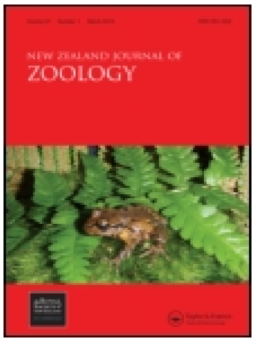

New Zealand Journal of Zoology

ISSN: 0301-4223 (Print) 1175-8821 (Online) Journal homepage: http://www.tandfonline.com/loi/tnzz20

Breeding biology and breeding success of the blue penguin (Eudyptula minor) on the West Coast of New Zealand's South Island

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0301–4223/08/3501–0063

Breeding biology and breeding success of the blue penguin (*Eudyptula minor*) on the West Coast of New Zealand's South Island

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Abstract This paper presents the first detailed study of the timing and breeding success of an apparently declining population of blue penguins (*Eudyptula minor*) on the West Coast, South Island, New Zealand. Nest contents of 138 natural burrows and 19 nest boxes were determined at regular intervals during the 2006 breeding season. Hatching, fledging, and overall breeding success rates were comparatively high at 78.9, 83.9, and 66.2%, respectively, suggesting that the apparent population decline cannot be explained solely by low breeding success. With 1.18 fledglings produced per pair, productivity was lower than on the east coast of the South Island, possibly due to the absence of double clutching. The high incidence of road kills suggests that road traffic may be a major contributing factor to the decline of the blue penguin population in the study area.

Keywords *Eudyptula minor*; breeding success; breeding timing; conservation; New Zealand; productivity; road kills; threats; West Coast

Z07031; Online publication date 22 February 2008
Received 5 July 2007; accepted 10 December 2007

INTRODUCTION

The blue penguin (*Eudyptula minor*) is the world's smallest penguin, and the only penguin species that is nocturnal on land (Stahel & Gales 1987; Davis & Renner 2003). During the breeding season at least one adult will stay in the burrow all day throughout both the incubation and the guard periods, in order to incubate the eggs or protect the chicks from hypothermia and predators.

Blue penguins are amongst the most variable of penguins in terms of their breeding sites: they breed in burrows, under trees and other vegetation, in piles of driftwood, in rock crevices, under buildings and in caves (Marchant & Higgins 1990). Nesting configurations range from dense colonies or loose aggregations to (less often) single breeding pairs (Nakagawa et al. 2001; Davis & Renner 2003).

Breeding dates and breeding success are dictated by local conditions, especially those associated with food supply (Collins et al. 1999; Perriman et al. 2000), and the start of the breeding season will often be delayed or the season shortened in years of poor food supply (Perriman et al. 2000; Davis & Renner 2003; Robinson et al. 2005). Clutch size is normally two, but clutches of one egg are known. In many areas there may be a second or sometimes even a third clutch, either in response to breeding failure (replacement clutches) or after successfully fledging chicks (double clutching) (Gales 1984; Perriman et al. 2000; Davis & Renner 2003). The ability of blue penguins to fledge chicks from more than one clutch during a single breeding season makes them unique among penguin species (Johannesen et al. 2003).

Blue penguins are still relatively common on offshore islands around the coast of New Zealand, but many of the mainland populations are declining (Dann 1994; Dann et al. 2000; Perriman & Steen 2000; Bull 2000a; Houston 2007). The total population size of blue penguins on the West Coast of the South Island has not been assessed, but according to Blyth et al. (2006) and subsequent surveys by the West Coast Blue Penguin Trust, it is thought to be in the hundreds rather than in the thousands.

Anecdotal evidence suggests there is a population decline that—according to many West Coast residents—started a decade ago or longer.

This paper reports the first comprehensive study of the breeding cycle of the blue penguin on the West Coast of New Zealand's South Island. It was designed to determine the role of breeding success in the reported population decline, and the timing and length of the breeding season of West Coast blue penguins. Furthermore, it aimed to identify potential threats to blue penguins in the study area. The results provide a basis against which future population changes can be compared, and to guide further research on the population trends and breeding success of the blue penguin on the West Coast.

MATERIAL AND METHODS

Study sites

Nine study sites (Fig. 1) along c. 60 km of coast between Westport and Punakaiki were selected, based on the findings of a distribution study carried out during the 2005 breeding season (Blyth et al. 2006). Penguin nest sites were located mainly in coastal vegetation (82.1%, n = 129), but also under driftwood (6.4%, n = 10), in caves (8.3%, n = 13), and under houses (3.2%, n = 5). At two sites (Limestone Creek and Nile River Mouth, see Fig. 1), 19 wooden nest boxes were installed. The nest boxes in the Limestone Creek area were moved to their current position in September 2006. At Nile River mouth, nest boxes were first installed in early 2004, and the last nest boxes were put in place in February 2006. Most penguins in the study area were unmarked. However, 12, 3, and 14 penguins were flipper banded in the study area in September 2005, January 2006, and October 2006, respectively (see Heber 2007).

