was determined by t-tests.

3. Results

The main organochlorine contaminants found in eggs were PCBs, generally followed by DDE (Table I). PCBs were highest in eggs of fork-tailed storm-petrels from off the east coast of the Queen Charlottes (Site 11, Figure 1), and in double-crested and pelagic cormorant eggs from the Fraser River estuary (Site 8) and the Strait of Georgia (Site 6). Since 1980, the highest level of DDE (1.49 mg kg^{-1}) was detected in an ancient murrelet egg from Reef Island (Site 13) on the east coast of the Queen Charlotte Islands. A pool of three fork-tailed storm petrel eggs, from Hippa Island (Site 11), on the west coast of the Queen Charlotte Islands, contained 1.68 mg kg^{-1} DDE.

Dieldrin, heptachlor epoxide, oxychlordane and HCB levels were present in eggs of all species sampled, between 0.01 and 0.1 mg kg^{-1}. Residues of α-HCH, β-HCH and mirex were present in most seabird eggs at levels less than 0.01 mg kg^{-1}. The β-HCH isomer was generally higher than α-HCH. Ancient Murrelet eggs collected from the east coast of the Queen Charlottes in 1986 (Site 13) contained the highest levels of β-HCH, up to 0.67 mg kg^{-1}, wet weight. Highest mirex levels were in fork-tailed storm-petrel eggs from Hippa Island (Site 11).

There was no clear-cut pattern of geographical differences in residue levels, except that PCB levels were higher in eggs of species from the Strait of Georgia area. Eggs of pelagic cormorants from Mandarte Island (Site 6) had comparable levels of organochlorines to eggs from Nipple Rocks (Site 2) on the west coast of Vancouver Island, except that PCB levels were about three times as high at Mandarte Island. Organochlorine levels in Leach's strom-petrel eggs were very similar among the Queen Charlotte Islands (Site 11) in 1983 and two colonies on western Vancouver Island (Sites 3 and 4, about 600 km south) in 1985.

There was no consistent pattern of temporal changes in residue levels. In the Strait of Georgia (Mandarte Island, Site 6) between 1973 and 1985, all measured contaminants in pelagic cormorant eggs decreased significantly ($p < 0.05$) with the exceptions of HCB and HCH isomers. In double-crested cormorant eggs from Mandarte Island (Site 6) between 1970 and in 1979, PCBs dropped four-fold, and DDE and HCB, eight- to ten-fold; little further change occurred between 1979 and 1985. Dieldrin levels increased marginally between 1970 and 1979 but decreased significantly ($p < 0.05$) between 1979 and 1985. Heptachlor epoxide and HCH were not measured in 1970 but decreased from 1979 to 1985, while oxychlordane increased slightly.

Further north at Lucy Island (Site 9) in the Hecate Strait, between 1970 and 1985, PCB and DDE levels in rhinoceros auklet eggs decreased three- to five-fold while HCB levels remained constant.

In other areas, none of the species was sampled at the same sites in the 1980s as in the 1970s, nevertheless, some general comparisons are possible. On the west coast of Vancouver-Island, in Leach's storm-petrels from Thornton and Thomas Islands (Sites 3 and 4), DDE and dieldrin were lower in 1983-85 than in 1970 at Cleland Island (Site 1), although PCBs remained about the same. In eggs of glaucous-winged gulls collected from Thornton and Guillam's islands (Sites 3 and 5), DDE, PCBs and HCB were about 60% lower in 1983 than in 1970 at Cleland Island (Site 1), although significance could not be established due to pooled analyses.

In fork-tailed storm-petrels from the Queen Charlotte Islands (Sites 11 and 12) between 1970 and 1983, DDE, PCBs and HCB appeared to decrease while dieldrin increased. In Leach's storm-petrels from the Queen Charlotte Islands (Sites 10 and 11), DDE, HCB and PCBs, but not dieldrin and heptachlor epoxide, were lower in 1983 than in 1970. Dieldrin and heptachlor epoxide levels were somewhat lower and DDE levels were about the same in eggs of ancient murrelets collected in the Queen Charlotte Islands (Sites 10 and 13) in 1986 compared to 1968 (Ohlendorf *et al.*, 1978; Table I.).

