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Band Loss in North Pacific Populations of Laysan Albatross (diomedea Immutabilis) and Black-footed Albatross (d Nigripes)

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Abstract

Size 7-B aluminum bands were recovered from Laysan (N=124) and Black-footed Albatrosses nesting at Midway Atoll in 1979 and 1992-93. Each band was weighed to the nearest 0.001 g and etched if illegible. Bands recovered from Laysans were carried from 0.6 to 30.4 years and lost an average of 2.42% of their weight per year (range 0.79-7.13%/yr). Band loss commenced about year 13 for most series, but as early as eight years in one corroded 807- prefix series. The oldest legible band was carried only 19 years; all bands worn longer required etching to recover the number; half were illegible by 14 years. When the average Laysan band had lost 54% of its original weight, it fell off. Once band loss begins, it adds an error of 9.45%/year to the estimated annual mortality rate.

Aluminum bands on Black-footeds averaged 1.4%/year weight lost (range 0.22-2.95%./yr.), with just 17 of 217 bands losing >2% of their weight/year. One band was recovered in the field shortly after it fell off; it had been carried 32.9 years and had lost 54% of its initial weight. Black-footeds will retain aluminum bands 23 years, and 50% of banded Black-footeds will retain aluminum bands for 37 years. Band loss will begin to bias data seriously after year 23 and be lost at the rate of 5.4%/year thereafter. Although many bands carried by Black-footeds longer than 15 years required etching to recover the number, 23% of bands carried 25.7-33.7 years were legible. Aluminum bands are not suitable to provide long-term survivorship and life table data for Laysans but are marginally suitable for Black-footeds. No difference was found in band wear rates among Black-footed Albatrosses banded as chicks and those banded as adults. Rebanding of albatrosses carrying aluminum bands should be a priority.

INTRODUCTION

The nature of band loss makes measuring loss rates difficult (Kadlec 1975). Abrasion may complicate the interpretation of data sets since band numbers may be recovered by professionals using etching techniques, but only if they have access to the illegible band (F.E. Ludwig 1941). For very long-lived species like albatrosses, loss of conventional aluminum bands is virtually certain to influence survivorship data (J.P. Ludwig 1981). Numerous authors have analyzed data for one species of interest to them (Anderson 1980, Bailey et al. 1987, DiCostanzo 1980, Hickey 1952, Poulding 1954, Spear 1980, Ludwig 1967), often speculating that band loss was an important source of error in their life table analyses (Hatch and Nisbet 1983, Ludwig 1967, Paynter 1966). Others had too few recovery data to correct life tables (e.g., Schreiber and Mock 1988, Fordham 1967). Various models of band loss have been proposed (Brownie 1973; J.P. Ludwig 1967, 1981; Nelson et al. 1980).

Reported wear rates of aluminum bands range from a minimum of 0.57%/year in Sooty Terns (*Sterna fuscata*) (Bailey et al. 1987) up to a maximum of >9.5%/yr in Ring-billed Gulls (*Larus delawarensis*) (Ludwig 1967) and Eared Grebes (*Podiceps nigricollis)* (Jehl 1990). Corrosion can cause the loss of monel and aluminum bands (Ludwig 1981). The mass of band worn away before loss occurs is also widely variable from 14% in Sooty Terns to 60-70% in Caspian

Terns (*Sterna caspia*) and Ring-billed Gulls. Each species seems to have a characteristics mass loss rate for each metal type and a typical end point. Empirical studies of bands recovered from birds offer the clearest picture of the ways that band loss influences life tables (Hatch and Nisbet 1983; Ludwig 1967, 1981). A typical survivorship curve is produced for data from birds banded as chicks that lose bands (Ludwig 1967, 1981; Bailey et al. 1987). This semi-logarithmic curve is characterized by four phases: (1) An initial rapid downturn phase in the first year post-fledging reflecting high first- and second-year mortality rates; (2) a linear section of varying length in the early adult life (four years in Ring-billed Gulls [Ludwig 1967]; 10-22 in Caspian Terns [Ludwig 1981]; 17-24 in Sooty Terns [Bailey et al. 1987]); (3) a curvilinear section where the *apparent* rate of death rises as band loss begins; and (4) a final steeper decline section where the rate of band loss adds to the real mortality (Ludwig 1967, 1981). Mortality estimates of older birds are typically grossly inflated by the effect of band loss. For short-lived species, this effect is largely irrelevant. However, these errors can lead to serious underestimation of age-specific survivorship and highly inaccurate population models for long-lived species that reproduce for decades.