Data collection

Monitoring began on 23 August 2006 and continued until the last chicks fledged on 18 December 2006. The largest colony in the area, at the Nile River mouth near Charleston, was the primary study site, and was monitored three times a week. The eight other sites (Truman's Cave, Limestone Creek, Fox River Cave, Doctor's Bay, Darkies Creek, Tauranga Bay, Okari Road, and Carters Beach) were visited once a week.

Data were collected from 138 natural blue penguin burrows and 19 nest boxes. Nest boxes could easily be checked by lifting the top of the wooden box. Natural burrows were checked using a burrowscope (hand made at the Bio-Protection and Ecology Division at Lincoln University). The number of adults, eggs, and chicks present was recorded on each visit, in order to tally nest successes and to determine the length of the incubation and nestling periods.

The date of lay was recorded as the date an egg was first observed in a burrow. Six eggs had already been laid when observations began. When the laying date was not known, e.g., when eggs were already present on the first visit or when a burrow was first discovered, it could be calculated by counting days backwards from either the hatching or the fledging date. The fledging date was assigned as the date the chick was last seen, provided it had been hatched for more than 7 weeks. To determine the lay date in cases where it was not possible to record it directly, a period of 90 days was subtracted from the fledging date. The 90-day period includes a nestling period of 54 days and an incubation period of 36 days (Heather & Robertson 2005).

Hatching success was defined as the proportion of eggs that hatched relative to the total number of eggs laid. Fledging success was defined as the proportion of chicks that fledged relative to the number of chicks that hatched. The overall breeding success was defined as the number of chicks that fledged relative to the number of eggs laid.

Ten tracking tunnels made of black corrugated plastic (Lincoln University, New Zealand) with ink pads (Trakka cards; Connovation Ltd, Auckland, New Zealand) were placed close to penguin burrows at five of the study sites and checked regularly to identify which potential predators were present. On each visit, new tracks were marked. Ink pads were replaced when they were either covered with tracks or when the ink had dried. During the course of the study, a total of 52 ink pads was set out in the tracking tunnels. Fenn (MK 4, Fenn & Co., Worcestershire, UK) and Thumper traps (DOC 200, Curtis Metal Products Ltd, Otahuhu, New Zealand) were set for stoats (*Mustela erminea*) and rats (*Rattus* sp.) at the Nile River mouth colony (eight traps) and Tauranga Bay (six traps). The traps were set in wooden tunnels with a small entry at each side and covered with twigs and other material. Both traps and tracking tunnels were baited with hen eggs and peanut butter, and checked on each visit.

