

## AN EXCEPTIONALLY DEEP DIVE BY A LITTLE PENGUIN *EUDYPTULA MINOR*

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### SUMMARY

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A female Little Penguin *Eudyptula minor* breeding at Phillip Island, Australia, dived to the exceptional depth of 66.7 m, as recorded in November 2005 by a depth and acceleration data logger. The dive lasted 90 s and reached the maximum theoretical depth for a penguin of this size. The closest maximum depth recorded for 37 other birds was 57 m, and very few penguins attained a depth of more than 50 m. Observations of flipper-beat activity, body angle and water temperature during the course of the dive highlight several outcomes of deep diving by Little Penguins and help explain how such deep dives are achieved.

Key words: Little Penguin, *Eudyptula minor*, accelerometers, buoyancy, thermocline, Phillip Island

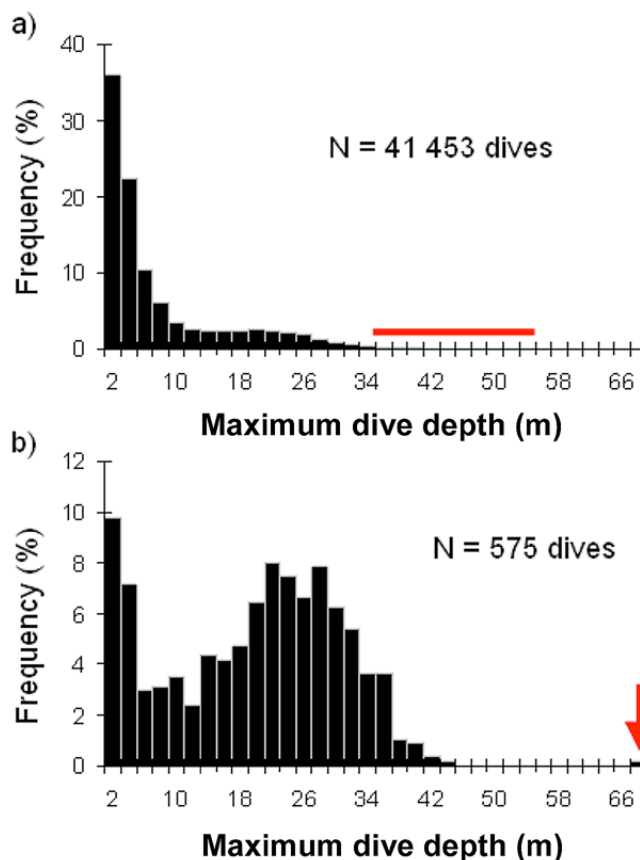
### INTRODUCTION

Since the middle of the twentieth century, the use of capillary depth gauges has revealed the remarkable diving capacities of several waterbird species (e.g. Montague 1969, Prince *et al.* 1994, Le Corre 1997, Freeman *et al.* 1997). However, capillary depth gauges can record only maximum depths, with an error ranging from 3% to 25% (Burger & Wilson 1988). The advent of continuously sampling time–depth recorders (TDRs) has allowed diving activity to be recorded as a function of time (see Ropert-Coudert & Wilson 2005 for the technical development of data-recording devices from capillary depth gauges to multi-sampling data-loggers). This advance has helped highlight the strategies of extremely deep-diving birds, notably the Emperor Penguin *Aptenodytes forsteri*, for which an exceptional 534-m–deep dive has been recorded (Kooyman & Kooyman 1995). However, data obtained from TDRs indicate only the presence of an animal in a specific zone of the water column over time; they do not provide insights into how such depths are achieved. The recent development of accelerometers has allowed investigation of the biomechanics of diving birds in great detail (e.g. Yoda *et al.* 2001, Sato *et al.* 2002, Watanuki *et al.* 2003, Ropert-Coudert *et al.* 2004).

Here, we report an exceptionally deep dive attained by a Little Penguin *Eudyptula minor* fitted with an accelerometer. Although rare, deep dives can inform on the ability of animals to adapt to extreme conditions.

### METHODS

During October–December 2005, we deployed data loggers on 38 female Little Penguins during the breeding season on Phillip Island, Victoria, Australia. Birds from Phillip Island breed in artificial wooden burrows, and each individual used in the present study carried a miniature electronic identification tag, allowing us to know its sex and to determine its presence in and absence from the



**Fig. 1.** Diving-depth distribution as recorded by depth–acceleration data recorders attached to (a) 37 female Little Penguins *Eudyptula minor* during October–December 2005 (the horizontal bar indicates that the frequency is less than 1 but not 0); and (b) a female that performed a single deep dive (arrowed) to 66.7 m during this period (detail of this deep dive is given in Fig. 2).

colony. The equipment used and procedures followed were as for the deep-diving bird as described below.

