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AGING HERRING GULLS FROM HATCHING TO FLEDGING

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Despite the large volume of literature on Herring Gulls (*Larus argentatus*), information necessary to determine accurately the age of chicks from hatching to fledging is still lacking. Harris (1963) and Davis (1974) considered the weight-age relationship of Herring Gull chicks, but that relationship is too variable for diagnostic purposes. Parsons (1975) used wing length to age chicks not found immediately after hatching, but with the graph provided, an experimenter must fit every chick by eye which is not satisfactory. Furthermore, as noted by Hailman (1961), the use of one measurement alone is not as likely to yield accurate results. Following his lead, Elowe and Payne (1979) developed an aging technique based on the multiple linear regression of culmen length, tarsus length, and the distance between the carpal joint and the tip of the third phalanx. Unfortunately, their sample sizes dropped to low (<15) numbers after 7 days of age and, had the authors been able to continue, they would have soon realized the inadequacy of assuming linear growth for these measurements. In this paper we present aging formulae specific to the Great Lakes population of *L. a. smithsonianus* which can be used at all stages of chick growth up to fledging.

STUDY AREA AND METHODS

The study took place from 14 May–8 July 1979 on Middle Island (41°41′N, 82°41′W) in western Lake Erie, Canada, where 790 pairs of Herring Gulls nested (Mineau and Markel 1981). Study plots were located on and inland from a pebble beach on the western tip of the island. Seven continuous wire mesh enclosures 1 m in height were constructed to enclose 95 nests. Approximately half of the area in each enclosure was covered by mature hackberry (*Celtis occidentalis*) trees which ensured shade for all chicks.

From the original sample of 95 nests, 155 chicks hatched and were web-tagged. The low hatching success (1.6 chick/nest or 0.61 chick/egg) was mostly attributable to a severe storm which washed a number of nests clear of their contents, and seemingly chilled other clutches, since a large number of eggs were addled. In an effort to obtain a larger sample size, 17 clutches (29 eggs) of pipped eggs from elsewhere on the island were fostered into nests which had recently lost their contents or which contained addled eggs. A total of 184 web-tagged chicks was then available initially. The study was terminated 55 days later, at which time 39 chicks were alive or known to have fledged.

Weather permitting, the nests were visited daily in late afternoon or early evening (mean time of visitation = 1700). The mean visit duration

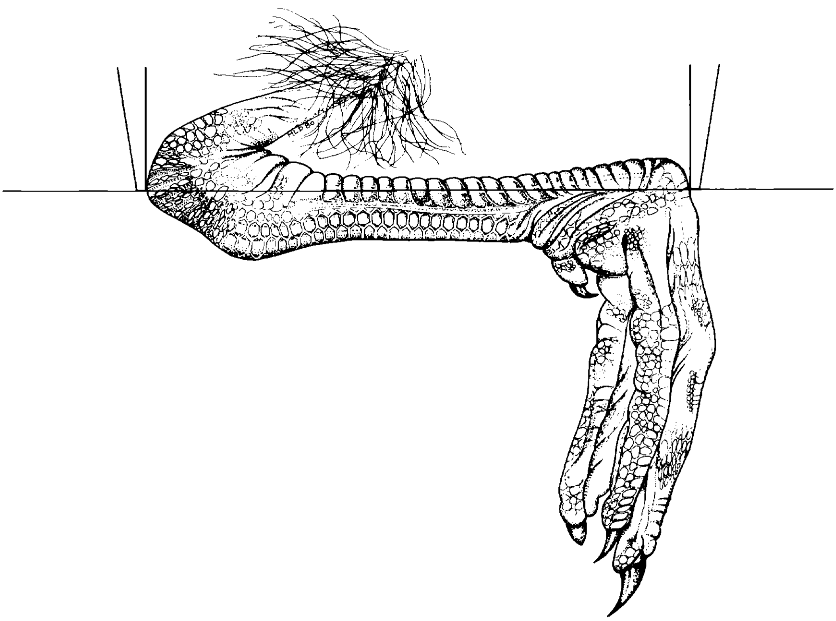

FIGURE 1. Tarsus measurement taken with calipers from the distal end of the tarsometatarsus in a straight line to the distal end of the tibiotarsus including the full thickness of the malleoli of the tibiotarsus.

was 2.6 h (approximately 25 min/enclosure). Chicks were first measured when found completely out of the shell and given an arbitrary age of 1 day (since the actual hatching could have taken place at any time during the previous 24 h). Two observers were usually present, but most of the measurements were taken by the same observer (R. M.) so as to reduce variability.