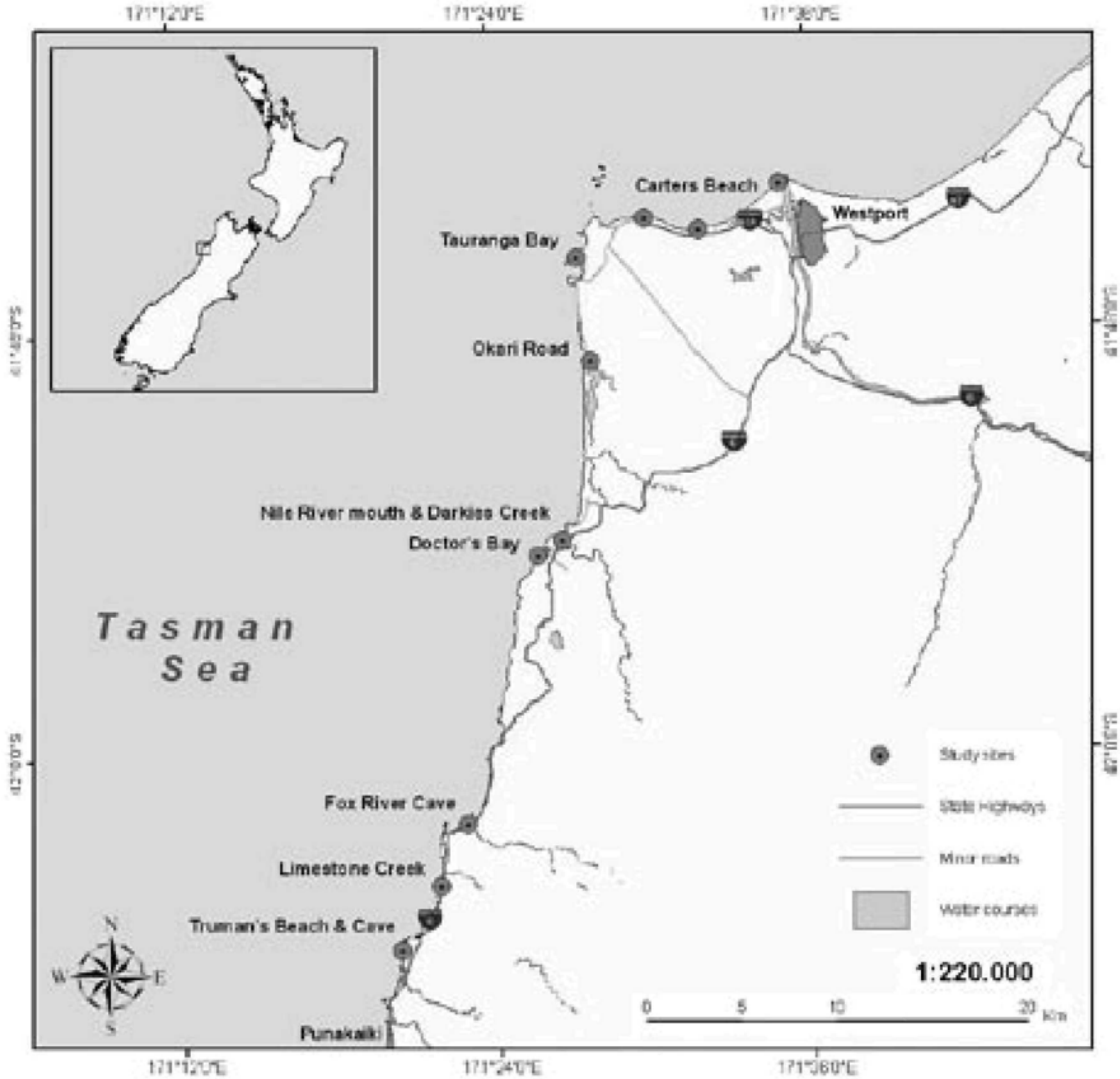

Fig. 1 Map showing the study area in the Buller District, on the West Coast of New Zealand's South Island. Scale 1:220 000.

RESULTS

Breeding cycle

Egg laying dates and incubation length

Egg laying started in late July and continued until early October, with a peak in August. The mean date of onset of breeding at all sites pooled was 30 August (range 28 July–3 October; $n = 67$). During the study, 31 clutches of two eggs (77.5%) and nine clutches of one egg (22.5%) were recorded, a total of 71 eggs produced by 40 breeding pairs. Eggs in clutches of two were laid on average 2 days apart ($x = 2.2 \pm 3.6$; $n = 9$). The average incubation period for all eggs with known laying and hatching dates was 34 days ($x = 33.9 \pm 4.0$, $n = 14$) and ranged from 30 to 38 days. No evidence of second clutches or replacement laying was found.

Hatching dates and hatching success

Hatching dates ranged from 1 September to 21 October 2006. The mean calculated hatching date was 26 September ($n = 54$). Eggs in clutches with accurate hatching date records hatched on average 2 days apart ($x = 2.0 \pm 3.6$; $n = 9$). Out of 71 eggs laid, 56 hatched, resulting in a hatching success of 78.9%.

Fifteen eggs failed to hatch. Most egg mortality was attributed to infertility or other causes (12.7%, $n = 9$). Six of the nine eggs that failed to hatch were recovered. Four of those (67%) contained fully or partially developed embryos, but no development could be detected in two eggs (33%). Two (2.8% of all eggs laid) were in a burrow that was flooded and consequently abandoned by the parents. Four eggs (5.6%) were destroyed by predators. The predators responsible could not be identified with certainty, although weka (*Gallirallus australis*) may have been involved in at least two cases, as they were seen examining the affected and nearby burrows on several occasions.

Guard stage and nestling length

The average guard stage for all nests containing chicks with known hatching dates was 26 days ($x = 25.6 \pm 10.1$, $n = 28$) and ranged from 18 to 38 days. The guard stage is defined as the period between the day of hatching of the first chick and the day when the chick(s) is/are first left alone during the day. The average nestling period—hatching to fledging—for all chicks with known hatching and fledging dates was 58 days ($x = 57.5 \pm 8.0$, $n = 26$) and ranged from 48 to 64 days.

Fledging dates and fledging success

Chick fledging began on 24 October and ended on 16 December 2006. The mean calculated fledging date was 20 November ($n = 47$). Chicks from two-egg nests fledged on average 4 days apart ($x = 4.3 \pm 5.5$, $n = 8$) ranging from less than 2 to 11 days apart (= 2 days, 37.5%; 2 days, 12.5%; 4 days, 12.5%; 8 days, 12.5%; 9 days, 12.5%; 11 days, 12.5%). Out of 56 eggs that hatched, 47 chicks fledged, resulting in a fledging success of 83.9%.

