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MAXIMUM DIVE DEPTHS OF THE PERUVIAN DIVING-PETREL[1]

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Abstract. The mean maximum dive depth attained for 22 adult Peruvian Diving-petrels (*Pelecanoides garnotii*) was 31.6 ± 3.6 m. The deepest dive was 83.1 m. This maximum dive depth was 81% deeper than that predicted by its body size (46 m) and the deepest reported for a seabird weighing less than 210 g.

Key words: Peruvian Diving-petrels, diving depths, foraging behavior, Pelecanoides garnotii.

The maximum dive depth of several taxa of free-living seabirds has been successfully determined using capillary-tube gauges. Although these devices provide only the record of the deepest dives, which normally represent less frequent exploratory dives beyond the animal's normal foraging depths (Lishman and Croxall 1983, Piatt and Nettleship 1985, Watanuki et al. 1996), they are useful in that they provide an initial insight into an animal's underwater capabilities, habitat use, and access to deep prey (Adams and Brown 1983, Harris et al. 1990, Prince and Jones 1992). Maximum depth gauges are light-weight and represent at present the only viable and reliable technique to measure the diving capabilities of small birds such as diving-petrels, which are incapable of carrying heavy and more sophisticated devices.

The Peruvian Diving-petrel (*Pelecanoides garnotii*), the largest of the four extant diving-petrels, is endemic to the cold nutrient-rich Peruvian Coastal Current (Murphy 1936). Once abundant, these birds have been adversely affected by hunting, fishing activities, and reduction of nesting habitat (Murphy 1936, Hays 1989). Although Peruvian Diving-petrels are considered endangered (Wege and Long 1995), information about the breeding and foraging ecology of these birds is scarce. The maximum breeding population in Peru was estimated to be 13,000 pairs in 1996, whereas their distribution was restricted to only two islands in central Peru: La Vieja and San Gallán (Jahncke and Goya, unpubl. data).

In this study we report maximum dive depths attained by breeding Peruvian Diving-petrels and compare them with data obtained from other wing-propelled divers.

METHODS

The field work was carried out on La Vieja Island, Peru (14°16′S, 76°11′W) from August 1995 to May 1996. The island lies at the entrance of Independencia Bay, about 50 km south of the Paracas Peninsula.

Depth gauges were deployed on 66 adult birds at different stages of the breeding cycle (incubation and chick rearing). Adults were captured in their burrows, weighed, measured, and ringed. Gauges were attached to feathers in the center of the bird's back using quick-set epoxy glue (Devcon 5-minute epoxy). The devices were retrieved after 1–3 days.

Capillary-tube depth gauges, similar to those described by Burger and Wilson (1988), consisted of a 6 cm length of flexible, clear PVC tubing (internal diameter of 0.8 mm), coated internally with a thin layer of indicator powder (one part methylene blue:three parts talcum powder). Once coated, the tube was heat-sealed at one end. Each tube weighed approximately 0.5 g, which was < 0.25% of adult body weight ($\bar{x}$ = 202 g, n = 65), and had a cross-sectional area of less than 10 mm^2, about 0.7% of the maximum cross-sectional area of an adult bird ($\bar{x}$ = 14.6 cm^2, n = 32).

During diving, water enters the tube by hydrostatic pressure, compressing the volume of air inside the lumen. The volume of compressed air varies inversely

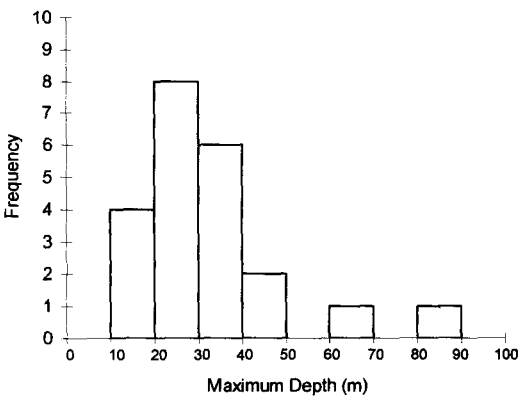

FIGURE 1. Maximum dive depths of Peruvian Diving-petrels (n = 22) breeding in La Vieja Island, Peru, between August 1994 and May 1995.

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TABLE 1. Maximum diving depths recorded for three species of diving-petrels and two similar-sized alcids. D_{max} predicted was determined by the equation $D_{max} = 75.905M^{0.316}$ (Burger 1991).

Species	Weight (g)	Mean D_{max} (m)	Observed D_{max} (m)	Predicted D_{max} (m)	*n*	Reference
Diving-petrels						
Pelecanoides georgicus	93.0	25.7	48.6	35.8	6	Prince and Jones 1992
P. urinatrix	147.4	38.9	63.6	41.1	103	Chastel 1994
P. garnotii	202.0	31.6	83.1	45.6	22	This study
Alcids						
Ptychoramphus aleuticus	190.0	—	43.0	44.9	23	Burger 1991
Alle alle	160.0	—	35.0	42.5	—	Burger 1991

with hydrostatic pressure (with increasing depth) as described by Boyle's Law. When the bird is at the surface, the water washes out the powder, leaving a line at the point of maximum compression. The maximum depth attained was calculated by the equation:

$$D_{max} = 10.08[(L_s/L_d) - 1];$$

where D_{max} is the maximum depth in meters, 10.08 is the height (m) of a column of sea water equivalent to 1 atmosphere of pressure, L_s is the total length of the tube, and L_d is the length of the tube with undissolved indicator (Burger and Wilson 1988). After recovery of the recorders, the length of the tube with indicator was measured to the nearest 0.1 mm using calipers. Tubes with water droplets in the lumen were discarded.

