Weight gain of Blue-footed Booby chicks: an indicator of marine resources

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We weighed and measured chicks of Blue-footed Boobies at 13 localities in the Galápagos Archipelago during July 1981. Chicks were reweighed and remeasured after 5 days. For data analysis, individuals were divided into four size groups based on wing length, within which initial weights were adjusted with respect to wing length, and weight increments were adjusted with respect to wing length and adjusted initial weight. Both adjusted initial weight and adjusted weight increment exhibited significant heterogeneity among breeding localities. In general, rapid growth was associated with cold, productive water in the western part of the island group, but adjusted initial weights indicated that growth performance immediately prior to the beginning of our study exhibited a different geographical pattern. Our results show that growth of seabird chicks may provide an indicator of feeding conditions useful to oceanographers, ecologists, and resource managers. Furthermore, each species of seabird will be sensitive to a different part of the marine environment, thus enabling researchers to assess the condition of many marine resources independently.

1. Introduction

Fishing is a major part of the economies of the inhabitants of tropical islands. Marine resources are coming under increasing pressure from local sources of pollution and intensive, mechanized fishing by developed nations. Because the impact of such factors on fish populations is difficult and expensive to measure directly, simple, indirect indices to marine productivity are needed. The growth of seabird chicks can vary both temporally and geographically and may be sensitive to local availability of marine food resources (Birkhead and Nettleship 1981, Dunn 1975, Lloyd 1979, Nelson 1978, Summers and Drent 1979, White et al. 1976). Spectacular reproductive failures involving pervasive starvation of chicks, abandonment of breeding colonies, and, occasionally, widespread mortality of adults, have been associated with El Niño conditions in the eastern Pacific Ocean (Hutchinson 1950, Schreiber and Schreiber 1983). Certain localities, such as Ascension Island, which lies close to the equator in the Atlantic Ocean, are surrounded by variable and generally unproductive waters. Seabirds there experience erratic breeding success (Dorward 1962). In general, breeding success and growth rate vary among localities and seasons in relation to marine productivity (Harris 1969, Nelson 1978). Therefore, these variables may provide an indirect index to levels of fish and other prey populations. In an effort to test the feasibility of techniques based on such premises, we weighed and measured Blue-footed Booby chicks over 5-day intervals at 13 breeding localities within the Galápagos Archipelago during July 1981.
The Galdipagos Islands present an unusual opportunity to study the relationship between marine productivity and seabird growth because during May through November the cold, productive upwelling of the Cromwell Current extends southeast through the Archipelago from its summer location off the western islands (Hovenaghel 1978, Pak and Zaneveld 1973). This current profoundly affects the marine and terrestrial environments of the Galapagos Islands and is responsible for, among other things, the occurrence of penguins at the equator (Boersma 1977, 1978).

2. Materials and methods

The Blue-footed Booby Sula nebouxii has a limited range of distribution, entirely within the eastern Pacific Ocean, and is the second rarest species of booby. Breeding colonies are located on islands off the coast of western Mexico and in the Gulf of California, in the Gulf of Panama, off the coasts of Ecuador and northern Peru, and in the Galapagos Archipelago (Nelson 1978). Within the archipelago, the boobies are widely distributed among approximately 25 small breeding colonies totaling about 10 000 pairs. Adults breed in all months of the year on a 9–10 month cycle. Two eggs constitute the normal clutch, but usually only the first-hatched chick survives the 100-d nestling period, while the second chick starves (Nelson 1978).

