research and management disturbance, p. 173–182. *In* B. A. Giron Pendleton, B. A. Milsap, K. W. Cline, and D. M. Bird [eds.], Raptor management techniques manual. Natl. Wildl. Fed., Washington, DC.

Jolly, A., and R. Jolly. 1984. Malagasy economics and conservation: a tragedy without villains, p. 27–54. *In* A. Jolly, P. Oberlé and R. Albignac [eds.], Key environments—Madagascar. Pergamon Press, New York.

Lack, D. 1954. The natural regulation of animal numbers. Oxford Univ. Press, London.

Langrand, O. 1990. Guide to the birds of Madagascar. Yale Univ. Press, New Haven, CT.

Langrand, O., and B.-U. Meyburg. 1984. Birds of prey and owls in Madagascar: their distribution, status, and conservation, p. 3–13. *In* J. M. Mendelsohn and C. W. Sapsford [eds.], Proc. Symp. African Predatory Birds. Natal Bird Club, Durban, South Africa.

Milon, P., J. J. Petter, and G. Randrianasolo. 1973. Faune de Madagascar. 35. Oiseaux. ORSTOM and CRNS, Tananarive, Madagascar and Paris.

Newton, I. 1979. Population ecology of raptors. Buteo Books, Vermillion, SD.

Rand, A. L. 1936. The distribution and habits of Madagascar birds. Bull. Am. Mus. Nat. Hist. 77: 143–499.

Sinclair, D. F. 1985. On tests of spatial randomness using mean nearest neighbor distance. Ecology 66: 1084–1085.

Steenhof, K. 1987. Assessing raptor reproductive success and productivity, p. 157–170. *In* B. A. Giron Pendleton, B. A. Milsap, K. W. Cline, and D. M. Bird [eds.] Raptor management techniques manual. Natl. Wildl. Fed., Washington, DC.

Thiollay, J. M. 1989. Area requirements for the conservation of rain forest raptors and game birds in French Guiana. Conserv. Biol. 3:128–137.

Thiollay, J. M., and B.-U. Meyburg. 1981. Remarques sur l'organisation d'un peuplement insulaire de rapaces: Madagascar. Alauda 49:216–226.

Watson, R. T. 1990. Breeding biology of the Bateleur. Ostrich 61:13–23.

The Condor 98:627–629
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DIVING ABILITY OF BLUE PETRELS AND THIN-BILLED PRIONS[1]

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Key words: Blue Petrel; Thin-billed Prion; maximum diving depths; foraging behavior; Halobaena caerulea; Pachyptila belcheri.

Capillary depth recorders (Burger and Wilson 1988) are useful tools for studying the foraging ecology of seabirds, and have been used successfully on penguins, alcids, shags and gannets (Burger 1991, Wanless et al. 1991, Adams and Walter 1993, Croxall et al. 1993). Recent studies of Procellariiformes have revealed that diving petrels (*Pelecanoides georgicus* and *P. urinatrix*) are able to dive routinely down to 25-40 m (Prince and Jones 1992, Chastel 1994). Furthermore, investigations on albatrosses (Prince et al. 1994), and on the White-chinned Petrel *Procellaria aequinoctialis* (Huin 1994), have shown that these seabirds can reach a depth of several meters, giving a new insight on the foraging techniques of albatrosses and petrels, which are generally regarded as surface-seizers (Harper 1987, Prince and Morgan 1987).

The Blue Petrel *Halobaena caerulea* and the Thin-billed Prion *Pachyptila belcheri* are small burrow-nesting petrels (190 and 150 g, respectively). At Kerguelen Islands these two seabirds breed in very large numbers (up to 1 million pairs, Weimerskirch et al. 1989); the prions particularly are believed to have a significant impact on subantarctic resources (Ridoux 1994). During the chick-rearing period (50 days, Weimerskirch et al. 1994), both species alternate long and short foraging trips over pelagic and neritic waters (Weimerskirch et al. 1994) and prey mainly on small crustaceans (Harper 1972, Prince 1980, Ridoux 1994), principally by surface-seizing (Harper 1987, Prince and Morgan 1987).

