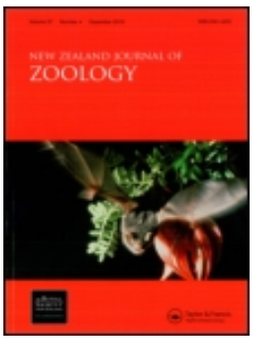

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Effect of habitat features on the breeding success of the blue penguin (*Eudyptula minor*) on the West Coast of New Zealand

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We estimated the effect of selected habitat variables on burrow occupancy rate and breeding success of blue penguins in two regions of the West Coast of the South Island of New Zealand, South Westland (three colonies) and Buller (five colonies), in order to measure the impact of habitat changes on the West Coast blue penguin population. In both regions, habitat type did not appear to influence the breeding success of burrows and there was no significant difference in breeding success between colonial and isolated breeders in either region. Proximity to the hightide line and scrubline influenced the occupancy of nests in Buller but not in South Westland. Breeding success was apparently unrelated to the proximity of nests to the sea or to a road/track, suggesting that disturbance did not influence breeding success. These findings provide baseline data against which to measure the consequences of changes in breeding habitat and their impact on West Coast penguin populations, and guide the placement of artificial nest boxes.

Keywords: blue penguin; *Eudyptula minor*; habitat features; breeding success; occupancy; nesting type

Introduction

Blue penguins (*Eudyptula minor*; Maori name: korora) are found in temperate seas all around New Zealand and the eastern and southern coasts of Australia (Marchant & Higgins 1990). They breed in colonies ranging in size from <10 pairs to thousands of pairs (Waas 1990) and nest densities vary both between and within colonies (Harris & Bode 1981; Fortescue 1995; Davis & Renner 2003). They nest in a variety of habitats including burrows, under trees, in rock crevices and sometimes in caves (Waas 1990; Fortescue 1995; Davis & Renner 2003; Bull 2000a), and have also been reported breeding under piles of driftwood (Heber et al. 2008), and in urban areas (Dann 1994; Fortescue 1995; Cullen et al. 1996). The type and structure of cover at breeding sites is highly variable, from grassy fields, herbfields, scrublands, and woodland forest to unvegetated caves and rock screes (Marchant & Higgins 1990; Dann 1994; Fortescue 1995).

Blue penguins are restricted to breeding at sites accessible from the sea, and where adequate food is available in inshore waters close to the colony (Williams 1995). Successful breeders are more likely to return to the breeding colony and their nest site for subsequent breeding attempts (Switzer 1997), whereas changing the nest site is likely after a failed breeding attempt (Johannesen et al. 2002).

Blue penguins are long-lived and highly philopatric, so habitat loss and modification,

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which may be detrimental to the breeding success of this species in the short term (Bull 2000b), may take some time to affect colony boundaries or nest densities (Dann & Cullen 1990). Small populations are particularly vulnerable to reduced genetic diversity and, perhaps of more concern, to unpredictable fluctuations in the environment (Couvet 2002; Jamieson et al. 2005). Similarly, a restricted distribution makes penguin populations vulnerable to local reductions in food supply, disease, predation or pollution (Davis & Renner 2003).

Blue penguins are classified as a species of 'Least Concern' in the International Union for Conservation of Nature Red List (IUCN 2008). Despite this, blue penguin populations are believed to have declined in many areas in Australia and New Zealand (Dann et al. 2000; Perriman & Steen 2000; Challies & Burleigh 2004; Houston 2007; Heber et al. 2008), largely due to predation, habitat loss and habitat modification. Anecdotal evidence suggests that one area with a declining population is the West Coast of the South Island. This paper represents the first study of blue penguin breeding biology in South Westland, and the second on the West Coast of New Zealand (Heber et al. 2008).

We aimed to determine the effect of different habitat variables on burrow occupancy rate and breeding success, in order to measure the impact of habitat changes on the blue penguin population on the West Coast. Our findings provide baseline data against which to measure future change in breeding habitat and colony size, as well as guidance on suitable placement of artificial nest boxes.