The accuracy of the depth gauges was checked by lowering nine of them into sea-water from the SNP-1 Research Vessel of IMARPE (Instituto del Mar del Peru) to known depths ranging from 10 to 150 m. Means are expressed ± SE.

RESULTS

Maximum depth gauges overestimated real depths by an average of 13.2% (2.2–35.0%), with shallower depths (< 70 m) being recorded more precisely (< 8% error) than deeper depths (> 70 m). Estimated depths could be corrected by the equation: Real depth = 3.12 + 0.8 × estimated depth, for estimated depths ranging from 10 to 150 m ($r^2 = 0.99$, $n = 9$).

Forty-one gauges (62%) were recovered after one foraging trip, but only 22 gave readable measurements. Mean maximum dive depth was 31.6 ± 3.6 m, and 91% of the maximum dives were between 10 and 50 m (Fig. 1). The shallowest dive was 10.0 m, and the deepest dive was 83.1 m. There was no significant difference in the maximum dive depth attained by birds incubating eggs ($\bar{x} = 34.4 \pm 3.8$ m, $n = 5$) and those rearing chicks ($\bar{x} = 30.8 \pm 4.6$ m, $n = 17$) (Mann-Whitney $U = 28$, $P = 0.27$).

DISCUSSION

The mean maximum dive depth attained by the Peruvian Diving-petrel was similar to those reported for other species of diving-petrels (Table 1). However, when the deepest dive depths recorded for each species are compared, values are related, among other things, to body size, as in other species of diving seabirds (Piatt and Nettleship 1985, Burger 1991).

Burger (1991) determined that maximum dive depths of penguins and alcids were positively correlated to body size and can be predicted by the equation $D_{max} = 75.905M^{0.316}$, where M = mass in kg, for both groups combined. Using this equation with the mean weight of Peruvian Diving-petrels (202 g), a maximum dive of 45.8 m is expected. This value is about half that of the observed maximum dive of 83.1 m. Likewise, maximum depths attained by the three species of diving-petrels were deeper than those recorded for similar-sized alcids (Table 1), which are recognized to be close ecological and morphological analogues of diving-petrels (Thoresen 1969). This evidence suggests that Peruvian Diving-petrels are capable of exploring deep waters and that diving capabilities of diving-petrels may differ from those exhibited by other wing-propelled divers.

Diving patterns of Peruvian Diving-petrels may be variable according to location, time of the year, and behavior of its prey (Wilson and Wilson 1990). The major prey species consumed by these birds around La Vieja Island during the study period were small crustaceans, mainly euphausiids (25.2% by mass) and larval stages of Peruvian anchovies (*Engraulis ringens*) and other fishes (27.3% by mass) (Jahncke et al., unpubl. data). Euphausiids are widespread to depths of at least 300 m (Brinton 1962, cited in Santander et al. 1981), whereas Peruvian anchovy larvae are confined to the upper 60 m (Sameoto 1981). Both prey types show diel vertical migration, remaining in deeper water strata during the day and rising to the surface by night (Brinton 1962, cited in Santander et al. 1981, Sameoto 1981). Because Peruvian Diving-petrels are mainly diurnal foragers (Jahncke, unpubl. data), it is expected that these birds need to reach deep water strata to catch food.

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DIVING DEPTHS OF TWO TROPICAL PELECANIFORMES: THE RED-TAILED TROPICBIRD AND THE RED-FOOTED BOOBY[1]

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Abstract. The diving ability of two tropical Pelecaniformes, the Red-footed Booby (*Sula sula*) and the Red-tailed Tropicbird (*Phaethon rubricauda*) was studied on Europa Island, southern Mozambique Channel, using capillary depth recorders fitted on breeding adults. Both species mainly exploited the first 4 m of the water column. Although such a depth can be reached solely by passive plunge diving, the range of depths reached by the two species suggests that they may, at least sometimes, use their feet and wings to perform active underwater pursuit swimming. Intraspecific comparison of the depth reached by Red-tailed Tropicbirds also suggests that this species may change its diving behavior seasonally.

Key words: diving depth, feeding ecology, Red-tailed Tropicbird, Red-footed Booby, Phaethon rubricauda, Sula sula, *Europa Island.*

Most boobies (tropical *Sulidae*) and all tropicbirds (*Phaethontidae*) are pelagic plunge diving seabirds (Ashmole 1971, Nelson 1978, Schreiber and Clapp 1987), foraging solitarily (tropicbirds, Masked Booby) or collectively (most boobies), and feeding mainly on flying fishes and squid (Ashmole and Ashmole 1967, Diamond 1974, 1975, Harrison et al. 1983). Plunge divers supposedly have limited diving capacities, the depth they reach depending mainly on the momentum gained during the plunge (Ashmole 1971). However, at least Cape Gannets (*Sula capensis*) can use their wings and feet to gain additional depth (Adams and Walter 1993). Here I report diving performances of two tropical plunge divers, the Red-tailed Tropicbird (*Phaethon rubricauda,* 0.8 kg) and the Red-footed Booby (*Sula sula,* 0.9 kg).

METHODS

The study was conducted on Europa Island (22°20′S, 40°22′E) in the southern Mozambique Channel. About 3,000 pairs of Red-footed Boobies and about 3,500

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