

Individual Diving Strategies in the Little Penguin

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Abstract.—Data on the diving activity of the Little Penguin (*Eudyptula minor*) as recorded by data loggers are few. We monitored the foraging parameters of free-ranging Little Penguins, breeding at Penguin Island, Western Australia, using a small, hydrodynamically shaped time-depth recorder. Data were obtained for one, two and three consecutive foraging trips of three, one and two birds, respectively. These data showed that individual Little Penguins presented distinct diving depths that are consistent from one trip to the next. Four birds exploited shallow depths, around 1-5 m, but two other birds always chose to dive deeper, to around 8-10 m. No trends could be established between the adult mass or the chick mass and the preferred diving depths. The causes and consequences of these individual diving strategies are discussed. Received 18 February 2003, accepted 21 September 2003.

Key words.—Foraging strategies, Little Penguins, *Eudyptula minor*, recurrent diving depth, data-loggers, consecutive foraging trips.

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Over the past decades, the development of small data logging devices have allowed investigations of the biology of species that exploit remote environments which are inaccessible to human investigators (Wilson *et al.* 1992; Le Maho 1994). Most of these studies have explored the ecophysiology of large marine top-predators, such as deep diving penguins (Kooyman *et al.* 1992; Kooyman and Kooyman 1995), but few have been conducted on small-sized species. Data-recording devices small enough to be fitted on free-ranging Little Penguins (*Eudyptula minor*) have been made only recently and therefore, studies investigating the foraging behavior of this species are few (Gales *et al.* 1990; Bethge *et al.* 1997). Little Penguins are found along the southern coast of Australia, around Tasmania and New Zealand (Marchant and Higgins 1993), and those from Penguin Island, Western Australia forage within 15-20 km from the island during the breeding season (R. D. Wooller *et al.*, unpublished data). Data on their diving behavior provided information on the daily use of the water column by birds, an important parameter in conservation and management. In September 2001, we were able to monitor continuously and with a high resolution, the diving activity of the Little Penguin. We report here on the diving strategies displayed by these

birds and discuss the consequences of individual diving strategies in this penguin species, with a special note on the implications of a recurrence in diving strategies over consecutive foraging trips.

STUDY AREA AND METHODS

Data-loggers were fitted to six Little Penguins in September 2001. All birds were nesting on the central part of Penguin Island, Rockingham (32°16'S, 115°21'E), Western Australia, in rectangular, wooden nest-boxes (see Klomp *et al.* 1991), allowing us to easily capture them and to check on the chicks.

Diving activity was monitored using two logger types in the UME series (Little Leonardo, Tokyo, Japan). Electronic components were housed in a black, cylindrical, hydrodynamically shaped aluminium case. One logger type recorded depth and temperature simultaneously at a sampling frequency of 1Hz using a 12-bit resolution, 16 Mbytes memory, two-channel UME-DT logger (48 mm long with diameter of 15 mm, 14 g in the air including batteries). The other recorded depth, temperature and acceleration along the two main axes of the penguins' body at sampling frequencies of 1, 1, 16 and 16 Hz, respectively, using a 12 bit resolution, 128 Mbytes memory, four channel UME-D2GT logger (53 mm long with diameter of 15 mm, 16 g in the air including batteries). Acceleration data recorded by UME-D2GT loggers will be discussed elsewhere. The accuracy for depth and temperature of both loggers were 0.1 m and 0.1°C, respectively.

Six penguins, three males and three females, were equipped with loggers, four with UME-DT and two with UME-D2GT (Table 1). Birds were captured at their nest site, either at night or before departure for sea in the early morning. Sex of birds was determined from the bill depth (R. P. Gales, unpublished). The breeding status, mass of the adults and the mass of chicks were noted. Loggers were attached using waterproof tape

Table 1. General information about sex, mass and status of the equipped Little Penguins, and logger deployment on 16 September 2001.

Bird ID	Sex	Mass at instrumentation (g)	Mass after instrumentation (g)	Number and mass (g) of chicks	Duration of deployment (h)	Number of foraging trips
19	M	1370	1350	1 (1270)	41.3	2
30	F	1000	1050	1 (1320)	67	3
33	F	1100	1100	2 (800/970)	97	1
35	M	1450	1400	2 (620/500)	23	1
36	M	1170	1250	2 (650/750)	65.7	3
37	F	1140	1350	2 (550/270)	17.7	1

(Wilson *et al.* 1997) on the median line of the birds' back and near the tail so as to minimize drag (Bannasch *et al.* 1994). The attachment of the logger was completed in less than five min and birds were released in the vicinity of their nest-box. Equipped birds were recaptured after one, two or three consecutive foraging trips. The instruments were removed, penguins reweighed and then released.