Two north Pacific albatrosses, Laysan *(Diomedea immutabilis)* and Black-footed *(Diomedea nigripes)*, were banded with aluminum butt end style bands beginning in the late 1930s. Large numbers were tagged after 1955. Experimental monel metal bands were applied to chick cohorts in 1967. Cohorts of Laysan and Black-footed chicks were banded with stainless bands in 1978 and 1979, respectively. After 1986, many previously banded albatrosses were rebanded with incaloy and stainless steel bands, and a few chicks were banded with these newer "hard" bands after 1984, as well as the readily available aluminum butt-end style bands. Because most of the albatrosses were banded in the north Pacific colonies with conventional aluminum bands, it is essential to study their wear patterns if those data are to be used to model populations or generate life tables. In 1979, while rebanding several thousand breeding adults of each species, the senior author recovered 173 aluminum bands from albatrosses at Midway. From November, 1992 through December, 1993, an additional 223 bands were recovered. Five monel bands were recovered in this same period from Laysan Albatrosses found dead. We describe patterns and rates of wear in the 346 of these 401 bands for which banding data were available. Our goal is to determine when band loss begins and to measure how it affects albatross survivorship data.

MATERIALS AND METHODS

We used the simple empirical band loss estimation model developed by Ludwig (1967, 1981). This model requires a sample of bands with 95% of the wear rates in a range of the mean value $\pm$ 2/3 of the mean, and a normal distribution of wear rates to be used. Only 2 of 112 uncorroded Laysan bands and four of all 217 Black-footed bands fell outside of these distribution and the range requirements. This model derives estimates from bands with particular wear rates and a known endpoint and projects the additive error for a life table calculated from raw banding data. We compared used albatross bands with 1226 new 7-B bands from three series; 1,000 from a 587-prefix series manufactured in the mid-1950s, 26 from a 1227-series manufactured in 1977; and 200 from a 1247-series manufactured in 1981. These reference bands averaged 1.846, 2.110, and 1.832 grams respectively (Table 1). Within each series, the variance was quite small (SDs 6.1-22.1). The newest aluminum bands manufactured from 1980 were heavier but more variable. We used 1.846 g for the base weight of calculations, except for the five bands made after 1981 for which 2.11 g was used.

First, bands placed on Black-footed chicks were separated from those placed on adults, but we

Table 1. Weights of Representative New 7-B Butt-end Aluminum Bands.

Band Series	Mean Weight (g)	Range	S.D.
587-67001-68000	1.846	1.793-1.867	11.3
1227-26675-2670	1.832	1.813-1.848	6.1
1247-87001-8720	2.110	2.049-2.139	22.1

could not detect measurable differences in wear rates between these groups (chick mean 1.38%/yr, SD= 0.27; adult mean 1.41%/yr, SD= 0.36; 0.10<P=0.20). Nine Black-footeds which were banded as chicks during 1960-1968 were recaptured in 1979 and rebanded with a new aluminum band: In 1992-94 we recaught these individuals and recovered their second bands. Three wore out their first bands more rapidly, two wore both bands at essentially the same rate, and four wore out second bands more rapidly as adults. For this group the mean rate of wear on the first (chick) band was 1.52%/year vs 1.54%/year for the second (adult) band. Therefore, we combined all bands of each species, whether banded as a chick or adult, into single samples for further analysis.

Each used band was weighed, and the time worn was used to calculate a specific weight loss [1.846-band weight = specific weight loss (SWL)], the annual rate of weight loss [SWL/years worn = annual rate of weight loss (ARWL)], and the life span of the band projected to an endpoint [ARWL/end point = band life span (BLS)] (Table 2). Endpoints were estimated from graphical plots of wear rates over time and field observations. One band, 54% worn, was found when it fell off a Black-footed. The most worn bands we encountered had lost 59.1% (Laysan) and 62.2% (Black-footed) of original weight, but very few (9) bands were found on either species that had lost >55% weight. Since we recaptured thousands of banded birds of these species including 137 birds known to be 30 years or older, if bands were surviving the loss of more than 55% of initial mass regularly, we would have encountered them. From these observations, we selected the average end points of 54% and 56% of metal loss for Laysan and Black-footed Albatrosses, respectively.