Methods

Study sites

The coastline had previously been extensively surveyed in 2007, from the Heaphy River mouth in the Buller Region to the Haast River in South Westland (Blyth et al. 2008). The coastline was covered by foot, and penguin tracks were recorded and mapped. In addition, eight breeding colonies, selected by their size and/or accessibility in South Westland (three sites) and Buller (five sites) (Fig. 1) were chosen for more intensive monitoring. In the Buller Region, this work was carried out by S Heber (2006), M Charteris (2007) and R Lane (2008) and in South Westland by I James and J Braidwood (2008). Data were analysed by region rather than by site, because some sites were close together and some were too small to analyse separately.

In South Westland and Buller, the vegetation at each of the monitored colonies was a mixture of scrub mainly consisting of New Zealand flax (*Phormium tenax*), gorse (*Ulex europeaus*) and swamp astelia (*Astelia grandis*), and regenerating coastal forest including mahoe (*Melicytus ramiflorus*), pigeon wood (*Hedycarya arborea*) and tree ferns (*Cyathea* spp.).Three habitat types were recognized for analytical purposes: coastal forest, scrubland, and near human habitation (within 100 m).

Predation by mustelids (*Mustela* sp.) and dogs (*Canis familiaris*) is the biggest threat to penguins throughout coastal New Zealand (Taylor 2000). Heber et al. 2008 lists the specific threats to the penguins at the Buller colonies. Hence, predator control was implemented at several sites in both regions during this study. At Three Mile beach, a trapline consisting of 15 DOC 200 traps and a poison line of 23 Kiwicare Cholecalciferol Gel Bait stations runs the length of the scrubline. Both lines were established in 2007 and are checked fortnightly. At Nile River mouth and Rahui, traplines consisting of Fenn and DOC 200 traps are checked regularly.

Data collection

Nest boxes were placed in the Nile River mouth colony between early 2004 and February 2006 (Heber et al. 2008). At Rahui, nest boxes were put in place in July 2008 at the beginning of the breeding season. There were no nest boxes in South Westland.

In the Buller region, 145 natural burrows and 22 nest boxes spread between five colonies

