

GENERAL NOTES

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 nebouxi*), 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 $H = (T_{30} - T_A)/(T_0 - T_A)$ 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

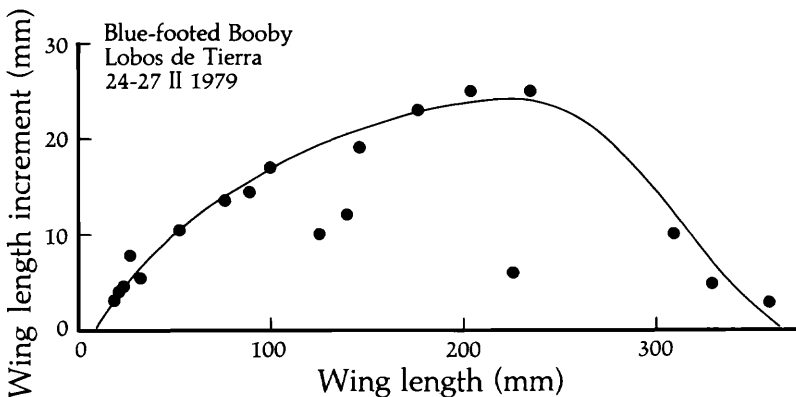


FIGURE 1. Increments in the wing length of Blue-footed Booby chicks over a 3-day period plotted as a function of initial wing length. The solid curve, drawn by eye, was used to construct the composite growth curve.

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 ($K_G = .062, .066$) is intermediate among species in the genus *Sula*. Three studies of the smaller Red-footed Booby (*S. sula*) yielded estimates of K_G of .039, .052, and .056; the larger Masked Booby (*S. dactylatra*) has an intermediate growth rate ($K_G = .060, .094$) (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 *Ornithodoros amblyus* (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 ($\pm .16$ 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

