JOURNAL OF FIELD ORNITHOLOGY

Formerly BIRD-BANDING

A Journal of Ornithological Investigation

VOL. 54, NO. 1 | WINTER 1983 | PAGES 1–112

J. Field Ornithol., 54(1):1–16

BAND WEAR AND BAND LOSS IN COMMON TERNS

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Loss of bands can be an important factor biasing the results of studies of the survival and longevity of banded birds and may result from removal of the bands by the birds, from wear, or from both. Band wear is particularly important for long-lived birds such as seabirds, whose bands are subject both to abrasion by rocks or sand and to corrosion by salts or polluted water. In Herring Gulls (*Larus argentatus*), for example, band wear is relatively rapid and band loss has been implicated as a major source of bias in survival studies (Poulding 1954, Harris 1980, Kadlec and Drury 1969, Ludwig and Steblay 1972, Kadlec 1975, 1976, Coulson 1976, Ludwig 1981). Similar findings have been reported in Ring-billed Gulls (*L. delawarensis*; Ludwig 1967, 1981), Silver Gulls (*L. novaehollandiae*; Mills 1971, 1972), Common Gulls (*L. canus*; Onno 1969), Dominican Gulls (*L. dominicanus*; Fordham 1967), Lesser Black-backed Gulls (*L. fuscus*; Coulson 1976), Western Gulls (*L. occidentalis*; Spear 1980), Black-legged Kittiwakes (*Rissa tridactyla*; Coulson and White 1955, 1959), and Caspian Terns (*Sterna caspia*; Ludwig 1981). However, it is difficult to generalize these results to other species, because the rates of band wear are known to vary according to the metallurgy of the bands and the habitats and habits of the species involved (Serventy 1970, Coulson 1976, Harris 1980, Spear 1980).

Nisbet (1978) pointed out discrepancies among published estimates of survival rates of Common Terns (*Sterna hirundo*) and suggested band loss as one likely factor contributing to the differences. However, only preliminary data are available on band wear in this species (Ludwig and Steblay 1972, Ludwig 1981). In this paper we analyze data on band wear in Common Terns and use them to estimate the likely rate of band loss. We also analyze factors affecting the rate of band wear and report preliminary results obtained with incoloy (stainless steel) bands. Comparative data on band wear in Arctic (*S. paradisaea*) and Roseate terns (*S. dougallii*) are presented in separate notes (Hatch and Nisbet 1983, Nisbet and Hatch 1983).

MATERIALS AND METHODS

Worn bands.—We obtained worn bands from three sources: (1) James P. Ludwig supplied 67 bands and data on a further 72 bands which had been returned to the Bird Banding Laboratory by finders of dead Common Terns between 1966 and 1973. Data on wear of 71 of these bands have been summarized by Ludwig and Steblay (1972). (2) Helen Hays supplied 121 bands removed from Common Terns trapped at Great Gull Island, New York, in 1975 and 1976. (3) Nisbet removed 131 bands from Common Terns trapped (113) or found dead (18) at various colonies in Massachusetts between 1973 and 1982. Twenty-three of these were incoloy bands placed on chicks in Massachusetts between 1975 and 1977.

So far as we can ascertain, each of these sets of bands was an unbiased sample of those encountered. Neither Hays nor Nisbet selected bands for removal on the basis of their degree of wear. We assume that bands returned by the public would be an unbiased sample, since only on the most worn bands are the addresses illegible and we exclude these bands from analysis (see below). Hays and Nisbet verified the specific identity of the Common Terns trapped by them. All the bands reported by members of the public had been banded as Common Terns: although there is a slight possibility that some Arctic Tern chicks have been included; few of the birds had been banded in mixed colonies.

We obtained data on the circumstances of banding and recovery from the Bird Banding Laboratory and/or from the banders. Data used in this study include dates and localities of banding and age at banding. We were not able to obtain information on the substrates on which birds had been nesting in enough cases to be useful. Complete data were obtained on 391 bands, of which 372 had been worn for at least 1.5 yr. With few exceptions, most birds were both banded and recovered in May, June, or July, so that most bands had been worn for approximately an integral number of years.

We also obtained 150 worn bands collected by Oliver L. Austin, Sr., prior to 1959. Most of the birds had been banded by Austin at colonies in Massachusetts between 1934 and 1954. Unfortunately, most of the birds had been retrapped by Austin more than once, and we have been unable to determine from his records when the bands were removed. In addition, the sample may be biased because Austin rebanded birds when they were found to be carrying worn bands (Austin and Austin 1956). Although we present data for 11 of these bands for which we obtained unequivocal recovery information, we do not combine them with more recent data for statistical analysis.