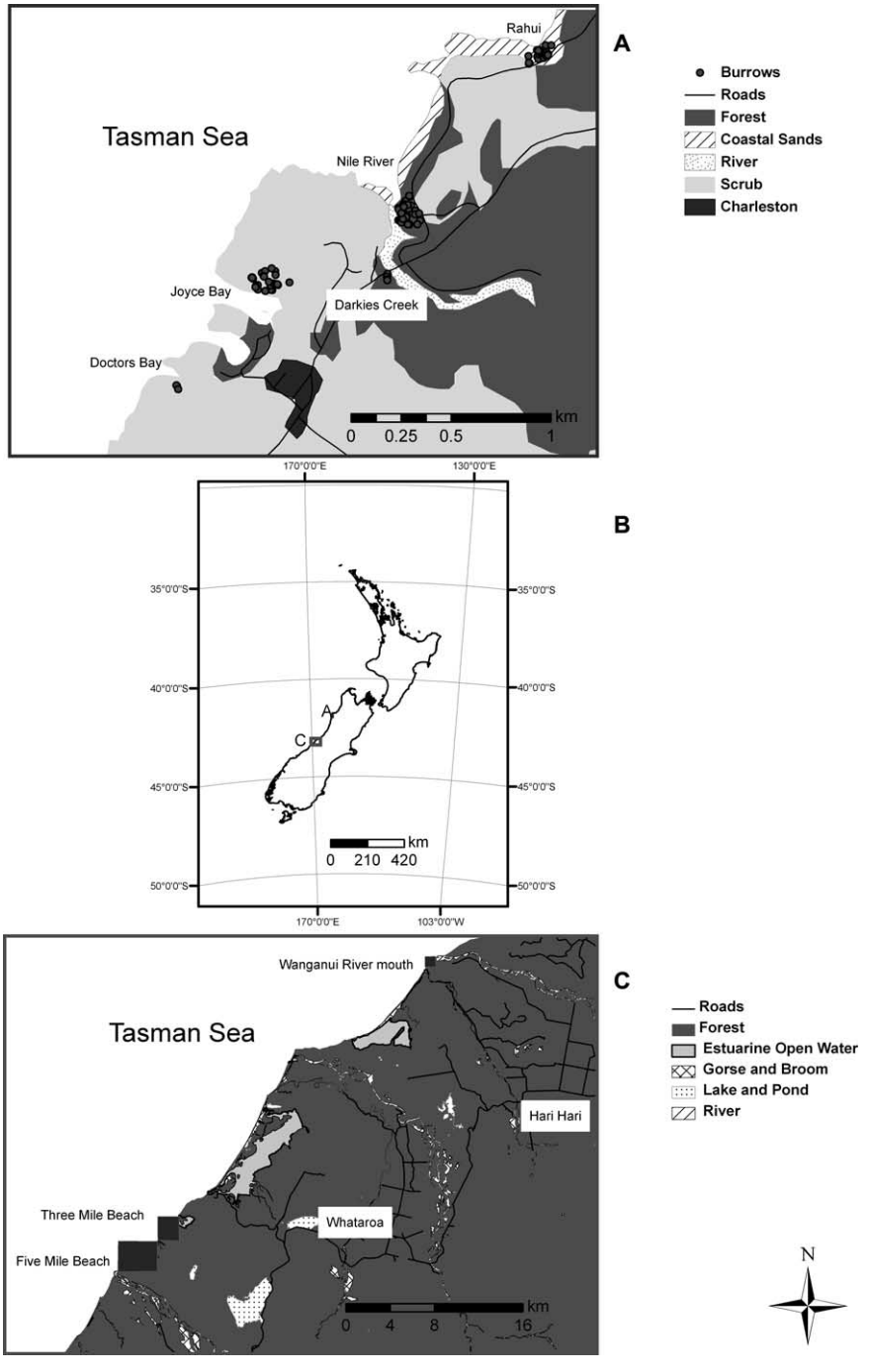

Figure 1 Study area and monitoring sites described in this study. **A**, Detail of Buller region study area; **B**, map of New Zealand showing study area locations; **C**, detail of South Westland study area.

were monitored in 2008, and 112 burrows and 21 nest boxes in 2007. Access to the Buller colonies is limited to a few landing sites at each colony. In South Westland, 110 natural burrows spread between three colonies were monitored. Nest boxes were checked by lifting the top of the wooden box, and natural burrows were checked using a burrowscope (Sextant Technologies, Wellington). The South Westland colonies are linear, lying parallel to the coastline.

Monitoring dates varied slightly between years. In 2007, all Buller sites were monitored monthly from 8 August 2007 to 6 June 2008. In 2008 in South Westland, monitoring began on 23 July 2008 and continued until the last chicks fledged on 21 December 2008. In 2008 in Buller, monitoring began on 3 July 2008 and finished on 8 January 2009. All sites were monitored weekly, except the Three Mile colony, where penguin burrows were inspected three times a week.

The number of adults, eggs, and chicks present was recorded on each visit, to tally nest successes. The date eggs and chicks were first observed and the date chicks were last seen was recorded. When the laying date was unknown, it was estimated by subtracting 90 days from the fledging date, allowing for a nestling period of c. 54 days and an incubation period of c. 36 days (Heather & Robertson 2005).

Mapping of breeding habitat

The high tide line was mapped by walking along the highest water line during high tide. Information on physical structure, vegetation, burrow type and distance to the high tide line was documented for each natural burrow and nest box. In South Westland, the breeding habitat and the precise location of all natural burrows in three colonies (Five Mile Beach, Three Mile Beach, and Wanganui River) was mapped using a GPS 60CSx (Garmin) with ≤ 5 m accuracy. In the Buller region, the dense vegetation cover and complex cave systems found at the study sites made it necessary to use a measuring tape and compass to measure the distance and direction of each burrow or nest box from the nearest GPS accessible point.

Qualitative analyses

The occupancy status of burrows and nest boxes was categorized as defined by Heber (2007): burrows and nest boxes considered to be occupied were those in which a breeding attempt took place, whether successful or not. In the Buller colonies, burrows found during the 2007 breeding season were included in our analyses of occupancy rate.

Breeding success was calculated as the percentage of the total number of eggs laid in each breeding season that produced fledglings. Only those nests for which the number of eggs laid, eggs hatched and chicks fledged were known were included in the analysis for breeding success. In Buller, breeding success was calculated only for the 2008 breeding season, as the monthly monitoring of burrows during 2007 produced insufficient data over the breeding season.