4. Discussion

Organochlorine levels in Canadian Pacific coast seabirds were generally low compared to levels in similar species from California (Gress *et al.*, 1973), the Atlantic coast of Canada (Pearce *et al.*, 1989) or the Geat Lakes (Weseloh *et al.*, 1983) and were comparable to those in Oregon (Henny *et al.*, 1982).

Judging by levels in seabirds, the Strait of Georgia is more contaminated with organochlorines relative to other locations in the study area. Double-crested cormorant eggs from Mandarte Island in the Strait of Georgia contained similar levels of most organochlorines but slightly higher levels of PCBs than eggs from a colony in the Fraser Estuary. Albright *et al.*, (1975) reported that PCBs were the dominant organochlorine contaminant in fish, crabs and shellfish from the Fraser Estuary in 1972–73. They did not detect any organochlorines in fish and shellfish samples collected in the Strait of Georgia and areas distant from the influence of the Fraser

River. However, we found that pooled samples of potential cormorant prey such as stickleback (*Gasterosteus aculeatus*) and perch (*Cymatogaster aggregata*), collected near Gabriola Island (49° N 123° W) on the south-eastern shore of Vancouver Island in Georgia Strait contained 25 μg kg^{-1} total PCBs compared to 45 μg kg^{-1} in the same species from Iona Island (49° N 123° W) in the Fraser River estuary (Norstrom, unpub. data).

4.1. Temporal trends

Based on the data presented here, levels of DDE, PCBs, dieldrin and heptachlor epoxide have declined in seabird eggs, particularly in those birds breeding in the Strait of Georgia and the Fraser estuary, closer to point sources of pollutants. Whitehead (1989) reported significant declines in levels of those same four chemicals in great blue herons (*Ardea herodias*) between 1977 and 1987 at a colony on the Strait of Georgia. These declines followed severe restrictions on the applications of DDT, dieldrin, and heptachlor by legislative action in both Canada and the United States during the 1970s. PCB sales were restricted voluntarily by industry in 1971 and were further restricted by legislation in both countries in 1977. The declines in DDE levels during the 1970s are similar to those observed in other relatively contaminated areas of North America (Addison *et al.*, 1984; Elliott *et al.*, 1988a; Mineau *et al.*, 1984; Pearce *et al.*, 1989).

We observed no significant changes in oxychlordane or HCB in marine bird eggs from the Strait of Georgia. Whitehead (1989) found that those chemicals had not decreased in great blue herons in the same area. Increased use of chlordane during the 1970s in North America following the restrictions on DDT may account for the lack of declines in levels, also reported in other studies (Elliott *et al.*, 1988a, 1988b). The significant increase in β-HCH levels in pelagic cormorant eggs between 1973 and 1985 suggests that uses of the pesticide, technical BHC, increased during this period. The increase in use was probably in Asia, since the HCH pesticide used in most developed countries is Lindane, which does not contain the β-HCH isomer (Tanabe *et al.*, 1982a).

Information on historical use of organochlorines is difficult to obtain. About 90 000 kg of DDT and some endosulfan and lindane were used for forest insect control in British Columbia from the mid-1940s to the mid-1960s (Nigam, 1975). Pesticide and industrial chemical usage was probably high in the lower mainland of British Columbia and in the developed areas of the Pacific Northwest in the U.S.A. Large quantities of DDT were used in Oregon until 1974 (Henny, 1977) and heptachlor was used in Oregon as recently as 1981 (Henny *et al.*, 1983). Significant amounts of organochlorines, including dicofol, chlordane, toxaphene and lindane were in recent use in California (Ohlendorf and Miller, 1984).

In birds breeding in remote locations, the pattern of organochlorine changes with time is more complex. Levels of DDE and PCBs and other compounds have not changed significantly or have increased in some species since 1968–1970. Pearce *et al.* (1989) reported slower rates of decline in organochlorine levels in seabird eggs

from remote locations. This pattern probably reflects global atmospheric dispersion of PCBs and organochlorines from both past and ongoing release. Murphy *et al.* (1985) estimated that 900 000 kg of PCBs cycle through the United States atmosphere each year, of which less than 0.01% is from new emissions. PCB levels in areas remote from major pollution sources are unlikely to decline in the near future because of the quantities still in use and re-emission and cycling of quantities already released (Stout 1986, Tanabe, 1988).