This paper reports the first study on maximum dive depths attained by Blue Petrels and Thin-billed Prions, during the chick-rearing period at Kerguelen Islands.

METHODS

Field work was carried out on Mayes Island, Kerguelen Archipelago (48°28 S, 69°57 E), between 17 January and 7 February 1993. Maximum depth recorders consisted of 12 cm lengths of plastic tubing (internal diameter, 0.8 mm.) lined with icing sugar and sealed at one end. Each tube weighed approximately 1 g (< 0.7%

[1] Received 25 August 1995. Accepted 17 May 1996.

TABLE 1. Maximum diving depths and gauge deployment durations of Blue Petrels and Thin-billed Prions at Kerguelen Islands.

	Gauge deployment (days)	Initial tube length (mm) L_s	Length (mm) compressed L_d	Maximum depth (m)
Blue Petrel	7	97	69.5	4.0
	4	99.5	64.5	5.5
	9	106	71.5	4.9
	1	104.5	95.5	1.0*
	7	83	51.5	6.2*
	9	98	66	4.9
Thin-billed Prion	2	101	66.5	5.2
	1	101	58	7.5
	5	97	60	6.2
	4	96	65.5	4.7
	1	108.5	79	3.8

* Maximum depths attained by the same individual.

of adult body mass) and was attached to the back feathers using waterproof adhesive tape. On recovered gauges the length of tube still covered with icing sugar was measured to the nearest 0.5 mm. Maximum dive depth was calculated by the equation: $d_{max} = 10.08(L_s/L_d - 1)$ where d is depth (m), L_s is the initial length (mm) of undissolved indicator, and L_d its length on recovery (Burger and Wilson 1988).

In both species, the single chick is left alone in the burrow within a few hours after hatching (late December and early January for the Blue Petrel and the Thin-billed Prion, respectively; Weimerskirch et al. 1989) and thereafter fed regularly by both parents. To identify the parent and to recover the depth gauges, traps were installed at the entrance of 13 Blue Petrel and five Thin-billed Prion burrows during the course of the study. The trap was fitted with a swing-door that let the parent enter the burrow when coming from the sea to feed the chick, but trapped it when it tried to return to the sea. Birds were banded with monel rings for identification. During the course of the study, 19 Blue Petrel and 12 Thin-billed Prion depth gauges were attached to adult birds that returned to feed their chick. The traps were inspected every hour at night and the trapped adults were identified and released immediately after recovery of the capillary gauge.

RESULTS

Eleven capillary tubes were successfully recovered from five individuals in each species (Table 1). The mean (± SD) maximum depths were 4.4 ± 1.8 m (range: 1.0–6.2 m) and 5.5 ± 1.4 m (range: 3.8–7.5 m) for the Blue Petrel and the Thin-billed Prion, respectively. In the Blue Petrel, the shallowest and the deepest dives were performed by the same bird. Maximum depths recorded and gauge deployment durations were not correlated for either species (Spearman rank correlation: Blue Petrel: $r_s = 0.24$, $n = 6$, $P > 0.05$; Thin-billed Prion: $r_s = 0.10$, $n = 5$, $P > 0.05$).

DISCUSSION

Most Procellariiformes are unlikely to exhibit significant diving abilities, due either to low wing loading, high aspect ratios or unstreamlined tarsi (Warham 1977). Considering these morphological features, shearwaters, and particularly diving petrels (the southern ecological and morphological analogues of alcids, Thoresen 1969), should be the most proficient divers (Warham 1977). Anecdotal observations have revealed that Short-tailed Shearwaters, *Puffinus tenuirostris* (Skira 1979) and Sooty Shearwaters, *P. griseus* (Brown et al. 1981) could reach 10 m down; likewise, Flesh-footed (*P. carneipes*) and Fluttering Shearwaters (*P. gavia*) were recorded to depths of about 5 m and 2–3 m, respectively (Wood 1993). Two studies using maximum depth gauges have shown that the highly specialized diving petrels dove as deep as 48 m in the South Georgia Diving Petrel (Prince and Jones 1992) and 63 m in the Common Diving Petrel (Chastel 1994).