Spatial analysis

All spatial analysis was carried out using ArcGIS 9.3 (ESRI, Redlands, USA). To compare breeding success in colonial versus isolated burrows, a buffer area extending to 25 m around each burrow and nest box was defined. The maximal distance of 50 m between burrows was assumed to be easily bridged by penguin calls (Heber 2007). If a burrow's buffer intersected with more than five other burrows, it was considered to be part of a colony; if the buffer intersected with fewer than five other buffers, the burrow was defined as isolated (Heber 2007).

For nest density calculations, the area of each colony was determined in ArcGIS using a polygon to join the locations of the outermost nests. The Near Analysis tool in ArcGIS was used to determine distances between natural burrows or nest boxes, and their proximity to nearby land features within each study site.

If the land feature was a polyline (*hightide line*, *scrubline*, and *road/track*) the distance was calculated from the point on the polyline that was closest to a natural burrow or nest box. *Hightide line* was defined as the most inland line where seawater reached during high tide, and proximity was analysed land wards to each nest. *Scrubline* was defined as the outer edge of scrub vegetation, and proximity was determined inwards to the natural burrow or nest box. The results of these spatial analyses were then used for further statistical analyses as described in the following section.

Statistical analysis

Statistical analyses were used to determine the relationship between breeding success and each of the following habitat variables; proximity to land features (high tide line, scrub line and road/track), vegetation structure and nest type. A Pearson correlation, calculated in Minitab 15, was used to measure the strength of each linear relationship. Two-sample t-tests were conducted to test the difference between the two study areas, and the difference between occupied and unoccupied burrows in terms of different habitat variables. Statistical significance was accepted at $P = 0.05$.

Results

Occupancy rate

In the Buller region, 75 (51.7% of 145) natural burrows and 6 (27.3% of 22) nest boxes were occupied by blue penguins in the 2008 season, an increase over the 36 (32.1% of 112 natural burrows) and 5 (23.8% of 21 nest boxes) occupied in the same region in 2007. However, more natural burrows were occupied in South Westland (74, or 67.2% of 110) than in the Buller region in 2008.

Distribution of natural burrows and nest boxes

Table 1 gives the densities of both the total number of natural burrows and nest boxes and of the number that were occupied. The largest colony in the Buller region was at Joyce Bay ($220\,m^2$), where the total density of nests was $0.25/100\,m^2$. The largest colony in area was at Three Mile Beach ($25{,}895\,m^2$), where total nest density was $0.003/100\,m^2$. In general, the density of occupied nests was higher in the Buller region ($0.13–0.21/100\,m^2$) than in South Westland ($0.002–0.006$ nests$/100\,m^2$).

Table 1 Densities of the total number of natural burrows and nest boxes, and of occupied natural burrows and nest boxes in the Buller and South Westland regions. (Darkies Creek and Doctors Bay were excluded due to small sample size).

Study site	Density of total no. of natural burrows and nest boxes/ $100\,m^2$	Density of occupied natural burrows and nest boxes/ $100\,m^2$
Buller		
Rahui	0.26 (n = 29)	0.13 (n = 14)
Nile River Mouth	0.45 (n = 72)	0.21 (n = 35)
Joyce Bay	0.25 (n = 53)	0.18 (n = 39)
South Westland		
Wanganui River	0.01 (n = 22)	0.006 (n = 14)
Three Mile Beach	0.003 (n = 80)	0.002 (n = 51)
Five Mile Beach	0.002 (n = 8)	0.002 (n = 6)

Colonial versus isolated nests

In the Buller region, 157 burrows and nest boxes were classed as colonial, compared with eight isolated. In South Westland, 68 burrows were considered to be colonial and 42 isolated.

Occupied versus unoccupied nests

To determine whether proximity to land features or colonial versus isolated location influenced burrow or nest box occupancy, two-sample t-tests were carried out on the data from the 2008 breeding season.

Proximity to land features

Table 2 shows that, in the Buller region, burrows or nest boxes further from the hightide line and the scrubline were significantly more often occupied than those closer. Three colonies in the Buller region (Darkies Creek, Rahui, and Nile River Mouth) were situated close to a road or track, but this presumed source of disturbance did not significantly affect the relative numbers of occupied or unoccupied nests (Table 2).