4.2. Comparison of organochlorines in pacific and atlantic seabirds

Figure 2 compares organochlorine levels in Pacific seabird populations to those in eggs of Atlantic populations (Pearce *et al.*, 1989), sampled at about the same time. The Atlantic puffin (*Fratercula arctica*) was treated as an approximate ecological equivalent to the rhinoceros auklet. It feeds mainly on small schooling fish such as capelin and sandlance and inhabits the continental shelf (Noble and Elliott, 1986).

PCB levels in alcid and storm-petrel eggs from colonies remote from industrial sources on both coasts suggest that PCB levels are higher in the marine food chains of the Atlantic than the Pacific coasts. This is in agreement with measurements in fish and marine mammals (Tanabe and Tatsukawa, 1986). DDE levels in Pacific alcid

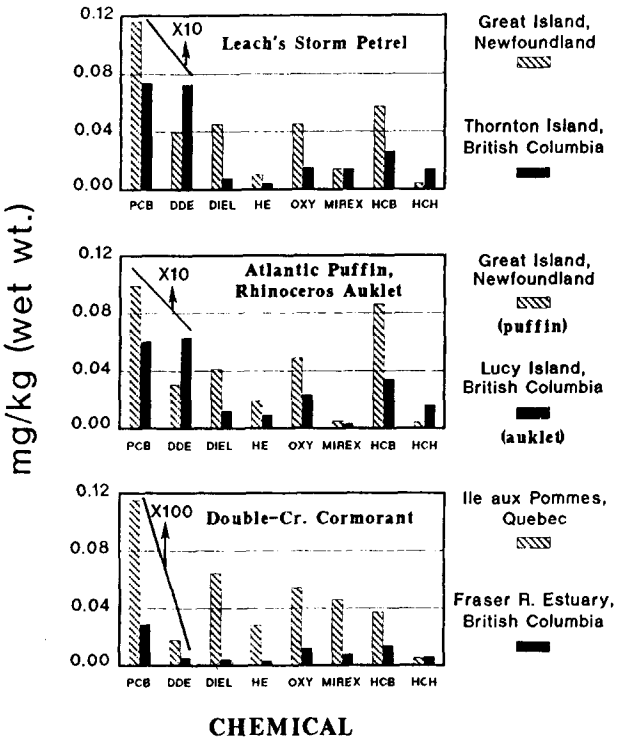

Fig. 2. Comparison of organochlorine levels in eggs of the same, or ecologically similar, seabird species in 1984/1985 on the Canadian Pacific coasts (this study) and Atlantic coast (Pearce *et al.*, 1989).

and petrel eggs were approximately two-fold higher than those in 'offshore' Atlantic samples (from Great Island, Newfoundland, 47°11′ N 52°49′ W). DDT-related compounds were reported to be higher in air and water samples from the north Pacific than from the north Atlantic (Norstrom and Muir, 1988; Tanabe *et al.*, 1982a; Bidleman *et al.*, 1981). Although DDT is still heavily used in Central America, levels of DDT compounds in air from the Gulf of Mexico and the Caribbean (Chang *et al.*, 1985), were lower than north-west Pacific air samples, suggesting substantial input of DDT from Asia. On the Atlantic coast only Newfoundland seabird eggs contained less DDE than Pacific coast samples. Seabird eggs from the Bay of Fundy and Gulf of St. Lawrence River had higher DDE levels, showing the influence of local use of DDT (Pearce *et al.*, 1989).

Like DDT, HCH isomers were higher in alcid and storm-petrel eggs from the Pacific than the Atlantic coast, whereas levels of dieldrin, heptachlor epoxide, oxychlordane and HCB were consistently higher in Atlantic alcid and storm-petrel eggs. Prevailing winds on both coasts are mainly from the west, northwest or southwest. Thus, atmospherically borne contaminants on the Pacific coast are expected to have a mainly Asian origin. The relatively higher levels of HCH and DDT in Pacific coast birds is an indication of the heavy use of these chemicals in Asia (Tanabe *et al.*, 1982a). Asian countries (except Japan) are probably a less important source of the other organochlorines. Furthermore, the Pacific coast air masses have passed over thousands of km of open ocean from Asian sources, and scavenging of contaminants to the ocean surface probably reduces the atmospheric burden of the other organochlorines considerably before reaching the North American coast (Tanabe *et al.*, 1982b). The Atlantic coast receives airborne contaminants directly from the main industrial and agricultural areas of the U.S.A. and Canada, which is undoubtedly the main factor in the higher levels of PCBs, chlordane-related compounds and HCB in Atlantic coast seabirds. Most of the more water soluble contaminants of North American origin, such as dieldrin, are probably scavenged in the western Atlantic ocean (Norstrom and Muir, 1988) which probably accounts for the large differences in dieldrin levels in Atlantic and Pacific storm-petrels.