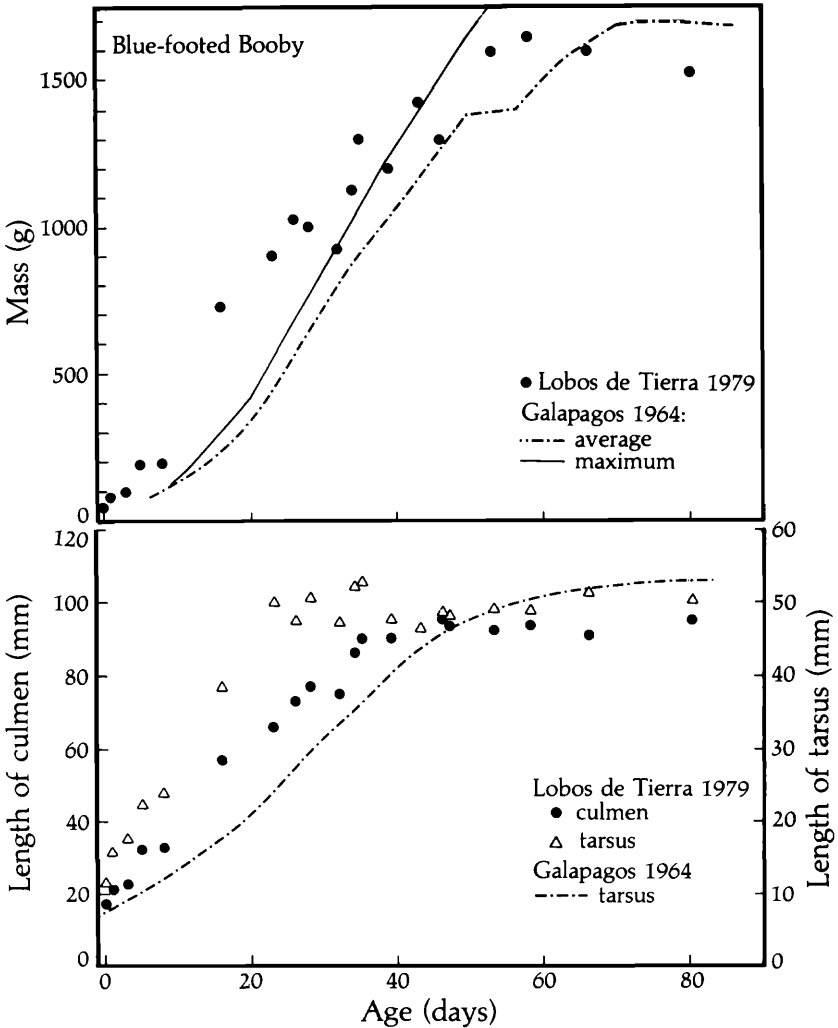


FIGURE 2. Increase in body mass (top) and tarsus and culmen (bottom) as a function of estimated age in the Blue-footed Booby on Lobos de Tierra. Nelson's (1978) data for the Galapagos Islands are indicated for comparison.

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,

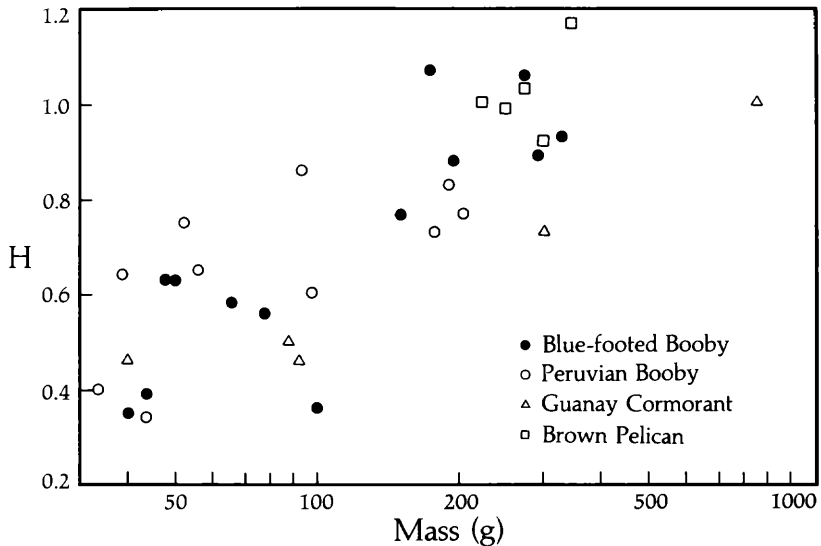


FIGURE 3. Relationship of the coefficient of homeothermy (H) to body mass in 4 species of seabirds in Peru.

compared to 150–200 g for the Blue-footed and Peruvian boobies. When tested at 20°C, the Double-crested Cormorant (*Phalacrocorax auritus*) achieved $H = .75$ at 500 g.

In general, cormorants grow more rapidly (values of K_G , .078–.133) than do boobies (.039–.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

- DUFFY, D. C. 1980. Comparative reproductive behavior and population regulation of seabirds of the Peruvian coastal current. Ph.D. thesis, Princeton University, Princeton, N.J.
- DUNN, E. 1975. The timing of endothermy in the development of altricial birds. *Condor* 77:288–293.
- HARRIS, M. P. 1977. Comparative ecology of seabirds in the Galapagos Archipelago. Pp. 65–76, in B. Stonehouse and C. M. Perrins (eds.), *Evolutionary ecology*. Macmillan, London.
- LACK, D. 1968. *Ecological adaptations for breeding in birds*. Methuen, London.
- MURPHY, R. C. 1936. *Oceanic birds of South America*. Am. Mus. Nat. Hist., New York.
- NELSON, J. B. 1977. Some relationships between food and breeding in the marine Pelecaniformes. Pp. 77–87, in B. Stonehouse and C. M. Perrins (eds.), *Evolutionary ecology*. Macmillan, London.
- . 1978. *The Sulidae: gannets and boobies*. Oxford University Press, Oxford, England.
- RICKLEFS, R. E. 1967. A graphical method of fitting equations to growth curves. *Ecology* 48:978–983.