Because Blue-footed Boobies are observed to feed close to shore and feed their chicks frequently during the day, they are believed to restrict their foraging to within a few km of their colonies. Hence, their breeding may be sensitive to the productivity of the water immediately surrounding the nestling area. During July 1981, we measured the growth of booby chicks at 13 localities among the major islands in the archipelago (see Figs. 1 and 2). At this time, water temperatures off the southern and western coasts of Isabela Island, and surrounding Fernandina Island, ranged between 17 and 20°C, whereas temperatures in the eastern part of the archipelago were mostly between 21 and 23°C. Measurements of sea surface temperatures were made from two vessels, a 6-knot fishing boat and a 12-knot research boat, in the course of travel between breeding colonies. Temperatures were taken at 0.5–2 h intervals depending on boat speed. Median sea temperatures were 18.7°C (n = 192) in the western part of the archipelago, 22.2°C (n = 58) in the center, and 21.4°C (n = 40) in the south. Secchi disk measurements of water transparency were made irregularly during stops in open water. Median Secchi disk readings were 5.5 m (n = 30) in the west, 11 m (n = 7) in the center, and 12 m (n = 17) in the south. The readings indicated greater turbidity, and therefore likely productivity, of the colder water. Feldman (1983) has shown a general relationship between sea surface temperature and chlorophyll concentration in the area of the Galapagos Islands.

We visited 13 localities initially between 3 and 26 July 1981, and returned to each 5 days later. Each nesting colony was visited at the same time of day, although logistics prevented us from gathering data in all colonies at the same time of day. Initial visits were scheduled as follows: locs. 1, 2, 4, 5, 6, and 7 between 22 and 26 July; locs. 15 and 16, 3 and 4 July; locs. 23, 24, 28, 30, and 33 between 15 and 18 July. We also obtained data at location 15 on 2 and 7 February 1981 and at location 28 on 27 May and 1 June 1981. During the entire study, we banded, weighed, and measured 495 chicks. These were weighed with Pesola spring scales readable to 25 g. Wing length from the wrist to the tip of the manus or the longest primary feather was measured along a meter stick.

We expected the sensitivity of weight gain to food resource level to bear some relationship to the size and food requirements of chicks and assigned them to four size (age) categories based on wing length: small, 20–40 mm, approximately 0–12 d; medium, 40–80 mm, 12–23 d; large, 80–200 mm, 23–43 d; extra large, 200–500 mm, 43–100 d (Duffy and Ricklefs 1981). Wing lengths of adults average 432 mm for males and 457 mm for females (Nelson 1978). The lower boundaries of the age class intervals corresponded to average weights of 111, 358, 772, and 1492 g. Adult weights average 1283 g for males and 1801 g for females (Nelson 1978). Sexes of chicks were not distinguished.

Weight changes were calculated by subtracting the weight at first visit from that at the second. Within each size class, initial weights and weight increments were adjusted using wing length to correct for differences in growth rate associated with age; weight increments were additionally adjusted by initial weight to correct in part for the effect of recent feeding on subsequent weight change. We calculated residuals about the regression of initial weights (WTI) against the length of the wing (WN) and WN². We then calculated residuals about the regression of weight increments (DWT) on WN, WN², and WTI. Analyses were performed with the GLM Procedure of the Statistical Analysis System (SAS).

3. Results

Adjusted weight increments were subjected to a two-way analysis of variance to determine differences associated with brood size (and hatching order in broods of two) and breeding locality. None of the interactions between brood size and locality were statistically significant (P > 0.05). Variation in RWTI was significant among localities for chicks of all sizes: small [F(14,98) = 2.93, P = 0.0009, R² = 0.30], medium [F(14,99) = 3.45, P = 0.0001, R² = 0.34], and extra large [F(14,146) = 2.64, P = 0.019, R² = 0.30], and extra large [F(14,85) = 2.04, P = 0.0305, R² = 0.24]. Variation in RDWT among localities was significant for small [F(14,89) = 4.13, P = 0.0001, R² = 0.44], medium [F(14,93) = 9.80, P = 0.0001, R² = 0.60], and large [F(14,141) = 7.19, P =
Fig. 1. Adjusted weight increments of Blue-footed Booby chicks in each of four size classes at each of 13 localities. Zero represents the mean value for the size class within the sample as a whole. Localities are numbered according to the scheme in Nelson (1978). Island acronyms: ES = Espanola, FA = Fernandina, IS = Isabela, SC = San Cristobal, SM = Santa Maria, SS = San Salvador, SZ = Santa Cruz.

