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ABRASION AND LOSS OF BANDS FROM DRY TORTUGAS SOOTY TERNS

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Abstract.—During the past 25 yrs more than 400,000 Sooty Terns (*Sterna fuscata*) have been banded at Dry Tortugas, Florida, with size 3 aluminum bands of several different alloys. Based on large samples of bands removed from the terns, regression lines were established for each of four alloys. Differences in the slopes of the regression lines for certain of the four alloys demonstrated differences in rates of abrasion. Band loss was evident for bands of the fastest abrading alloy (2-SO) that were carried more than 20 yrs by terns banded as chicks because all band weights fell above an extension of the regression line. For this alloy, the plots of weight loss showed that band loss becomes significant at 86% of original weight. Bands of alloy 2-SO began reaching 86% of original weight at age 14 when placed on adults and 20 when placed on chicks. The regression lines for the other 3 alloys suggest that loss is likely after 17–28 yrs for bands placed on adults and after 20–25 yrs for bands placed on chicks. Band loss probably occurs through abrasion of the inner surface, which increases the inner diameter until the band can slip over the toes. Any gap that develops would hasten loss.

At the Tortugas, many terns carrying bands for more than 20 yrs have been recaptured; the record to date is 32 yrs. Clearly Tortugas Sooty Terns outlive their bands. Suggestions to reduce the problem of band loss include ignoring data on terns recaptured in years after band loss is suspected when calculating demographic parameters, regularly adding new bands to banded terns recaptured after about a decade, and using bands of harder metals such as stainless steel.

DESGASTE Y PERDIDA DE BANDAS EN ESPECIMENES DE *STERNA FUSCATA* ANILLADOS EN DRY TORTUGAS, FLORIDA

Sinopsis.—Durante los últimos 25 años más de 400,000 especimenes de *Sterna fuscata* han sido anillados en Dry Tortugas, Florida, con bandas de diferentes aleaciones de metal. Se establecieron líneas de regresión para 4 aleaciones basado en bandas que se removieran las propias gaviotas. Diferencias en la pendiente de la línea de regresión para algunas de las aleaciones demostraron diferencias en el estimado de desgaste. La perdida de bandas fue evidente en aquellas hechas de metal con el mayor grado de desgaste (2-SO) y que fueron cargadas por más de 20 años por gaviotas anilladas como polluelos. Esto debido a que el peso de estas bandas cayó bajo la extensión de la línea de regresión. Al graficarse el peso perdido de estas bandas se encontró que la perdida de estas fué significativa al llegar al 86% de su peso original. Las bandas 2-SO alcanzan este nivel de desgaste a la edad de 14 años cuando son colocadas en adultos y a la edad de 20 años cuando son colocadas en polluelos. Las líneas de regresión para otros tres tipos de bandas (con aleaciones diferentes) sugiere que la perdida de las mismas debe ocurrir entre los 17–28 años luego de ser colocadas en adultos o entre 20–25 años cuando son colocadas en polluelos. La perdida de las bandas probablemente ocurre debido a desgaste de la superficie interna, lo que causa aumento en el diámetro interno y permite que la banda se deslice sobre los dedos de la pata.

En Tortugas se han recapturado gaviotas de más de 20 años de anilladas siendo el record un especimen de 32 años; las aves sobrepasan la vida útil de las bandas. Para reducir el problema de perdida de bandas se sugiere se ignore la data de aves recapturadas en años posteriores a la vida promedio de las bandas, cuando se trata de calcular parametros demográficos. Se sugiere además el anillar nuevamente a aves que han sido recapturads una década más tarde y la utilización de bandas construidas con metales más duros como el acero inoxidable.

