Notornis, 2019, Vol. 66: 129–138
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Parameters influencing selection of nest boxes by little penguins (*Eudyptula minor*)

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Abstract: Little penguins (*Eudyptula minor*) readily breed and moult in nest boxes. The selective placement of nest boxes can enhance their use, improve breeding success and increase recruitment. I examined nest parameters for 171 nest boxes at Pilots Beach, southern New Zealand, in relation to their use for breeding and for moulting in the 2016 breeding season. Linear models to assess the relative importance of nest box parameters produced definitive results where a higher likelihood of use was interpreted to indicate a preference. The only preference for breeding or moulting was for shaded boxes that were free of vegetation at ground level. These trends were supported by comparisons of proportions of boxes used for breeding and moulting that indicated shaded boxes surrounded by bare ground were preferred to unshaded boxes surrounded by introduced grasses. Proportions also indicated that boxes on flat ground with a flat entrance were preferred to boxes on sloped ground or a sloped entrance for breeding and moulting. About half of the boxes between 61 and 90 m distance to the landing were used for breeding and moulting. Females nesting in shaded boxes had a higher breeding success than those in unshaded boxes but their chick masses were similar. To optimise nest box use by little penguins and encourage recruitment, nest boxes ideally should be placed under bushes or artificial structures on open ground up to 90 m from the landing.

Ratz, H. 2019. Parameters influencing selection of nest boxes by little penguins (*Eudyptula minor*). *Notornis 66(3)*: 129–138.

Key words: New Zealand, breeding success, moult, habitat, accessibility

INTRODUCTION

Little penguins (*Eudyptula minor*) are colonial burrow-nesting seabirds found in southern Australia and New Zealand (Marchant & Higgins 1990). This species has been divided into two lineages, Australian and New Zealand, based on genetic, morphological, and behavioural characteristics (Peucker *et al*. 2009; Grosser *et al.* 2015). The Australian lineage encompasses Australia and south-eastern New Zealand, with the remainder belonging to the New Zealand lineage. The breeding biology of the Australian lineage has been studied extensively in Australia (e.g. Fortescue 1999; Dann *et al.* 2000) and in New Zealand (e.g. Johannesen *et al.* 2002; Agnew *et al*. 2014). Little penguins from the Australian lineage can lay a second clutch after successfully raising the first resulting in two broods in one breeding season, termed double brooding (Gales 1985).

Natural burrows of little penguins have been supplemented with nest boxes at some locations in New Zealand (Houston 1999; Johannesen *et al*. 2002; Agnew *et al*. 2014) and in Australia (Wienecke *et al.* 2000; Daniel *et al.* 2007; Sutherland *et al*. 2014). The penguins prefer nest boxes to natural burrows at some locations (Houston 1999; Agnew *et al*. 2014), and nest boxes can improve breeding success and generate local population increases (Perriman & Steen 2000; Sutherland *et al.* 2014). Nest boxes are also a bonus for research because their contents are easier to monitor than natural burrows (Priddel &

Received 20 August 2018; accepted 20 May 2019
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Carlile 1995; Perriman & Steen 2000; Johannesen *et al.* 2003).

The use of nest boxes by little penguins from the Australian lineage breeding at Pilots Beach, Taiaroa Head, Otago Peninsula, South Island, New Zealand was investigated in this study (Fig. 1). Little penguins were studied at Taiaroa Head in the 1980s by Gales (1985) who found only one pair breeding at, or in the vicinity of, Pilots Beach (Dann 1994). Nest boxes (an unknown number) were first deployed at Pilots Beach in 1987 and some were promptly occupied by penguins (Houston 1999). In the 1992/93 breeding season 29 nests were found at Pilots Beach (McKinlay and Perriman 1995), followed by 15 nests in 1993/94 and 17 nests in 1994/95 (Perriman 1997). In the early 1990s, about 20 nest boxes were placed throughout the colony (L. Perriman *pers. comm.*) and from the early 2000s another 150 wooden nest boxes were added to facilitate undisturbed use by little penguins in the presence of uncontrolled public access (H. Langsbury *pers. comm.*). About 50 nest boxes were placed from 2015 to 2017 by high school students.

