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Contaminants in Eggs of Western Snowy Plovers and California Least Terns: Is There a Link to Population Decline?

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Environmental contaminants may have adverse effects on avian reproduction and may be contributing to declines of avian species nesting along the southern California Coast. Examples of impaired reproduction caused by organochlorine pesticides, PCBs, and elements such as mercury (Hg) and selenium (Se) include delayed ovulation, reduced egg production, defective eggshells, decreased hatchability, embryotoxicosis, aberrant incubation behavior, and mortality of chicks and adults (Heinz 1976; Blus 1982; Ohlendorf et al. 1986).

The federal government listed the California least tern *(Sterna antillarum browni)* as endangered in 1970 (U.S. Fish and Wildlife Service 1985). The Pacific Coast population of western snowy plover *(Charadrius alexandrinus nivosus)* was listed as threatened by the federal government in 1993 (Federal Register 1993). Habitat loss and human-related disturbance have been identified as primary causes of the decline of both the primarily insectivorous plover (Powell 1998) and the primarily piscivorous tern, but local food shortages have also limited the terns.

Both species breed along the highly urbanized coastline of southern California. A portion of the snowy plover population is present on the breeding grounds year-round, while the remainder winters along the Pacific Coast south into Baja California, Mexico (Stenzel et al. 1994). Least terns winter primarily along the Pacific Coast of Central America (Massey et al. 1992). This study was designed to evaluate the effects that contaminants acquired on the breeding or wintering grounds might be having on reproduction by snowy plovers and least terns.

MATERIALS AND METHODS

Reproductive success of western snowy plovers was monitored in San Diego County during 1994-1996. Nests were marked during 1 March-31 August and monitored to determine clutch size, hatching success, causes of nest failure, and renesting attempts. The U.S. Fish and Wildlife Service monitored California least tern colonies in 1994. Eggs were salvaged from these breeding sites for chemical analyses (Fig. 1). Tern eggs were collected after the nesting season from Naval Air Station (NAS) North Island, Sweetwater Marsh National Wildlife Refuge (NWR), Naval Amphibious Base (NAB) Coronado, and Tijuana Slough NWR.

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Abandoned or inviable snowy plover eggs were collected from five southern California sites: Marine Corps Base (MCB) Camp Pendleton, Batiquitos Lagoon, NAB Coronado, Sweetwater Marsh NWR, and Tijuana Slough NWR (Fig. 1).

We collected 3 snowy plover eggs in 1994, 32 in 1995, and 33 in 1996. The U.S. Fish and Wildlife Service collected 72 least tern eggs in 1994. Each egg was refrigerated until processed; it was then weighed, measured, and its volume estimated. Embryos were examined to determine fertility and developmental stage. Egg contents were frozen in chemically clean jars until they could be analyzed for contaminants.

Samples were analyzed for both organic and inorganic contaminants by Hazleton Environmental Services, Inc., Madison, WI. Nine tern and 23 plover samples were analyzed for metals and trace elements. Samples were homogenized and dried for moisture determination. Samples were analyzed for total Hg using cold vapor atomic absorption spectrophotometry, with a lower limit of detection (LOD) of 0.025 µg/g, wet wt. Samples were analyzed for Se and arsenic (As) using graphite furnace atomic absorption spectrophotometry; the LOD was 0.1 µg/g, wet wt. Eggs were analyzed for aluminum (Al), boron (B), barium (Ba), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), strontium (Sr), vanadium (V), and zinc (Zn) using Inductively Coupled Plasma-Atomic Emission Spectroscopy. LODs ranged from 0.02 µg/g for Cd to 2.25 µg/g for Fe and Mg.

Twenty plover and 14 tern eggs were individually homogenized and analyzed for hexachlorobenzene (HCB), a-, β–, and γ–BHC, heptachlor epoxide, oxychlordane, α-and γ-chlordane, *trans*-nonachlor, endrin, toxaphene, o,p'-DDE, p,p'-DDE, o,p'-DDD, p,p'-DDD, o,p'-DDT, p,p'-DDT, mirex, dieldrin, and total PCBs by Soxhlet extraction. Because the mass available for analysis was small, the LOD for organochlorine pesticides and metabolites was 0.06 µg/g, wet wt; for total PCBs and toxaphene the LOD was 0.31 µg/g, wet wt. Accuracy of all chemical analyses, as measured by spike recovery and reference material analysis, and precision, as measured by duplicate sample analysis, were acceptable for all analytes.

Results for inorganics are expressed on a dry-weight basis, while organochlorines are on a fresh wet-weight basis. Concentrations were transformed to common logarithms to improve homogeneity of variances, and geometric means were calculated when a contaminant was detected in at least 50% of the samples. When means were calculated, a value equal to one-half the detection limit was assigned to any not-detected values prior to logarithmic transformation. Analysis of variance and Tukey's multiple comparison test were used to compare geometric means between species and among sites.

