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Cadmium in ocean-skaters, *Halobates sericeus* (Insecta), and in their seabird predators

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Abstract

Between February 1978 and February 1981, the content of cadmium was measured (1) in specimens of *Halobates sericeus* picked out from regurgitates of 9 species of seabirds, and (2) in the feathers of some seabirds which nested on 8 islands or atolls in the Northwestern Hawaiian Islands. In the 4 major avian predators of this ocean-skater, the Cd concentrations increased from roughly 2 to 8 $\mu\text{g g}^{-1}$ dry wt towards the northwest, over a linear distance of about 1 500 km. The correlation between Cd levels in the insects and in the feathers of their predators suggests that this heavy metal is transmitted along the food chain.

Introduction

Cadmium (Cd), a widespread environmental pollutant, has toxic effects on many animal species. High levels of Cd in several species of pelagic seabirds have caused concern, because Cd might reduce their breeding success (Nicholson and Osborn, 1983). Some of the birds containing high Cd levels have been found in areas with no known sources of industrial pollution (Anderlini *et al.*, 1972; Bull *et al.*, 1977). The metal ion probably came from food concentrated in the food chain (Stoneburner and Harrison, 1981a), but it is uncertain whether the primary source of the Cd was natural or anthropogenic (Murton *et al.*, 1978). Although data on the Cd contents of most of the specific food items of pelagic seabirds are difficult to obtain, it is relatively easy to sort out unispecific samples of marine insects for Cd assays. We were able to pick out ocean-skaters, *Halobates sericeus* (Insecta: Gerridae), from food samples regurgitated by several seabird species. We

present here data on the Cd concentrations found in these insects and in the feathers of some of their major avian predators.

Materials and methods

One hundred and thirty seven regurgitated food samples were collected from 9 species of seabirds from 8 of the Northwestern Hawaiian Islands (Fig. 1) between February 1978 and February 1981. (Detailed information on bird species studied, sampling procedure, frequency, etc. can be found in Cheng and Harrison, 1983). Specimens of *Halobates sericeus* were picked out from each formalin-preserved regurgitate, rinsed briefly in distilled water, and stored in 70% ethanol. After the insects from each regurgitate had been identified and counted, they were rinsed again twice in glass-distilled water, blotted, and dried in 7 ml polyethylene vials at $60^\circ\text{C} \pm 3^\circ\text{C}$ for 48 h. They were later digested overnight in an acid mixture of $\text{HNO}_3:\text{H}_2\text{SO}_4=4:1$. Cd was determined by flameless atomic-absorption spectroscopy (limit of detection = $10^{-2} \mu\text{g g}^{-1}$; see Schulz-Baldes and Cheng, 1980).

Primary and tail feathers were removed from 5 individuals of each bird species from each island. About 0.3 g of each feather sample was digested in 5 ml of concentrated HNO_3 for 2 h, then 5 ml of 30% H_2O_2 were slowly added, and the mixture was allowed to digest until no visible particulate matter remained. Cd contents of the feathers were obtained by analysing the samples in an inductively coupled plasma spectrometer (Jerrold-Ash Model 750 Atocomp) after making corrections for background and possible acid and peroxide contamination. Cd data for each bird species were pooled to obtain mean and standard errors.

Results and discussion

The number of *Halobates sericeus* in each regurgitated food sample varied from 1 to 336 and dry weights ranged