- . 1968. Patterns of growth in birds. *Ibis* 110:419–451.
- . 1973. Patterns of growth in birds. II. Growth rate and mode of development. *Ibis* 115:177–201.
- . 1979a. Patterns of growth in birds. V. A comparative study of growth and development in the Starling, Common Tern, and Japanese Quail. *Auk* 96:10–30.
- . 1979b. Adaptation, constraint, and compromise in avian postnatal development. *Biol. Rev.* 54:269–290.
- , and S. C. White. 1975. A method for constructing nestling growth curves from brief visits to seabird colonies. *Bird-Banding* 46:135–140.

DAVID C. DUFFY, *Percy Fitzpatrick Institute of African Ornithology, University of Cape Town, Rondebosch 7700, South Africa*, AND ROBERT E. RICKLEFS, *Department of Biology, University of Pennsylvania, Philadelphia, Pennsylvania 19104*. Received 20 Mar. 1981; accepted 23 July 1981.

Rat Predation on Bonin Petrel Eggs on Midway Atoll.—Rats (*Rattus* spp.) are native to few oceanic islands and where introduced have generally caused extensive damage to the vegetation and avifauna. Introduction of rats to Sand and Eastern Islands, Midway Atoll (28°13'N, 177°23'W), in the Leeward Islands of the Hawaiian Archipelago occurred in 1943 with the buildup of military activities (Alsatt 1945). Insular tameness due to the historical lack of predators renders many species vulnerable to predation by rats. Rats have been very successful on islands and are extremely difficult to exterminate once established. A vigorous rodent control program during and prior to 1970 (Howell 1978a,b; T. R. Howell and G. A. Bartholomew, pers. comm.) by the U.S. Navy on Midway Atoll reduced the impact of rats on birds' eggs. During our stay on Midway Atoll during the springs of 1980 and 1981 we noted high roof rat (*Rattus rattus*) populations on both Eastern and Sand Islands and intense predation on the eggs of Bonin Petrels (*Pterodroma hypoleuca*). Predation by the Polynesian rat (*R. exulans*) on eggs, young, and/or adult albatrosses, petrels, shearwaters, tropicbirds, frigatebirds, and terns on nearby Kure Atoll has already been documented (Robbins 1966, Kepler 1967, Fleet 1972, Woodward 1972).

Materials and methods.—Bonin Petrels excavate burrows .6 to 3 m long; at the end of each burrow is an enlarged chamber containing a well-lined nest. A single white egg weighing ca. 39 g is laid. To quantify egg predation we dug vertical shafts 15–20 cm in diameter to the nest chamber which was .3 to 1.3 m vertically below the surface. The shafts were covered with plywood. The two main study areas chosen on Sand Island were a colony of 654 nest burrows south of the Chapel (hereafter designated the chapel colony), and a colony of 225 nest burrows north and east of the Cannon School (hereafter designated the school colony). Egg neglect (adult not present) and orientation in the nest chamber with respect to the long axis of the tunnel were recorded. The shaft covers were lifted and the orientation was noted without disturbing the incubating bird.

Results.—In 1980, 26 eggs were monitored periodically in the chapel colony during the course of incubation. Of these, 25 were eaten by rats and one hatched. Of 21 eggs monitored periodically in the school colony, 19 hatched and 2 were broken by incubating petrels. In addition, 94 other partially eaten eggs were found scattered on the ground in the chapel colony. Some eggs were consumed by rats inside the burrows (partially eaten eggs were found in the nest chamber), thus evidence that predation had occurred was not always available on the surface of the ground. Only one egg in the chapel colony of 654 burrows is known to have hatched in 1980. In 1981, 130 partially eaten petrel eggs were found in the chapel colony. These two colonies are about 100 m apart and separated by a narrow paved road.

Rats were frequently seen in both colonies at night. Rat traps were set in the chapel colony almost every night from 31 January to 29 February 1980. We caught 16 rats inside the chapel colony (area = 2548 m²) during 269 trap nights (number of traps set × number of nights). Traps were set inside the school colony (area = 1766 m²) from 1–11 March 1980. We caught 7 rats during 130 trap nights. Thus the numbers of rats caught per trap night are similar in the two colonies.

Egg neglect occurs regularly in some of the smaller procellariiform birds (Boersma