

A MAXIMUM DIVE RECORDER FOR LITTLE PENGUINS

Until recently estimates of the depths to which birds dive have been largely based on reports from fishermen who have found birds drowned in nets or caught in lines set at various depths (Dewar 1924; Conroy & Twelves 1972; Brown *et al.* 1978; Falla 1937). However these reports cannot be relied upon because birds may have been caught or drowned as the line or net was being set or retrieved. Recently electronic and radiographic dive recorders have been developed but they have size limitations and can be expensive (Kooyman *et al.* 1983; Wilson & Bain in press). A capillary dive recorder avoids these problems and provides a cheap and accurate method of recording this important aspect of foraging behaviour. My recorder is similar in principle to that used by Kooyman *et al.* (1971) and more recently by Adams & Brown (1983) for use with diving animals. However neither described the manufacture of the recorder in detail so the purpose of the present paper is to do this and to show how simply and inexpensively the device can be manufactured and used without the need for suturing or clamping the recorder to the penguin's neck or feathers (Kooyman *et al.* 1971; 1983) or using a harness (Adams & Brown 1983). The results of trials using the recorder with Little Penguins *Eudyptula minor* are given and the maximum diving depth is then compared to similar estimates of maximum diving depths for other aquatic birds.

Recorders consisted of a 6 cm length of clear PVC tubing (internal diameter 1 mm, external diameter 2 mm) dusted on the inside with a water soluble powder (one part congo red; two parts talcum powder). The tube's interior was dusted by drawing a piece of strong cotton thread covered with powder several times back and forth through the tubing. The thread had five or six knots spaced along it to promote an even coating and was initially fed through the tubing using a fine piece of wire with a hook at one end to which the thread was tied. Once dusted the tube was sealed at one end with epoxy resin and then attached to a flipper band of a aluminium similar in shape and size to the CSIRO band

used for Little Penguins (Fig. 1). The complete unit (band and recorder) weighs less than one gram and when attached to the bird does not appear to annoy, hinder or restrain the bird, nor were any attempts seen to preen it off. When the bird dives the water enters the capillary and washes out the powder to the air-water interface leaving a line at the point of maximum compression. Occasionally the line became blurred presumably due to repetitive dives of similar depth; recordings of this type were discarded. The maximum depth dived was then calculated using Boyles law.

The accuracy of the recorders was checked by suspending them in water down to 15 m deep and by having them taken down by SCUBA divers who compared recordings to depth gauge readings at depths up to 30 m (US Divers depth gauge — Depth Master 1). The recorders were found to be accurate to within 5% of actual depth.

To improve the chance of recovery depth recorders were attached to birds with chicks within 14 days of hatching. During this stage adults daily alternate nest and foraging duties (Hodgson 1975) so that a bird in a burrow on one day is likely to return the following night after having been to sea.

Recorders were attached to 50 birds and 32 of these were recovered and easily read. The average maximum depth dived was 30 m with a range of 9–69 m; only 10% of birds were recorded to depths greater than 50 m (Table I). In other words some birds could spend a day or two feeding within 10 m of the surface while others might sometimes go as deep as 69 m. The mean maximum dive for males was no different from that of females (Welch test, $t = 0.58$ $df = 21.91$ $p > 0.05$). It is possible that birds could dive to greater depths but the depth of water within 100 km of Phillip Island rarely exceeds 60 m.

Little Penguins probably dive to lesser depths than other penguins but to greater depths than most flying