In 2012 Blue Penguin Pukekura (2018) started guided tours each evening at a raised wooden platform accessed by a raised wooden walkway and positioned to overlook the beach for visitors to view little penguins returning from the sea. The present study was initiated in September 2016 by the Pukekura Trust (Korako Karetai Whanau/ Otago Peninsula Trust, Joint Venture) to investigate the population size and breeding success of little penguins at Pilots Beach. The purpose of this investigation is to inform and facilitate on-going conservation efforts to restore the local fauna and flora as part of the owner's *kaitiakitanga* (guardianship) obligations. Students from local high schools contributed to the data collection as part of the community science project. Here I report the first year of investigating nest box use by penguins for breeding and for moulting in relation to habitat parameters of each nest box at Pilots Beach. Determination of the importance of parameters that influence the selection of nest boxes by little penguins will help ensure the optimal placement of boxes and development of habitat to facilitate future population growth.

METHODS

Study area

This study extended from September 2016 to April 2017 at Pilots Beach, beside Taiaroa Head at the northern tip of Otago Peninsula (45°46.6′S, 170°43.7′E) (Fig. 1). It is a 2 ha fenced area abutting Otago Harbour, with a maximum distance from the foreshore at mean high tide to the perimeter fence of 124 m. The substrate is sand. The original habitat here was cleared at least 150 years ago with the present vegetation a mix of shrubs and trees; mainly native ngaio (*Myoporum laetum*) and poroporo (*Solanum laciniatum*), with introduced tree lupin (*Lupinus arboreus*) and elderberry (*Sambucus nigra*). Ground cover comprises of introduced marram (*Ammeophila arenaria*) and pasture grasses growing to 1 m tall, along with South African iceplant (*Carpobrotus edulis*) growing to 20 cm tall. Grasses and iceplant form a barrier difficult to traverse by penguins. The ground is bare under shrubs and trees and under the walkway and viewing platform.

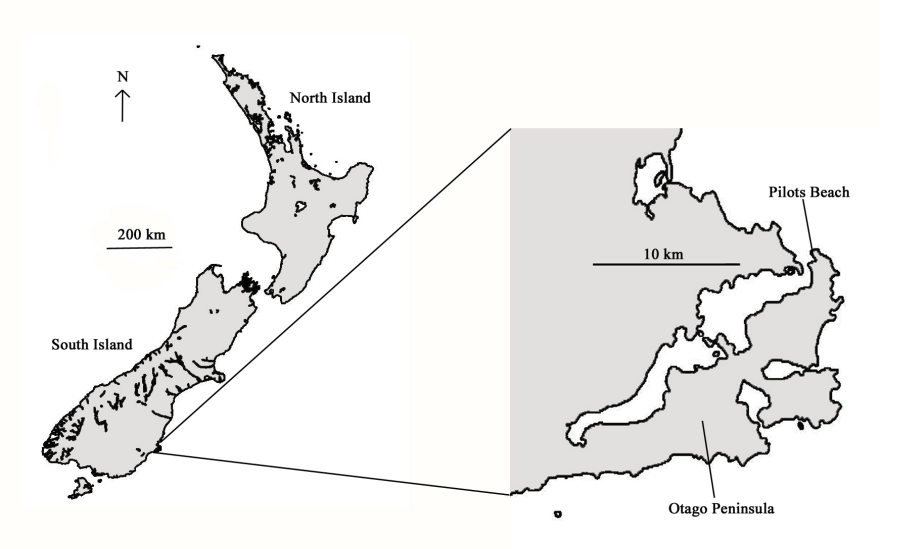

Figure 1. Map showing the location of Pilots Beach (45°46.6′S, 170°43.7′E), Otago Peninsula, South Island, New Zealand.

No precise records exist for the number and timing of deployment of nest boxes but the total is likely to be in the range 200–250. These nest boxes are of two designs. 'Old' boxes were deployed from 1987 to 2009; they were made with treated timber 20 mm thick and are 500 mm long, 400 mm wide and 290 mm tall, with an entrance tunnel along the long side 200 x 200 x 170 mm. 'New' boxes were deployed from 2012 to 2016; they are made of 10 mm thick treated plywood and are 440 x 500 x 250 mm with an entrance tunnel along the long side 200 x 180 x 150 mm. All boxes sit horizontally and are on flat ground or embedded into slopes.

