Arch. Environ. Contam. Toxicol. 31, 115–119 (1996)

ARCHIVES OF
Environmental
Contamination
and Toxicology

Lead Exposure in Laysan Albatross Adults and Chicks in Hawaii: Prevalence, Risk Factors, and Biochemical Effects

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Received: 3 November 1995/Revised: 27 December 1995

Abstract. Prevalence of lead exposure and elevated tissue lead was determined in Laysan albatross (*Diomedea immutabilis*) in Hawaii. The relationship between lead exposure and proximity to buildings, between elevated blood lead and droopwing status, and elevated liver lead and presence of lead-containing paint chips in the proventriculus in albatross chicks was also examined. Finally, the effects of lead on the enzyme δ-aminolevulinic acid dehydratase (ALAD) was determined. There was a significant association between lead exposure or elevated tissue lead and proximity to buildings in albatross chicks and presence of lead paint chips in the proventriculus and elevated liver lead in carcasses. Although there was a significant association between elevated blood lead and droopwing chicks, there were notable exceptions. Prevalence of elevated tissue lead in albatross chicks was highest on Sand Island Midway and much less so on Kauai and virtually nonexistent in other areas. Prevalence of lead exposure decreased as numbers of buildings to which chicks were exposed on a given island decreased. Laysan albatross adults had minimal to no lead exposure. There was a significant negative correlation between blood lead concentration and ALAD activity in chicks. Based on ALAD activity, 0.03–0.05 μg/ml was the no effect range for blood lead in albatross chicks.

In Hawaii, Laysan albatross (*Diomedea immutabilis*) can be found nesting on the 10 islands comprising the northwestern Hawaiian islands (Figure 1); on the main islands of Hawaii, Laysan albatross nest only on Kauai and Oahu. Of the islands on which albatross nest, chick nesting areas are located near buildings on two of these (Kure and Midway).

Sileo and Fefer (1987) documented lead poisoning in albatross chicks on Midway and attributed droopwing in chicks to lead poisoning. However, they also found droopwing chicks without detectable tissue lead and "normal" chicks with elevated blood lead. Sileo *et al.* (1990) subsequently state that lead poisoning was a major cause of mortality in albatross chicks and that albatross became poisoned through ingestion of lead paint from buildings. However, a bias was introduced by testing for lead in animals only near buildings on Sand Island, Midway. Others (Osborn *et al.* 1979; Muirhead and Furness 1988; Honda *et al.* 1990; Ohlendorf 1993) have noted that seabirds can harbor high tissue levels of certain heavy metals such as mercury with no apparent ill effect. This suggests that lead too may be a general environmental contaminant for albatross in Hawaii.

In light of pending military base clean up operations of Midway, managers of Midway Atoll National Wildlife Refuge (NWR) wanted an updated assessment of the status of lead in albatross chicks. The goals of the study were to determine if 1) lead exposure in albatross chicks still existed on Midway and whether buildings served as a source of this lead; 2) if there was a significant association between elevated blood lead and droopwing birds; 3) if lead exposure in albatross adults and chicks was limited to Midway Atoll; and 4) if antemortem effects of lead in albatross were detectable using the enzyme δ-Aminolevulinic acid dehydratase (ALAD).

Methods

Sampling Areas

Midway atoll (28°13′N177°22′W) consists of three islands located 2110 km from Honolulu (Figure 1). Sand Island is the largest and contains the naval air facility and associated personnel, air strips, and >140 occupied and abandoned buildings all accessible to nesting chicks. Eastern Island contains abandoned air strips and 4 buildings accessible to nesting chicks. Spit Island, between Eastern and Sand Islands, currently has no existing structures. The off-Midway sampling sites included Laysan Island (25°46′N171°44′W), Tern Island in French Frigate Shoals (23°45′N166°10′W), and Kilauea Point National Wildlife Refuge on Kauai (Fig. 1). Details on the biota of these islands are given by Amerson (1971), Ely and Clapp (1973), and USFWS (1991). Nesting chicks do not have access to structures on Tern Island, Kauai or Laysan Island.

