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Organochlorines in Sea Otters and Bald Eagles from the Aleutian Archipelago

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Organochlorine compounds (OCs) are known hazards to many life forms (Blus *et al.*, 1971; Peakall *et al.*, 1975; Weimeyer *et al.*, 1975, 1984; Henny *et al.*, 1977; Blus, 1982; Enderson *et al.*, 1982; Grier, 1982). These hazards are acute in coastal marine habitats where many industrial and agricultural wastes accumulate (MacGregor, 1974). The marine birds and mammals that feed in these productive coastal waters are particularly vulnerable because of their high trophic status and the tendency for OCs to bioaccumulate (Connel, 1990). Although elevated OC levels have been documented in numerous marine birds and mammals (Risebrough *et al.*, 1968; Reijnders, 1980; Addison, 1989), including some in remote regions (Muir *et al.*, 1988; Norstrom and Muir, 1994), the sources of these compounds are often obscured by long-distance movements that typify such species.

Sea otters (*Enhydra lutris*) and their principal prey (benthic invertebrates and coastal fishes) are comparatively sedentary, thus limiting the possibility of contaminant uptake to local environments. These characteristics, coupled with the existence of well-delineated otter populations in both urban/industrial and remote areas, provide an unusual opportunity to examine large-scale spatial variation in contaminant levels for a marine mammal. OC concentrations in sea otters are reported here from central California, south-east Alaska, and the western Aleutian islands (Fig. 1). This comparison was made because of inter-regional differences in the growth rates and reproductive success of sea otters, and in their exposure to OCs. The population growth rate of sea otters is ~5% yr^{-1} in California, compared with 17–20% yr^{-1} in south-east Alaska and the Aleutian Islands (Estes, 1990). Much of this difference can be attributed to high pre-weaning mortality in California (Riedman *et al.*, 1994). The coastal zone of central California is densely populated by humans, highly industrialized, and high OC concentrations have been measured in numerous species from the region. OC levels in south-east Alaska and the Aleutian Islands are more poorly known. However, because these regions are so much less populated and industrialized than central California, and are also 'upstream' from convective transport by the predominantly southward-flowing California Current, OC exposure was expected to be less in Alaska than in California. However, unexpectedly high OC levels were found at Adak Island in the west-central Aleutians (see below). We wished to determine if these high OC levels were localized near Adak or were more widely occurring. Because sea otter carcasses were not readily available from elsewhere in the Aleutian Islands, OC concentrations were also measured in unhatched bald eagle (*Haliaetus leucocephalus*) eggs from Adak, and from three other islands at varying distances from Adak. Bald eagles were chosen as a surrogate species because they breed throughout most of the Aleutian Islands, where they are non-migratory and feed predominantly in coastal marine habitats (Sherrod, 1975). Elsewhere in North America, bald eagles accumulate DDTs and PCBs to levels that reduce reproductive success (Grier, 1982; Weimeyer *et al.*, 1984; Anthony *et al.*, 1993).

PCBs, PCDDs and PCDFs in sea otters were analysed using the methods of Jarman *et al.* (1993). Total PCBs as quantified herein is the sum of 48 congeners; the standard used was a mixture developed in our laboratories (see Jarman *et al.*, 1993 for details). Liver samples from 23 sea otters were obtained in 1991–1992 from beached carcasses or freshly killed specimens in central California ($n=9$), south-east Alaska ($n=7$), and the Aleutian Islands ($n=7$). Tissues were prepared and analysed using standard techniques. Briefly, the