The deep-diving bird weighed 1020 g on departure to sea and 1050 g upon return. It was equipped with a 12-bit resolution, 53×15-mm, 17-g, UME-D2GT data-logger (Little Leonardo, Tokyo, Japan). The logger recorded depth and temperature every second and acceleration along two axes at 32 Hz (Ropert-Coudert *et al.* 2005). The absolute accuracies for the depth and temperature sensors were 0.1 m and 0.1°C, respectively. The accelerometer was attached with Tesa tape (Wilson *et al.* 1997a) to the back of the bird, close to the tail, with its long axis parallel to the main body axis of the bird. In this position, it recorded any acceleration along the bird's front–rear and back–belly axes. After a single foraging trip, the bird was recaptured in its nest box, the logger and the tape were removed and the bird's breeding activities were subsequently monitored for several weeks.

## RESULTS

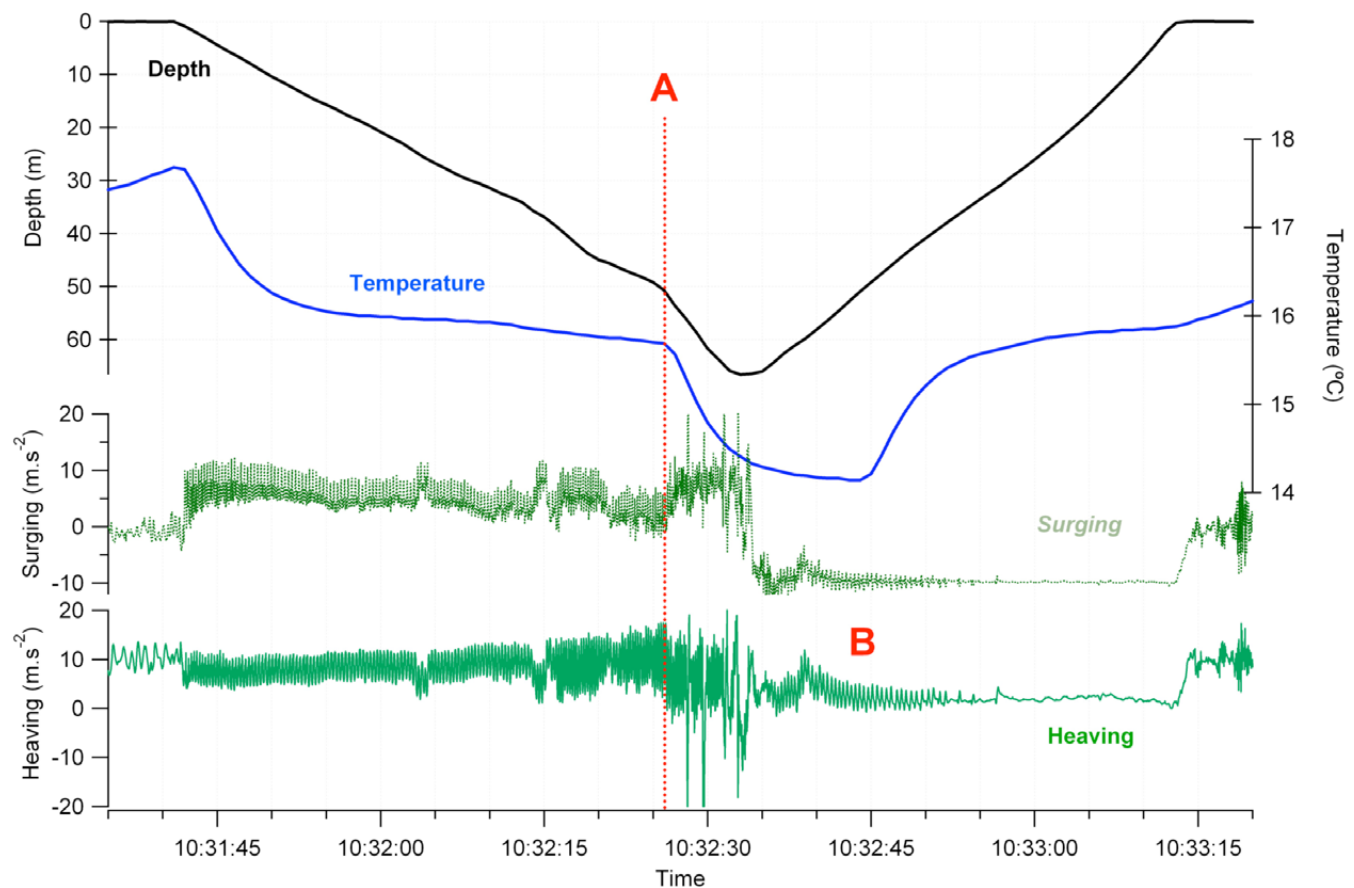
We recorded 42 028 dives for the 38 Little Penguins being monitored. Nearly all (99.98%) dives did not exceed a depth of 50 m [Fig. 1(a)]; only seven dives reached greater depths. One bird, which was brooding small chicks, performed an exceptionally deep dive to 66.7 m, recorded at 10h31 Eastern Standard Time during its one-day trip on 16 November 2005 (Fig. 2). Overall, 85% of the dives by this female reached less than 30 m [median: 20.8 m;

Fig. 1(b)], but deeper than the median of the depths recorded for the other 37 penguins (range of medians: 1.9 m–15.1 m). The deep dive is an outlier, given that the bird's second-deepest dive reached only 43 m [Fig. 1(b)].

