Observations on Growth of Blue-footed Boobies and Development of Temperature Regulation in Peruvian Guano Birds.—Growth rates of seabirds have been related to the availability of food such that pelagic species usually grow more slowly than coastal species (Lack 1968, Harris 1977, Nelson 1977). Differences in growth rates between populations of the same species have been correlated with distance to food supplies or productivity of the surrounding ocean (Nelson 1978), but more comparative data are needed to fully describe these relationships. In this paper, we report upon the growth of the Blue-footed Booby (*Sula nebouxii*), and the development of temperature regulation in the Peruvian Booby (*Sula variegata*), Guanay Cormorant (*Phalacrocorax bougainvillii*), and Brown Pelican (*Pelecanus occidentalis*) on two guano islands in the Peruvian coastal current, formerly one of the richest fisheries in the world.

Study sites and methods.—Duffy visited Lobos de Tierra Island between 24 and 27 February 1979, and Macabi Island between 18 and 21 February 1979. Chicks were weighed with Pesola spring balances and the wing chord, tarsus, and exposed culmen were measured at the beginning and end of a 3-day interval on each island. Growth increments were used to construct composite growth curves according to the method of Ricklefs and White (1975). In addition, proventricular temperatures of chicks isolated from the nest at prevailing ambient temperatures (23–28°C) were measured with a thermistor thermometer (YSI) at 10-min intervals over a period of 30 min. A coefficient of homeothermy was calculated by the expression

$$H = \frac{(T_{30} - T_A)}{(T_0 - T_A)}$$

where $T_0$ and $T_{30}$ are the body temperatures at 0 and 30 min, and $T_A$ is the ambient temperature.

Results.—Of the 4 species, there were sufficient data only for the Blue-footed Booby on Lobos de Tierra to construct a composite growth curve. The relationship between the 3-day increment of wing length and the initial wing length is shown in Fig. 1. Of the 20 observations of wing length increment, 4 deviated greatly from the trend and were disregarded as either measurement errors or resulting from poor nutrition. From Fig. 1, we constructed the following aging criterion (age in days, wing length in mm): (0, 20), (3, 23), (6, 28), (9, 34), (12, 40), (15, 48), (18, 58), (21, 70), (24, 83), (27, 97), (30, 114), (33, 132), (36, 152), (39, 173), (42, 196), (45, 219), (48, 243), (51, 267), (54, 288), (57, 306), (60, 319), (63, 329), (66, 336), (69, 342), (72, 346). The smallest chick encountered had a wing length of 20 mm and weighed 40 g. Because eggs of the Blue-footed Booby on Hood Island, Galapagos, Ecuador weigh 65 g on average (Nelson 1978), and assuming

![Figure 1](attachment:figure1.png)
that Peruvian birds lay eggs of similar size, this chick must have just hatched. We therefore estimated the wing length at day 0 as 20 mm. The largest chick measured had a wing length of 360 mm and was judged to be about 80 days old. On Hood Island, the fledgling period averaged 102 days in 1964 (95–107 days) (Nelson 1978).

It is difficult to place confidence limits on our estimates of age; similar increment analyses of known-age seabird chicks have produced estimates that are generally ±3 days of true age (e.g., Ricklefs and White 1975). Furthermore, the composite growth curve is intended to represent the growth process averaged over the sample as a whole during a brief period. The aging criterion can change from period to period as the growth performance of the population is affected by environmental conditions.

Increase in body mass and the lengths of the tarsus and culmen of the Blue-footed Booby are presented in Fig. 2, where they are compared to Nelson’s data from Hood Island. We fitted Gompertz growth equations to the individual data points for Peruvian birds and to weekly averages of Nelson’s data for the Galapagos Islands. The Gompertz equation has the form

\[ M(t) = A \exp(-\exp(-K(t - i))) \]

where \( M(t) \) is the mass (g) at age \( t \) (days), \( A \) is the asymptote of the growth curve (g), \( i \) is the age at the inflection point (days), and \( K \) is the growth rate constant (days\(^{-1}\)) (see Ricklefs 1967, 1968). The curves were fitted by a nonlinear least-squares regression (SAS procedure NLIN) that employs a modified Gauss-Newton method. The estimated parameters were \( A = 1618 \pm 70 \) SE g, \( K = .66 (\pm .008 \) SE) days\(^{-1}\), and \( i = 16.6 (\pm 1.4 \) SE) days for the Peruvian birds, and \( A = 1741 \) g, \( K = .062 \) days\(^{-1}\), and \( i = 27.9 \) days for the Galapagos birds. Because averages were used to fit curves to the latter sample, we could not obtain meaningful estimates of the standard errors of estimated parameters. If we assumed similar standard errors in both samples, the two populations would differ significantly only in the age at inflection.