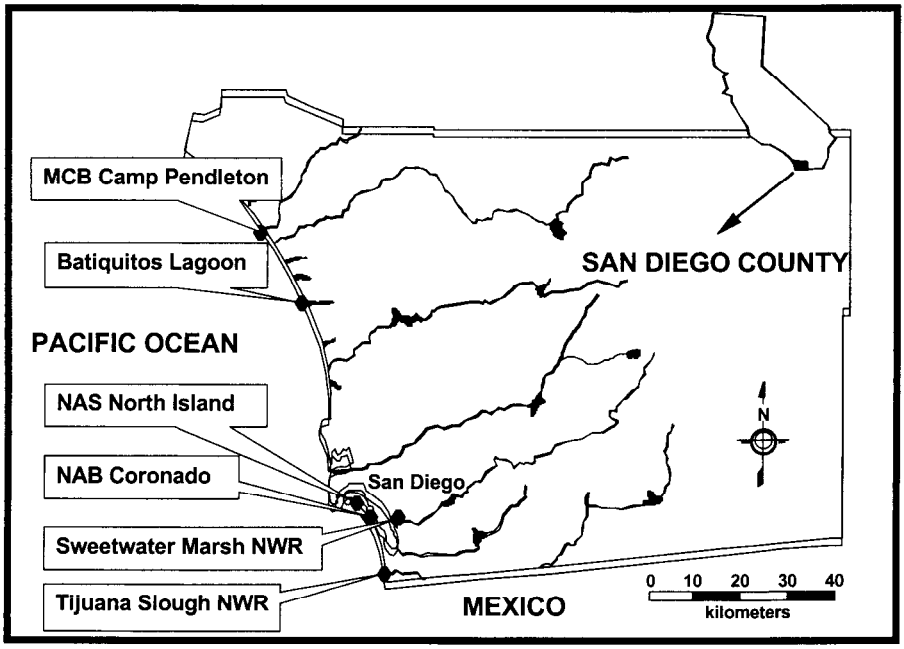

Figure 1. Sampling sites for California least tern and western snowy plover eggs along the coast of San Diego County, California.

RESULTS AND DISCUSSION

The MCB Camp Pendleton, Batiquitos Lagoon, and Tijuana Slough NWR sites included agricultural land uses within their watersheds and adjacent to nesting areas. Elevated levels of DDT and DDE have been found at Tijuana Slough NWR, presumably from wastewater discharges from Mexico (Fairey et al. 1996). NAS North Island, NAB Coronado, and Sweetwater Marsh NWR were all within San Diego Bay, where copper, mercury, zinc, chlordane, and PCBs have been found at levels of concern (Fairey et al. 1996). In addition, San Diego Bay has historically received untreated sewage and industrial waste discharges.

Five metals (Be, Cd, Mo, Pb, and V) were below the LOD for all eggs analyzed. Al and Ba were rarely detected in eggs. With the exception of Ni in least terns at Tijuana Slough NWR, geometric means were calculated for all other combinations of species, site and inorganic element (As, B, Cr, Cu, Fe, Hg, Mg, Mn, Se, Sr, and Zn). Although many inorganics were detected in a high percentage of analyzed eggs, Se and Hg are the two elements that have been most often implicated in cases of impaired avian reproduction (Ohlendorf 1989; Schuehammer 1987). Means of Cr, Mn, and Sr differed between species and are presented (Table 1).

Table 1. Inorganic (μg/g, dry wt.)[1] and organic (μg/g, fresh wet wt.) contaminants in eggs from southern California, 1994-1996.

	California Least Terns, 1994				Western Snowy Plovers, 1994-1996				
Contaminant	NAB Coronado	NAS North Island	Sweetwater Marsh NWR	Tijuana Slough NWR	Batiquitos Lagoon (1996)	MCB Camp Pendleton (1995)	NAB Coronado (1994-1996)	Sweetwater Marsh NWR (1995)	Tijuana Slough NWR (1995-1996)
Metals (N)	4	0	2	3	4	10	4	2	3
Chromium	0.475	NA[2]	0.547	0.483	0.631	1.03	1.14	2.06	1.64[3]
Manganese	1.08	NA	1.81	1.21	1.56	1.56	1.79	2.68	2.49[3]
Mercury	0.509	0.913[4]	0.530	0.684	0.309	0.217	0.529	0.250	0.480
Selenium	2.38	2.21[4]	4.40	3.53	2.05	1.65	1.97	2.18	1.34
Strontium[5]	2.88	NA	6.18	6.18	33.1 BC	19.5 C	39.6 AB[3]	15.6 BC	84.2 A[3]
Organochlorines (N)	5	4	0	5	5	5	5	1[6]	4
Total PCBs[7]	0.789 A	1.61 A	NA	0.232 B	0.330 B	0.219 B	2.36 A[3]	0.66	0.845 A
p,p'-DDE	0.230	0.562	NA	0.470	1.03	0.868	0.566	0.62	1.40[3]
Dieldrin	ND[2]	NC[2]	NA	ND	0.017	0.009	ND	ND	ND