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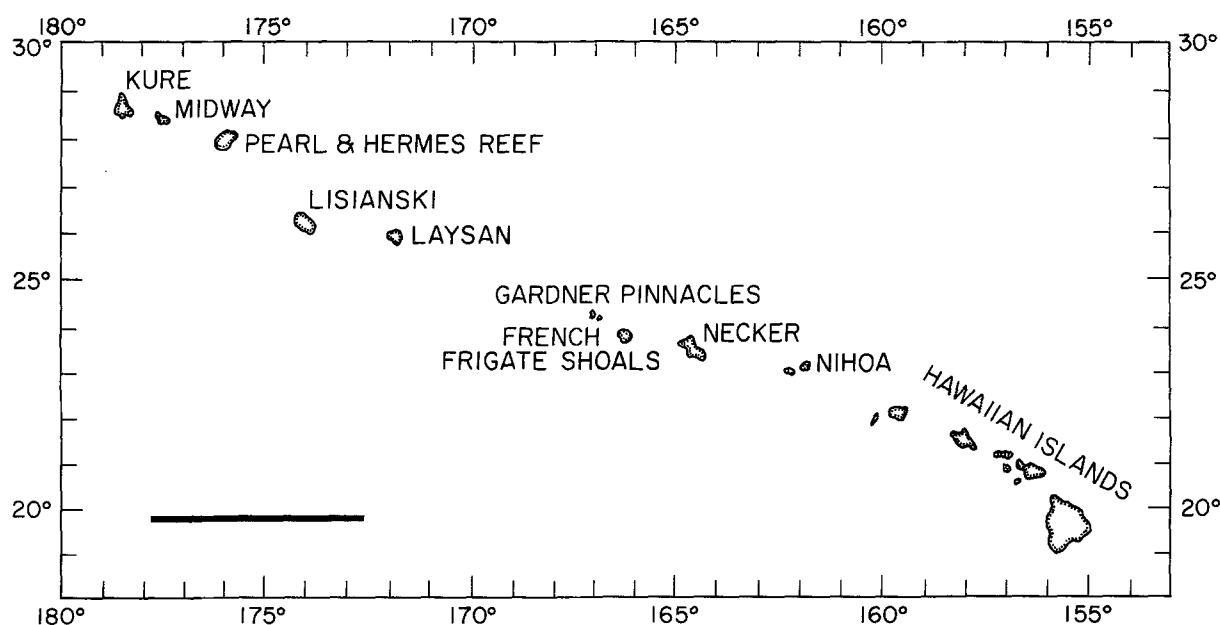


Fig. 1. Map showing Hawaii and northwestern islands of the Hawaiian Archipelago used for collections in present study. (Scale bar = 500 km)

Table 1. Cadmium concentrations in regurgitated *Halobates sericeus*. Mean concentrations ($\mu\text{g g}^{-1}$ dry wt ± 1 SD) are given by seabird species and by island. Dash indicates no birds found on island. No. of samples is shown in parentheses

Island	Seabird species:				Mean Cd (by island) in regurgitated <i>H. sericeus</i>
	<i>Procelsterna cerulea</i> (blue-gray noddy)	<i>Pterodroma hypoleuca</i> (Bonin petrel)	<i>Sterna lunata</i> (gray-backed tern)	<i>Bulweria bulwerii</i> (Bulwer's petrel)	
Nihoa	2.32 ± 2.27 (25)	—	1.26 (1)	2.59 (1)	2.29 ± 2.19 (27)
Necker	1.07 ± 0.97 (47)	—	4.09 (1)	—	1.15 ± 1.04 (48)
Laysan	—	9.40 ± 8.80 (20)	8.22 ± 5.72 (10)	3.49 ± 4.90 (10)	7.51 ± 7.25 (40)
Lisianski	—	2.40 ± 2.43 (3)	4.54 ± 0.56 (5)	—	3.74 ± 1.76 (8)
Pearl and Hermes	—	—	8.01 ± 7.26 (4)	—	8.01 ± 7.26 (4)
Mean Cd (by bird)	1.85 ± 3.26	8.49 ± 8.56	7.05 ± 5.24	3.40 ± 4.66	

from 0.2 to 125 mg. However, at least 50% contained more than 20 insects. Cd concentrations ranged from 0.3 to $30 \mu\text{g g}^{-1}$ dry wt. About 75% of the insect samples had less than $5 \mu\text{g g}^{-1}$ Cd; most of those with higher Cd contained relatively few insects with dry weights of less than 5 mg. However, we did not find a significant correlation between Cd concentration and insect dry weight ($r = -0.082$; $p > 0.1$). Eighteen regurgitates were big enough to be divided into two to four subsamples, which were checked for homogeneity: there was no significant variation in the Cd concentrations among these ($\text{SD} \leq 0.05 \mu\text{g g}^{-1}$ in most cases).