Based on the resolution of the depth sensors, only dives >0.5 m were considered for analysis. Differences per day or per birds were tested using one-way analysis of variance (ANOVA). When sample sizes were too small, non-parametric tests were used following the procedures recommended by Sokal and Rohlf (1969). All tests were performed using Statview (Abacus concepts, U.S.A. 1996). Values are presented as mean \pm SD.

RESULTS

Adults weighed an average of $1,205 \text{ g} \pm 170 \text{ g}$ at initial capture, males ($1,330 \text{ g} \pm 145 \text{ g}$) being significantly (Mann-Whitney $Z = 1.96$, $P < 0.05$) heavier than females ($1,080 \text{ g} \pm 72 \text{ g}$). Chicks' masses ranged from 270 to $1,320 \text{ g}$ (mean $770 \text{ g} \pm 333 \text{ g}$, $N = 10$).

Reliable depth and temperature data were obtained for all equipped birds, accounting for a total of eleven foraging trips. Data were monitored during three, two and one successive foraging trips for two, one and three birds, respectively. These data overlapped, so that there were four, five and two birds foraging simultaneously on the 16, 17 and 18 September 2001, respectively. All birds dived between 06:00 h and 18:00 h, with a mean time at sea of $12.85 \text{ h} \pm 0.03 \text{ h}$. The mean number of dives per trip for all birds was $1,148 \pm 404$.

Overall, the birds could be separated into two groups (Fig. 1): birds 19, 30, 33, 37 were shallow diving birds ($1.9 \text{ m} \pm 1.7 \text{ m}$, $N = 9,920$ dives), while birds 36 and 35 dived significantly deeper ($8.1 \text{ m} \pm 4.7 \text{ m}$, $N = 2,717$ dives; one-way ANOVA $F_{5,12911} = 1,611$, $P < 0.001$).

The distribution of time-at-depth was similar from one day to the next in each bird, i.e. a shallow diving bird on one day also exhibited a shallow diving mode on subsequent days

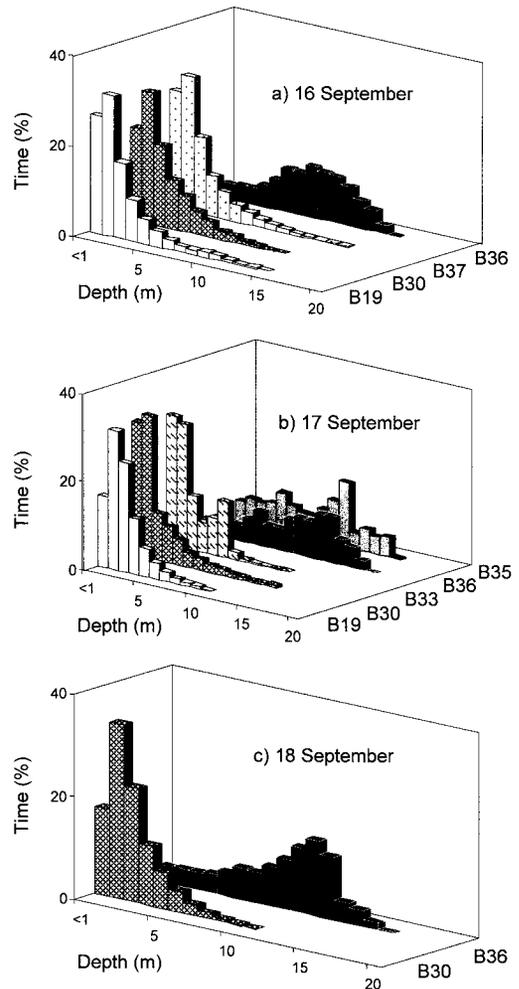


Figure 1. Frequency distribution of the time-at-depth of Little Penguins on: a) 16 September, b) 17 September and c) 18 September 2001, detailed for each individual.

(Fig. 1). Shallow diving birds had $93 \pm 2.4\%$ of the dives ≤ 5 m and their time-at-depth distribution followed an exponentially decaying curve, except for bird 33 which showed a slight bimodal distribution. Deeper diving birds showed a combination of unimodal (mode around 8–11 m, the first foraging day of bird 36) and bimodal distribution (first small mode around 4 m and second bigger mode around 10–15 m, bird 35 and the second foraging day of bird 36) with $68\% \pm 6.8\%$ of dives over 5 m. The average maximum depth (x) and the average dive duration (y) were linearly and positively related by the following equation: $y = 3.86 * x + 1.64$, $r^2 = 0.80$, $P < 0.001$). However, the dive duration for any given maximum depth was greater (test of homogeneity of slopes: $F_1 = 415$, $P < 0.001$) in deep diving birds (Fig. 2a) than in shallow diving birds (Fig. 2b, regression details for each individual in Table 3).