The most common method for marking a bird is to place a uniquely numbered metal band or ring loosely around the leg. Loss of bands, which has been investigated most in seabirds, skews the estimates of many life-history parameters (Anderson 1980; Coulson 1976; Coulson and White 1955, 1957, 1959; Harris 1964; Hatch and Nisbet 1983a,b; Kadlec and Drury 1968; Ludwig 1967, 1981; Paynter 1966; Poulding 1954). Abrasion seems to be the most common cause of band loss. Abrasion on the inner surface may cause the internal diameter of a band to increase enough for it to slip over the bird's toes. Abrasion may make a band thin enough to form a gap or break and fall off. Band loss can also occur if the bird intentionally removes its band (Ludwig 1967, Poulding 1954, Rowley 1966). Finally, a band can be caught on debris or vegetation, and pulled open and off as the bird struggles to free itself (Spear 1980). Schemnitz (cited by Hatch and Nisbet 1983b), for example, found a band caught on a mist net being used to catch Arctic Terns (*Sterna paradisaea*).

Several investigators have concluded that bands abrade at a fairly constant rate for a given species in a particular habitat (Coulson 1976; Coulson and White 1959; Fordham 1967; Ludwig 1967, 1981). If correct, it is possible to estimate how long bands can be carried by individuals in a population before they begin to come off. These estimates are derived from comparing rates of abrasion to weights when bands first disappear. The weights of bands when they come off birds rarely are known but can be estimated by comparing weights of samples of bands carried by birds for varying lengths of time. To make this estimate we assume that when losses become frequent the mean weights of the samples of bands arranged chronologically by duration on the birds, will level off or rise.

During the past 25 yrs more than 400,000 Sooty Terns (*Sterna fuscata*) have been banded at the Dry Tortugas, a group of seven keys about 112 km west of Key West, Florida. One objective of the massive banding program is to obtain demographic data for this abundant, long-lived, and otherwise well-studied pelagic bird. This study of band abrasion was conducted to determine whether band loss is occurring in the population, and if so at what age it begins. Advantages of this study over many others addressing the problem of band abrasion include: large samples of both abraded and unused bands available for analysis; bands of one size and one style carried by one species for up to 24 yrs; and fairly uniform nesting habitat, sparsely vegetated calcareous sand, and foraging habitat, tropical seas.

MATERIALS AND METHODS

By 1980, almost 300,000 Sooty Terns had been banded as chicks and 102,000 as adults, at the Dry Tortugas. Size 3 aluminum butt-end bands, supplied by the Bird Banding Laboratory, Patuxent, Wildlife Research Center, Laurel, Maryland, have been used exclusively. However, the various bands used include several aluminum alloys, of which four were analyzed in our study. Prior to 1960, bands of two other alloys were used. We collected 28 of these from terns after they had been carried for 6–32 yrs. Unfortunately, small samples prevented the bands applied early in the study from being treated statistically. The Bird Banding Laboratory supplied the names of the four alloy types we studied; Hatch and Nisbet (1983a: Table 3) measured their concentrations of minor constituents. The names match with columns in their Table 3 as follows: alloy 2-SO with their year column 1959, alloy 3003-0 with 1960, alloy 1100-H14 with 1964, and alloy 5052-0 with columns 1965 and 1968. In 1968 and 1969 large numbers of abraded bands were collected randomly for this study. More recently, to increase sample sizes of bands carried for longer periods of time, we removed bands carried by terns for 15 or more yrs. The sample used in our study consists of more than 2000 abraded bands of which 942 are from terns banded as adults and 1283 are from terns banded as chicks. A total of 2227 unused bands of the series used on Sooty Terns between 1959 and 1969, obtained from the Bird Banding Laboratory, are also used in this study.

Bands were weighed to the nearest 0.0001 g. Repeat weighings indicated errors ranged only from 0.0001 g to 0.0006 g. The mean weights of unused bands of the same prefixes and alloys as the abraded bands were used to estimate the original weights of the abraded bands. Even within the same alloy significant differences in mean weight were found among prefixes of unused bands. Weights of the abraded bands were converted to percent of the estimated original weight, so that the weights of bands with different prefixes could be compared.

We obtained Knoop hardness values for each alloy using a Leco M-400 microhardness tester (Table 1). Hardness values are a quantitative measure of a metal's resistance to pressure. A hard metal, such as stainless steel, has a much higher hardness value than a soft metal, such as aluminum.

We attempted to test for linearity of our data on the percent of weight lost from bands over time. To determine if the variances were homogeneous, residuals were plotted (Zar 1974) for each of the 4 alloys placed

TABLE 1. Knoop hardness values for four alloys used in bands placed on Dry Tortugas Sooty Terns.