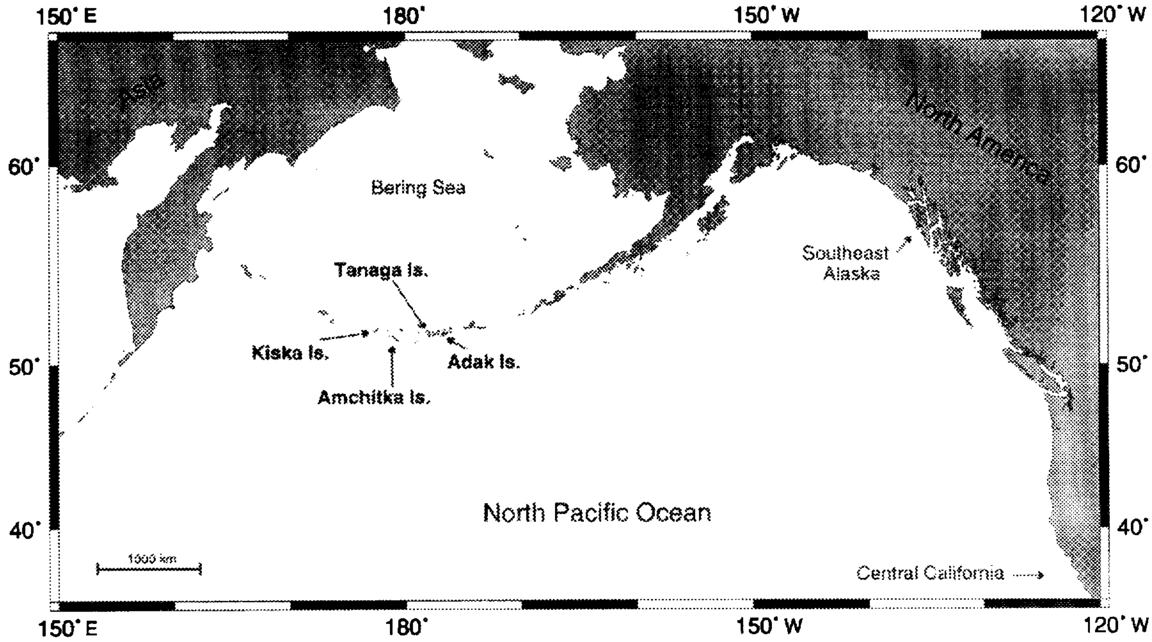

Fig. 1 Map of the North Pacific Ocean showing sites (bold arrows) from which materials were collected.

samples were spiked with extraction surrogates, extracted with DCM:hexane (1:1) and cleaned up using Florisil. Extracts were analysed using dual column GC/ECD (gas chromatography with electron capture; DB-5 and DB-17 columns). A subsample of livers from each otter population was analysed by high resolution gas chromatography/mass spectrometry. Eighteen of the 23 animals were males, and 17 were judged to be adults on the basis of body size and tooth wear. There was no apparent relationship between OC concentration and age, sex, or whether the samples were from beached carcasses or freshly killed specimens, for any of the three regions. Therefore, all individuals within a particular region have been combined in the subsequent analyses.

Unhatched eggs were collected from 25 bald eagle nests during the summers of 1993 and 1994 from Adak ($n=10$), Tanaga ($n=5$), Amchitka ($n=4$), and Kiska ($n=6$) islands in the west-central Aleutian Islands, and were refrigerated until they could be processed. Egg contents were frozen and shipped to Hazelton Laboratories, Madison, Wisconsin for analysis. Sample preparation and the analysis of OCs were conducted according to Weimeyer *et al.* (1984). PCBs were quantified as Aroclor 1260. Analytical accuracy and precision were assessed through spiked sample recovery and duplicate analysis for 10% of the egg samples. For the detected organic compounds, spiked recoveries averaged 95.4% and the relative percentage difference of duplicate samples averaged 14.3%.

PCBs and DDTs were the principal OCs in sea otter livers (Table 1). ΣPCB and ΣDDT (*p,p*′-DDE, *p,p*′-DDD, *p,p*′-DDT) concentrations varied significantly among regions (1-way ANOVA; $p<0.01$ for each contaminant). ΣPCB concentrations in south-east Alaska (mean of 8 μg kg^{-1} wet weight) were among the lowest reported values for a marine or carnivorous mammal (Tatsukawa *et al.*, 1994; Lieberg-Clark *et al.*, 1995), indicating a largely uncontaminated population. Average ΣPCB concentrations were significantly higher than this in both California (23-fold) and the Aleutian Islands (38-fold; Student-Newman-Keuls' [SNK] tests for specific regional comparisons were all significant at $p<0.01$ except California vs Aleutian Islands [$p=0.341$]). Similarly, only trace ΣDDT concentrations (mean of 1 μg kg^{-1} wet weight) occurred in otter livers from south-east Alaska, whereas average concentrations were significantly higher in both California (846-fold) and the Aleutian Islands (36-fold; SNK tests for specific regional comparisons were all significant at $p<0.01$). The DDE/DDT ratio for the Aleutian Islands (25.97) was almost two orders of magnitude less than that for central California (2500), suggesting that DDTs in the