For birds with consecutive foraging trips (birds 19, 30 and 36), significant differences in the average maximum depths were found between days (Table 2). However, Fisher's post-hoc tests revealed that the average diving depths on the 16 September and 18 September were not significantly different for both birds 30 and 36. The average maximum depth of bird 36 was always deeper than that of birds 30 and 19. The average maximum depth of birds was neither significantly related to the mass of the chicks (Spearman correlation: $r_{s6} = -0.03$, n.s.), nor to the mass of the adults at departure ($r_{s6} = 0.43$, n.s.).

DISCUSSION

Although externally attached loggers potentially have an impact on the swimming ability, reducing speed (Wilson *et al.* 1986) and modifying the diving behavior of even large-sized penguins (Ropert-Coudert *et al.* 2000), the impact of the loggers on a bird's foraging behavior is reduced if certain precautions are followed (Ballard *et al.* 2001). Bethge *et al.* (1997), using loggers with a frontal area less than 2% of the bird's cross-section area, showed that overall the bird's swim speed was little affected by the presence of the device. Although devices may

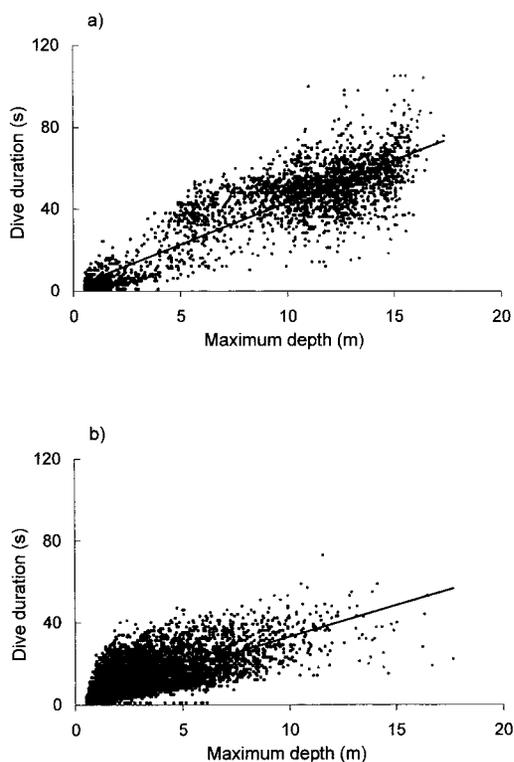


Figure 2. Relationships between dive duration (y) and maximum depth (x) of dives for a) deep and b) shallow diving Little Penguins. Simple regression analysis revealed that the relationships were best described by the following linear equations: a) $y = 4.13 (\pm 0.04) * x + 1.97$, $r^2 = 0.79$, $F_{1, 2715} = 9,997$, $P < 0.001$ for deep diving Little Penguins; and b) $y = 3.07 (\pm 0.03) * x + 2.35$, $r^2 = 0.56$, $F_{1, 9731} = 12,346$, $P < 0.001$ for shallow diving Little Penguins.

affect foraging parameters other than speed, the hydro-dynamically shaped loggers in our study were less than 2% of the bird's cross-section area. In addition, guidelines for reducing the effect of loggers' on the birds' behavior, such as using a non-conspicuous color, a point of attachment on the animal that minimizes the drag, and a method of attachment that preserves the integrity of the feathers (TESA tape, Wilson *et al.* 1997), have been followed (Wilson and Culik 1992). Finally, handling procedures were as short as possible in order to reduce the stress imposed to the birds (Le Maho *et al.* 1992). In the light of these precautions, the behavior of the Little Penguins in this study may be expected to reflect minor alteration from that of non-instrumented birds. Moreover, the same methodology (size differences be-

Table 2. Differences in average maximum depth of Little Penguins over consecutives days.

	Date (September)	Average maximum depth \pm SD (m)	Number of dive	Statistical results (one-way ANOVA)
B19	16	2.28 \pm 2.29	1294	$F_{1, 2690} = 9.3, P < 0.002$
	17	2.64 \pm 2.16	1420	
B30	16	2.91 \pm 2.49	1436	$F_{2, 4158} = 49.2, P < 0.001$
	17	2.13 \pm 2.18	1273	
	18	2.81 \pm 2.15	1452	
B36	16	10.19 \pm 3.68	636	$F_{2, 2089} = 160.9, P < 0.001$
	17	6.65 \pm 5.67	979	
	18	9.60 \pm 5.04	477	

tween loggers being small) has been used for all birds so that comparisons are performed between individuals that experienced the same level of disturbance.