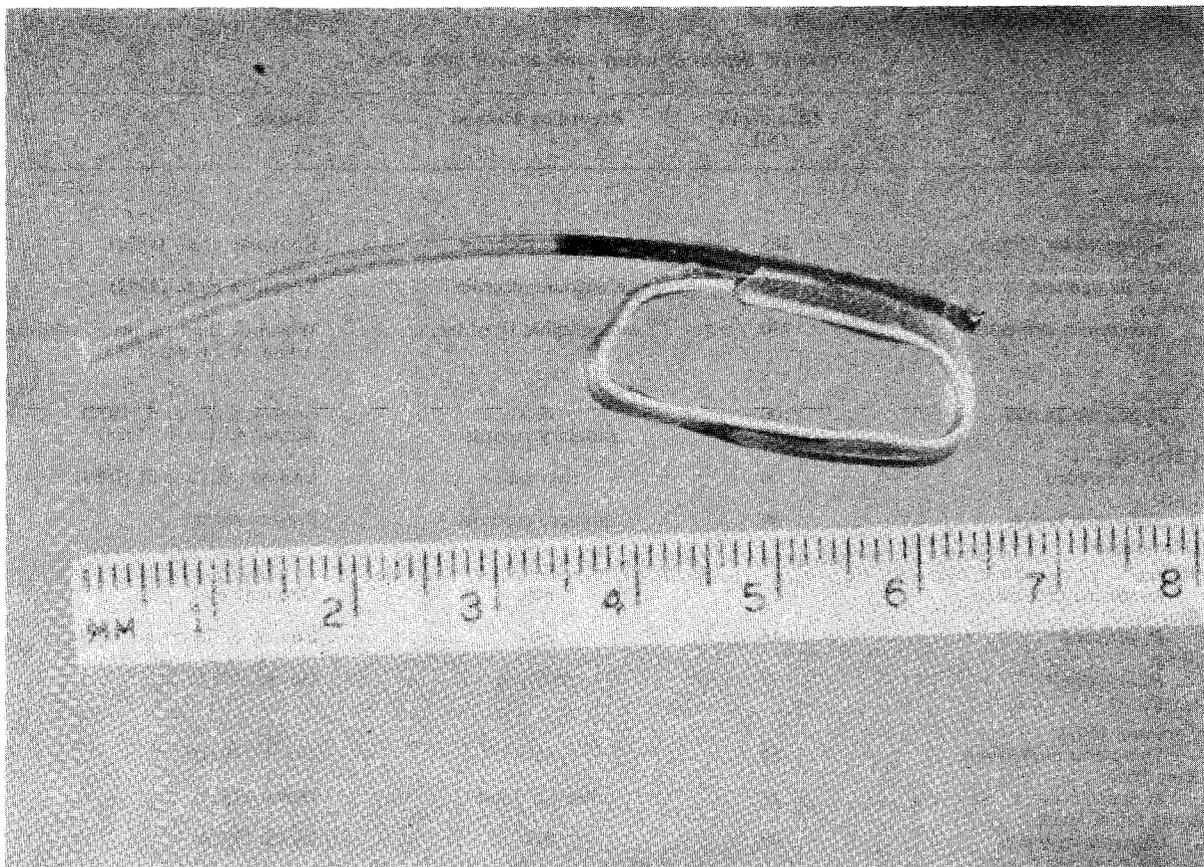


Figure 1. The design and size of the maximum dive recorder. The open end of the capillary is farthest from the band and points dorsally when affixed to the bird.

TABLE I

Maximum diving depths recorded for Little Penguins.

Depth M	Frequency	Sex		
		Male	Female	Unknown
0-	1	1		
10-	8	2	4	2
20-	7	3	2	2
30-	8	2	6	
40-	5	2	2	1
50-	1	1		
60-	2	1	1	
Total	32	12	15	5

birds (Table II). This agrees with physiological evidence showing that Little Penguin swimming muscles have the lowest aerobic capacity of seven penguin species ex-

amined (i.e. Little *E. minor*, Royal *Eudyptes schlegeli*, Rockhopper *Eudyptes cresta*, Gentoo *P. papua*, Adelle *P. adeliae*, Emperor *A. fosteri*, King *A. patagonica*) but in comparison to several flying birds their aerobic capacity is of an order of magnitude higher (Baldwin *et al.* 1984). The recorder could easily be adapted for use on flying aquatic birds by attaching the capillary tube to the shaft of the tail feathers with a fast drying glue and should prove very successful with burrowing seabirds which can be easily captured and retrieved.

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TABLE II

Maximum depths to which some aquatic birds dive.

Species	Dive depth (M)	Recording Method	Source
Penguins			
Emperor <i>Aptenodytes forsteri</i>	265	capillary recorder	Kooyman <i>et al.</i> (1971)
King <i>A. patagonica</i>	240	electronic recorder	Kooyman <i>et al.</i> (1982)
Jackass <i>Spheniscus demersus</i>	130	radiographic recorder	Wilson & Bain (in press, cited in Adams & Brown (1983))
Gentoo <i>Pygoscelis papua</i>			
	100 +	nets	Conroy & Twelves (1972)
	70 +	capillary recorder	Adams & Brown (1984)
Chinstrap <i>P. antarctica</i>	70	electronic	Lishman & Croxall (1983)
Little <i>Eudyptula minor</i>	69	capillary recorder	Present study
Cormorants			
Great <i>Phalacrocorax carbo</i>	37	nets	Dewar (1924)
Blue-eyed <i>P. atriceps</i>	25	nets	Conroy & Twelves (1972)
Shag <i>P. aristotelis</i>	37	crab pot	Dewar (1924)
Ducks			
Common Eider <i>Somateria mollissima</i>	55	nets	Dewar (1924)
King Eider <i>S. spectabilis</i>	18	benthic food	Dewar (1924)
Long-tailed Duck <i>Clangula hyemalis</i>	49	nets	Dewar (1924)
Auks			
Guillemot <i>Uria aalge</i>	37	nets	Dewar (1924)
Shearwaters			
Short-tailed <i>Puffinus tenuirostris</i>	12	diver obs.	Skira (1979)
Sooty <i>P. griseus</i>	5	removal of bait from hook	Brown <i>et al.</i> (1978)
Loons			
Great Northern Diver <i>Gavia immer</i>	55	net	Dewar (1924)