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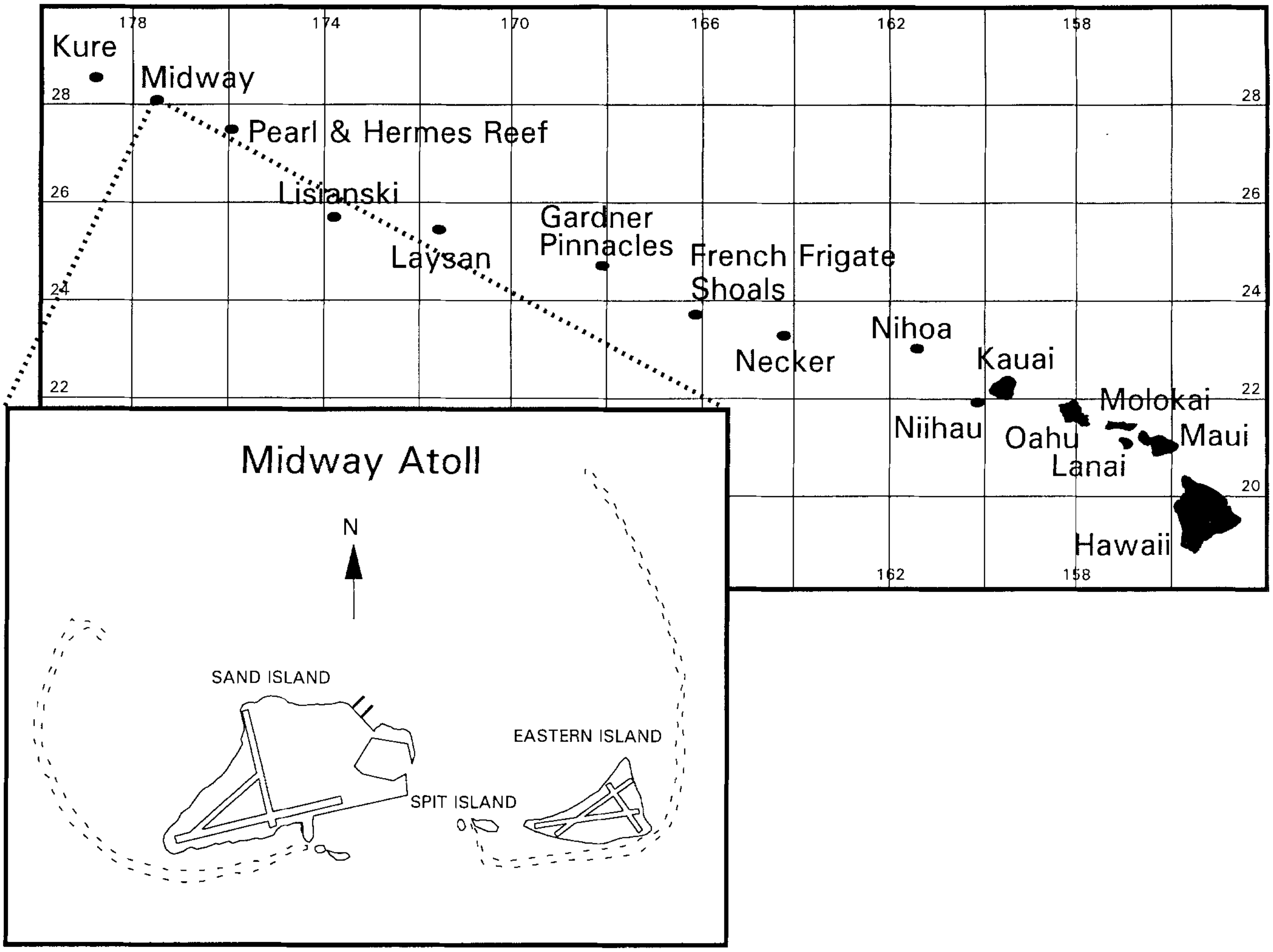

Fig. 1. Hawaiian islands and details of Midway Atoll

Sampling

Blood and liver samples were obtained from live and dead chicks, respectively, on Midway in early June 1993 and 1994; live chicks from Kauai were bled in early June 1994. During procurement of liver samples, stomach contents of carcasses were examined for presence of paint chips. Adults were bled from Midway in June 1994 and from Laysan and Tern Islands in October 1993. At the time of blood collection, chicks were assessed visually and classified as droop-wing or normal (Sileo and Fefer 1987). Lack of sexual dimorphism in albatross precluded gender classification.