All worn bands were cleaned and weighed to the nearest 0.1 mg. We flattened a number of bands and measured their thickness (using a micrometer) and their area and breadth (by projecting the silhouette of each band onto a screen). However, thickness and breadth were variable and these measurements were less precise than that of weight. Accordingly, we use weight loss as the primary measure of the degree of wear.

Unused aluminum bands.—To estimate the original weight of each worn aluminum band, we weighed unused aluminum bands preserved in the archives of the Bird Banding Laboratory. We also used weights supplied by J. P. Ludwig and G. Woolfenden and weighed some bands in our possession. In many cases we were able to obtain a small number (usually 10) of weights from the same series of 10,000 bands as the worn band.

TABLE 1. Measurements of unworn bands used on Common Terns.

	Type of band		
	Size 3 aluminum	Size 2 aluminum	Size 2/3 incoloy
Internal diameter (mm) (nominal)	4.8	4.0	4.3
Height (mm)	6.6	6.6	5.5
Approximate thickness (mm)	0.8	0.8	0.3
Weight (mg)	230	202	226

In these cases we used the mean weight of the unused bands as an estimate of the original weight of the worn band. In about half the cases we used the mean of the means of samples of unworn bands with the same prefix as that of the worn band (i.e., from the same set of 100,000 bands). In nine cases (2.4% of the total) no weights of unused bands with the same prefix were available; in these cases we used the mean weight of the nearest available set or sets of unused bands.

Variability in the weights of unused aluminum bands within and among series is analyzed in the Appendix. On the basis of the data presented therein, we believe that errors in our estimates of unworn weights would only rarely exceed 8 mg, and that the root mean square error would be between 2 and 3 mg. These errors would contribute directly to errors in estimates of weight loss. Since aluminum bands lose weight at an average rate of about 8–12 mg/year (see below), such errors would be important in the first year or two after banding, but would progressively decline in relative importance in succeeding years, becoming negligible after the third year. For the statistical analysis in this paper, we have excluded all bands worn for less than 1.5 yr. We include bands worn for approximately 2 yr, while recognizing that errors in estimating their original weights may contribute up to 3% of the variance in our estimates of their weight loss.

Unused incoloy bands.—For incoloy bands, we retained at least one unworn band as a sample from each series of 1000 bands and we also have numerous bands removed from dead chicks which had carried them for 10 days or less. To estimate the original weight of each worn incoloy band, we used the mean weight of the bands manufactured in the same year (227 mg in 1975 and 216 mg in 1976). Bands manufactured in 1976 were more variable in weight (standard deviation 4.49 mg versus 2.47 mg for 1975). This variability will contribute directly to errors in estimates of weight loss.

DESCRIPTIONS OF BANDS

Three major types of bands have been used on Common Terns in North America and are represented in our series. The dimensions and weights of these bands are summarized in Table 1.

Until 1970 the recommended band size was 3. According to records

TABLE 2. Nominal composition of aluminum bands used on Common Terns.

Band type	I	II	III	IV	III	V[1]
Dates issued[2]	1948	1948–1953	1955–1959	1960	1961–1963	1963–present
Band numbers[3]	thru 48.3	49.3–563	583–663.4	663.5–693.2	693.3–763.4	763.5–on
Primary components (nominal percentage composition)						
Aluminum	99+	99+	99+	98+	99+	97+
Magnesium	—	—	—	—	—	2.5
Manganese	—	—	—	1.2	—	—
Minor components and Impurities (max. percentage composition; nominal percentage composition in parentheses)						
Silicon	x	†	1.00	0.6	1.00	0.45
Iron	x	†		0.7		
Copper	x	†	0.20 (0.12)	0.20 (0.12)	0.20 (0.12)	0.10
Manganese	x	†	0.05	1.5 (1.2)	0.05	0.10
Magnesium	x	†	0.05	0.05	0.05	2.8 (2.5)
Chromium	x	†	0.05	0.05	0.05	0.35 (0.25)
Zinc	x	†	0.10	0.10	0.10	0.10
Others (each)	x	†	0.05	0.05	0.05	0.05
Others (total)	x	†	0.15	0.15	0.15	0.15

[1] Applies to both size 2 and size 3 bands.

[2] Bands accepted by Bird-Banding Laboratory during fiscal year indicated; fiscal years started on 1 October preceding the calendar year specified.

[3] Last 4 digits of band numbers omitted.

x Specifications not available: "commercially pure aluminum."

† Specifications not available: "pure aluminum, tempered three-quarters hard."