However, all Procellariiformes studied so far do dive, except the Wandering Albatross, *Diomedea exulans* (Prince et al. 1994). Black-browed (*Diomedea melanophris*) and Gray-headed Albatrosses (*Diomedea chrysostoma*) routinely dive to 3 m, whereas Light-mantled Sooty Albatrosses (*Phoebetria palpebrata*) on average attain 4.7 m, with a maximum depth of 12 m (Prince et al. 1994). Furthermore, the White-chinned Petrel has recently been shown to regularly dive to 6 m, with a maximum of 13 m (Huin 1994).

Blue Petrels and Thin-billed Prions are poorly suited for diving, having low wing loading (Warham 1977), and feeding mainly by surface seizing or dipping (Croxall and Prince 1980, Prince 1980, Harper 1987), although aerial plunging and surface diving have been reported in the Blue Petrel (Croxall and Prince 1980), more scarcely in the Thin-billed Prion (Harper 1987). The submersion duration in the Blue Petrel did not seem to exceed six seconds (Bierman and Voous 1950), suggesting shallow dives. Our results show that during the chick-rearing period, both species regularly dive to 5 m, and can attain a maximum depth of 7 m. These dives are shallower than those of diving petrels, and probably of shearwaters, but similar to those of albatrosses, consistent with their morphology.

Burger and Wilson (1988) pointed out that depths tended to be overestimated during shallow dives (39% overestimate at 5 m). Nevertheless, even if we take into account their corrections, Blue Petrels and Thin-billed Prions can still dive regularly to 3 m, and occasionally 5 m. Wanless et al. (1991) noticed that devices not recovered within 24 hours could also overestimate values. However, we found no correlation between gauge deployment time and maximum depth, suggesting that our results are reliable. Consequently, Blue Petrels and Thin-billed Prions forage not only on and near the sea surface, but also exploit a water column 5–7 m deep.

Studies using capillary tubes on Procellariiformes have shown that, by diving, these seabirds use more foraging techniques than previously supposed, probably allowing them to enlarge their dietary spectrum. Capillary gauges as maximum depth recorders, being simple and efficient, should be applied to other Procellariiformes particularly during diet studies.

Support for this study was provided by the Terres Australes et Antarctiques Françaises and Institut Français pour la Recherche et la Technologie Polaires and by a grant from the Groupement de Recherche en Environnement 1069 "Ecosystèmes Polaires et Anthropisation" (directed by P. Jouventin), from the C.N.R.S. Yves Cherel and Christophe Verheyden made helpful suggestions on the manuscript. We also thank François Mougeot and Daniel Haubreux for field assistance, and Claire Mac Arthur, who kindly improved the English.

LITERATURE CITED

ADAMS, N. J., AND C. B. WALTER. 1993. Maximum diving depths of Cape Gannets. Condor 95:734–736.

BIERMAN, W. H., AND K. H. VOOUS. 1950. Birds observed and collected during the whaling expedition of the Willem Barendz in the Antarctic 1946–1947. Ardea 37: 1–123.

BROWN, R. G. B., S. T. BARKER, D. E. GASKIN, AND M. R. SANDEMAN. 1981. The foods of Great and Sooty Shearwaters *Puffinus gravis* and *P. griseus* in eastern Canadian waters. Ibis 123:19–30.