Records for several decades of air temperature data at Taiaroa Head (Weather Station 5355) abutting Pilots Beach have been collated by the National Institute of Water and Atmospheric Research in The National Climate Database (2018). Some years had missing data and available records ceased in 2002, 14 years before this study began. Monthly data for each calendar year were realigned to match 12-month little penguin seasons from May of the year breeding started to April of the following year. Three monthly air temperature parameters were investigated: mean daily maximum for 32 of the seasons from 1967 to 2001; extreme maximum for 31 of the seasons from 1967 to 2001; and number of days with maximum ≥25.1°C for 28 of the seasons from 1972 to 2001.

Monitoring regime

The little penguin population was not enumerated in this first season of this study. Locating nest boxes was difficult as many were either buried in sand or hidden in long grass or under iceplant. Some remained undiscovered in 2016. In addition, natural burrows were found throughout the colony but not monitored because most were too deep (>1 m) to determine their contents without causing disturbance to the penguins.

Nest boxes were monitored twice weekly for adult attendance and breeding activity. Breeding parameters were assigned to females (not to males or to breeding pairs) following Agnew *et al.* (2014). Single broods were defined as the sum of all single clutches (only one clutch laid) and replacement clutches (a total of two or more clutches after the previous clutch was unsuccessful) that produced no more than a single brood in one season. Double broods were defined as a clutch laid after the first brood successfully fledged (Gales 1985; Agnew *et al.* 2014). Egg lay dates before the start of regular monitoring on 6 September 2016 were back-calculated from hatch dates, where duration of incubation averages 36 days (Marchant & Higgins 1990).

All adult little penguins encountered were implanted with Allflex 11 mm passive integrated transponder (PIT) tags supplied in sterile individually packed needles. These were injected into the loose skin at the neck and sealed with Opsite (Smith & Nephew Medical Ltd) to prevent loss of the PIT tag and infection. In case the PIT tag failed or was lost, each penguin was also externally marked on the outside web of the right foot with a small, self-piercing, numbered metal tag supplied by the New Zealand Department of Conservation. These tags, called No. 1 wing tags, are made of stainless steel (3 mm wide and 20 mm long and designed as ear tags for small mammals). If the outside web on the right foot was torn or damaged the web tag was placed either on the inside web of the right foot or on the outside of the left foot. There is no tag loss evidence to date.

When first encountered all adults were sexed by measuring their bills following Hocken & Russell (2002) and Gales (1988), and by observation of breeding mate affiliation (Johannesen *et al.* 2003) although this method is not 100% reliable (Renner & Davis 1999; Hocken & Russell 2002). Most chicks were weighed at about 6 weeks and marked in the same way as adults. Their bills were not measured as they could not be sexed (Johannesen *et al.* 2003) because bill size increases with age until breeding age (Hocken & Russell 2002).

After the completion of breeding little penguins undergo an obligatory annual moult ashore (Reilly & Cullen 1983). The presence of moulting penguins or discarded feathers were recorded for each box.

Nest box parameters

Information for eight parameters were collected for each nest box to determine how they were related to the selection of nest boxes by little penguins

Entries for three parameters were continuous numbers.

Distance to landing: Latitude and longitude for each nest box were recorded using a hand-held Garmin Oregon 400c GPS unit. Estimated Position Error was not recorded. Using the GPS coordinates of each nest box the distance from the main penguin landing site (yellow arrow in Fig. 2 & Fig. 3) to the nest box was calculated with Google My Maps. The distance of each nest box to the landing was then assigned to one of four categories: 1–30 m, 31–60 m, 61–90 m and >90 m.

Entrance facing: the compass direction of the entrance was recorded using a Laser Technology Inc. TruPulse 360°B laser range finder and entered in degrees.

Entries for five parameters had one of two options.

Shade: the exposure of nest boxes to sunlight was assigned as 'shaded' for boxes underneath the viewing platform and walkway or underneath shrubs and trees, or as 'unshaded' for boxes exposed to direct sunlight.

Ground vegetation (vegetation): the vegetative cover at ground level within a 1m diameter around the nest box was assigned as 'absent' if it had no vegetation and 'present' if it had vegetation.

Entrance topography: the topography in front of the entrance of the box was either 'flat' and had a flat area of at least 10 cm x 10 cm in front of the entrance of the nest box or 'sloped' if it lacked this flat area.

Box topography: the topography surrounding the nest box was either 'flat' when the box was on flat ground or on slopes <10° or 'sloped' when the boxes were embedded into slopes >10°.

Box age: there were two designs of nest boxes present in the colony and they were assigned to one of two options: 'old' or 'new' (defined earlier).