TABLE 3. Measured Concentrations (%) of minor constituents in 8 aluminum bands.[1]

Band series[2]	35.32	48.34	563.7	643.9	663.6	723.7	773.5	1083.2
Approx. year issued[3]	1935	1948	1956	1959	1960	1964	1965	1968
Copper	0.02	0.09	0.08	0.08	0.23	0.02	0.02	0.05
Zinc	0.02	ND	ND	ND	0.05	0.02	0.05	0.01
Tin	ND	ND	ND	ND	ND	ND	ND	0.03
Iron	0.5	0.5	0.5	0.5	0.8	0.2	0.3	0.3
Manganese	0.04	0.04	0.01	0.01	0.02	0.04	0.04	ND
Magnesium	<0.05	<0.05	<0.05	<0.05	ca. 0.5	ca. 2.0	ca. 2.0	ca. 2.0
Silicon	0.3	0.1	0.2	0.2	0.5	0.1	0.2	0.1
Chromium	ND	ND	0.1	ND	ND	0.1	0.1	0.1

[1] From spectrographic analyses by IMI Analytical Services, Witton, U.K.
[2] Each series contained 10,000 bands.
[3] The earliest calendar year for which we have banding data.
[ND] Less than 0.01%. Lead, nickel, and bismuth were not detected at this level of sensitivity.

of the Bird Banding Laboratory, bands were manufactured from several different aluminum alloys, as shown in Table 2. Our measurements of the composition of 8 individual bands, presented in Table 3, show agreement with the specifications except in the case of band 663-65719, which contained .5% magnesium instead of 1.2% manganese, and also contained higher levels of copper and iron than the nominal maxima for the specified grade. Since 1970 most Common Terns have been banded with size 2 bands manufactured from the magnesium/aluminum alloy identified as type V in Table 2. Since 1975 we have been banding Common Terns with incoloy bands, whose composition is listed in Table 4.

In addition to the compositional differences listed in Table 2, there may have been other significant metallurgical variations in bands used before 1970. For example, Jay M. Sheppard (in litt.) informs us that some bands were anodized during the 1950's, but that the anodized layer was normally worn off quite rapidly. We have not identified any anodized bands in our sample. J. P. Ludwig (in litt.) informs us that some bands manufactured in the early 1960's were of an inferior grade of aluminum and corroded rapidly, developing large pits and hollows. We have not identified bands with this pattern of corrosion, but band no. 663-65719 (manufactured in 1960) contained relatively high levels of copper, iron, and silicon (Table 3); this band had lost weight slightly more rapidly than average (46% in 7.9 yr). Unpublished diaries of O. L. Austin refer to year-to-year variations in the hardness of bands, which may indicate differences in the degree of tempering. If these unrecorded metallurgical differences had significant effects on the rate of band wear, they may have interfered with our attempts to detect the influence of the compositional differences listed in Table 2.

TABLE 4. Nominal composition of incoloy.[1]

Element	Percent composition
Nickel	38.0–46.0
Iron	about 30 (balance)
Chromium	19.5–23.5
Molybdenum	2.5–3.5
Copper	1.5–3.0
Titanium	0.6–1.2
Manganese	1.0 (maximum)
Silicon	0.5 (maximum)
Aluminum	0.2 (maximum)
Carbon	0.05 (maximum)
Sulfur	0.03 (maximum)

[1] Conforming to ASTM specification B424.

PATTERNS OF WEAR

Aluminum bands on Common Terns wear primarily from the inside. Even the most worn bands (those reduced to less that 50% of their original weight and about half their original thickness) appear only moderately worn on the outside and their numbers are clearly legible. We assume that the primary mechanism of wear is abrasion by particles of sand held temporarily between the leg and the band, accompanied by corrosion of the abraded surface.

Size 3 bands appear to wear fairly uniformly until they have been reduced to about 70% of their original weight and thickness. After this point, one edge (the lower edge in a few cases where we examined the band prior to removal) becomes thin and irregularly scalloped. The most worn bands that we have examined weighed 38–45% of their unworn weight and were reduced to about 70% in width at the narrowest point as well as to about 55% in thickness. In such bands the inscription along one edge is partly lost so that the address may be illegible.

In many size 2 bands the first sign of wear (not evident in size 3) is bevelling of the inside lower edge, where the band rests against the metatarsus. This bevelling may cause loss of the lower inscription more rapidly than in size 3 bands, but we have no bands in which this form of wear has proceeded to the point where the number is illegible.