Alloy	Prefix	Mean Knoop hardness values
2-SO	643	33.4
3003-0	683	38.7
1100-H14	743	66.2
5052-0	963	66.8

on adults (years 2–15) and chicks (years 4–18). We also plotted residuals for the bands from adults after including the data from years 18 through 21 with similar results. In all plots of the originals, variances appeared homogeneous, therefore we concluded that linear regression properly describes our data.

Linear regressions and correlations were performed using the Statistical Analysis System (SAS, 1982 Version) procedures REG and CORR. Linear regression and correlation statistics were used to compare the relationship between weights of abraded bands, expressed as percent of estimated original weight, and the number of years carried by a tern. These analyses were performed separately for bands originally placed on chicks and on adults, and also on these two groups sorted by alloy. Bands were recovered for this study at approximately the same time of year as they were originally placed on the terns. Thus, band age is given as the number of years the band was carried by a tern. Included in the regression analysis were band age catagories for which we had sample sizes of 30 or more. Two exceptions for chicks were bands carried for 11 yrs (n = 29), and 12 yrs (n = 23). The one exception for adults was bands carried for 12 yrs (n = 28). Sooty Terns hatched at the Dry Tortugas usually do not return to their natal colony until their fourth year (Harrington 1974, Robertson 1964), therefore for chicks we had sufficient samples only for bands carried from 4 through 18 yrs. Bands carried by adults from 2 to15 yrs are analyzed. Analysis of covariance (Zar 1974) was performed to determine if significant differences occurred between slopes of regression lines for alloys within each group. Where appropriate a Student-Newman-Keuls multiple range test was used to determine where differences occurred.

In order to make our data comparable to those from other studies, we calculated a mean annual percent loss of weight for bands of all alloys combined. To do this, first we calculated a mean for the percent of estimated original weights for each year sample taken from the terns. The differences between successive yearly means were averaged to produce the mean annual percent loss of weight. The mean annual percent of weight loss for bands placed on chicks was not statistically different from the mean for bands placed on adults, therefore a single mean annual percent loss (0.57%) was calculated for Sooty Terns.

TABLE 2. Rates of abrasion of bands placed on Dry Tortugas Sooty Terns.

Alloy	Slopes of regression lines	
	Banded as adult	Banded as chick
2-SO	−0.806	−0.804
3003-0	−0.685	−0.594
1100-H14	−0.476	−0.514
5052-0	−0.410	−0.572

RESULTS

Abrasion of Sooty Tern bands is concentrated on the inner surface, and as field observation proved, especially at the lower edge. This abrasion, no doubt caused by rubbing against the tarsus (Olsson 1958), may be enhanced by particles of sand lodged between the band and the leg (Hatch and Nisbet 1983a, Ludwig 1967). The average rate of weight loss for all bands is 0.57%/yr and is similar for birds banded as chicks and those banded as adults. However, for bands carried for equal durations the weight of bands placed on adults is lower than for those placed on chicks by the equivalent of 2.6 yrs of abrasion (range: 1.93–3.72 yrs). Sooty Terns are pelagic and are on land only during the annual breeding season (Dinsmore 1972). A few young terns may return to the colony as early as 3 yrs after fledging, but most will not breed for another 3–4 yrs (Harrington 1974, Robertson 1969). We suspect that most abrasion occurs while the terns are on the ground for breeding; therefore, considerable loss of weight from bands placed on chicks should not begin until 6 or 7 yrs after banding. However, only a 2–4 yr difference exists in the amount of weight lost from bands placed on chicks and those placed on adults. Clearly some abrasion occurs in the years prior to breeding. We suspect much of this abrasion occurs before the chicks first leave the island, because preflying chicks spend much time running about in the colony.