Three measurements were used in our age determination formula:

(1) Culmen length—measured with calipers from the tip of the beak to the edge of the skin covering the beak, the nasal tuft having been pushed back, with a wetted finger if necessary.

(2) Wing length—measured on the folded wing from the most anterior point of the wrist joint to the tip of the longest primary or the longest feather sheath (not including down) if the primaries were not yet out. The wing was not flattened (preserving the natural camber of the primaries in older chicks), but the phalanges were straightened as shown in Godfrey (1966) so that the 10th primary lay straight along the edge of the ruler.

(3) A modified "tarsus" measurement (Fig. 1)—taken from the squarish distal end of the tarsometatarsus (the digits having been pushed down and out of the way) in a straight line to the distal end of the

tibiotarsus including the full thickness of the malleoli of the tibiotarsus. Taken with a pair of calipers, this measurement was faster and offered less possibility of inter-observer variability than the usual tarsometatarsus measurements.

All measurements were taken to the nearest mm (±.5 mm). Repeated measurements as well as inter-observer comparisons indicated that a greater level of accuracy on live individuals would not be realistic.

RESULTS

A total of 2004 complete sets of measurements was obtained from chicks aged 1 to 47 days. Sample size ranged from 134 for day 1, to 7 for day 47. We were able to keep sample size above 25 up to day 36.

There are several mathematical models which relate age and a body measurement during a "typical" growth process. Ricklefs (1967), working with weight only, described the logistic, Gompertz, and von Bertalanffy, to which we can add the exponential power equations (Table 1). To ascertain whether such a growth model was needed, the data were also fitted to linear equations. Given a model, f, which relates age, y, and a body measurement, x, i.e., x = f (y, *P*) where *P* is a set of parameters, one may estimate age from a body measurement by solving for x. These are univariate models, since an estimate of age is obtained from one body measurement only.

There are numerous ways to incorporate several body measurements into the prediction of age to yield multivariate models. We formed, for each univariate model in Table 1, a multivariate model to estimate age by taking a linear combination of the formulas for each body measurement. This results in the models described in Table 2. Mixed models, e.g., a model which is logistic in wing length, Gompertz in culmen, etc., could be considered, but preliminary analysis of the univariate models suggested that none of the first four models in Table 1 was clearly superior and little would be gained by considering the 120 possible mixed models generated in this way.

For each model in Table 2, the parameters were estimated using the nonlinear least squares method of Marquardt (1963). Although we used a specialized computer program, the method is available in several statistical packages. Examples are procedure NLIN in the package SAS (Helwig and Council 1977); procedure P3R in the package BMDP (Dixon 1975).

Among the 5 models considered, the logistic provided the best overall fit to the data, giving a root mean square residual error, i.e., the average error in the estimation of age (hereinafter called the mean error) of 1.90 days (Table 2). Hence this model was used in the subsequent analysis. The linear model fared poorest, indicating the inadequacy of multiple linear regression when dealing with growth data. The evaluation of the parameters in the logistic model yields the estimation equation:

TABLE 1. Five univariate growth models.