We have no direct evidence about the ways in which bands are lost. Size 3 bands which are reduced to 60–70% of their original weight can be pulled by hand over a tern's foot. Not long after this point, the bands become fragile and we suspect that some may break or spring open before they can be shaken over the foot. However, we have not observed terns carrying partly-open bands. Although size 2 bands cannot be pulled over the foot as easily as size 3 bands worn to the same degree, they also become fragile and it cannot be assumed that they would last substantially longer.

Incoloy bands that have been on Common Terns for up to 4 years show no signs of wear except that the original matt surfaces become brightly polished (especially on the inside) within one year.

RATES OF WEAR

In other species, the rate of band wear has been reported to be constant, at least until the bands start to fall off (Ludwig 1967, Coulson 1976). Hence, a suitable measure of the rate of band wear is the percentage of original weight lost per year. In this section, we analyze variations in this quantity within our series of Common Tern bands. Because the sample is heterogeneous, we have divided it into 4 subsamples for analysis.

Size 3 bands, manufactured since 1948.—Our sample includes 183 bands, representing 5 grades of aluminum (Table 3), two age classes (banded as adults and as chicks), and a number of breeding locations. For analysis, we grouped the locations into 2 categories: (1) inland (mostly Great Lakes), and (2) coastal (Virginia to New Brunswick, but mostly Long Island, New York, and Massachusetts). Our sample of recoveries indicates no movement between the areas. Terns from both areas winter in coastal regions of Central and South America (Austin 1953). Initially, we excluded data for bands carried less than 1.5 yr, because of uncertainty in unworn weights (see above), and for bands carried 6.5 yr or more, because of likely bias due to band-loss (see below). For the remaining 96 bands, the rate of weight loss was 5.42 ± .18%/yr (mean ± SE).

Analysis of variance showed no significant associations between rate of weight loss and either age at banding or composition of metal. However, among bands placed on chicks, the rate of band wear was significantly higher inland (6.29 ± .31%/yr, n = 31) than on the coast (4.64 ± .19%/yr, n = 42; $P < .001$). This effect could not be investigated in adults because we had only 3 bands placed on adults inland. Combining data for bands placed on adults and chicks, the mean rate of wear inland was 6.47 ± .33%/yr (n = 34) and that on the coast was 4.85 ± .17%/yr (n = 62; $P < .001$).

Table 5 shows the mean and standard deviation of the rate of weight loss as a function of the number of years between banding and recovery. Through the sixth year, both the mean and the variance of the rate of weight loss remained essentially constant. This suggests that each band continued to lose weight at approximately the same rate. After the sixth year, the average rate of weight loss of the surviving bands decreased significantly and progressively, while in most years the variance was reduced also. These changes suggest that the bands subject to the most rapid wear were progressively lost after the sixth year, so that only the bands subject to less rapid wear survived to be recovered. Ludwig (1967) observed the same phenomena in bands carried by Ring-billed Gulls, and proposed the same explanation. Rates of band loss are calculated in a subsequent section of this paper.

Size 3 bands, manufactured prior to 1948.—We have full data for only

TABLE 5. Rate of wear of size 3 bands as a function of the number of years between banding and recovery.

Years worn[1]	No. of bands	Rate of weight loss (%/yr) Mean	SD	
1	14	4.12	2.89	
2	12	5.13	1.56	For years 2–6: mean 5.42%/yr, SD 1.72%/yr (n = 96)
3	15	5.98	2.19	
4	28	5.19	1.40	
5	18	5.16	1.92	
6	23	5.65	1.69	
7	19	4.31**	0.77**	
8	15	4.69	2.15	
9	20	3.63**	1.47	
10	9	4.06**	0.89**	
11–20	10	3.35**	0.87**	

[1] Most bands were carried for about an integral number of years.
** Mean or variance significantly less than mean or variance for years 2–6 ($P < .01$).

11 bands used at coastal colonies by O. L. Austin, Sr. between 1934 and 1948 and carried for between 1.5 and 6.5 yr before being recovered. The mean rate of weight loss of these bands was 6.62 ± .96%/yr (standard deviation 3.184). Compared to size 3 bands used on the coast after 1948, the mean rate of weight loss of the earlier bands was higher, but not significantly so ($t = 1.82$, $.05 < P < .1$); the variance in the wear of the earlier bands was much higher ($F = 5.66$, $P < .01$).