Statistical analyses

Means were compared using t-tests and proportions were compared using binomial tests. A 4x2 Chi-squared test was used to determine a pattern of nest box use for breeding and moulting at the four categories of distance to the landing. Akaike's information criterion (AIC) was used to determine whether nest box parameters were related to the use of nest boxes for breeding and moulting. The Akaike model weight for the data provides a relative weight or importance for each model relative to the entire set (Johnson & Omland 2004). If the value of the difference between each model and the best model (ΔAIC) was ≤2 it was considered to have substantial support (Burnham & Anderson 2004).

RESULTS

Use of nest boxes

A total of 175 nest boxes were located by 30 April 2017, of which 80 (46%) were used for breeding (Fig. 2) and 103 (59%) were used for moulting (Fig. 3). These totals included 66 (38%) used for both breeding and moulting. No boxes were both unshaded and surrounded by bare ground. Four boxes were both shaded and surrounded by ground vegetation with none of these boxes used for breeding and two used for moulting. These four were subtracted from the total of 175 nest boxes resulting in a total of 171 nest boxes used in analyses (80 used for breeding and 101 used for moulting). Shade and ground vegetation were then treated as one box parameter ('shade/vegetation') with the two options 'shaded/absent' and 'unshaded/present'.

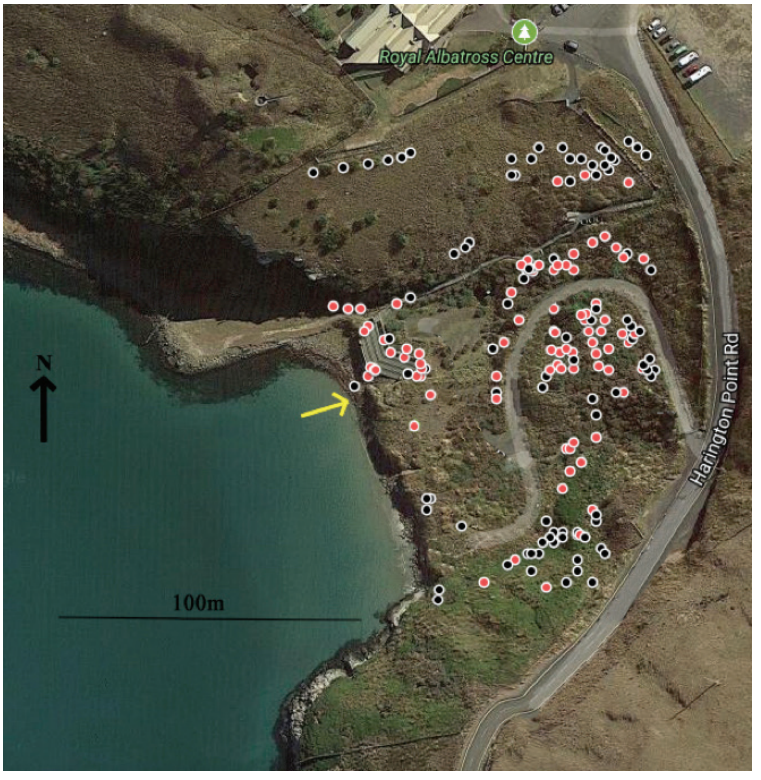

Figure 2. Nest box positions at Pilots Beach in the 2016 season for boxes used (red circles) or not used (black circles) for breeding; the yellow arrow indicates the main landing site; positions plotted on Google My Maps.