In South Westland, there was no significant difference between the number of occupied and unoccupied nests in relation to proximity to hightide line or scrubline (Table 3), and there were no tracks or roads located close to the colonies monitored there.

Occupied nests were significantly closer to the hightide line in Buller (43.4 ± 36.4 m) than in South Westland (60.6 ± 20.8 m) ($P = 0.002$). Occupied nests were further from the scrubline in Buller (35.4 ± 34.3 m) than in South Westland (22.0 ± 15.9 m) ($P < 0.05$).

Colonial versus isolated location

There were no significant differences between the proportions of suitable colonial (t-value = 0.5; $P = 0.635$) or isolated nest sites (t-value = 1.26; $P = 0.056$) that were occupied.

Breeding habitat

In the Buller region, 161 (97.6% of 165) natural burrows and nest boxes were situated in coastal forest; plus three in scrubland and one near human habitation. Of the burrows and nest boxes in coastal forest, 95 (59.0%) of the 161 were occupied, compared with one of three in scrubland plus the only one near human habitation (Table 4).

In South Westland, 61 (55.5% of 110) natural burrows were in coastal forest (38 occupied, 62.3%), and the remaining 49 in scrubland (37 occupied, 75.5%).

Nest type

In Buller, the majority 119 (72.1% of 165) nests were situated under rocks, 10 (6.1%) were located in caves and 12 (7.3%) were dug in soil, but none in sand. A further 24 (14.5%) were artificial burrows, of which 22 were nest boxes and 2 situated under water tanks.

In South Westland, the majority of the 110 burrows were located in soil (43%) or sand (23.3%). There were no caves or rock formations available to blue penguins at the colonies in South Westland.

In the Buller colonies, the four nests situated in caves had an occupancy rate of 80.0% and these breeding pairs had the highest breeding success of 100.0%. The four nests in a soil/sand mixture under vegetation were nearly as desirable (occupancy rate of 70%) and successful (90% from ten eggs laid). Occupancy rate (one of three) and breeding success (64.0% from six eggs laid) were lowest in nest boxes.

Burrows located in soil in South Westland had the highest breeding success (87.1% from 31 eggs laid).

Table 2 Mean distance from occupied and unoccupied natural burrows and nest boxes to three land features in the Buller region (two-sample t-tests). Values in bold indicate significant results.

Feature	Mean distance of occupied natural burrows and nest boxes (m)	Mean distance of unoccupied natural burrows and nest boxes (m)	t-value	*P*
Hightide line	45.7 ± 35.4 (n = 81)	33.5 ± 28.8 (n = 84)	2.42	**< 0.05**
Scrubline	38.1 ± 33.4 (n = 81)	26.9 ± 25.9 (n = 84)	2.38	**< 0.05**
Road	41.8 ± 28.7 (n = 44)	40.9 ± 28.1 (n = 69)	0.04	0.96

Table 3 Mean distance from occupied and unoccupied natural burrows and nest boxes to three land features in the South Westland region (two-sample t-tests).

Feature	Mean distance of occupied natural burrows and nest boxes	Mean distance of unoccupied natural burrows and nest boxes	t-value	*P*
Hightide line	62.5 ± 21.5 (n = 74)	57.2 ± 24 (n = 36)	1.13	0.26
Scrubline	22.9 ± 16.2 (n = 74)	16.9 ± 14.9 (n = 36)	1.94	0.06

Breeding success

Out of 137 eggs laid in South Westland in 2008, 108 chicks fledged, giving an overall breeding success of 78.8%. In Buller, 64 chicks survived to fledging from 101 eggs laid, resulting in an overall breeding success of 63.4%.

Relationship between breeding success and habitat parameters

Land features

Proximity to the hightide line did not appear to influence the breeding success of burrows in either Buller ($r = -0.165$, $P = 0.199$) or South Westland ($r = -0.031$, $P = 0.805$). Neither did proximity to scrubline, in Buller ($r = -0.207$, $P = 0.107$) or South Westland ($r = -0.103$, $P = 0.409$).

At Nile River Mouth, Rahui, and Darkies Creek colonies, breeding success was unaffected by nearby roads or tracks ($r = -0.107$; $P = 0.535$).

Colonial versus isolated nests

In the Buller region, breeding success was not affected by whether a burrow was colonial (70.5% successful from 158 eggs) or isolated (58.5% from 14 eggs) ($P = 0.580$).