Size 2 bands, manufactured since 1970.—Size 2 bands have been used for Common Terns only since 1970, so most bands in our sample were carried for 7 years or less. Table 6 summarizes the rate of weight loss of these bands as a function of the number of years between banding and recovery. Through the seventh year both the mean and the variance of the rate of weight loss remained essentially constant. The mean rate of weight loss for years 2–7 was 4.08 ± .089%/yr (SD = 1.16). This is significantly less than that for size 3 bands used on the coast ($t = 3.99$, $P < .001$). In contrast to the data for size 3 bands, there was no clear evidence of a shortfall in the more rapidly worn bands in the seventh year, but the 2 bands recovered after the seventh year had very low rates of weight loss (Table 6).

Incoloy bands.—Incoloy bands were first used on Common Terns in 1975, and most of the 23 bands in our sample were carried for only 2 or 3 yr. Estimates of rates of wear for these bands are subject to substantial random errors because the mean weight change after 3 yr was comparable to the range of variability in unworn bands (see under Materials and Methods). The rate of weight loss for 17 bands worn for 2 or 3 yr was .63 ± .60%/yr (mean ± 1 SD), and for 6 bands worn for 4 to 7 yr was .46 ± .15%/yr. Thus, the mean rate of weight loss from incoloy bands is scarcely one-tenth of the rate from aluminum bands.

TABLE 6. Rate of wear of size 2 bands as a function of the number of years between banding and recovery.

Years worn[1]	No. of bands	Rate of weight loss (%/yr) Mean	SD	
1	5	4.52	1.86	
2	9	4.06	1.76	For years 2–7: mean 4.08%/yr, SD 1.16%/yr (n = 169)
3	21	3.93	0.95	
4	25	4.37	1.12	
5	34	4.01	1.17	
6	40	4.19	1.14	
7	40	3.95	1.18	
8	1	2.75		
10	1	2.92		

[1] Most bands were carried for about an integral number of years.

MODELS FOR BAND LOSS AND BAND SURVIVORSHIP

We now use the data summarized in Table 5 to estimate the range of weights at which size 3 bands are lost by Common Terns and hence to construct a survivorship curve for these bands. To do so, we make the following assumptions: (1) Each band loses weight at a constant rate until it falls off the bird. (2) The rates of weight loss of individual bands follow a Gaussian distribution with mean 5.42%/yr and standard deviation 1.72%/yr (the parameters observed in the bands carried for 2–6 yr). (3) All bands are retained by the birds until they have lost at least 30% of their original weight. We have examined the validity of these 3 assumptions and find that the data agree with assumption 2 and the results are not sensitive to variation in assumptions 1 and 3.

In the absence of band loss, the distribution of weight losses in the i'th year would then have been Gaussian with a mean $5.42i$ and standard deviation $1.72i$%/yr (from assumption 2). The observed distribution of weight losses is then fitted to the lower part of such a Gaussian distribution, using assumption 3, and the number of bands that would have been expected in various weight loss intervals (30–35%, 35–40%, etc.) is calculated. Comparison of the expected number with the observed number provides an estimate of the number that had been lost. This calculation is repeated for each year from year 3 (prior to which the expected number of bands with weight loss greater than 30% is negligible) to year 10 (after which the observed number of bands with weight loss less than 30% is too small to perform the calculation). The observed and expected numbers in each weight loss interval are summed, weighting them in proportion to the observed number of bands with weight loss less than 30% in the same year. This procedure yields an estimate of the fraction of bands surviving in each weight-loss interval.

In mathematical terms, we denote the number of bands observed in year i in the weight-loss interval between j and k% as $N(i, j, k)$. We

TABLE 7. Estimates of the proportion of bands surviving into various weight-loss intervals.

	Weight-loss interval (percent of original weight lost)							
	25–30	>30–35	>35–40	>40–45	>45–50	>50–55	>55–60	>60–65
Unweighted totals								
Expected no.	25.6	25.4	24.4	23.3	20.8	17.6	13.9	10.4
Observed no.	29	21	12	7	7	7	2	1
Weighted[1] ratio								
S(j,k)	107%	77%	46%	24%	26%	32%	18%	7%

[1] See text for explanation of weighting.

denote the probability that a Gaussian variable with mean $5.42i$ and standard deviation $1.72i$ will fall in the interval between j and k as $Q(i, j, k)$. Then the number of bands expected, in the absence of band loss, in year i in the weight-loss interval between j and k% is $Q(i, j, k)N(i, 0, 30)/Q(i, 0, 30)$, which we denote as $L(i, j, k)$. Our estimate of the fraction of bands surviving in the weight-loss interval between j and k% is then the weighted fraction:

$$S(j, k) = \sum_{i=3}^{10} N(i, 0, 30)N(i, j, k)/\sum_{i=3}^{10} N(i, 0, 30)L(i, j, k).$$

Table 7 presents the values of $S(j, k)$ obtained by this procedure.