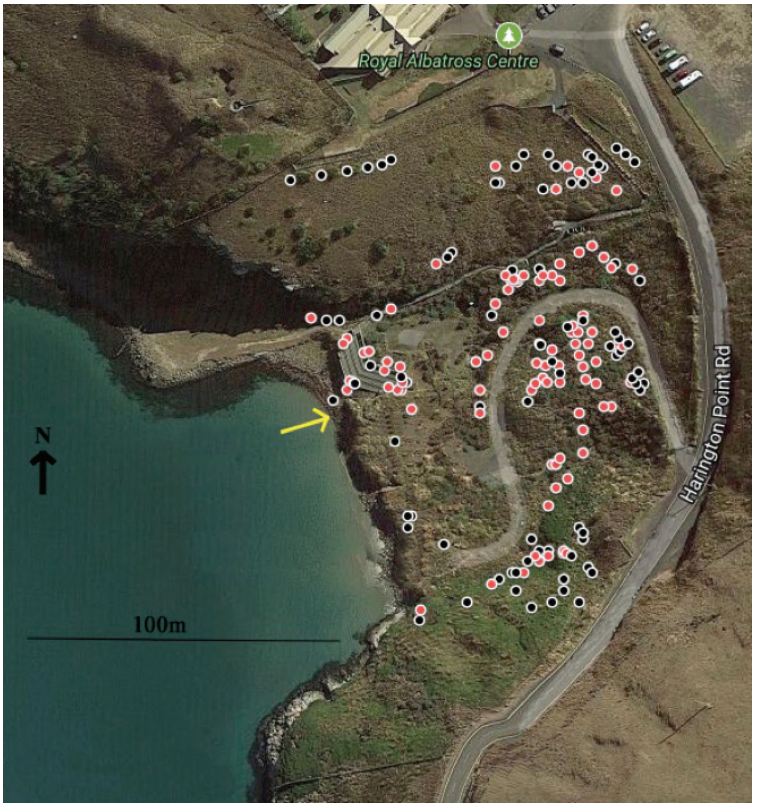

Figure 3. Nest box positions at Pilots Beach in the 2016 season for boxes used (red circles) or not used (black circles) for moulting; the yellow arrow indicates the main landing site; positions plotted on Google My Maps.

Over half of nest boxes used for breeding were 61–90 m from the landing and 21% were within 30 m of the landing. (Table 1), a statistically significant pattern. Nest boxes used for moulting showed a similar significant pattern (Table 1).

Significantly more boxes were used for breeding that were shaded and surrounded by bare ground (Table 2). They also had flat entrances, were on flat ground and were old (Table 2). Only boxes that were shaded and surrounded by bare ground and were on flat ground were used significantly more often for moulting (Table 2)

Table 1. Comparison of the distance to landing categories (in 30 m intervals) for nest boxes used for breeding or moulting. N is the number of boxes for each nest box use.

		Proportion at					
Nest box use	**N**	**0–30 m**	**31–60 m**	**61–90 m**	**>91 m**	**Chi**	**P**
breeding	80	0.21	0.06	0.55	0.18	19.952	<0.001
not breeding	91	0.05	0.11	0.41	0.43		
moulting	101	0.18	0.09	0.56	0.17	24.965	<0.001
not moulting	70	0.06	0.09	0.34	0.51		

Table 2. Comparison of box use by breeding and moulting penguins for the four nest box parameters presented as options. n_T is the total number of boxes in each option for each parameter; n is the number of boxes in each option used for breeding or moulting. Proportions (ppn) were compared with binomial tests where 95% CL shows the 95% confidence limits.

	Nest box parameter	Options	n_T	n	ppn	95% CL	Z	P
Breeding	Shade/vegetation	shaded/absent	54	42	0.78	0.64–0.88	5.354	<0.001
		unshaded/present	117	38	0.33	0.23–0.41		
	Entrance topography	flat	153	77	0.50	0.42–0.59	2.458	0.014
		sloped	18	3	0.17	0.04–0.41		
	Box topography	flat	101	58	0.57	0.47–0.67	3.194	0.001
		sloped	70	22	0.31	0.21–0.44		
	Box age	old	126	71	0.56	0.47–0.65	4.021	<0.001
		new	45	9	0.20	0.10–0.35		
Moulting	Shade/vegetation	shaded/absent	54	45	0.83	0.71–0.92	4.217	<0.001
		unshaded/present	117	56	0.48	0.39–0.57		
	Entrance topography	flat	153	94	0.61	0.53–0.69	1.587	0.113
		sloped	18	7	0.39	0.17–0.64		
	Box topography	flat	101	69	0.68	0.58–0.77	2.798	0.005
		sloped	70	32	0.46	0.34–0.58		
	Box age	old	126	82	0.65	0.56–0.73	2.500	0.124
		new	45	19	0.42	0.28–0.58		

The combination of shade and ground vegetation was the most important nest box parameter (ΔAIC ≤2) for breeding and moulting penguins. This parameter respectively accounted for 17% (Model 1) and 11% (Model 7) of the variation in data (Table 3).

Table 3. Models examining the variation in nest box parameters in relation to nest box use for breeding or moulting in the 2016 season. AIC is the Akaike's information criterion; ΔAIC is the value of the difference between each model and the best model; w_i are the Akaike weights; R^2 is the proportion of model deviance accounted for by each parameter.