We did not find any significant differences among Cd concentrations of regurgitated insects from the same bird species taken in different years, so samples were combined for further analysis. Table 1 shows, for five of the islands (Nihoa, Necker, Laysan, Lisianski, and Pearl and Hermes Reef), the number of samples of regurgitated *Halobates sericeus* analysed for each of four major bird predators

[blue-gray noddy (*Procelsterna cerulea*), Bonin petrel (*Pterodroma hypoleuca*), gray-backed tern (*Sterna lunata*), and Bulwer's petrel (*Bulweria bulwerii*)]. The mean Cd concentrations are expressed in $\mu\text{g g}^{-1}$ dry wt ± 1 SD.

There were considerable differences among the mean Cd concentrations in regurgitated insects. *Halobates sericeus* from birds from Nihoa and Necker had significantly less Cd than those from Laysan, Lisianski or Pearl and Hermes Reef. There were significant differences in the Cd concentration in *H. sericeus* eaten by the same bird species from different islands. Thus, it appears that the Cd content of *H. sericeus* eaten by various avian predators reflects not only predator-specific, but also geographical differences. However, a closer inspection of the data revealed that the species difference could probably be better explained by the geographical trend. There appears to be an increase in Cd concentration as we move from Nihoa and Necker (which are situated close together) northwestwards towards Laysan, Lisianski, and Pearl and Hermes Reef

Table 2. Cadmium concentrations in regurgitated *Halobates sericeus*. Significance matrix based on analysis of variance; the lower the value, the greater the difference between the islands

	Nihoa	Necker	Laysan	Lisianski	Pearl and Hermes
Nihoa		0.30	0.00***	0.43	0.02*
Necker			0.00***	0.14	0.00***
Laysan				0.03*	1.00
Lisianski					0.13

*** Significant at $P=0.001$; * Significant at $P=0.01$

Table 3. Mean cadmium concentrations and standard deviations of regurgitated *Halobates sericeus* and seabird feathers from each species. No. of samples is shown in parentheses. Mean body weight of seabirds are also given

Seabird species	Mean body wt (g)	Feather Cd ($\mu\text{g g}^{-1}$ wet wt)	Regurgitated <i>H. sericeus</i> Cd content ($\mu\text{g g}^{-1}$ dry wt)
<i>Procelsterna cerulea</i> (blue-gray noddy)	53	27 ± 6 (11)	1.85 ± 3.26 (73)
<i>Bulweria bulwerii</i> (Bulwer's petrel)	99	8 ± 2 (18)	3.41 ± 4.66 (11)
<i>Sterna lunata</i> (gray-backed tern)	146	15 ± 6 (30)	7.05 ± 5.24 (22)
<i>Pterodroma hypoleuca</i> (Bonin petrel)	176	2 ± 1 (11)	8.49 ± 8.56 (23)

(Fig. 1). An analysis of variance for the five islands confirms that differences exist between these two island groups (Table 2).

As can be seen in Fig. 1, Nihoa and Necker are separated from Laysan, Lisianski, and Pearl and Hermes Reef by a 700 km stretch of water where the Subtropical Countercurrent intersects the island group (Grigg, 1981). These two more southwestern islands are more under the influence of the North Equatorial Current, whereas the three northwestern islands are more under the influence of the North Pacific Current and perhaps also the Kuroshio Current Extension.

The relatively high Cd concentrations found in ocean-skaters around Laysan, Lisianski, and Pearl and Hermes Reef probably reflect the higher heavy-metal concentrations in the surface waters of these current systems. Ohlendorf and Harrison (in preparation) have found that mercury concentrations in eggs of the red-footed booby *Sula sula* increased similarly along such a southeast-to-northwest axis among the same islands.

Ocean-skaters generally prey on zooplankton organisms trapped at the sea-air interface. Heavy metals such as Cd are accumulated by these surface-feeding insects not only from food, but also from water drunk at the sea surface. Schulz-Baldes and Cheng (1981) suggested that drinking may be a more important route for Cd uptake than feeding, since many of the prey organisms accumulate much less heavy metal in their soft tissues (which

are digested) than in the cuticle (which is not). If the Cd contents of the ocean-skaters are directly correlated to the concentrations of this metal in the surface film that they drink, then the differences that we found in Cd contents of ocean-skaters eaten by the same bird species nesting on different islands would indicate that the birds had been feeding on insect populations from different water masses. Unfortunately we have no foraging data for the seabirds to allow us to test this hypothesis. Alternatively, the birds may be foraging over the same water mass but at different times of the year. The differences in Cd contents of *Halobates sericeus* eaten by the Bonin petrel or the gray-backed tern, and those eaten by Bulwer's petrel on Laysan, could perhaps be explained by seasonal differences. Samples of the two former predators were collected mostly in April and May, while those of Bulwer's petrel were collected in August. For example, insect samples from the blue-gray noddy collected in the same months (May and June) from both Nihoa and Necker show differences in their Cd content (Table 1).