Birds were manually apprehended and 7 cc of blood procured from the cutaneous ulnar vein. In 1993, 1-cc aliquots of whole blood were placed in 2-cc EDTA tubes for blood lead analysis. In 1994, 2 cc of whole blood were collected, half of which was placed in 1.5 ml cryovials and frozen in liquid nitrogen for δ-aminolevulinic acid dehydratase (ALAD) determination; the remainder was stored in EDTA at 4°C for blood lead analysis. Livers were obtained from birds estimated to have died within the previous 12 to 24 h. They were individually stored at −20°C in sealed plastic bags until processing for lead levels. Seventeen and 20 adults from Tern and Laysan Islands, respectively, were bled in October 1993 and 43 adults were bled from Midway in June 1994. Seventy three chicks (32 droopwing, 41 normal) from Midway were bled in June, 1993, 41 (23 droopwing, 18 normal) chicks from Midway and 16 normal chicks from Kauai in June 1994. Seventy one carcasses were examined in June 1993 and 1994.

Blood and liver lead concentrations were analyzed to assess effects of lead on albatross (Eisler 1988). δ-aminolevulinic acid dehydratase (ALAD) was also analyzed, because this enzyme is specifically inhibited by lead in other avian species (Lumeij 1985). Blood lead (μg/ml) (Fernandez and Hilligoss 1982), liver lead (μg/g wet weight [ww] (Locke *et al.* 1991), and ALAD activity (nmoles ALA/min/ml RBC) (Pain 1987) were analyzed at the National Wildlife Health Center, Madison, Wisconsin, USA. Detection limits for blood lead were 0.02 μg/ml, and 0.25 μg/g ww for liver lead. Chicks with blood lead ≥0.2 μg/ml or liver lead ≥2 μg/g ww were considered to have elevated levels (Eisler 1988). Birds with blood or liver lead at or above limits of detection were considered exposed, and those with lead levels below limits of detection were considered unexposed.

Data Analysis

To evaluate the effects of proximity to buildings on lead exposure on Midway, we noted whether the bird or carcass was situated near to (<17 m) or away from (≥17 m) buildings. This distance was chosen because chicks have little tendency to wander from the nest until the latter part of June and early July when fledging occurs (Fisher and Fisher 1969). Coversations with seabird biologists indicated that 17 m would be adequate to encompass any movement made by pre-fledging chicks from the nest thus allowing for some localization of lead exposure hazards. Separate two-by-two contingency tables for blood and liver lead were made using exposed and unexposed birds as row categories to determine effects of proximity to buildings in 1993. This was not done in 1994 as insufficient data were available. Odds ratios (OR) and 95% confidence intervals (CI) (Kelsey *et al.* 1986) were calculated and significance determined with chi square tests (Daniel 1987). Similar analyses were done to assess the relationship between incidence of droopwing syndrome and elevated blood lead in live chicks and, separately, the relation between presence/absence of paint chips in the proventriculus and elevated liver lead in chick carcasses in 1993 and 1994.

Prevalence of lead exposure on Midway for each year was assessed in live and dead chicks separately using blood and liver lead concentrations, respectively. To evaluate prevalence of lead exposure in adults on islands other than Midway, blood lead levels for adults sampled from Laysan and Tern Islands were used; for chicks, samples from nesting birds on Kauai were used. Similar analyses were done to calculate prevalence of elevated liver and blood lead.

Linear regression was used to determine the relationship between ALAD activity and blood lead concentration; t-tests were used for all group comparisons (Daniel 1987).

Results

In 1993, live chicks sampled near (<17 m) buildings ($N = 34$) on Midway were more likely to be lead exposed than chicks away (≥17 m) from buildings ($OR = 23$; $CI = 3–185$; $p < 0.01$); chicks found dead near buildings ($N = 32$) were more likely to be lead exposed ($OR = 9$; $CI = 3–30$; $p < 0.01$) and also more likely to have elevated liver lead levels ($OR = 17$; $CI = 8–37$; $p < 0.01$). In 1993, 17 of 79 chicks had paint chips in the proventriculus; in 1994, 5 of 71 chicks had paint chips in the proventriculus. Paint chips from two birds were analyzed and found to be positive for lead with levels ranging from 821 to 22,000 ppm. Other proventricular contents included squid beaks and plastic fragments; however, aside from paint chips, no other potential sources of lead were noted in proventricular contents. Although not all chicks with elevated liver lead had paint chips in the proventriculus, chicks with paint chips were more likely to have elevated liver lead in 1993 ($OR = 168$, $CI = 35–802$, $p < 0.01$) and 1994 ($OR = 84$; $CI = 14–493$; $p < 0.01$). In 1993, droopwing chicks were more likely to have elevated lead than normal chicks ($OR = 53$; $CI = 14–200$; $p < 0.01$). In 1994, droopwing chicks were no more likely to have elevated lead than normal chicks ($OR = 2$; $CI = 1–7$; $p = 0.36$).