Model	Parameter	ΔAIC	w_i	R^2	AIC
	breeding				
1	Shade/veg	0	1.00	0.17	220.0
2	Box age	14.97	0.00	0.10	234.9
3	Distance (30 m)	20.34	0.00	0.00	240.3
4	Box topography	21.93	0.00	0.00	241.9
5	Entrance topography	27.00	0.00	0.00	247.0
6	Entrance facing	33.53	0.00	0.94	253.5
	moulting				
7	Shade/veg	0	0.86	0.11	228.1
8	Distance (30 m)	3.73	0.13	0.09	231.8
9	Box topography	11.43	0.00	0.05	239.5
10	Box age	13.08	0.00	0.04	241.2
11	Entrance topography	18.34	0.00	0.01	246.5
12	Entrance facing	20.38	0.00	0.00	248.5

Air temperatures
Monthly mean maximum daily temperatures at adjacent Taiaroa Head peaked at averages of 17.3°C in January and 17.2°C in February (with respective maxima of 19.6°C and 19.9°C) from data for 32 seasons ending in 2001. The corresponding most extreme maximum daily temperature was 31°C. Daily maximum temperatures equalled or exceeded 25°C on 57 days, equivalent to 4% of days from data for 28 seasons. These 57 days were spread though the six months from October to March with 63% (36 days) in January or February.

Breeding success
In the 2016 season 74 nest boxes were used for breeding by 71 females. Of these, 62 females had single broods (which include replacement clutches) and they used 65 nest boxes, i.e. some females used a different box for the second clutch. Nine females used nine boxes for double-brooding. Each of 62 single-brood females fledged an average 1.74 chicks and each of the nine double-brood females fledged an average of 3.22 chicks (Table 4).

Table 4. Breeding success for little penguins at Pilots Beach for the 2016 season.

	Single broods	Double broods	Total
Number of females	62	9	71
Number of clutches laid	66	18	84
Eggs laid	132	36	168
Chicks hatched	112	31	143
Chicks fledged	108	29	137
Mean chicks fledged/female	1.74	3.22	1.93

The mean number of chicks fledged from shaded boxes surrounded by bare ground was significantly higher than that from unshaded boxes surrounded by grasses or iceplant (Table 5). None of the other comparisons generated significant difference in the mean number of chicks fledged. None of the comparisons of options for nest box parameters generated significant difference in the mean peak mass of chicks (Table 6). No pattern of the number of chicks fledged per box or the mean mass of chicks at the four categories of the distance to the landing were observed (Table 7).

Table 5. The mean number of chicks fledged per box for the two options for each of the four nest box parameters; n_B is the number of nest boxes; n_c is the number of chicks.

Nest box parameter	Options	n_B	n_c	Chicks/box	Range	sd	t	P
Shade/vegetation	shaded/absent	39	80	2.05	0–4	0.69	2.297	0.0246
	unshaded/present	35	57	1.63	0–4	0.88		
Entrance topography	flat	71	131	1.88	0–4	0.80	0.316	0.7532
	sloped	3	6	2.00	1–3	1.00		
Box topography	flat	52	100	1.92	0–4	0.76	1.179	0.2421
	sloped	22	37	1.68	0–3	0.89		
Box age	old	66	124	1.88	0–4	0.83	0.829	0.4096
	new	8	13	1.63	1–2	0.52		

Table 6. Mean body mass (g) of chicks at peak mass (age 6 weeks ± 4 days) in relation to four nest box parameters; n_B is the number of nest boxes; n_c is the number of chicks.

Nest box parameter	Options	n_B	n_c	Mass (g)	Range (g)	sd	t	P
Shade/vegetation	shaded/absent	24	52	1,127	500–1,460	172	0.150	0.8818
	unshaded/present	16	28	1,135	710–1,380	153		
Entrance topography	flat	37	74	1,135	500–1,460	160	0.730	0.4696
	sloped	3	6	1,063	710–1,290	227		
Box topography	flat	29	59	1,132	500–1,460	171	0.102	0.9192
	sloped	11	21	1,126	710–1,340	164		
Box age	old	37	76	1,140	500–1,460	161	2.002	0.0525
	new	3	4	948	820–1,140	136		

Table 7. The number of chicks fledged per nest box at the four categories of distance to the landing; and the mean body mass (g) of chicks at peak mass (age 6 weeks ± 4 days) in relation to four categories of distance to the landing; n is the number of nest boxes.