[1] Mean percent moisture: Least terns = 65.2%; Snowy plovers = 63.9%.
[2] NA = no samples analyzed; ND = not detected in any samples; NC = mean not calculated because <50% of samples above limit of detection.
[3] These means for snowy plovers were higher ($P<0.05$) than comparable means for least terns at the same site.
[4] Data from 1981-1987 (Hothem and Zador 1995).
[5] For snowy plovers, strontium concentrations not sharing the same letter are different from one another ($P<0.05$).
[6] Only one sample analyzed for organochlorines at Sweetwater Marsh: therefore, it cannot be compared with other sites.
[7] Within species, PCB concentrations not sharing the same letter are different from one another ($P<0.05$).

The mean concentration of mercury in eggs from a study of mallards *(Anas platyrhynchos)* fed 0.5 µg/g methylmercury was, assuming moisture content of 80%, about 4.3 µg/g (dry wt.). These mallards displayed abnormal egg-laying behavior, impaired reproduction, and slowed duckling growth (Heinz 1976). The highest individual value from the current study (1.18 µg/g) was less than one-third the mean from the laboratory study. The mean mercury concentration in unhatched California least tern eggs collected from Seal Beach NWR (-145 km north of San Diego Bay) in 1991-1993 was 0.82 µg/g, dry wt (M. Rivera, U.S. Fish and Wildlife Service, pers. commun.), slightly higher than the means we observed. Mean mercury concentrations (wet wt) in eggs of Forster's terns *(Sterna forsteri)* (0.40 µg/g), Caspian terns *(S. caspia)* (0.20 µg/g), and least terns (0.34 µg/g) from the Texas Gulf Coast were not related to hatching success (King et al. 1991). Hatching and fledging success were not reduced in common tern *(S. hirundo)* eggs from Germany with 6.7 µg/g mercury (wet wt) (Becker et al. 1993). Using an average moisture content of 65%, our mean wet-wt values for plovers and terns (0.076-0.239 µg/g) were similar to those for terns from Texas, but far lower than those in terns from Germany. California least tern mean mercury concentrations were about one-half the overall mean found for interior least terns *(Sterna antillarum athalass*os) from the Northern Great Plains (1.44 µg/g, dry wt.) (Allen et al. 1998). Mercury concentrations were lower in both terns and plovers from this study than those that have impaired reproduction in other species. There were no differences ($P<0.05$) among sites or between species for mercury.

Based on a feeding study of mallards, selenium's threshold for reproductive impairment was >17 µg/g (dry wt) selenium in the egg (Heinz et al. 1989). Plover eggs collected at evaporation ponds in the Tulare Basin of California had mean selenium concentrations as high as 37.4 µg/g, a concentration that likely impaired reproduction in those birds (J. Skorupa, U.S. Fish and Wildlife Service, pers. commun.). Mean selenium concentrations in terns from the Texas Coast were considered to be at background levels (≤ 1 µg/g, wet wt) (King et al. 1991). In the present study, mean selenium concentrations were >3 µg/g in least tern eggs from Sweetwater Marsh NWR (4.40 µg/g, dry wt.) and Tijuana Slough NWR (3.53 µg/g); other terns and plovers were within the "no effect" range (l-3 µg/g, dry wt) suggested by Ohlendorf (1989). By comparison, mean selenium concentrations in eggs of interior least terns from the Northern Great Plains were >3 µg/g in 11 of 12 site-year combinations (Allen et al. 1998). There were no differences ($P<0.05$) among sites or between species for selenium in our study. Between-species differences were noted for strontium, chromium, and manganese (Table 1). The mean strontium concentration was greater in plovers at both Tijuana Slough NWR and NAB Coronado ($P<0.0001$). Chromium and manganese were higher in plovers at Tijuana Slough NWR. Strontium in plovers differed among sites, with the highest mean being at Tijuana Slough NWR. These concentrations were not thought to have impaired reproduction.

Every analyzed sample had detectable concentrations of total PCBs (Table 1).