Nearly half the bands (186) carried longer than 10 years by Laysan Albatross or 18 years by Black-footed Albatross were partially or completely illegible and were etched to recover the number. Every Laysan band older than 19 years required etching, but some Black-footed bands as old as 33.7 years were still legible. Numbers were found on all these bands, but up to four etchings were required for a few bands. Experimental etching of three bands revealed an average loss of 2.3 mg weight per treatment with acid etch solution to the whole numbered surface of the band. This could add an error of up to 1% to the wear calculations made for a band that had lost 40% of its base weight and was completely etched four times. This potential error was ignored since it was close to the variance of weights of new bands. Most bands required only 1 or 2 etchings on part of the band surface to recover one to three digits of the number.

RESULTS

Laysan Albatross bands averaged 2.46%/year of metal loss with a wide range of rates (0.78 - 7.06%). The fastest rates, 5.39 - 7.06%/year were by 12 bands all in a series of 807-prefix bands which had corroded: these were the only corroded aluminum bands encountered (Table 2). These 12 bands were eliminated from the analysis as atypical. The average 112 uncorroded Laysan band lost 2.42%/year (range 0.78 - 4.75%); 98% of this band sample fell within the range required by the Ludwig (1981) model. With a 54% endpoint and an average wear rate of 2.42%/year, half of the bands would last 22 years. Band loss for a cohort of Laysans, calculated from the mean value (2.42%/yr $\pm$ 1.61 = 0.81 to 4.03%/year wear rates) would begin at 13 years, and the last band will be lost at 52 years (Tables 3 and 4). Many Laysan bands were already illegible after 13 years; thus, the effects of wear on the data will be even greater than this calculation unless all the bands found are etched for data used to calculate life tables. Sixty of the 124 bands in this sample were etched. One subsample of 50 Laysan bands in an 1117-prefix series applied by the senior author in 1979 was recovered after 12.8-14.0 years of wear; 32 (64%) were etched to recover the full number. Once band loss begins, the proportion of surviving birds retaining bands decreases very rapidly (Table 4). Following Fisher's (1976) estimate of a mean survivorship of 94% for adult Laysans, by age 40 when 65 survivors from a cohort of banded chicks would be alive, only four will retain bands. Another way of stating this is that the probability of recovering an aluminum banded 40-year-old Laysan is only 6% (1-61/65=0.06)of what it would be if durable bands had been used (Table 4).

Table 2. Wear Characteristics in Aluminum Bands on Albatrossses.					
		Percent Per Year Wear Rates			
Species	Number in Sample	Mean	Maximum	Minimum	Estimated Mean End Point
Laysan - all	124	2.46%	7.13%	0.78%	54% of weight lost
Laysan - 807 Series	12	6.23%	7.13%	5.39%	"
Laysan Less 807 Series	112	2.42%	4.75%	0.78%	"
Black-footed	217	1.40%	2.95%	0.22%	56% of weight lost

Five legible monel metal Laysan bands were recovered. The mean weight of two carried 12.2 years compared to three carried 26 years was only 7.16% different, for an estimated ARWL of only 0.52%. No unused bands of this type were available to compare with these five bands. If this wear rate is representative for monel bands on Laysans, then loss of monel bands would not begin until year 62 on this species (Table 2). However, we saw monel bands (none in our sample of five) in the field with significant corrosion and pitting around the numbers that may well lead to unpredictable loss rates in the future, similar to Eared Grebes (Jehl 1990) and Caspian Terns (Ludwig 1981).