In 1970, HCB levels in double-crested cormorants from Mandarte Island in the Strait of Georgia were much higher than in cormorants from east coast colonies in the early 1970s. This probably indicates a local industrial source which decreased significantly during the 1970s. HCB levels in seabird eggs have generally remained stable or increased on the east coast, suggesting that global distribution of HCB is more uniform than that of most organochlorines. HCB was found to be the most evenly distributed of organochlorines in Polar Bears in the Canadian arctic (Norstrom *et al.*, 1988). Mirex levels were similar in eggs on both coasts.

Double-crested cormorant eggs from Ile aux Pommes, Quebec (48°06′ N 69°19′ W) in the St. Lawrence River estuary contained about four times as much PCB and DDE as eggs from the Fraser River estuary. Levels of other contaminants were also much higher in eggs from Ile aux Pommes. This may be the result of greater pollution from organochlorine chemicals in lakes and rivers in the St. Lawrence

River/Great Lakes drainage basin (especially mirex in Lake Ontario, Norstrom *et al.*, 1980) or atmospheric transport and local deposition of contaminants from the North American mainland including re-emission from the Great Lakes system (Eisenreich *et al.*, 1981; Bidleman *et al.*, 1981). Only HCH isomers were lower in St. Lawrence estuary cormorants, which is consistent with the pattern observed in the other species.

4.3. Toxicological implications

Pearce *et al.* (1979) calculated a critical value of 12 mg kg^{-1} DDE, wet weight, to cause 20% eggshell thinning in Leach's storm-petrel. Levels of all contaminants in strom-petrel eggs from British Columbia were well below concentrations known to reduce reproductive rates or survival in related species elsewhere (Coulter and Risebrough, 1973; Pearce *et al.*, 1979). A single fork-tailed storm-petrel egg from Oregon in 1979 (Henny *et al.*, 1982) contained significantly more DDE (12 mg kg^{-1}) but not PCBs than any of our samples, probably enough to cause some eggshell thinning. Although both storm-petrel species appear to be abundant, little quantitative information is available on the population status of either species in British Columbia. Organochlorine levels in the pool of three fork-tailed storm-petrel eggs from Hippa Island in 1983 were considerably higher than in Leach's storm petrel eggs from the same island location. Foraging by Leach's on plankton further offshore may account for lower levels in this species. The plankton diet of both storm-petrels would expose them to the more volatile organochlorines, such as toxaphene and HCH isomers which are deposited from the atmosphere onto the oily surface layer of the ocean (Norstrom, 1988; Seba and Corcoran, 1969). Occasional carrion-feeding by fork-tailed storm-petrels (Gill, 1977) could result in elevated organochlorine intake, as the carcasses of marine mammals and large commercial fish often contain high levels of lipid-soluble contaminants (Addison *et al.*, 1984; Musial and Uthe, 1983).

DDE levels in double-crested cormorants from Mandarte Island in 1970 were 4.07 mg kg^{-1} (Ohlendorf *et al.*, 1978). Cormorants, like pelicans, are relatively sensitive to the effects of DDE on egg shell thickness and subsequent hatching failure (Cooke, 1973; Hickey and Anderson, 1968). Weseloh *et al.* (1983) reporting on Great Lakes cormorant populations and Pearce *et al.* (1979) on the Atlantic coast cormorants found that 10 mg kg^{-1} DDE was associated with 20% shell thinning. Gress *et al.* (1973) reported almost complete reproductive failure in a California cormorant population with DDE egg levels of 32 mg kg^{-1}. Although some shell thinning may have occurred at double-crested cormorant colonies from British Columbia in the 1960s and 1970s, populations have increased markedly over the past twenty years (Vermeer and Sealy, 1984).