The results in Table 7 suggest that some bands fall off before they have lost 35% of their original weight (although the shortfall is not statistically significant until the interval 35–40%). Although the estimates of $S(j, k)$ are variable because of small sample sizes, they are consistent with an hypothesis that bands fall off at a linear rate within the range of weight losses between 32 and 62%, i.e., when the bands weigh between 68 and 38% of their original weight. They appear inconsistent with an alternative hypothesis that the distribution of fall-off weights is peaked in the center of this range, and certainly conflict with an assumption that all fall off at or near the same weight.

The hypothesis that bands fall off at a linear rate between 32 and 62% is now used to compute a survivorship curve for size 3 bands. For each band within our sample of 96 bands recovered in years 2–6 (i.e., with unbiased data on the rate of weight loss), we selected a random number between 38 and 68% as the fall-off weight, and computed the age at which the band would have fallen off (assuming that the band would continue to wear at the same rate). The calculation was repeated 5 times for each band, to generate 480 estimates of fall-off age. Figure 1 presents the computed survivorship curve. It suggests that the first bands may be lost as early as 3–4 yr after banding, but that band loss is not significant (over 5%) until after year 5. Thereafter it progresses at an increasing rate until half the bands are lost by year 9, and then bands are lost at a steady rate of about 24% per year between years 9

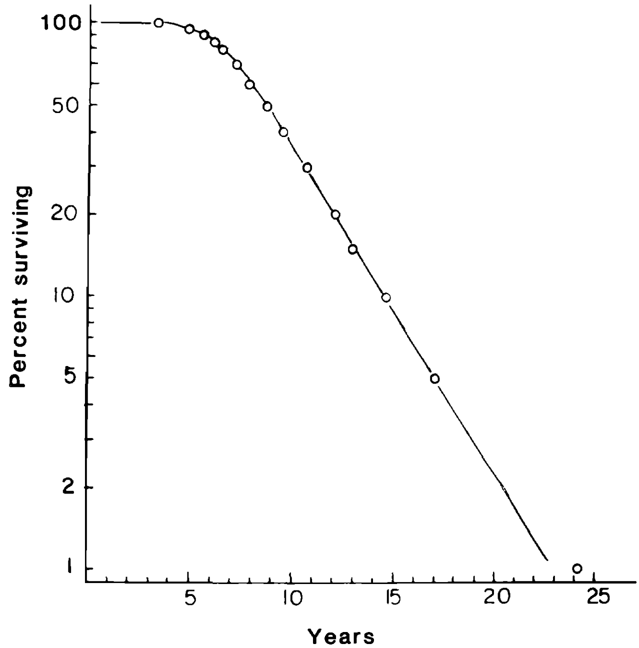

FIGURE 1. Calculated survivorship curve for size 3 aluminum bands on Common Terns.

and 17; only about 5% of bands survive to year 17. This is consistent with the data in Table 5, although in our sample there is no clear evidence of a shortfall in the more worn bands until the seventh year.

Strictly, the above estimates of fall-off weights can be applied only to samples of size 3 bands used at the same period and with the same geographical distribution as those for which data are summarized in Table 5. However, if we assume that the mean fall-off weights of other groups of aluminum bands would be similar (i.e., when 47% of original weight had been lost), the mean survival times of different band types can be calculated. These are shown in Table 8.

If it is assumed that other groups of bands would start to fall off after losing about 32% of their initial weight, then loss of size 3 bands would begin to be significant (i.e., greater than 5%) in years 4–6, but loss of size 2 bands would probably not be significant until year 7. It is difficult to make similar estimates for incoloy bands because of the statistical uncertainty in estimating the range of rates of weight loss, but it is unlikely that loss of incoloy bands will be significant before year 40.

DISCUSSION

Improvements in bands.—Table 8 shows that changes in the composition and size of aluminum bands used on Common Terns in the period 1934–1976 have led to a progressive improvement in their durability.

TABLE 8. Comparison of rates of wear of 6 samples of bands carried by Common Terns for 2–6 yr.