Black-footed Albatross bands wore out at much slower rates, averaging 1.4%/year; only 12 bands in the 217 band sample had lost >2%/year of their weight. Four bands (2%) fell outside the required range criterion of the model ($1.4 \pm 0.93 = 0.47$ - 2.33%/year). With an endpoint of 56% weight lost, band loss is estimated to begin at 23.1 years. Half the bands would be lost at 37 years, and the last band would fall off at 104 years (Table 3). The oldest Black-foot band recovered for this analysis was 33.8 years, but 77 of the 217 bands (35%) had been carried >25 years. Of these oldest 77 bands, 18 (23%) were still legible. The effect of band loss on life table estimates of Black-footed is much less severe than for Laysan Albatrosses. Serious

Table 3. Distribution of Band Loss in Albatrosses.				
Species/Band	Start of Band Loss	End of Band Loss		Effect on Survivorship Rate
Metal and Series	Endpont/max rate	Endpoint/min rate	Endpoint/mean	Increased Rate
Laysan/Aluminum Except 807 Series	54/4.75 = 11.4 y.	54/0.78 = 69 y.	54/2.42 = 22.3 y.	9.95%/year after year 11
Laysan 807 Series - Aluminum	54/7.13 = 7.6 y.	54/5.39 = 10 y.	54/6.23 = 8.67 y.	30.8%/year after year 9
Laysan Model for 98% of Sample	54/4.03 = 13.4 y.	54/0.81 = 66.7 y.	54/2.42 = 22.3 y.	9.45%/year after year 13
Laysan Monel			54/0.52 = 104 y.	1.92%/year after year 62
Black-footed all Alum.	56/2.95 = 19 y.	56/0.22 = 255 y.	56/1.40 = 40 y.	5.6%/year after year 22
Black-footed Model for 98% of Sample	56/2.33 = 23.1 y.	56/0.47 = 119 y.	46/140 = 40 y.	5.6%./year after year 22

Table 4. Life Table Calculations Including the Timing of Impacts of Band Loss on Data.						
Age of Birds in Years	Number Alive		Number Alive Still Carrying Bands		Underestimation of Age-Specific Survivorship	
	LAAL	BFAL	LAAL	BFAL	LAAL	BFAL
FLEDGING	1,000	1,000	1,000	1,000	NONE	NONE
7	500	500	500	500	NONE	NONE
13	345	345	345	345	NONE	NONE
LAAL band loss begins at 13 years. Tag loss of 9.45%/year + 6% natural mortality.						
15	305	305	247	305	52	0
20	224	224	107	224	117	0
BFAL band loss begins at 23.1 years. Tag loss of 5.6%/year + 6% natural mortality.						
25	164	164	46	155	118	9
30	120	120	20	84	100	36
35	88	88	9	46	79	42
40	65	65	4	25	61	40
45	47	47	2	13	45	34
50	35	35	1	7	34	28
55	26	26	0	4	26	22
60	19	19	0	2	19	17
65	14	14	0	1	14	13
70	10	10	0	1	10	9
104	1	1	0	0	1	1

biases do not occur until year 23, and the rate of loss is lower at 5.6% (Table 4). At year 40, 38% will still have their bands compared to 6% of Laysans. The last Black-footed from a banded cohort would lose its band at age 72.

DISCUSSION

The patterns of band wear are virtually identical for these species. Abrasive wear is concentrated on the outside of bands, often causing loss of the number before the band falls off. Many other long-lived birds tend to abrade bands most rapidly on the inside (Ludwig 1981). More wear may occur on the outside because they nest on coral sand. Their eggs are laid directly on the ground in unlined or poorly lined nests. It is common to encounter bands with one or two of the eight digits readable and still a significant thickness of metal remaining. All bands weighing 60% or less of their initial weight had to be etched. This abrasion pattern will further bias survivorship and life table data contributed by the public which is less likely to send in unreadable bands to an unknown address. The fact that etching allows professionals to recover these numbers is somewhat reassuring.

Clearly, aluminum bands are not suitable for collecting survivorship data for Laysan Albatrosses breeding first at ages 6-9 and having a 6%/year adult death rate (Fisher 1976). Assuming half of a banded fledged Laysan chick cohort were to die before first nesting at age 7 and a 6% adult death rate, then band loss begins when two-thirds of chicks that survived to become breeding adults were still alive (Table 4); 38% of these adults would be alive when half the bands were lost

(Table 4). Band loss is estimated to proceed at 9.45%/year, the apparent death rate after year 14 would be over 15% (real mortality of 6% + 9.45% band loss). Because abrasion obliterates so many band numbers, the effect on life table data is surely even greater than we calculate.