TABLE 1

Average ΣPCB and ΣDDT concentrations (μg kg^{-1} wet weight) in sea otter livers from California, south-east Alaska, and the Aleutian Islands. 'Other compounds' include the sum of total chlordane, PCDDs, PCDFs, HCB, dieldrin and tris (4-chlorophenyl)-methanol.

	Compound		
Region	ΣPCBs	ΣDDT	Other
Aleutian Islands	309	36	22
South-east Alaska	8	1	5
California	185	846	43

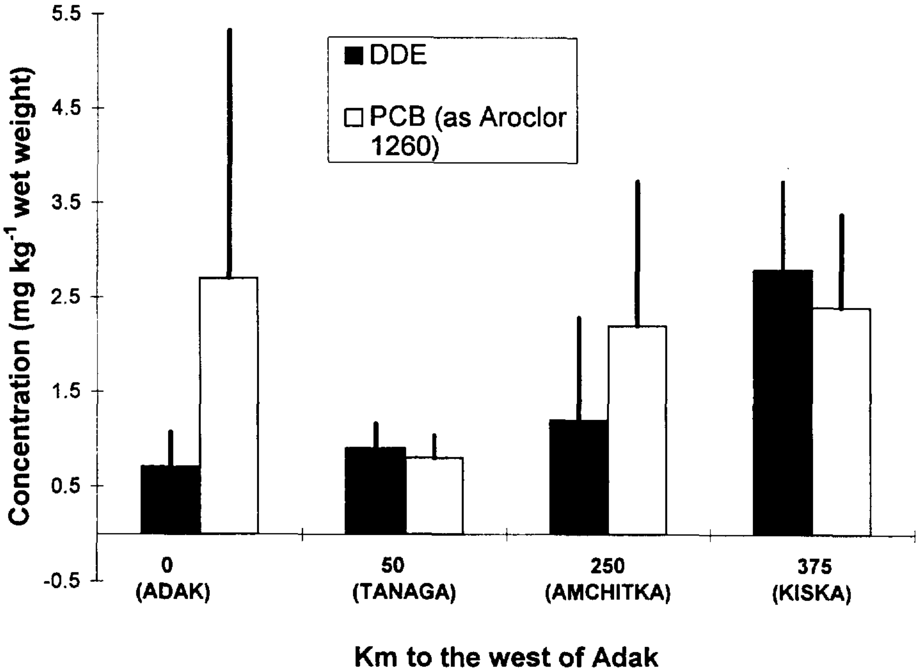

Fig. 2 DDE and PCB (Aroclor 1260) concentrations in bald eagle eggs from Adak ($n = 10$), Amchitka ($n = 4$), Kiska ($n = 6$) and Tanaga ($n = 5$) islands. Bars over histograms are +1 standard error.

Aleutians are from a currently active or atmospheric source (Weimeyer *et al.*, 1984; Iwata *et al.*, 1994).

Bald eagle eggs from Adak, Tanaga, Amchitka and Kiska islands also contained elevated DDE and PCB levels (Fig. 2), thus establishing the widespread occurrence of these compounds in the Aleutian archipelago. DDT levels were below the lower detection limit (0.01 mg kg^{-1}) for 14 of the 25 eggs, so DDE/DDT ratios could not be computed. Levels of DDT in the remaining eggs ranged from 0.01 to 0.06 mg kg^{-1} wet weight. Aroclor 1260 was elevated in all eggs (0.41–10.0 mg kg^{-1} wet weight). The carcass of 1 nestling bald eagle from Kiska Island had detectable levels of DDE (0.44 mg kg^{-1}) and PCBs (0.28 mg kg^{-1}), indicating exposure to these compounds early in life. There are several noteworthy patterns in egg contaminant levels among the islands and between the classes of compounds. DDE levels increased from east-to-west, being highest at Kiska and lowest at Adak. In contrast, ΣPCB levels were roughly similar at Adak, Amchitka and Kiska islands, but substantially lower at Tanaga Island.