PCBs are generally slow to degrade and persist in aquatic environments even though their manufacture and use were prohibited in the United States in 1979 (Eisler 1986). In 1981, mean PCB concentrations in eggs of Caspian and elegant terns (*S. elegans*) from San Diego Bay were 1.70 µg/g and 1.55 µg/g, respectively (Ohlendorf et al. 1988). In this study, the highest mean PCB concentrations in eggs of least terns from NAS North Island (1.61 µg/g) and snowy plovers from NAB Coronado (2.36 µg/g) were generally within the ranges found in Caspian tern eggs from Texas (1.0-5.4 µg/g) (King et al. 1991) and least tern eggs from South Carolina (0.25 - 1.9 µg/g) (Blus and Prouty 1979). Mean concentrations of PCBs in least terns and snowy plovers from the South Coast of California were generally higher than those in interior least terns from the agricultural Northern Plains states (all means < 0.284 µg/g) (Allen et al. 1998). However, they were less than those measured in Caspian tern eggs from the Great Lakes (18.5-39.3 µg/g) where no adverse reproductive effects were noted (Struger and Weseloh 1985). There were among-site differences for both species, and, at NAB Coronado, total PCBs were higher in snowy plovers than least terns.

All but one sample, from NAB Coronado, had detectable p,p'-DDE. Although DDT was banned in the early 1970s, this pesticide and its metabolites tend to persist in aquatic environments. The mean DDE concentration (9.99 µg/g) in 16 California least tern eggs collected from Venice Beach, Los Angeles County, California, during 1981-1985 (Boardman 1988) were higher than those observed in our study. Higher mean concentrations have also been reported for eggs of Caspian (9.30 µg/g) and elegant terns (3.79 µg/g) from San Diego Bay (Ohlendorf et al. 1988). In the current study, mean concentrations of DDE in least terns from the three San Diego Bay sites (0.230 -0.562 µg/g) were all lower than the overall mean (0.936 µg/g) observed in least tern eggs from San Diego Bay in the mid-1980s (Hothem and Zador 1995). It appears that DDE concentrations in least terns nesting in San Diego County are declining over time. Although mean DDE concentrations were generally higher in snowy plover eggs than in the least terns, the difference was significant only at Tijuana Slough NWR ($P<0.05$). Similar or higher mean concentrations in least terns (0.19-1.22 µg/g) from South Carolina (Blus and Prouty 1979) and in Forster's terns from Texas (1.6 µg/g) (King et al. 1991) were not thought to pose a threat to reproduction. Likewise, DDE should not pose a threat to either species in our study.

Six organochlorine compounds were not detected in any samples: α– and γ-BHC, γ–chlordane, endrin, toxaphene, and mirex. Three organochlorines were only detected in two or three samples of snowy plover eggs and at low levels (≤ 0.03 µg/g); they are not considered further. β-BHC and heptachlor epoxide were detected at low levels in one sample from Batiquitos Lagoon. HCB and β-BHC were detected in one sample from MCB Camp Pendleton.

For least terns, the only other organochlorines with ≥ 50% detected residues were o,p'-DDE and α-chlordane, both from NAS North Island. Of the possible 24 combinations of site and organochlorine for least terns, only two had ≥ 50% of

the samples with detected residues, compared with 23 of 56 possible site-organochlorine combinations for snowy plovers.

Although few data are available for other organochlorines in least terns and snowy plovers, concentrations in eggs of Caspian and Forster's terns, snowy egrets *(Egretta thula),* and black-crowned night-herons *(Nycticorax nycticorax)* from San Francisco Bay in 1982 (Ohlendorf et al. 1988) were higher but were thought not to have impaired reproduction.

Hatching rates for least terns and snowy plovers are heavily impacted by predation, despite predator management efforts in southern California (Powell and Collier 2000). In 1994, hatching success for all California least tern breeding colonies was 70.7% (Caffrey 1995). Hatching success varied from 50-87% at our study sites, and most losses were from predation. Snowy plover hatching success ranged from 76% in 1994 to 59% in 1996. This is generally higher than the 53% average reported in 17 studies of snowy plovers across their range in the United States (Page et al. 1995). In that study, most egg losses were caused by predators (15-35%), but 13% were abandoned, and 5.2-14.2% failed for unknown reasons.

Contaminants may be among several interacting factors contributing to recent declines of California least tern and western snowy plover populations. In conjunction with declining nesting and feeding habitats and other stressors, elevated levels of contaminants could be detrimental to population growth and stability. In this study, however, contaminants were not sufficiently elevated to cause major concern. Variations among concentrations in least tern and snowy plover eggs are most likely a reflection of their different food sources and foraging habitats. Variations among sites are likely related to different sources of contamination. However, more information on both species is needed to determine isolated and combined effects of contaminant concentrations.

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