In both years, prevalence of elevated tissue lead in live and dead chicks was greatest on Sand Island; there was no elevated tissue lead on Eastern and Spit Islands (Table 1). In 1993, prevalence of lead exposure in live chicks was 95% and 60% on Sand and Spit Island, respectively. In 1994, prevalence of lead exposure in live chicks on Sand, Eastern, Spit and Kauai was 89%, 70%, 33%, and 18%, respectively. Numbers of buildings to which nesting chicks had access on Sand, Eastern, Spit and Kauai were 140, 4, 0, and 0, respectively. All but two adults, including 23 sampled near buildings on Sand Island, had undetectable blood lead; two from Sand Island, Midway, had levels of 0.02 and 0.03 μg/ml. On Kauai, only one of 16 chicks had elevated lead levels (0.2 μg/ml); all others had blood lead levels ≤0.02 μg/ml. Blood lead levels in chicks on Midway ranged from ≤0.02 to 29.69 and liver lead levels ranged from ≤0.25 to 70.5 μg/g ww.

In chicks from Kauai and Midway in 1994, ALAD activity decreased in a somewhat linear fashion at blood lead concentrations >0.05 μg/ml and remained at low levels at concentrations >0.5 μg/ml (Figure 2). For pooled data from the two sites, there was significant correlation ($r = -0.91$, $p < 0.01$) between natural log of blood lead and natural log of ALAD activity. There was a 94% decrease ($p < 0.01$) in mean ALAD (mean ± SD) activity in chicks with blood lead levels >0.5 μg/ml (4.00 ± 1.83) compared to those with levels ≤0.03 μg/ml (65.72 ± 15.16). Mean ALAD activity in chicks with blood lead ≤0.03 μg/ml was not significantly different ($p = 0.73$) than that of adults (66.44 ± 12.43) on Midway in 1994.

Discussion

Lead exposure in albatross chicks throughout Sand Island was associated with buildings, probably from chicks ingesting paint chips as hypothesized by Sileo and Fefer (1987). Several chicks were noted with paint chips in their proventriculus and several live chicks ingested paint directly from buildings. Although Sileo *et al.* (1990) also concluded that lead poisoning in abatross chicks was associated with buildings, the findings in this study are more representative, since the decision to analyze samples for lead was not biased towards animals collected near buildings. Prevalence of elevated tissue lead was lower when liver lead was examined. This suggests that choice of live vs dead birds could affect conclusions regarding prevalence of elevated tissue lead levels; in the former, one examines possibly transient exposure while in the latter, one looks at potential cause of death (lead poisoning).

Elevated tissue lead in albatross chicks was most prevalent on Sand Island and prevalence of lead exposure on islands appeared to decrease with decreasing numbers of buildings; however, this relationship was not consistent. Specifically, the higher prevalence of exposure on Spit Island, Midway vs Kauai (both with no buildings) may be explained by historical presence of structures on Spit which were subsequently razed possibly leaving residual lead as reflected by the low tissue lead levels seen in chicks there. Buildings were not present historically on the site where chicks nest on Kauai. The minimal blood lead levels in Kauai chicks, along with those of adults from Laysan and Tern Islands indicate that lead is probably not a widespread environmental contaminant in Laysan albatross in Hawaii. The source of lead for the one chick with elevated lead on Kauai is unknown. Chicks at Kilauea Point are situated in ironwood groves away from buildings, no sources of lead have been identified, and no hunting occurs or has in the past. As people have fished from Kilauea Point, the one poisoned chick may have ingested a lead fishing sinker.