Model	Form	Inverse form	Relationship between parameters
Logistic	$y = \frac{a}{1 + be^{-kx}}$	$x = \alpha + \beta \ln\left(\frac{1}{y} + \gamma\right)$	$\alpha = \frac{1}{k} \ln\left(\frac{a}{b}\right); \quad \beta = \frac{-1}{k}; \quad \gamma = \frac{-1}{a}$
Gompertz	$y = ae^{-kx}$	$x = \alpha + \beta \ln(1 + \gamma \ln y)$	$\alpha = \frac{1}{k} \ln\left(\frac{\ln a}{b}\right); \quad \beta = \frac{-1}{k}; \quad \gamma = \frac{-1}{\ln a}$
von Bertalanffy	$y = a(1 - be^{-kx})^3$	$x = \alpha + \beta \ln(1 + \gamma y^{1/3})$	$\alpha = \frac{1}{k} \ln b; \quad \beta = \frac{-1}{k}; \quad \gamma = -a^{-1/3}$
Exponential power	$y = a(1 - be^{-kx})^c$	$x = \alpha + \beta \ln(1 + \gamma y^{\delta})$	$\alpha = \frac{1}{k} \ln b; \quad \beta = \frac{-1}{k}; \quad \gamma = -a^{-1/c}; \quad \delta = \frac{1}{c}$
Linear	$y = a + bx$	$x = \alpha + \beta y$	$\alpha = \frac{a}{b}; \quad \beta = \frac{1}{b}$

y = body measurement.
x = age.

TABLE 2. Comparison of the five multivariate growth models using all 3 body measurements of herring gull chicks.

Multivariate model for estimating age[1]		# Parameters	R^2	Root mean square[2] error (mean square)
Logistic	$x = \alpha + \sum_{i=1}^{3} \beta_i \ln\left(\frac{1}{y_i} + \gamma_i\right)$	7	.97668	1.901
Gompertz	$x = \alpha + \sum_{i=1}^{3} \beta \ln(1 + \gamma_i \ln y_i)$	7	.97334	2.034
von Bertalanffy	$x = \alpha + \sum_{i=1}^{3} \beta_i \ln(1 + \gamma_i y_i^{1/3})$	7	.96244	2.414
Exponential power	$x = \alpha + \sum_{i=1}^{3} \beta_i \ln(1 + \gamma_1 y_1^{\delta_i})$	10	.96221	2.423
Linear	$\alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3$	3	.96034	2.478

[1] y_1, y_2, y_3 refer to wing length, culmen and tarsus measurements, respectively.
[2] The degrees of freedom for the root mean square error are assumed to be the number of observations (2004) − 1.

$$\begin{aligned} \text{Age} = & -54.454 - 8.9665 \ln(1/\text{Wing} - 0.00261) \\ & + 3.304 \ln(1/\text{Tarsus} - 0.0113) \\ & - 16.049 \ln(1/\text{Culmen} + 0.02700) \end{aligned} \quad (1)$$

Since the birds were measured only once each day, and since we wished to estimate age in an integral number of days, the result was rounded to the nearest integer. In the univariate logistic models, wing length was best correlated with actual age ($R^2 = .973$ vs $R^2 = .941$ for both culmen and tarsus). Estimation was then considered using wing alone or in combination with either of the other 2 measurements to see if all 3 measurements were needed. The estimation equation using wing only is:

$$\text{Age} = -26.799 - 8.9770 \ln(1/\text{Wing} - 0.00259) \quad (2)$$

Age again was rounded to the nearest integer. The relative performances of equations (1) and (2) are given in Table 3. With both equations, when actual age was regressed on calculated age, t-tests showed that y-intercepts were not significantly different from zero, nor did the slopes differ from 1 ($P > .05$). A combination of wing with either of the 2 other measurements did not fare any better than wing alone and hence a 2-measurement approach was not considered any further. Using the 3 measurements rather than wing alone reduced the mean error by an additional 6.5% or from 2.032 to 1.901 days. The nonlinearity of the

TABLE 3. Analysis of the logistic model for Herring Gull chicks using 3 measurements and wing length alone.