The deep-diving penguin remained submerged for 90 s. The deep dive was the last in a sequence of 24 dives, which attained an average depth of  $25.9 \pm 9.8$  m. The surface time between the 24 previous dives was, on average,  $40.5 \pm 25.0$  s, but the surface time after the 66.7-m dive was 1050 s.

## DISCUSSION

This deep dive is very close to the 69-m dive recorded by Montague (1985) using less-accurate capillary depth gauges. The previous deepest dive, after that reported by Montague (1985), was 57 m (measured by a Lotek TDR in 2001—AC unpubl. data). Most other dives previously recorded for Little Penguins in various locations were generally shallower than 30 m (e.g. Gales *et al.* 1990; Bethge *et al.* 1997; Ropert-Coudert *et al.* 2003, 2005; Kato *et al.* 2006). Although only female dive depths are discussed here, we also used the same device type to record the diving activity of five males from Phillip Island breeding chicks during the guard phase. Of their dives, 99.6% were less than 50 m, with the deepest dive recorded reaching a depth of 55.1 m. Based on the empirical formula advanced by Wilson *et al.* (1997b), Little Penguins weighing 1020 g and 1050 g



**Fig. 2.** A 66.7-m-deep dive that lasted 90 s by a female Little Penguin *Eudyptula minor*. Note the increase in descent rate (visible on the depth axis), flipper-beat frequency and amplitude (visible on the heaving and surging acceleration axes), and concurrent decrease in the water temperature as the bird passes below 51 m (point A). The bird subsequently beats its wing for a short period of time (point B) to initiate ascent to the surface.

would theoretically be able to attain maximum depths of 66.0 or 66.5 m, respectively. The 90-s dive length was far longer than the calculated aerobic dive limit (ADL) of 44 s (Bethge *et al.* 1997).

Why did the bird dive to its maximum limit? An analysis of the descent rate and flipper-beating activity provides a tentative answer. At 50.7 m (point A in Fig. 1), the descent rate of the bird increased from  $1.11 \text{ m}\cdot\text{s}^{-1}$  to  $2.53 \text{ m}\cdot\text{s}^{-1}$ . At the same time, the bird started to increase the amplitude and frequency of its flipper beats. Little Penguins generally do not change the frequency and amplitude of strokes during the descent phase (Kato *et al.* 2006), and a transitory increase in flipper-beat frequency and amplitude has been suggested to reflect prey encounter and pursuit (Ropert-Coudert *et al.* 2005). The bird may thus have detected a prey item at around 51 m and pursued it deeper.

Two interesting facts emerged from the reading of the acceleration and temperature data for this deep dive.

First, the bird beat its flippers at the beginning of the ascent phase (point B in Fig. 1). Little Penguins should still be buoyant at this depth, but the upthrust force should be very small (Kato *et al.* 2006). The fact that the Little Penguin beat its flippers during the early part of the ascent suggests either that it was insufficiently buoyant to ascend passively in the way that the species and other shallow-diving seabirds usually do (Sato *et al.* 2002, Ropert-Coudert *et al.* 2005) or alternatively that it did not intend to dive so deep. This latter option may be plausible, because penguins are known to plan the time, and consequently the volume of air, that they will expend during their next dive (Wilson 2003). If the bird had to engage in an unexpected pursuit that brought it deeper than intended, it would then have had to use an additional amount of oxygen. Consequently, it would need to increase its transit speed back to the surface to replenish body stores. The few flipper beats performed at the onset of the ascent could be a way for the bird to rapidly reach a depth where the upthrust force would be sufficient to bring it back to the surface quickly.

Second, the water temperature below 54 m dropped from  $15.7^\circ\text{C}$  to  $14.4^\circ\text{C}$  (point A in Fig. 1). In the course of the deep dive, the bird apparently crossed a thermocline that Little Penguins do not usually cross. In 22 foraging trips recorded in 11 birds—including the deep-diving individual—at the same period of the year, only three foraging trips by three different birds showed a similar step in the temperature profiles (unpubl. data). Although three birds crossed the thermocline, they spent a total of only 336 s below  $15^\circ\text{C}$  out of an accumulated 33 hours underwater (in water below 5 m). The rarity of this exposure to colder water is in itself interesting: Do Little Penguins generally prefer to swim in warmer waters to reduce thermoregulatory costs? Or are they following the distribution of their main prey, whose boundaries may also be defined by water temperature profiles? Besides the evident limitations to deep diving (e.g. the volume of air that can be stored), the cost of swimming in colder waters is certainly not negligible. This cost is even more acute in the case of the Little Penguin, whose small body size implies a substantial area:volume ratio, which in turn increases the heat loss and consequently implies greater energy requirements (Schmidt-Nielsen 1991). Together with other factors, heat loss could discourage birds from using colder parts of the water column.

Even a single dive highlights some of the constraints under which a penguin is probably operating when exploiting shallower

zones—one example being thermoregulatory costs. It also reveals that, although most of the diving activity occurs at depths and for durations that are physiologically optimum, Little Penguins have the physical capacity to perform dives outside those limits.

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