With the exception of dieldrin and β-HCH, organochlorine levels in pelagic cormorant eggs from Mandarte Island were generally lower than in eggs from the closely related double-crested cormorant from the same location, and not likely to be of concern. Considerable similarities in the diet of the two species during the

breeding season have been reported with the pelagic cormorant perhaps eating more zooplankton and pelagic fish than the double-crested (Robertson, 1974; Palmer, 1962). Although neither species is migratory, wintering sites and therefore diets may be different.

Recent organochlorine levels in glaucous-winged gull eggs from British Columbia are similar to concentrations in gulls from various locations in Alaska, where glaucous-winged gulls were feeding largely on seabird eggs and nestlings. The levels of organochlorines in eggs of glaucous-winged gulls reported here and in Ohlendorf *et al.* (1978) are not high enough to be associated with reproductive effects. Calambokidis *et al.* (1985) reported 10% eggshell thinning, enlarged livers and hepatic lesions in glaucous-winged Gulls from Puget Sound (just south of Vancouver Island) in 1982, but reproductive rates were normal. *Larus* gulls are able to tolerate higher contaminants levels than most seabirds. For example, Keith and Gruchy (1972) calculated a critical value of 162 mg kg^{-1}DDE to cause 20% eggshell thinning in the Herring gull (*L. argentatus*). Since glaucous-winged Gulls are currently increasing in B.C. (Vermeer and Devito, *in press*), toxic chemicals are apparently not affecting the population.

It seems unlikely that the organochlorine levels found in eggs of the rhinoceros auklet would have any significant toxic effect, based on toxicity studies elsewhere (Miller *et al.*, 1976; Harris and Osborn, 1981). However, as in puffins from the eastern Atlantic, it is possible that organochlorines could reach dangerous levels in starving chicks during years of low food availability (Noble and Elliott, 1986). Vermeer (1980) reported occasional reproductive failure in this species at Triangle Island (50°52′ N, 129°5′ W), probably due to a shortage of preferred prey.

Organochlorine levels in eggs of ancient murrelets collected from Reef Islands in 1986, were among the highest recently recorded for Pacific coast seabirds. HCH isomers were paticularly high, though still well below levels associated with toxic effects in other alcids (Gress *et al.*, 1971; Miller *et al.*, 1976). As discussed above, the comparatively high levels of β-HCH in murrelet eggs probably resulted from long range transport of this compound from Asia Organochlorine pesticides were suggested as the cause of declining numbers of seabirds on Langara Island (54°15′ N, 132°58′ W) in the early 1970's (Nelson and Myres, 1976). This seems unlikely, considering that DDE and other organochlorines detected in eggs averaged less than 1.0 mg kg^{-1}, wet weight.

Since ancient murrelets constitute the main prey of peregrine falcons (*Falco peregrinus*) and bald eagles (*Haliaetus leucocephalus*) in the Queen Charlottes (Nelson and Myres, 1976; Vermeer *et al.*, 1984), the chemical burden in these prey species may affect productivity of peregrines and bald eagles. Enderson *et al.*, (1982) suggested that DDE greater than 1.0 mg kg^{-1} in prey represented a significant threat to reproductive success of peregrine falcons in the Rocky Mountain area of the United States.

5. Summary and Conclusions

Organochlorine levels in the marine ecosystem of the Canadian Pacific coast, as indicated by levels in seabird eggs, have generally declined since the early 1970s. There is no indication that the current organochlorine burden of west coast Canadian seabirds is affecting their health. However, rhinoceros auklet chicks, representative of the alcid family, may be at risk of serious organochlorine poisoning from contaminant mobilization during years of food shortage.

Eggs of seabirds foraging in offshore locations in British Columbia have higher levels of DDE and HCH and lower levels of PCBs, dieldrin, oxychlordane and HCB than eggs of the same or ecologically similar Atlantic coast seabirds. Eggs of seabirds from inshore locations, such as the Fraser Estuary and the Strait of Georgia are generally less contaminated than seabird eggs from colonies in the St. Lawrence River estuary.

We plan to continue a modest monitoring scheme to track organochlorines in Pacific seabird eggs and to expand the program to include heavy metal and petroleum hydrocarbon contamination.

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