The major differences in growth in the samples of Peruvian and Galapagos chicks were that the phase of rapid growth in mass of the latter was delayed by about 10 days compared to the former, and that growth of the tarsus was delayed by up to 3 weeks in the Galapagos chicks (Fig. 2). These differences may reflect either the quality of the season or that of the locality. The data from Hood Island were collected during a period of food shortage and high chick mortality.

The growth rate of the Blue-footed Booby (\( K_0 = .062, .066 \)) is intermediate among species in the genus Sula. Three studies of the smaller Red-footed Booby (\( S. sula \)) yielded estimates of \( K_0 \) of .039, .052, and .056; the larger Masked Booby (\( S. dactylatra \)) has an intermediate growth rate (\( K_0 = .060, .094 \)) (Ricklefs 1973). Each of the species exhibits marked variation in growth rate among studies, which may reflect either locality or seasonal differences. The Brown Booby rarely and the Blue-footed Booby commonly rear two chicks. Both feed in inshore waters. The more slowly growing Masked and Red-footed boobies are pelagic feeders and rear only one chick: distance to feeding area, brood size, and growth rate are strongly associated in the Sulidae (Lack 1968, Nelson 1977, 1978).

The 25 growth increments obtained for the Peruvian Booby were so variable that it was impossible to construct a reliable growth curve. The largest increments in wing length were similar to those of the Blue-footed Booby, but growth performance was very poor in many nestlings, especially on Macabi Island, where 6 of 12 chicks died or disappeared during the 3-day period and 4 of the remaining lost 150 to 575 g. Many chicks on Macabi Island were deserted following infestation of the colony by the tick Ornithodorus ambus (Duffy 1980).

We obtained 7 growth increments of Brown Pelicans on Macabi Island, mostly from very young birds (<3 kg; weights of 1♂ and 1♀ were 7.0 and 5.1 kg, Murphy 1936). The smallest chick, which had just hatched, weighed 66 g and had a wing length of 20 mm. We did not attempt to construct a composite growth curve.

In the Blue-footed Booby, the coefficient of homeothermy, determined at 23–28°C, was .46 (±.16 SD, n = 3) for hatchlings, and increased to 1.0 by 10–15 days of age. According to Nelson (1978), Blue-footed Booby chicks on Hood Island are brooded continuously during the first 2 weeks after hatching. The coefficient of homeothermy is
related to body mass for all the species in this study in Fig. 3. Development of homeothermy appears to follow a similar course in the 2 species of boobies, which attain $H = 1.0$ at a weight of 200–300 g. The few data for the Guanay Cormorant suggest that development of homeothermy is delayed with respect to the boobies. We were unable to obtain measurements on Brown Pelican chicks less than 200 g body mass.

Boobies appear to achieve homeothermy at a lower mass than does the Guanay Cormorant (Fig. 3). This difference is supported by the following data in Table 1 of Dunn (1975). When tested at 28°C, the Masked Booby achieved a value of $H = .75$ at 300 g.
compared to 150–200 g for the Blue-footed and Peruvian boobies. When tested at 20°C, the Double-crested Cormorant (*Phalacrocorax auritus*) achieved \( H = 0.75 \) at 500 g.

In general, cormorants grow more rapidly (values of \( K_c, 0.078–0.133 \) than do boobies (0.039–0.094, Ricklefs 1973) which is consistent with the general inverse relationship between precocity of thermoregulation and growth rate (Ricklefs 1979a,b). There are not yet sufficient data for boobies to allow us to determine whether or not this relationship pertains to species within the genus *Sula*.

We suggest that studies involving visits as brief as 3 days, as in the present study, or separate visits at similar intervals, could yield much valuable information on variation in rate of growth and development among seasons, years, populations, and species. These data might be used to test ideas about factors determining growth rates in seabirds and to provide an index to conditions for reproduction, particularly the availability of food.

### LITERATURE CITED