In South Westland, mean breeding success at both isolated and colonial nests was higher than in the Buller region, but within the South Westland region, the breeding success of isolated burrows (81.6% from 78 eggs) was not significantly higher than for colonial burrows (74.1% from 56 eggs) ($P = 0.397$).

Discussion

Occupancy rate and breeding success

Over all the monitored colonies in the Buller region, occupancy rate increased between 2007 and 2008 by 19.3% in natural burrows and 3.5% in nest boxes. Occupancy rate was also much higher than the 38% of 116 recorded in 2006 (Heber et al. 2008) for natural burrows and nest boxes over nine colonies. The pooled

Table 4 Occupancy rate and breeding success of natural burrows and nest boxes for each habitat type in both regions.

Region	Type	Occupancy rate (%)	Breeding success (%)
Buller	Coastal forest	59 (n = 161)	70.3
	Scrubland	33.3 (n = 3)	100.0
	Near human habitation	100.0 (n = 1)	*
South Westland	Coastal forest	62.3 (n = 38)	74.3
	Scrubland	75.5 (n = 31)	83.3
	Near human habitation	–	–

Note: *Exact egg and fledgling numbers were not available.

increase between 2006 and 2008 implies a slight recovery of a previously declining population (Heber et al. 2008) but the data are not directly comparable because different study sites were monitored in 2006 and 2008.

The data for breeding success in the Buller region during 2008 fell within the range reported from elsewhere in Australia and New Zealand, but in South Westland breeding success (78.8%) was higher than at most other colonies (Table 5). Oamaru reports a high breeding success in most years, and is considered to be an optimal colony in terms of breeding productivity (Heber et al. 2008). For Oamaru colonies, high breeding success can be related to an exclusive use of nest boxes, fencing of the breeding area to prevent human disturbance, good food availability most years and intensive predator control since 1993. These protective actions are combined with favourable environmental offshore conditions (Bradford & Roberts 1978; Fraser & Lalas 2004).

Although blue penguins are assumed to prefer nest boxes over natural burrows (Perriman & Steen 2000), only six out of 22 suitable nest boxes available in all our study areas were occupied by breeding pairs in 2008, two more than in 2006 (Heber et al. 2008).

Table 5 Breeding success of blue penguins at locations in New Zealand and Australia.

Location	Breeding success (%)	Reference
North Harbour, Australia	67–74	Priddel et al. 2008
Bowen Island, Australia	66–86	Fortescue 1995
Wellington, NZ	47.0	Bull 2000a
Taiaroa Head, NZ	23–78	Perriman & Steen 2000
Oamaru, NZ	67–71	Agnew 2008
Buller, NZ (2006)	66.2	Heber et al. 2008
Buller, NZ (2008)	63.4	This study
South Westland, NZ (2008)	78.8	This study

Penguins searching for a suitable new breeding site are the most likely to move into a nest box, rather than established pairs returning to a familiar site, so predator control at these colonies might have helped the apparent increase in the number of first time breeders in the Buller region, and in the occupancy rate, between the 2006 and 2008 breeding seasons. Double clutching was not observed at any of the colonies on the West Coast of New Zealand during this study or in previous years (Heber et al. 2008).

There are other possible reasons for the increase in breeding success in the Buller region from 2006 and 2008, such as varying food availability or adult mortality rates between breeding seasons. In blue penguins, both parents are required to rear the chicks (Davis & Renner 2003), so the loss of one breeding penguin can cause the deaths of up to three other individuals. In 2006 a total of fifteen adult blue penguins were killed by road traffic between August and December in the Buller region (Heber et al. 2008) while in 2008, twenty blue penguins were found dead from predation, road kill or natural causes. However, since these figures do not represent the total number of penguins killed, there are no means of quantifying the annual variation in blue penguin survival in the Buller region.

Breeding habitat

Mean burrow density in all our study areas was lower than on the flax habitats of Taieri Island in New Zealand (Dann 1994) and in study areas in Australia (Marchant & Higgins 1990; Fortescue 1995). However, the variation in mean burrow density between studies is very high, and suitable breeding habitat is not considered to be a limiting factor in either Buller or South Westland. Therefore, reasons for the low burrow densities remain unclear.