Comparing the slopes of the regression lines (Table 2) through an analysis of covariance demonstrates that significant differences exist between the four alloys placed on adults ($F = 29.71$, $P < 0.05$) and chicks ($F = 14.08$, $P < 0.05$). Results of the Student-Newman-Keuls multiple range test showed that on adults alloys 3003-0 and 2-SO abrade at faster rates than alloys 1100-H14 and 5052-0. The latter 2 have equal rates of abrasion, and alloy 2-SO abrades fastest ($P < 0.05$). The same test shows that on chicks alloy 2-SO abrades faster than the other three alloys, which have statistically equal slopes.

Our results support the opinions of others that band abrasion is constant through time (Coulson 1976; Coulson and White 1959; Fordham 1967; Ludwig 1967, 1981). Plots of residuals demonstrated that regardless of alloy type, the rate of abrasion is constant for Sooty Terns banded as adults from years 2 through 15, and for individuals banded as chicks from years 4 through 18.

The regression lines were extended beyond the years for which they

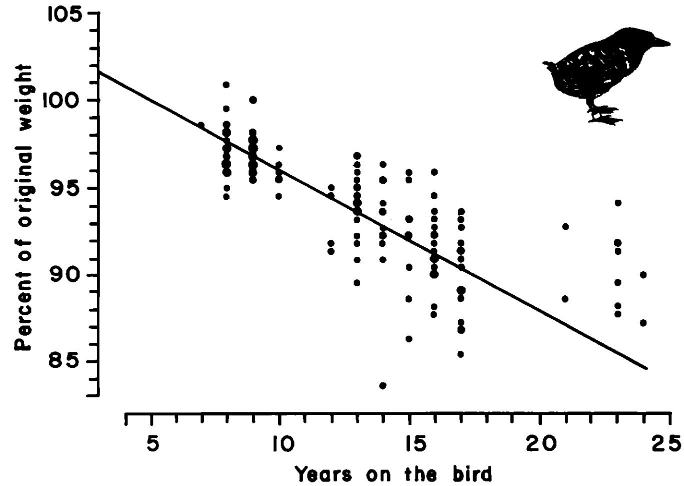

FIGURE 1. Relationship of weight lost over time for bands of alloy 2-SO placed on Sooty Tern chicks. The regression line was calculated for years 4–18. Four increasing dot sizes represent samples of 1, 2, 3–5, and 6–10 weights, respectively.

were calculated and their extensions were compared to actual data points for bands carried by chicks for 18 or more yrs (17 yrs for alloy 2-SO) and for bands carried by adults for 15 or more yrs. A noteworthy trend was demonstrated for bands made of alloy 2-SO that were placed on chicks (Fig. 1). The weights for all 11 bands carried for more than 20 yrs lay above the extended regression line. Unfortunately, no alloy 2-SO bands carried by chicks for yrs 18 to 20 were available. As exemplified by alloy 3003-0 placed on chicks (Fig. 2), no such trend was evident for the other three alloys. These results suggest no loss through the years analyzed.

DISCUSSION

Sooty Terns lose bands, and the most probable cause of band loss is excessive abrasion. The rate of abrasion for aluminum bands carried by Sooty Terns is much lower than the rates for many other long-lived seabirds (Table 3). This may be explained in part by differences in habits between the species. Many seabirds are far more terrestrial, spending more time moving about on the ground, than the highly pelagic Sooty Tern, and this may increase abrasion of the bands. Many also spend more time on the water than do Sooty Terns, and this may increase corrosion of the bands.

Differences in fit of the band may account for different abrasion rates, with a closer fit resulting in less abrasion (Hatch and Nisbet 1983a; Ludwig 1967, 1981). Sooty Terns, which show lower abrasion rates than Arctic Terns, have larger feet. Based on measurements taken from a series of skeletal specimens (G.E.W. collection) the tarsometatarsi of Sooty