Band size	Metal	Location	Years used	n	Rate of weight loss (%/yr) Mean	SD	Time (yr)[1] for band loss 5%	50%
3	Aluminum	Coast	1934–1941	11	6.62[ab]	3.19	4.0	7.1
3	Aluminum	Coast	1948–1970	62	4.85[b]	1.33	5.4	9.7
3	Aluminum	Inland	1948–1970	34	6.47[a]	1.92	4.1	7.3
3	Aluminum	Coast + Inland	1948–1970	96	5.42[ab]	1.72	4.9	8.8
2	Aluminum	Coast	1970–1975	169[2]	4.08[c]	1.16	6.4	11.5
2/3	Incoloy	Coast	1975–1976	23[2]	0.58[d]	0.52	ca. 40	>70

[1] Assuming mean fall-off weight is 53% of original weight (see text).
[2] Includes bands carried for 2–7 yr.
[a–d] Figures in the same column without a letter in common are significantly different ($P < .05$).

However, it also suggests that metallurgical changes within bands of the same size played a relatively small part in this improvement. In view of the major changes in specifications (Table 2) and the reports of rapid corrosion in bands made from some batches of metal (see under Materials and Methods), we had expected major variations in the rates of wear of bands made at different periods. However, such differences were not statistically significant, although our sample sizes were large enough to have detected differences of the order of 30% (e.g., 5.0%/yr versus 6.5%/yr). This suggests that the rate of wear of aluminum bands is dependent more on external factors (such as intensity of abrasion and corrosivity of water) than on metallurgical properties.

The only statistically significant difference in the rate of band wear within our sample of size 3 bands is that wear was significantly more rapid in bands used inland than in those used at coastal colonies. The principal environmental difference is that the inland birds spend 4–5 months of the year in fresh water habitats (Austin 1953). A priori, we had expected band wear to be more rapid in salt water. However, the water around some Great Lakes colonies is relatively alkaline and/or polluted (M. Gilbertson, pers. comm.), and it is possible that the bands are corroded more rapidly for one or both of these reasons.

The other factor that led to a significant reduction in the rate of band wear is the change from size 3 to size 2 bands (Table 8). Ludwig (1981) similarly found that a change to a smaller band-size in Caspian Terns led to a significant reduction in the rate of band wear. A plausible explanation for this difference is that smaller bands fit more closely to the leg, so that there is less abrasion by sand grains inside the band.

Despite these improvements, size 2 aluminum bands on Common Terns still wear relatively rapidly. Our data suggest that they begin to fall off in the sixth year and that half may be lost by the twelfth year. Such losses would lead to significant biases in studies of a species with a relatively high survival rate (Nisbet 1978, DiConstanzo 1980). In view of the vastly superior durability of incoloy bands on this species (Tables 7 and 8), we recommend that incoloy bands should be used for any study in which age of banded birds is an important parameter.

Band survival.—Our estimates for the rate of loss of size 3 bands on Common Terns are somewhat higher than those of Ludwig (1981), who estimated that bands would be lost between 6.6 and 22 yr after banding, at an average rate of 21.9%/yr. Ludwig's model predicts that half the bands would be lost by 11.9 yr, which is substantially later than our estimate of 8.8 yr. He used similar figures for the rates of weight loss (mean 5.45%/yr, range 2.23–9.9), but assumed that all bands would be retained until they had lost 65% of original weight. In contrast, our data show significant shortfalls in the numbers of bands recovered in all weight loss intervals from 35% onwards.

An important implication of our results concerns rebanding as a strategy for avoiding biases in data from loss of bands. Unless most bands are replaced by 5 yr (size 3) or 6 yr (size 2) from time of banding it is impossible to assume that no significant band loss has occurred.

Life tables.—Finally, we consider whether our estimates of the rate of loss of size 3 bands can resolve the problems involved in constructing life tables for Common Terns. Austin and Austin (1956), using data on retrapping of banded Common Terns, estimated the adult mortality rate as 25–29%/yr. Birds banded as adults showed a significant increase in the rate of disappearance (to about 40%/yr) from the 6th yr after banding, but birds banded as chicks showed no such increase until the 19th yr. Our results suggest that band loss can explain much of the increase in the rate of disappearance of birds banded as adults after the 6th yr. However, it is difficult to reconcile the constant rate of disappearance of birds banded as chicks with the expected rapid increase in band loss after the 5th yr. Austin and Austin reported rebanding birds retrapped after eight or more years, which may explain part of this discrepancy, but would then raise problems with the interpretation of the data on birds banded as adults. A further problem is that the rate of disappearance of birds banded as adults (47% in the first yr, 29% in yr 2–7) was much too high to be compatible with data on recruitment (Nisbet 1978). This suggests that factors other than band loss reduced the rate of retrapping of banded birds. One such factor is trap-shyness (Nisbet 1978).