Sources of error	Sum of squares	Mean square error*	Root mean square error (mean error)	Additional % reduction in mean error
Deviation between actual age and:				
Mean age	309,621	154.579	12.433	
Age (wing, culmen, tarsus) (Equation 1)	7,231	3.610	1.901	6.50
Age (wing) (Equation 2)	8,270	4.129	2.032	83.7

* The mean square error was calculated using n-1 or 2003 degrees of freedom. While this gives an unbiased estimate for the expected mean square (SE) about the mean, it is only approximately true for the other MSE's since the models are nonlinear. This precludes the use of classical F-tests for significance.

models prevented the use of standard techniques to determine whether this reduction was statistically significant. However, if one goes through the calculations based on Table 3, there is an indication that the error reduction is significant. Since age was rounded to the nearest day, it could be argued that the improvement achieved through the use of all 3 measurements was not worth the effort or disturbance associated with the extra measurements. Table 4 shows the error distribution obtained by comparing actual versus estimated age for our sample of 2004 data

TABLE 4. Distribution of the error in the prediction of age of Herring Gull chicks using the logistic model.

Residual error (estimated age–actual age)	Number of cases: Wing, Culmen, Tarsus	Wing
−10	0	0
−9	1	1
−8	1	2
−7	1	9
−6	8	23
−5	39	31
−4	57	70
−3	97	85
−2	176	170
−1	318	269
0	443	454
1	462	467
2	252	174
3	128	113
4	20	33
5	1	3

points using: (a) the 3 measurements and (b) wing only. The most obvious advantage of the multivariate model is the smaller proportion of outliers or gross miscalculations than when using wing alone. In either case, the proportion of calculated points falling within 2 days of their actual value was better than 80%. We can show that this mean error is approximately uniform over all ages.

A last consideration is that a large part of the mean error is due to the fact that the experimental chicks were aged only to the nearest day. The formula tends to slightly overestimate chick age since a chick determined to be x days old will actually attain that age some time in the following 24 h. Given an equal chance of hatching at any time of day or night, the mean bias is then an overestimate of 12 h. This overestimate may be overcome by truncating (ignoring the fractional part of) the estimated age instead of rounding.

DISCUSSION

Several factors must be considered in evaluating the usefulness of our aging method. First, the measurements were arbitrarily chosen for convenience and reproducibility. Other possibilities exist. Second, the accuracy of the formula as it applies to the Great Lakes gull population at large is not known. We did not test a sample of chicks other than that used to elaborate the formula and hence the estimates of error given in Table 4 are minimal figures. Another consideration is the degree to which the formula is universally applicable. Differences in body measurements have been reported among different races of Herring Gulls (Dwight 1925). On a smaller scale, Moore (1976) speculated on a division of the Great Lakes population into Superior and Michigan birds, on one hand, and Huron, Ontario, and Erie individuals, on the other. Limited data from the winter of 1979–80 (Mineau, et al. unpubl. report) suggest that a major proportion of the Great Lakes population is likely to spend at least some time on Lake Erie. We hypothesize that the formula given in this paper is applicable at least to all the Great Lakes colonies.

Although an exact survival rate to a given age was not computed, it is evident that our population suffered from higher than average mortality. Most casualities were young birds pecked to death by neighboring adults when they moved out of their feeding territories in response to our presence. The net effect of the extra stress placed on the birds, whether from the fencing or interruption of feeding, is not known. Osteological and feather growth processes are less variable than weight increase (e.g., Ricklefs 1968, Dunn and Brisbin 1980, unpubl. data), but there is undoubtedly some bias introduced by our presence, the magnitude of which is impossible to determine.

Of the 2 aging formulae presented in this paper, one using wing length only, the other a combination of wing length, culmen length, and a modified tarsus measurement, the combination formula has a somewhat better predictive capability. The greatest disadvantage of the wing-only formula is its greater vulnerability to measurement error. However, if the experimenter is more interested in the age profile of a population rather than in determining, with the least error, the age of focal individuals, the wing-only formula is adequate. That is especially true if the time needed for taking the measurement(s) is a concern.

SUMMARY

Formulae which make use of the logistic model are used to age Great Lakes Herring Gulls from birth to fledging through measurement of body parts. Whether using wing length alone or using wing length in combination with two other body measurements, over 80% of all sets of measurements give rise to an estimated age that is within ±2 days of true age. Using three body measurements slightly decreases the number of "serious mistakes."

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