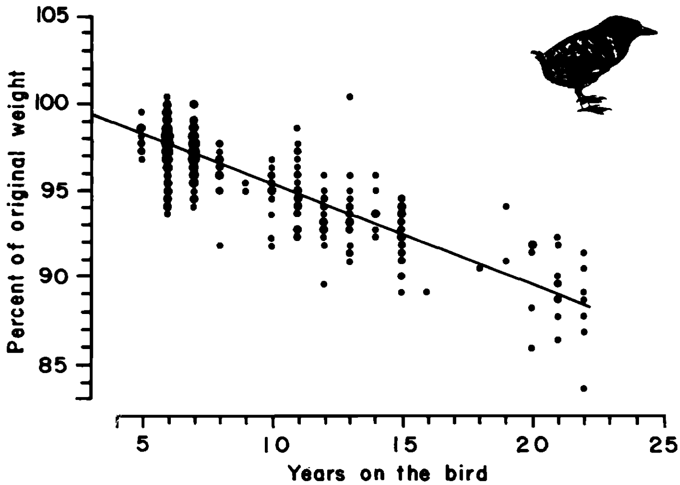

FIGURE 2. Relationship of weight lost over time for bands of alloy 3003-0 placed on Sooty Tern chicks. The regression line was calculated for years 4–18. Seven increasing dot sizes represent samples of 1, 2, 3–5, 6–10, 11–15, 16–20, and 21–26 weights, respectively.

Terns are larger at mid shaft and at the trochleae than those of Arctic Terns. Smaller tarsi at the base of the toes also increases the probability of band loss by slipping over the toes. Hatch and Nisbet (1983b) found a few number 3 bands that could be pulled off the feet of Arctic Terns after the bands had lost 30% of their estimated original weight. We predict a larger percent weight loss is necessary before number 3 bands can be pulled off the foot of Sooty Terns.

We analyzed no bands from Sooty Terns that had lost more than 17% of their estimated original weight. Furthermore, the most abraded band we obtained would not slip over a Sooty Tern's toes provided it was closed. Nevertheless, we have evidence of band loss for certain alloys. We suspect the losses in part at least, can be explained by gaps that form between the butt ends of the bands. At the Tortugas, bands placed on terns are closed tightly around the tarsi with pliers. Yet we see gaps between the ends on some bands carried by the terns. We suspect these gaps develop slowly through the years after the band has been closed. Gaps in initially closed bands could develop through relaxation of the metal. A hot environment such as the beaches at the Dry Tortugas, where air temperatures regularly exceed 32 C (Dinsmore 1972) may hasten the process. Hatch and Nisbet (1983b) report no gaps in the bands they observed on Arctic Terns. A size 3 band with a gap could slip over the toes of the larger Sooty Tern earlier in its history of abrasion than could a closed band on the smaller Arctic Tern.

Conceivably, Sooty Terns lose bands that get caught on vegetation or debris, and are pulled open as the bird struggles to free itself. To evaluate the probability of this kind of band loss, Bailey experimentally determined

TABLE 3. Annual abrasion percentages for aluminum bands carried by various seabird species.

Species	Band size and style	Abrasion rate (% initial weight yr^{-1})	Reference
Northern Fulmar	30.4 mm		
Fulmarus glacialis	Butt-end	5.26	Anderson 1980
Fulmarus glacialis	——[1]		
	Double-ended	3.64	Anderson 1980
Ring-billed Gull	5 long 10 mm		
Larus delawarensis	Butt-end	9.55	Ludwig 1967
Herring Gull	——		
L. argentatus	Butt-end	3.05	Kadlec 1975
Dominican Gull	S		
L. dominicanus	Lock-type	4.90	Fordham 1967
Black-legged Kittiwake	——		
Rissa tridactyla	Butt-end	9.30	Coulson and White 1959
Caspian Tern	5 long 10 mm		
Sterna caspia	Butt-end	3.04	Ludwig 1981
Sterna caspia	5 short 7 mm		
	Butt-end	2.38	Ludwig 1981
Sterna caspia	4A		
	Butt-end	2.22	Ludwig 1981
Roseate Tern	2	yrs. 6–11	
S. dougallii	Butt-end	5.67	Nisbet and Hatch 1982
Common Tern	3		
S. hirundo	Butt-end	5.42	Hatch and Nisbet 1983a
S. hirundo	2		
	Butt-end	4.08	Hatch and Nisbet 1983a
Arctic Tern	3		
S. paradisaea	Butt-end	0.91	Hatch and Nisbet 1983b
Sooty Tern	3		
S. fuscata	Butt-end	0.57	This study

[1] Not stated in the reference.

the pulling strength of adult Sooty Terns, and then compared the results to the amount of pull required to open an abraded band. The amount of weight required to open the lightest weight band of the softest alloy was more than seven times the maximum weight lifted by a Sooty Tern. Therefore, we suspect that band loss caused by Sooty Terns pulling open bands caught on debris is at most rare (Jones 1985).