SUMMARY

Factors associated with band wear and band loss in Common Terns (*Sterna hirundo*) were investigated by comparing weights of 402 worn bands with weights of unworn bands. Bands on Common Terns wear primarily from the inside, presumably due to abrasion by sand grains between the band and the leg. Different types of aluminum bands lose

weight at average rates of between 4.1 and 6.6%/yr. No significant differences were found in the rates of wear of bands made of different grades or composition of aluminum. However, bands used in the Great Lakes wore significantly faster than those used at coastal colonies. Size 2 bands wore significantly more slowly than size 3 bands of the same metallurgical composition.

Size 3 aluminum bands appear to fall off Common Terns after losing between 32 and 62% of their original weight. Bands are first lost 4 to 5 yr after banding and are lost at an exponential rate of about 24%/yr between years 9 and 17. The half-life of these bands is about 8.8 yr. These estimates of rates of band loss do not resolve discrepancies beween published life tables for the species.

Incoloy (stainless steel) bands used on Common Terns lose weight at an average rate of only .5–.6%/yr. Their minimum life is expected to be about 40 yr. Incoloy bands are recommended for future studies.

ACKNOWLEDGMENTS

We thank J. P. Ludwig and H. Hays for providing bands and G. Woolfenden and J. P. Ludwig for band weights. C. D. T. Minton kindly arranged for analyses of band-composition. J. Sheppard, G. Jonkel and other personnel of the Bird-Banding Laboratory were very helpful in providing archival bands and other information. For help with weighing and measuring the bands we thank F. Morano, J. Sandel, and D. Spero.

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APPENDIX

VARIABILITY IN WEIGHTS OF UNWORN ALUMINUM BANDS

In this appendix, we restrict the term "series" to a sequence of 1000 bands with consecutive numbers starting with the same 5 digits. For example, the numbers 983-53xxx specify a series of 1000 size 3 bands. We have weights of unworn bands drawn from 74 series of size 3 bands and 11 series of size 2 bands. In most cases, we have samples of 4–30 (usually 10) unworn bands from each series. However, in 27 cases we have samples of 37–100 bands, and one series is represented by 899 bands (weighed by James Ludwig). Altogether, we have weights for 3099 size 3 bands and 250 size 2 bands.

Table 9 summarizes statistical data on the variability in the weights of these bands. The size 3 bands are divided into two groups because bands manufactured before 1958 were generally heavier and more variable than those manufactured subsequently.

In most cases, within-series variance in weights was small, ranging between .03 and 1.5 mg^2. However, in 7 series of size 3 bands, within-series variance was much larger, ranging between 4.4 and 9.6 mg^2. We found similar heterogeneity in variance within the series of 899 bands weighed by Ludwig. Dividing this series into 9 subseries of 99-100 bands each, the variance within subseries was in most cases between .40 and .83 mg^2, but in 3 subseries was much higher (1.51–2.34 mg^2). Despite the differences in variance among subseries, there were no systematic changes in mean weight; none of the subseries means differed by more than .7 mg from the series mean.

In all 3 groups of bands, among-series variance was much higher than within-series variance. This was particularly marked in the early size 3 bands, for which the mean weights of different series varied between 232 and 269 mg. However, among-series variance was much smaller in the later size 3 bands and in the size 2 bands. Among these two groups of bands, the mean weights of contiguous series differed in most cases by less than 4 mg, and in no case by more than 7.3 mg.

TABLE 9. Variability in weights of unworn aluminum bands.

Size	Series	n	Dates[1]	Mean weight (mg)	Within-series variance (mg^2)		Among-series variance (mg^2)
					Range	Mean	
3	34.30–623.60	19	1934–1958	245.7	0.08–9.7	1.89	112
3	643.07–1083.34	55	1958–1967	238.4	0.03–9.6	0.98	26
2	742.84–812.90	11	1966–1973	201.8	0.04–0.64	0.24	9

[1] Approx. dates of receipt by the Bird Banding Laboratory.

These data can now be used to assess the likely magnitude of errors in estimates of weight loss of worn bands. Where weights are available for unworn bands within the same series, the root-mean-square error introduced by using the mean of these weights to estimate the original weight of a worn band is expected to be less than 1.5 mg in all cases (Table 9). However, where data from the nearest available series have to be used to estimate the original weights of unworn bands, an additional error is introduced, whose r.m.s. value is about 3 mg for size 2 and recent size 3 bands. For early size 3 bands, this additional error may range up to about 20 mg, but errors of greater than 10 mg are likely to have occurred only for bands manufactured prior to 1948. Such errors probably contributed to the large variance in estimates of the rate of weight loss of Austin's bands (see text), but they are unlikely to have contributed significantly to the variance observed in other groups of bands.