Among the four major avian predators of *Halobates sericeus*, the blue-gray noddy is the most important (Cheng and Harrison, 1983). It is also the smallest, with a mean body weight of about 53 g (Harrison *et al.*, 1983). This species has been found to have the highest Cd content in its feathers. In Table 3, the average numbers and Cd contents of *H. sericeus* obtained in the food regurgitates of each seabird, and the Cd concentrations in the feathers of the four bird species – the blue-gray noddy, Bulwer's petrel, the gray-backed tern and Bonin petrel – are plotted in relation to the mean body weights of the birds. Although the Cd concentrations in the *H. sericeus* eaten by the blue-gray noddy were the lowest among the four bird species, this predator took the largest numbers of ocean-skaters and, on the average, had the highest content of Cd in its feathers. How much of the feather-Cd is attributable to *H. sericeus* in the diet is difficult to determine. This prey item occurred in 81% of the blue-gray noddy samples and, on the average, constituted 19% of the volume of their food. At certain times these ocean-skaters seem to be the only food taken by this small noddy (Cheng and Harrison, 1983). Although we have no direct evidence for a transfer of Cd from the ocean-skaters to their avian predators, it is reasonable to assume that the birds augment their Cd load by ingesting these insects in large numbers.

White and Finley (1978) reported that in mallard ducks (*Anas platyrhynchos*) fed with $200 \mu\text{g g}^{-1}$ wet wt Cd-enriched diet for 60 d, Cd levels of 109 and $134 \mu\text{g g}^{-1}$ wet wt were found in their liver and kidney, respectively. They did not analyse feathers. There was no mortality, but egg production was suppressed and there was kidney lesion. After 90 d on this artificial diet, the testis atrophied (White *et al.*, 1978). Kidney lesions were also found in wild populations of puffins (*Fratercula arctica*), Manx shearwaters (*Puffinus puffinus*) and fulmars (*Fulmarus glacialis*) by Nicholson and Osborn (1983), where Cd levels were 114, 94.5 and $228 \mu\text{g g}^{-1}$ dry wt, respectively (Osborn *et al.*,

1979). They also found considerable Cd in the liver, pancreas and gonads of these seabirds, but the Cd level in feathers ranged from non-detectable (in puffin) to less than $1 \mu\text{g g}^{-1}$ dry wt. Such low feather-Cd levels (0.11 to $0.29 \mu\text{g g}^{-1}$ wet wt) were also found in brown pelicans (*Pelicanus occidentalis*; Ohlendorf, personal communication) and sooty terns (*Sterna fuscata*: $0.02 \mu\text{g g}^{-1}$ wet wt) from Lisianski Island and Laysan ducks (*Anas laysanensis*: $0.2 \mu\text{g g}^{-1}$ dry wt) from Laysan Island (Stoneburner and Harrison, 1981a, b). Kidney Cd levels in the terns and ducks were considerably higher than those found in feathers (4.2 and $16.65 \mu\text{g g}^{-1}$ wet wt, respectively). Cd concentrations in the feathers of the species we studied ranged from 2 to $27 \mu\text{g g}^{-1}$ wet wt (see Table 3); other tissues were not analysed for this heavy metal. The levels of Cd, such as those we found in feathers of the blue-gray noddy ($27 \mu\text{g g}^{-1}$) and the gray-backed tern ($15 \mu\text{g g}^{-1}$), could indicate corresponding levels in the kidney, liver or gonads, perhaps high enough to cause organ dysfunction or reproductive failure. One obviously needs more data and experimental studies on the effects of dietary Cd on the physiology of seabirds.

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