It is unlikely that adult albatross provide lead (Pb) to chicks through regurgitation given the low blood lead levels seen in adults. On Midway, this was surprising because incubating adults on Sand Island are presumably exposed to lead paint since they share the same habitat as chicks. Either insufficient amounts of lead are ingested to result in detectable tissue levels, lead exposure in adults occurs during a short period of their stay on Midway, or adults do not ingest paint chips at all. The latter is probably a behavior limited to chicks as suggested by Sileo and Fefer (1987). Whether live chicks with lead poisoning can eliminate the contaminant is unknown. Other studies indi-

Table 1. Ranges of tissue lead levels and percent of Laysan albatross chicks with liver lead ≥2μg/g ww or blood lead ≥0.2μg/ml on islands of Midway atoll in 1993 and 1994

	Liver						Blood					
	1993			1994			1993			1994		
Island	N	%	Range	N	%	Range	N	%	Range	N	%	Range
Sand	71	27	≤0.25–70.5	71	10	≤0.25–50	63	62	≤0.02–22.47	19	74	≤0.02–26.69
Spit	0	NA[a]	NA	0	NA	NA	10	0	≤0.02–0.03	12	0	≤0.02–0.13
Eastern	0	NA	NA	0	NA	NA	0	NA	NA	10	0	≤0.02–0.12