Band loss projections for Black-footed Albatross are more encouraging. The lower wear rates in this species indicate that band loss will not bias the survivorship data until after year 23 when 37% of the adults are still alive (Table 4). Half the bands should be left when only 13% survive, if model parameters are accurate. The constant band loss error (5.6%/year) added to the real Black-footed mortality is significantly less than the 9.45% for Laysan Albatross data. Roughly 1% of the Black-footed Albatross bands could be expected to survive to age 72 when nine of a cohort of 1,000 banded Black-footed Albatrosses fledged would be alive. However, the probability of recovering a legible band on aged birds of either species is very low.

It is somewhat surprising that Laysans wear out their bands at close to twice the rate of Black-footeds. Black-footeds prefer to nest on open beaches in nests scooped out of coral sand. Laysans prefer to nest under vegetation and often line nests with leaf litter. Given the abrasiveness of coral sand, it might be expected that the reverse would be true. However, we have noted that Laysans are more restless when incubating. Laysan nests are often heavily infested with *Argus argus* ticks, but few Black-footed nests had ticks. Laysans were often captured with numerous tick bites on their feet and brood patches. Ticks may stimulate Laysans to move legs frequently, thus wearing out bands more rapidly. It was also a surprise that wear rates did not differ among those Black-footed Albatrosses banded as chicks and those banded as adults. Intuitively, we expected that chicks would wear bands more slowly because they spend much of their juvenile life at sea where abrasion is thought to be minimal.

The model we use does not make allowances for senescence or increasing mortality rates in aged birds of these species and is not realistic for very old birds (Table 4). However, during our studies we encountered banded Laysan Albatrosses nesting at ages 43 and 45. A Black-footed banded as an adult in 1956 was recaught on a nest in 1994, making this bird at least age 43 and possibly significantly older. In three years of field studies, we encountered 137 banded birds of both species nesting that were 30 or more years of age. Because albatrosses are among the longest lived of all birds, their bands should be suited to their life span and extended breeding period.

Other novel marking techniques of producing mark-recapture data are reported. These include web tags (Haramis and Nice 1980), plastic neck collars (Raveling et al. 1992), radiotelemeters (White 1983), and specially modified leg bands (Blums et al. 1994). However, each of these techniques has been applied to relatively short-lived species with much higher natural death rates. For species with lower survivorship rates, loss of their conventional metal bands will be less important to the integrity of the data collected on populations since very few birds would be alive when band loss begins (Ludwig 1981). Some very desirable techniques, such as satellite radiotelemetry, have been used successfully on Wandering Albatross *(Diomedea exulans)*, for relatively short periods at a very high cost per individual monitored (Weimerskirch et al. 1993). Banding is likely to remain the method used to mark large numbers of birds for population studies.

Band retention is critical to interpretation of all mark-recapture data sets. Several studies used metal bands to verity retention of other types of tags in the short term of weeks to a few years (Nichols and Hines 1993). However, each of these thoughtful approaches was applied to species for a few years or less rather than the five to seven decades that some albatrosses live. Conventional banding will be the method of choice to study the very long-lived albatross populations for the foreseeable future. The challenges are to render the available banding data as accurate as possible and to use durable bands on albatrosses. Abandoning banding in favor of other unproven methods which are very expensive or are unsuited to the long-term performance required of albatross tags is not recommended.

CONCLUSIONS

Standard butt-end aluminum bands are not durable enough to produce accurate life table data for either albatross species directly. However, aluminum bands may be good enough to produce useful data for Black-footed Albatrosses, provided illegible bands are etched and these data segregated from those produced by recoveries obtained from the general public which is less likely to send in illegible bands. For these two albatrosses which had large numbers banded with conventional aluminum tags during the 1960s and 1970s, it is now critical to reband these adults to retain at least part of the very old banded cohorts for future research. Aluminum bands are better than no bands. But, considering the high cost to reach albatrosses for banding, stainless steel "hard" bands with very low rates of metal loss must be used. Banding authorities should encourage the use of bands made of the appropriate metals with deeply inscribed numbers to lessen number loss from abrasion of the band surface.

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