BURGER, A. E. 1991. Maximum diving depths and underwater foraging in alcids and penguins. *In* W. A. Montevecchi and A. J. Gaston [eds.], Studies on high latitude seabirds. 1. Behavioural and oceanographic aspects of seabird feeding ecology. Canadian Wildl. Serv., Occ. Paper 68:9–15.

BURGER, A. E., AND R. P. WILSON. 1988. Capillary tubes depth gauges for diving animals: an assessment of their accuracy and applicability. J. Field Ornithol. 59:345–354.

CHASTEL, O. 1994. Maximum diving depths of Common Diving Petrels *Pelecanoides urinatrix* at Kerguelen Islands. Polar Biol. 14:211–213.

CROXALL, J. P., D. R. BRIGGS, A. KATO, Y. NAITO, Y. WATANUKI, AND T. D. WILLIAMS. 1993. Diving pattern and performance in the Macaroni Penguin *Eudyptes chrysolophus*. J. Zool. 230:31–47.

CROXALL, J. P., AND P. A. PRINCE. 1980. Food, feeding ecology and ecological segregation of seabirds at South Georgia. Biol. J. Linn. Soc. 14:103–131.

HARPER, P. C. 1972. Field identification and distribution of the Thin-billed Prion *Pachyptila belcheri* and the Antarctic Prion *Pachyptila desolata*. Notornis 19: 140–175.

and the Antarctic Prion *Pachyptila desolata*. Notornis 19: 140–175.

HARPER, P. C. 1987. Feeding behaviour and other notes on 20 species of Procellariiformes at sea. Notornis 34: 169–192.

HUIN, N. 1994. Diving depths of White-Chinned Petrels. Condor 96: 1111–1113.

PRINCE, P. A. 1980. The food and feeding ecology of Blue Petrel (*Halobaena caerulea*) and Dove Prion (*Pachyptila desolata*). J. Zool. 190:59–76.

PRINCE, P. A., AND MORGAN, R. A. 1987. Diet and feeding ecology of Procellariiformes, p. 102–114. In J. P. Croxall [ed.], Seabirds feeding ecology and role in marine ecosystems. Cambridge Univ. Press, Cambridge.

PRINCE, P. A., AND JONES, M. 1992. Maximum dive depths attained by South Georgia Diving Petrel *Pelecanoides georgicus* at Bird Island, South Georgia. Ant. Sci. 4:433–434.

PRINCE, P. A., N. HUIN, AND H. WEIMERSKIRCH. 1994. Diving depths of albatrosses. Ant. Sci. 6:353–354.

RIDOUX, V. 1994. The diets and dietary segregation of seabirds at the subantarctic Crozet Islands. Marine Ornithol. 22: 1–192.

SKIRA, I. J. 1979. Underwater feeding by Short-tailed Shearwaters. Emu 79:43.

THORESEN, A. C. 1969. Observations on the breeding behaviour of the Diving Petrel *Pelecanoides urinatrix* (Gmelin). Notornis 16:241–260.

WANLESS, S., A. E. BURGER, AND M. P. HARRIS. 1991. Diving depths on Shags *Phalacrocorax aristotelis* breeding on the Isle of May. Ibis 133:37–42.

WARHAM, J. 1977. Wing loadings, wing shapes and flight capabilities of Procellariiformes. N.Z. J. Zool. 4:73–83.

WEIMERSKIRCH, H., O. CHASTEL, L. ACKERMANN, T. CHAURAND, F. CUENOT-CHAILLET, X. HINDERMEYER, AND J. JUDAS. 1994. Alternate long and short foraging trips in pelagic seabird parents. Anim. Behav. 47:472–476.

WEIMERSKIRCH, H., R. ZOTIER, AND P. JOUVENTIN. 1989. The avifauna of the Kerguelen Islands. Emu 89:15–29.

WOOD, K. A. 1993. Feeding behaviour, offal preferences and tarsus shape of Puffinus shearwaters off central New South Wales. Notornis 40:123–127.