Information on the diving activity of the Little Penguin in Australia is mainly available for individuals foraging nearby the Tasmanian coast or in the Bass Strait region. Bethge *et al.* (1997) reported on an average maximum depth of 3.4 m (maximum 27 m) for Little Penguins foraging in Marion Bay. Gales *et al.* (1990) gave a similar range of maximum depth with seasonal differences in the average maximum depth of the Little Penguin foraging in the Bass strait, Tasmania. Although the foraging grounds were different, these averaged values accord well with that found in our birds, which forage mainly in the shallow (0-20 m), neighboring Comet Bay.

However, our analysis of the maximum depth of Little Penguins showed specific diving strategies, birds specializing into deep or shallow divers. These inter-individual diving depth differences can be potentially attributed to individual feeding habits. Several seabird species have been shown to display

fidelity to foraging sites (Mehlum *et al.* 2001; Grémillet *et al.* 1999; Kato *et al.* 1998; Irons 1998; Weimerskirch *et al.* 1993; Watanuki *et al.* in press). Closely related species have been shown to segregate in the water column, capturing different prey that use different microhabitats, as already noted for cormorants (Ainley *et al.* 1981). In diving petrels species, birds foraged on different prey and foraging in different habitats, inducing a complete trophic segregation (Bocher *et al.* 2000). This is the first time that recurrence in individual diving strategies have been recorded in the Little Penguin. The Adélie Penguin (*Pygoscelis adeliae*) has been shown to have similar time-at-depth distribution over two consecutive foraging trips (Wilson *et al.* 1991). However, for both the Adélie Penguin and the Little Penguin, it is difficult to determine if this consistency is the result of a local prey distribution that remains stable over time, or if this is the result of birds specializing in the use of a specific depth zone. Constancy in inter-individual diving depth differences is sometimes the consequence of sexual dimorphism, as shown in cormorant species (Kato *et al.* 1999, 2000

Table 3. Equation, coefficient of determination and results of ANOVA test of simple regression analyses performed for each Little Penguin.

	Birds	Regression equation (standard error of the slope) and coefficient of determination (R^2)	ANOVA
Shallow divers	B19	$y = 3.23 (\pm 0.56) * x + 1.87, R^2 = 0.55$	$F_{1, 2712} = 3334, P < 0.0001$
	B30	$y = 3.03 (\pm 0.04) * x + 2.41, R^2 = 0.55$	$F_{1, 4159} = 4982, P < 0.0001$
	B33	$y = 2.82 (\pm 0.07) * x + 2.42, R^2 = 0.57$	$F_{1, 1171} = 1548, P < 0.0001$
	B37	$y = 3.09 (\pm 0.06) * x + 0.2, R^2 = 0.60$	$F_{1, 1683} = 2488, P < 0.0001$
Deep divers	B35	$y = 3.40 (\pm 0.08) * x + 7.04, R^2 = 0.75$	$F_{1, 623} = 1916, P < 0.0001$
	B36	$y = 4.30 (\pm 0.05) * x + 0.64, R^2 = 0.80$	$F_{1, 2090} = 8182, P < 0.0001$

and references therein) or the Gentoo Penguin (*Pygoscelis papua*; Croxall *et al.* 1988). It should be noted here that even within a sex, individual differences occur, some female cormorants dived deeper than others (Kato *et al.* 2000). In this study, male Little Penguins were either shallow or deep divers, while all females were shallow divers. A greater body mass would allow males to exploit a broader depth range and/or to capture larger prey. Another possibility would be that the strategy observed in our study is age-dependent, with younger birds being less able to compete against older birds in the search for, and use of, different foraging zones. Although the sexual size dimorphism noted in our study, as well as the absence of trends between the diving depth and both the adults and chick mass, should be accepted with caution because of the small sample size, difference in the foraging behavior between members of a pair in both sexually dimorphic and monomorphic species is a common feature in seabirds (Fairbairn and Shine 1993; Lewis *et al.* 2002 and references therein). Synchronous diving, as found in other penguins species (Tremblay and Cherel 1999), may also lead birds that dive together to use the same strategy. Further studies should investigate the proportion of birds from a same colony that share similar foraging strategies. By doing so, subtle sub-divisions in an apparently homogenous colony may be defined, i.e. some birds may depart together for their daily trip and visit the same foraging zone.

Larger sample sizes, diet data, simultaneous information on the location and diving depth of Little Penguins are required for further understanding. Answering the questions cited above would certainly bring substantial information about the underlying mechanisms of the learning processes and the level of inter-individual cooperation in colonial individuals, exploiting specific ecosystems.

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