0.0001, R² = 0.43] chicks, but not for extra large chicks [F (14,80) = 1.48, P = 0.15]. Brood size had a statistically significant effect only among small chicks; single chicks and first-hatched chicks in broods of two gained significantly more weight than second-hatched chicks [F (2,98) = 8.9, P = 0.003, means 16.2 g (single chicks), 6.6 g (larger of twins), and −22.2 g (smaller of twins), SD = 48.7 g].

The influence of breeding locality on weight increment is shown in Fig. 1, where the average adjusted weight increment for each size class is portrayed for each breeding colony. The localities form three groups with respect to weight changes. In the western cold-water region (locs. 1–7) chicks exhibited substantial weight increases in most size categories, whereas in the southeastern part of the archipelago (locs. 23–33) most of the chicks lost weight, often in considerable amounts. In the central colonies (locs. 15–16), weight changes during the 5-d period were close to the average for the study. These results are consistent with the presence of cold, productive waters at the western edge of the archipelago.

If the differences in growth performance among localities observed during this study reflected persistent conditions during the season, adjusted initial weights of birds should have borne a close correspondence to observed weight changes. The situation is shown in Fig. 2. Although weight increments in the west were large and positive compared with those in other parts of the archipelago, initial weights tended to be average or low, and did not differ from those in the southeast, where subsequent weight gains were poor. Initial weights were highest at the two colonies in the center of the island group. This pattern indicates that feeding conditions in the west may have been better during our study than during the preceding period and that conditions in the center of the archipelago may have deteriorated between our first and second visits.

Variation in adjusted weight increments in our sample was of the same order of magnitude as variation in adjusted initial weights (Tab. 1). Hence differences in initial weights among colonies could have been generated by differences in feeding conditions experienced during the preceding 5–10 d. This implies short-term
fluctuations in food resources, perhaps tied to changes in the location of water masses within and around the archipelago. Weight increments recorded at location 15 in February and location 28 in May (generally good in both cases) suggest the possibility of seasonal differences as well.

4. Discussion

Our observations show that growth of seabird chicks can provide a valuable indicator of conditions of interest to oceanographers, ecologists, and resource managers. Some species, such as Sooty Terns *Sterna fuscata* and Red-footed Boobies *Sula sula*, are widely distributed in tropical oceans and could provide information on geographical and seasonal variation in marine resources and could be used to monitor longer-term changes in areas where marine life is coming under intense commercial exploitation. By choice of appropriate indicator species, investigators will be able to distinguish nearshore and pelagic conditions, or focus upon particular parts of the oceanic system or marine food webs. In the Galápagos Islands, for example, Blue-footed Boobies fed close to colonies and reproductive performance appears to reflect nearshore conditions. Masked Boobies *S. dactylatra* and Red-footed Boobies, breeding in the

<table>
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<th>Wing length class (mm)</th>
<th>20–40</th>
<th>40–80</th>
<th>80–200</th>
<th>200–500</th>
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<tr>
<td>Initial weight (g)</td>
<td></td>
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<tr>
<td>Mean</td>
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<td>615</td>
<td>1092</td>
<td>1693</td>
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<td>SD</td>
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<td>190</td>
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<tr>
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<td>141</td>
<td>176</td>
<td>249</td>
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<tr>
<td>Weight increment (g)</td>
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<td>SD of adjusted value</td>
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<td>118</td>
<td>125</td>
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same area, feed at great distance from breeding sites and restrict foraging to warm, tropical water. Many tropical seabirds, e.g., Sooty Terns, Brown Noddies *Anous stolidus*, and shearwaters *Puffinus* spp., feed predominantly in association with schools of tuna and dolphins on smaller fish forced to the surface to escape predation from below (Ashmole and Ashmole 1967, Ashmole 1971). The reproductive performance of these birds probably depends on the size and location of tuna schools and the smaller prey fish. Other seabirds, particularly many of the petrels, feed much closer to the bottom of the food chain on planktonic crustacea, and variation in their growth performance will reflect different aspects of the marine environment.

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