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T. MONTAGUE, *Zoology Department, Monash University, Melbourne, Australia 3168.*

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MORTALITY AND GROUP COHESION IN MIGRATING RAINBOW BEE-EATERS

Rainbow Bee-eaters *Merops ornatus* migrate annually between Australia and New Guinea (Blakers *et al.* 1984). Two aspects of this migration are of particular interest: the high mortality on waterless islands in Torres Strait during the southern migration (Anon 1975; Draffan *et al.* 1983) and their social organization in transit.

The high mortality appears to be from starvation and/or dehydration (Draffan *et al.* 1983). Bee-eaters caught during migration at Booby Island in Torres Strait weighed only 22.2 g (18-25, n = 30, R.D.W. Draffan pers. comm.) whereas the mean weight of all Bee-eaters banded in southern Australia between October and March is 29.3 g (24-33, n = 96 Australian Bird Banding Scheme) and of Bee-eaters wintering in northern New Guinea is 28.2 g (25-32, n = 9, Diamond & LeCroy 1979). Fry (1984) has suggested that the condition of birds dying in Torres Strait would indicate a continuous flight of 1,000 km from islands around the Banda Sea rather than from nearby New Guinea. Such mortality has not been noted among migrant European Bee-eaters *M. apiaster* and Blue-cheeked Bee-eaters *M. persicus*, which travel much greater distances than the Rainbow Bee-eater, although less over water.

Rainbow Bee-eaters are communal breeders (Filewood *et al.* 1978). In all but a few communally breeding species social groups are cohesive throughout the year. The high mortality Bee-eaters reported from Torres Strait would appear to act against such social cohesion since the probability of mating with the same individual in successive years would be so much reduced. It has been suggested that the sexual dimorphism of Rainbow Bee-eaters, the only bee-eater species exhibiting differences in both plumage and weight (males 30.0 ± 1.5 , females 28.4 ± 1.7 , t 3.65, $P < 0.001$, ABBS), is due to a need to re-establish social bonds annually (Fry 1984). Sexual dimorphism is lacking in the migratory White-throated Bee-eater *M. albicollis* and is almost absent from the European Bee-eater, both of which have perennial pair-bonds (C.H. Fry pers. comm.) as do all sedentary species that have been studied (Fry 1984). However the only strong evidence

for social cohesion among bee-eaters during migration is of adult European Bee-eaters feeding young on their non-breeding grounds (Robinson & Robinson 1975). There is no information on the structure of migratory flocks of any bee-eater species.

I visited Booby Island from 28 August to 4 September 1984, which coincided with the early stages of the Rainbow Bee-eater migration. Booby Island is a rock of 6.3 ha 35 km west of Thursday Island with no surface water and only 1 ha of vegetation. The Bee-eaters on Booby Island fell into two categories: those that stayed for a single night, or less if they arrived before 1700 hrs, and those that remained for longer periods. The former were heavier: males 27.0 g (24.8-29.2, n = 15), females 25.1 g (23.8-26.9, n = 8). Only one, a bird which was regrowing its entire tail, was moulting its flight feathers, while none had more than a few body feathers in sheaths. Birds in the group that stayed were much lighter (19.9 g, 17.4-25.7, n = 9, 6 males, 3 females, sexes similar) and, of seven birds examined, five were in heavy body moult. Four of these also had growing feathers in the wing and tail. The only one weighing more than 22 g was among those in heaviest moult. Seven of these emaciated birds were present when I arrived. Of these, four died the following day and only one survived the full week of my stay, declining in weight from 21.2 to 19.1 g over that period. Two birds that arrived with migrating flocks did not continue and also lost weight on the island: 20.8 to 16.2 g, 25.7 to 20.7 g, both over two days. None gained weight in contrast to some of those that remained at Booby Island during their northward migration (R.D.W. Draffan pers. comm.). Dissection of the four that died revealed no pathology but neither was there any fat around the neck or viscera. Their gizzards were lined with black viscous material, lacking solid contents, although all Bee-eaters were observed feeding sporadically on the flying insects available.

Bee-eaters dying on Booby Island were either underweight or in heavy moult. Of the 135 birds seen to arrive or pass by during my stay only two remained and died. While this may have been a function of the