The 'clean' OC profiles of sea otter livers from southeast Alaska establish that levels measured from the Aleutian Islands and central California are abnormally high. This is not surprising for California, because of the well-known occurrence of organochlorine contaminants in the California Current ecosystem and their resulting high concentrations in numerous marine species from this region (Risebrough, 1969; Le Boeuf and Bonnel, 1971; Gress *et al.*, 1971; Anderson *et al.*, 1975; Jensen and Janson, 1979; Spies *et al.*, 1989; Connel, 1990; Bacon *et al.*, 1992). However, the finding of elevated OC concentrations in sea otters from the remote and purportedly undefiled Aleutian Islands was unexpected. This raises two important questions, what is the source of these compounds, and what is their impact on the regional biota? Although the threshold of PCB toxicity to sea otters is unknown, the concentrations of PCBs in the livers of otters from Adak are similar to those causing reproductive failure in captive mink (Platanow and Carstad, 1973; Aulerich and Ringer, 1977) and have also been associated with population declines or extinctions of Eurasian otters (Mason, 1989).

Although the productivity of bald eagles was normal at Adak, Tanaga and Amchitka islands (means of 1.09, 0.96 and 1.21 young $pair^{-1}$, respectively), it was depressed at Kiska Island (mean of 0.58 young $pair^{-1}$). At this latter site, DDE levels in eagle eggs were within the range known to cause reproductive supression, and the maximum concentration (4.1 mg kg^{-1} wet weight) is close to that associated with a 40–50% reduction in average productivity of regional populations (Weimeyer *et al.*, 1984). Thus, detrimental impacts of OCs on these and other species in the Aleutian Islands are likely. Various marine birds and mammals are experiencing population declines in the western North Pacific/Bering Sea region and whereas changes in the abundance or quality of food is the proposed cause (Castellini, 1993), this remains uncertain. Our findings indicate that elevated OC concentrations should be considered among the possible factors.

Although the source of OCs in the Aleutian Islands is presently unknown, there are several possibilities. Many of the Aleutian Islands have been occupied by military forces at one time or another during the past 50 years. It is noteworthy that PCB levels in eagle eggs were similar and highest at Adak, Amchitka and Kiska islands — all sites of past military activity (Fig. 2). Alternatively, high oceanic and atmospheric OC levels have been measured near south-east Asia and Japan (Iwata *et al.*, 1993, 1994), and the prevailing westerly winds and currents in this region are a potential means of delivery of contaminants to the Aleutian Islands. The source of DDE in the Aleutian Islands is particularly interesting in view of the observed levels and patterns of these compounds in sea otters and eagles (Fig. 2); bans on the use of DDT in most northern hemisphere industrialized countries since the early 1970s, and the fact that the west-central Aleutian Islands are several thousand kilometres distant from agricultural activities, the usual source of this contaminant. DDT residues (mainly DDE) still contaminate many aquatic ecosystems (Steidl *et al.*, 1991; Anthony *et al.*, 1993), and DDT remains in use throughout much of Asia. These facts, and the 100-fold greater DDE/DDT ratio in sea otters from California compared with the Aleutian Islands, suggest that the DDE in California constitutes residues from prior use, whereas the DDT residues and metabolites in the Aleutian Islands are from areas of more recent use, probably in Asia (Iwata *et al.*, 1993, 1994). The east-to-west increase of DDE levels in bald eagle eggs (Fig. 2) is also consistent with an Asian source.

In summary, these findings demonstrate that potentially harmful OC levels occur in the Aleutian Islands, one of the most remote areas of North America. Sources of these compounds should be determined, because the likely alternatives have substantially different implications to the conservation and management of fisheries, seabirds and marine mammals. If the high OC levels in the Aleutian chain are from one or several local sources, mitigation may be in order. Conversely, the possibility of more distant sources raises a larger suite of issues including health risks to wildlife and humans, the practicability of mitigation, and policy implications for the non-purposeful transport of environmentally harmful substances across national borders.

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