Hatch and Nisbet, working with bands from Common Terns (*Sterna hirundo*) (1983a) and Arctic Terns (1983b), found no significant differences in rates of abrasion for the same four alloys we investigated. Limited sample sizes probably were most important in making it difficult for them to detect such differences (Nisbet, pers. comm.). In our study, we found that bands of alloy 2-SO, which had the lowest hardness values (Table 1), showed the fastest rates of abrasion (Table 2). Therefore, if band loss occurs, it should appear first in this alloy, as indeed it did. For bands of alloy 2-SO placed on chicks, all points plotted for bands carried for more

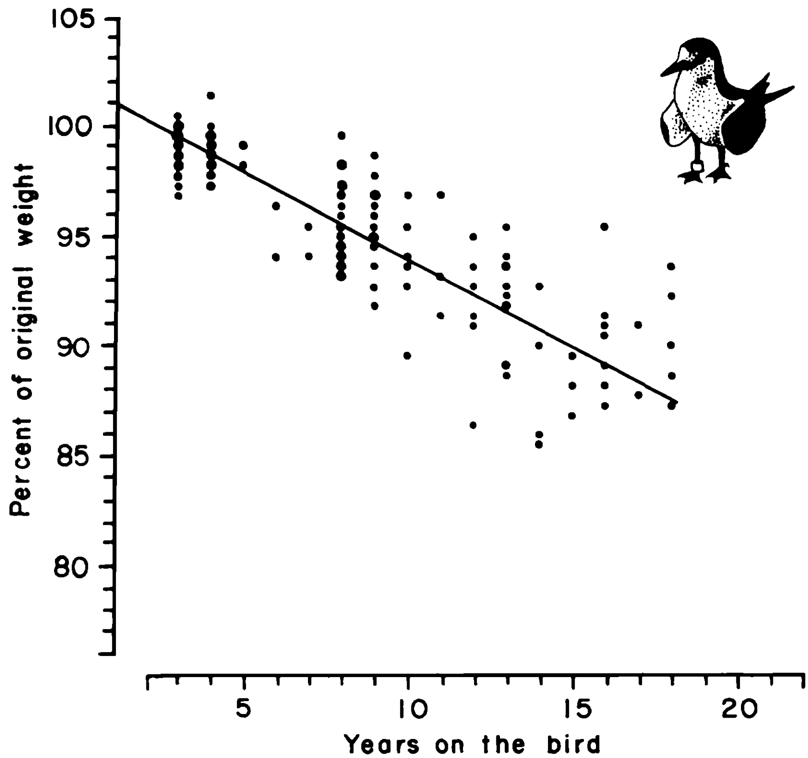

FIGURE 3. Relationship of weight lost over time for bands of alloy 2-SO placed on Sooty Tern adults. The regression line was calculated for years 2–15. Three increasing dot sizes represent samples of 1, 2, and 3–5 weights, respectively.

than 20 yrs fell above the independently determined, extended regression line (Fig. 1). This biased distribution indicates band loss. Bands whose weights lie below the line were lost. Band loss is suggested for bands of alloy 2-SO placed on adults (Fig. 3), but because the samples contained none carried for more than 18 yrs, the evidence is weak.

An estimate of the percent of original weight below which bands will fall off can be made from the plots of weight loss for alloy 2-SO (Figs. 1 and 3). For terns banded as adults, several bands weighing 87% of the estimated original weight were collected, but only one that was lighter than 86%. Therefore, 86% was chosen as the weight at which bands first come off Sooty Terns. For bands of alloy 2-SO placed on chicks, the pattern is similar (Fig. 1), only two bands weighing less than 86% were retrieved. As the next step, lines were drawn parallel to each regression line that included 95% of the points around each of the regression lines. The point at which the lower of the two lines intersected 86% of the estimated original weight was taken as the age when band loss first occurs. Naturally, the actual regression line reaches 86% a few years later than the lower 95% line. At the number of years the regression line reaches 86%, about half of the 2-SO bands have been lost.