Distance to landing	n	Chicks/box	n	Mass (g)	Range (g)	sd
0–30 m	13	2.00	4	1,156	920–1,320	143
31–60 m	5	1.80	4	1,227	1,020–1,410	139
61–90 m	43	1.79	27	1,115	500–1,460	176
>90 m	13	1.92	5	1,128	990–1,290	100

DISCUSSION

Shaded nest boxes surrounded by bare ground at Pilots Beach were used for breeding and for moulting by little penguins in preference to unshaded boxes surrounded by vegetation at ground level. There was also higher breeding success in shaded boxes than in unshaded boxes, although there was no difference in the mass of their chicks. All shaded boxes were surrounded by bare ground because the local ground-cover vegetation at Pilots Beach thrives only in sunny conditions. As Pilots Beach lacks native ground-cover species, introduced grasses and South African iceplant dominate and can form vegetative barriers difficult for penguins to traverse. Consequently, the preference for shaded boxes here may be a preference for easy access rather than for shade.

The most obvious reason for selecting shaded boxes is to minimise the likelihood of encountering high air temperatures. Little penguins ashore increase oxygen consumption at ambient temperatures >25°C (Baudinette *et al.* 1986), expend more energy at >27°C (Dann & Chambers 2013), and hyperventilate at >35°C (Baudinette *et al.* 1986; Stahel & Nicol 1988). Avoidance of high temperatures may impact on the timing of the breeding season: in Australia little penguins breed earlier in the year in the west than in the east, a difference attributed to avoidance of the hotter summer temperatures in the west (Klomp *et al.* 1991). Daily maximum air temperatures ≥25°C occurred on only 4% of days through 28 seasons at Pilots Beach. This indicated that temperatures in the range that challenge little penguins are rare and so avoidance of high temperatures is unlikely to be the key cause for the preference for shaded nest boxes.

Little penguins preferentially used nest boxes between 61 and 90 m from the landing for both breeding and moulting. However, linear models did not detect this preference as important for either breeding or moulting. The greater mass of penguins prior to moulting makes walking more energy demanding and laborious (Pinshaw *et al.* 1977; Reilly & Cullen 1983; Gales *et al.* 1988), perhaps making shorter distances more important during moult than during breeding. This possibility seems unlikely because it should also apply to breeders: little penguins that nest closer to the sea spend less energy walking and deliver larger amounts of food to their chicks (Miyasaki & Waas 2003).

Comparisons of means or proportions detected other preferences that were not regarded as important from linear models. Breeders preferred boxes on flat ground with a flat area in front of the entrance. Older boxes (deployed >7 years) were preferentially used for breeding but not for moulting. Little penguins have a high nest-site fidelity (Johannesen *et al.* 2002): they tend to re-use the same site annually and so older boxes are more likely to be used for breeding. The direction faced by the entrance of the box was not important for either breeding or moulting.

This investigation of the use of nest boxes for breeding and for moulting provided insight into

their optimal placement. The key prerequisite is unimpeded penguin access to the sea. To optimize nest box use by little penguins and encourage recruitment, nest boxes ideally should be placed in shaded sites with open ground.

ACKNOWLEDGEMENTS

I wish to thank the Pukekura Trust and Blue Penguins Pukekura for the opportunity to work with and for the little penguins at Pilots Beach, as well as their kaitiaki guardian partners, the Royal Albatross Centre, the Otago Peninsula Trust and the Korako Karetai Trust. Special thanks go to Chris Lalas for the feedback on this paper and many lively discussions; to Philippa Agnew for help with the linear model; and to Prof. John Cockrem for kindly commenting on this paper. Thanks are due to the many volunteers to assisted in the marking of the penguins, the data collection, nest box building and habitat work. Thanks to Sally Carson and selected students from Bayfield High School, Kavanagh College, Kings High School, Logan Park High School, Otago Boys High School, Otago Girls High School, Queens High School, St Hilda's Collegiate, and Taieri College who contributed to the field work as part of a community science project funded by the Otago Participatory Science Platform (Ministry of Business, Innovation and Employment's Curious Minds fund). The PIT and web tag tagging was authorised by the Department of Conservation, Dunedin, New Zealand (Authorisation Number 48461-FAU). Thanks also to two anonymous reviewers for taking the time and care to comment on this paper. It is better for it.

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