[a]NA = Not applicable

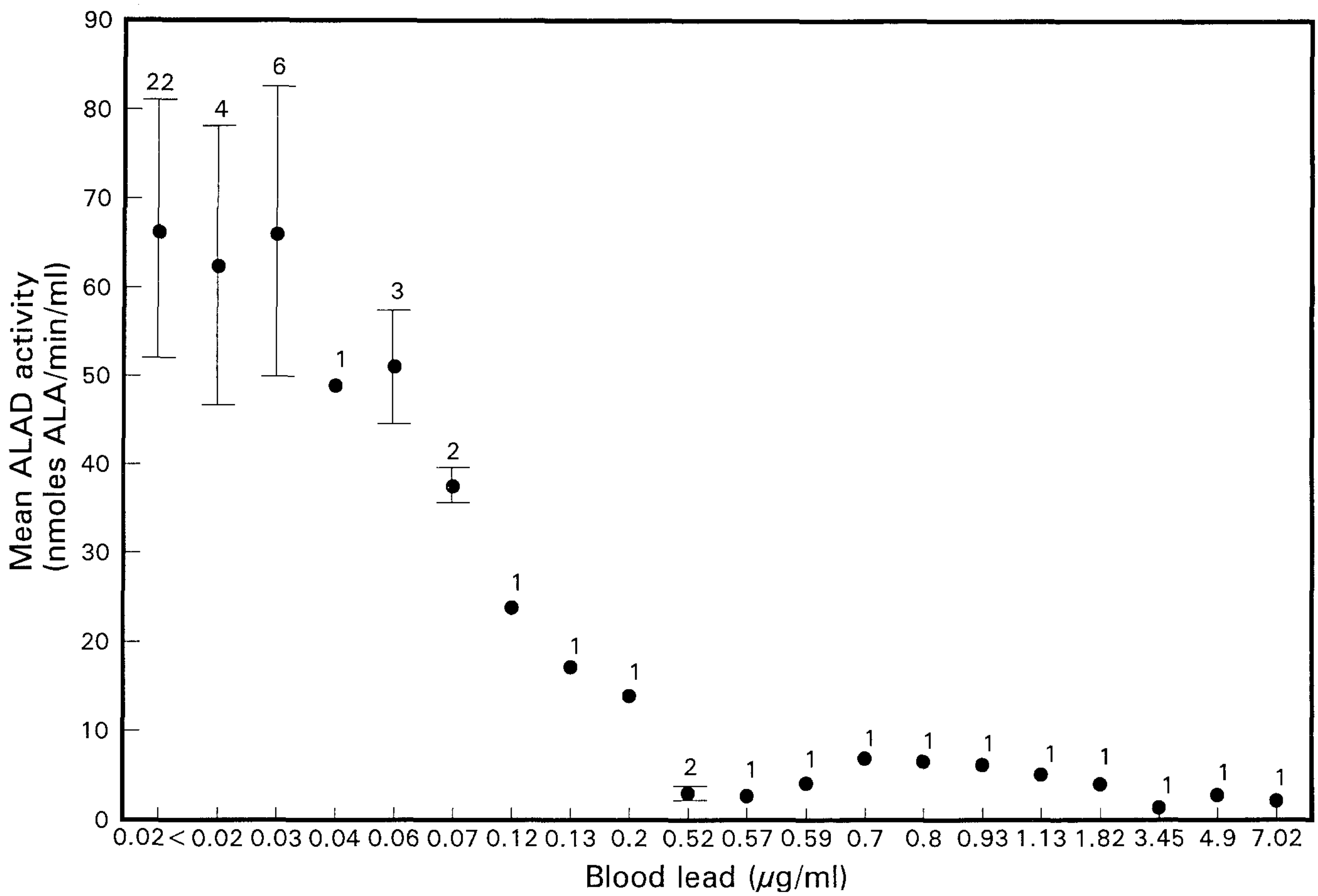

Fig. 2. Blood lead concentration versus mean ALAD activity in Laysan albatross chicks from Kauai and Midway in 1994. Blood lead axis is not to scale. Numbers above each point indicate sample size and bars identify standard deviation

cate that some species of seabirds can eliminate heavy metals through the feathers as they age (Becker *et al.* 1994).

Because lead poisoning on Midway is associated with buildings, mitigation for this toxicant should initially focus in those areas with highest densities of buildings. Stripping paint off buildings without proper containment of chips appears to increase the availability of lead to chicks and compounds the problem. Razing buildings (Sileo and Fefer 1987) is a possibility, but should be done with an eye to containment of paint chips. Burning buildings does not address the issue of concrete structures. Fencing (Sileo and Fefer 1987) appears to be a temporary measure. Demolition and burial of buildings on site are other possibilities.

Lead appears, in part, responsible for droopwing chicks, confirming findings of Sileo and Fefer (1987) and Sileo *et al.* (1990). This was dramatically illustrated in 1993 when paint was stripped from a building without containment of paint chips during routine facility maintenance operations. This resulted in large numbers of droopwing chicks which were seen around the building shortly thereafter. However, not all droopwing chicks were lead poisoned, and droopwing chicks have been observed on other islands without buildings. Apparently, normal chicks can harbor very high levels of lead, suggesting that albatross may be more tolerant to lead exposure than other species (Lumeij 1985). Lack of association between lead poisoning and droopwings in 1994 indicate that other factors play a role in causing droopwing in Laysan albatross chicks. Droopwing chicks have been observed by biologists on islands without buildings such as Laysan Island.

Lead depresses activity of ALAD in Laysan albatross chicks as in other avian species (Finley *et al.* 1976; Stone *et al.* 1977; Hoffman *et al.* 1981; Scheuhammer 1987). The percent inhibition in poisoned albatross chicks was similar to that observed by Finley *et al.* (1976) in mallards (91%) with 2.4 μg/ml of blood lead and Murase *et al.* (1993) in an unspecified species of duck (97%) with blood lead levels of 11 μg/ml. Percent ALAD inhibition in albatross chicks was higher than that seen in lead exposed quail (45%) with unreported blood lead levels (Stone *et al.* 1977) and bald eagles (80%) with blood levels of up to 8.8 μg/ml (Hoffman *et al.* 1981). The lack of difference in ALAD activity between chicks with blood lead ≤0.03 μg/ml and adults indicates that 0.03–0.05 μg/ml is a no observable effect level for lead in albatross chicks with regards to this enzyme (Figure 1). The use of 0.2 μg/ml as a cutoff for elevated tissue lead in albatross chicks also seems appropriate based on ALAD data. Hoffman *et al.* (1985) found higher ALAD in unexposed kestrel chicks than in adults. However, the chicks in their study were much younger relative to adults than the albatross chicks in our study which were close to fledging. This would probably account for lack of differences in ALAD activity between age groups in normal Laysan albatross.

Acknowledgments. We extend our gratitude to William Iko, Bob Dusek, Lawrence Ames, Bob Rameyer, and Allison Beale who provided field assistance on Midway. Sincere appreciation is due to Mike Nishimoto, Midway Atoll NWR refuge manager, for logistical support, and to Ken McDermond, Remote Refuges Manager, for permission to work on the northwest Hawaiian Islands. Mike Samuel and Tim Ragen provided useful advice regarding statistical analyses. Chris Franson, Lou Sileo, Dave Hoffman, Chris Brand, and anonymous reviewers provided constructive comments on the manuscript. Finally, the gracious loan of laboratory space to the Honolulu Field Station by the Hawaii Department of Agriculture, Veterinary Branch, made much of this work possible.

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