For 2-SO bands placed on adults, the lower 95% line reaches 86% of original weight at 14 yrs, and the actual regression line reaches 86% at 20 yrs (Fig. 3). For 2-SO bands placed on chicks, the 95% line reaches 86% at 18 yrs and the regression line does so at 23 yrs. Thus, loss apparently begins at 18 yrs for bands carried by terns banded as chicks, and at 14 yrs for bands carried by adults, and many bands have been lost by 23 yrs and 19 yrs, respectively.

The sample of abraded bands of the other three alloys did not include age categories old enough to indicate loss. However, assuming all other factors are equal, the method just described, wherein the 95% lines were used to determine years of first loss, can be used to predict when band loss will occur for the other alloys. Two assumptions that must be met before this method can be applied to the other alloys are described. First, abrasion must occur in the same way for all four alloys. Inspection of abraded bands supports this assumption. Second, the ratios of band weight to inner diameter must be equal within alloys.

Table 4 lists the results of the 95% line method for all four alloys. As expected a direct correlation exists between hardness values (Table 1) and expected duration of the bands on the terns. Furthermore, as expected, terns banded as adults begin to lose their bands 2–4 yrs before those banded as chicks. The exception, alloy 5052-0, may exist because the data for this alloy were clumped around the regression lines. Bands of this alloy have been used only relatively recently, and this enhanced clumping.

Clearly some Sooty Terns outlive the bands they carry. At the Dry Tortugas, many individuals that have carried bands for over 20 yrs have been recaptured. The current record is held by two terns known to have carried bands for 32 yrs. One, banded as a chick, held its original band for the first 32 years of its life.

Allowances must be made for loss of bands when analyzing demographic data. One solution is to estimate survivorship and related phenomena from data taken only during the time span when band loss is expected to be negligible. For bands placed on adults, we suggest that recovery data would be dependable through yr 14 for alloy 2-SO, yr 17 for alloy 3003-0, yr 23 for alloy 1100-H14, and yr 28 for alloy 5052-0. For bands placed on chicks, recovery data would be dependable through yr 18 for alloy 2-SO, yr 20 for alloy 3003-0, yr 25 for alloy 1100-H14, and yr 21 for alloy 5052-0. Estimates of survivorship beyond the time of first loss could be based on an extrapolation of data gathered before that time. Unfortunately this method requires that mortality be age independent, an increasingly unsafe assumption even for larids (Coulson and Wooller 1976).

To reduce band loss problems, in recent years Tortugas Sooty Terns captured carrying older bands have been given a new band on the opposite leg. Presently, the Bird Banding Laboratory discourages adding bands, and requires special authorization to do so (U.S. Fish and Wildlife Service

TABLE 4. Predicted age of loss of bands for four alloys used on Sooty Terns.

Alloy	Age stage at banding	Age at which the 95% line reaches 86% of original weight	Age at which the regression line reaches 86% of original weight
2-SO	Adult	14	20
	Chick	18	23
3003-0	Adult	17	21
	Chick	20	26
1100-H14	Adult	23	28
	Chick	25	28
5052-0	Adult	28	37
	Chick	21	27

1984). The information gained about band loss by adding bands may be worth the added cost and problems with record keeping.

Band loss, a serious problem known for many bird species undergoing long-term study, no longer should be studied only after-the-fact. Some bands should be weighed before being placed on birds in order to obtain more reliable information on rates of abrasion. Placing a band on each leg would permit detection of band loss and so increase accuracy of many life history estimates. When possible, long-lived birds should be banded with stainless steel or monel bands because of their resistance to mechanical abrasion. As demonstrated by this study, hardness values varied directly with the resistance of an aluminum alloy to abrasion. Because sometimes it is necessary to use aluminum bands, we recommend that only alloys with high hardness values, equalling those of alloys 1100-H14 or 5052-0 (Table 1) of the Bird Banding Laboratory, be used in the production of aluminum bands.

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