Blue penguins are amongst the most variable of penguins in terms of their breeding sites and breeding habitat. Nesting habitat is thought to be an important environmental factor in the

breeding success of seabirds; the physical structure can provide shelter from kleptoparasitism (Miyazaki 1996), security against predators (Nettleship 1972), and protection from severe weather (Renner & Davis 2001). Studies of yellow-eyed penguins (*Megadyptes antipodes*) (Seddon & Davis 1989) and Humboldt penguins (*Spheniscus humboldti*) (Mauricio et al. 1999) have suggested that nest type influences reproductive success, due to the different thermodynamic characteristics of each nest type. Fortescue (1995) found that blue penguins on Bowen Island, Australia, nesting in the *Banksia* woodland tended to have a higher breeding success than those nesting in tussock. Bull (2000b) also found that burrow type had a greater influence on egg success than date of lay, year and clutch size. Those nests found in vegetation, rock crevices and under such items as iron or logs, fledged the highest percentage of chicks compared to other nest types that were more prone to disturbances, such as in soil burrows, in caves and under boulders (Bull 2000b).

In this study most colonies were found in vegetation assemblages near or in regenerating coastal forests, although breeding success did not appear to be significantly different to that of burrows in scrubland. Heber et al. (2008) found blue penguins breeding under piles of driftwood in the Buller region, but there was no sign of penguins nesting in driftwood at South Westland despite plenty being available, which might suggest that habitat types such as scrubland or coastal forest are preferred by penguins. No nests were found in open fore dunes, as they were unlikely to protect the birds from climatic extremes and can easily be accessed by avian as well as ground predators.

The structure and sturdiness of nests influences fledging rates at least partially (Bull 2000b), and in this study, the few nests located in caves and in soil or/and sand directly underneath a log or root had the highest breeding success. Unexpectedly, only 64% of fledglings survived from the 22 nest boxes occupied in this study, perhaps because the nest boxes were placed in unsuitable habitat types or in locations easily accessible to predators. The high rainfall on the West Coast is a hazard for penguins because exposure to rain or burrow flooding can increase chick mortality (Renner & Davis 2001). There were no known instances of burrow flooding in either site during this study, and sample sizes of burrows in sand or soil burrows with no cover were too small to make robust comparisons of breeding success for each burrow type.

Effect of habitat parameters on occupancy rate and breeding success

Breeding success may be affected by the distance from the nest to the sea (Dann & Cullen 1990), because walking on land makes high energy demands on blue penguins in comparison with the energy expended while swimming (Pinshow et al. 1977). This energy expenditure may affect growth of offspring (Waas 2003).

In both study areas there was a tendency to nest close to the sea, with the highest number of occupied burrows found less than 25 m from the sea and less than 25 m land-wards from the scrubline. The distance of burrows from high tide line was especially important in South Westland because wide beaches separate the sea from nest sites there, whereas penguins in Buller occupy areas with mostly narrow rocky shorelines. However, proximity to different habitat features (hightide line and scrubline) influenced the occupancy of nests in Buller but not in South Westland, and breeding success did not appear to be influenced by the proximity of nests to the sea in either area.

Human disturbance was a potential factor only at Darkies Creek, Rahui and Nile River mouth and even there was relatively limited and unlikely to increase in the near future. Breeding success is unlikely to be affected by human activities at these sites.

It could be argued that penguins breeding in colonies create greater levels of activity and associated noise and smell, and so would be more likely to attract the attention of predators

than isolated breeders. Some studies have indeed found a higher predation risk in colonial breeders (Anderson & Hodum 1993), but in this study there was no difference in breeding success between colonial and isolated breeders in either area.

Studies of blue penguin breeding habitat in New Zealand are sparse, and information on breeding habitat on the West Coast mostly anecdotal. This study provides a robust baseline against which to measure any changes in the distribution of breeding penguins in the future. Results of this study may also help to improve the placement of nest boxes, or guide redistribution of nest boxes from less suitable habitats. For example, in modified habitats, blue penguin numbers increase with the provision of nest boxes (Perriman & Steen 2000). At sites that already have high burrow occupancy rates and few unoccupied burrows, the allocation of nest boxes may encourage first-time breeders to settle and nest, and so increase the overall number of blue penguin nests on the West Coast and elsewhere.

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