Nine chicks that hatched failed to survive to fledging. One chick, the smaller of two, was found trampled into the nesting material within 3 days of hatching. Two chicks (siblings which had both hatched between visits, so were at most 2 days apart in age) were found dead in the nest within few days of hatching. They were probably killed by their parents, who had previously been observed aggressively pecking at their offspring. One of these chicks had a physical deformity: the legs were arranged asymmetrically on the body. In most cases ($n = 6$, 10.7% of the 56 chicks hatched), chick mortality could not be attributed to any specific cause, as the chicks simply disappeared from their burrow without any direct sign of what happened. However, although no traces were found, some of these cases might have been predation events.

Breeding success

Out of 71 eggs that were recorded in this study, 47 chicks fledged, resulting in an overall breeding success of 66.2%. The mean number of chicks fledged per pair that produced eggs ($n = 40$) was 1.18. The mean number of fledglings produced for all pairs ($n = 44$; including pairs for which no breeding attempt was recorded) was 1.07. From a total of 40 breeding pairs, 40% produced two fledglings ($n = 16$), 37.5% produced one fledgling ($n = 15$ pairs), and 17.5% produced no fledgling ($n = 7$).

Two burrows were discovered near the end of the breeding season. Breeding had been attempted in them, because one egg that had apparently failed to hatch was found outside each burrow entrance. For these burrows (5% of all burrows subject to this study, $n = 2$) it is not known if a chick was raised or not.

Figure 2 shows the numbers of blue penguin eggs and chicks present in the study burrows each week.

Evidence of potential threats

Traps and tracking tunnels

Sixty percent of all 10 tracking tunnels recorded rat tracks ($n = 6$), identified from the key provided by Ratz (1997). On the basis of the size of the rat tracks, most of them were assumed to be made by ship rats (*Rattus rattus*), although some might have been from Norway rats (*Rattus norvegicus*). Twenty percent of all tracking tunnels featured mouse (*Mus musculus*) tracks ($n = 2$), and another 20% showed signs of weta (Families Anostostomatidae and Rhaphidophoridae; $n = 2$). Blue penguin tracks were recorded in one of the tracking tunnels. No stoat tracks were detected by the ink pads. Of the nine study sites, 22% recorded predator (rat) activity ($n = 2$).

Four rats were trapped in the Thumper traps at the Nile River mouth colony between August and October. Four stoats and four rats were caught in Thumper traps at Tauranga Bay between February and December 2006.

Burrow occupancy rate

Of 98 burrows and 18 nest boxes that were considered suitable for breeding (Heber 2007), 38% were

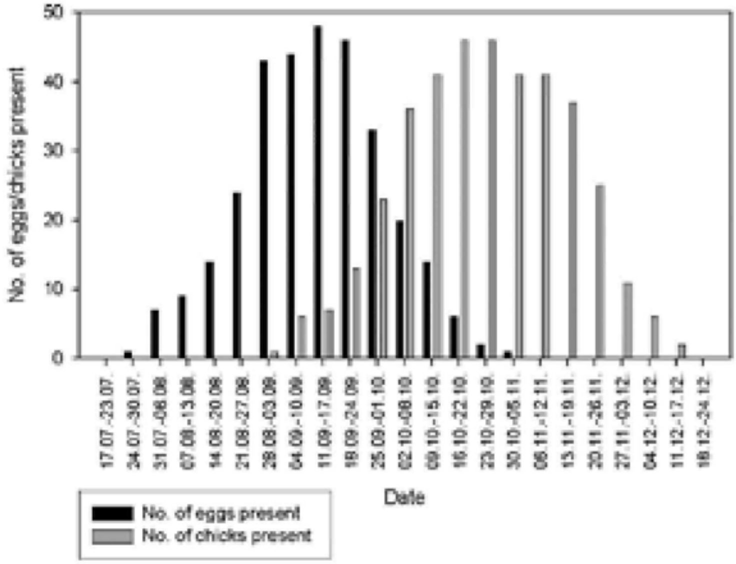

Fig. 2 Average numbers of blue penguin eggs and chicks present per week in the monitored burrows on the West Coast during the 2006 breeding season.

Table 1 Average length of incubation, guard, and nestling periods for blue penguins (in days) at various study sites in New Zealand and Australia.

Location	Incubation period	Guard period	Nestling period	Reference
Bruny Is., Australia	33.4	–	54–63	Marchant & Higgins (1990)
Phillip Is., Australia	33–37	–	58	Reilly & Balmford (1975)
Phillip Is., Australia	33–34	–	–	Kemp & Dann (2001)
Wellington, New Zealand	33–43	–	49–63	Marchant & Higgins (1990)
South Island, New Zealand	39	–	–	Marchant & Higgins (1990)
Otago, New Zealand	36	24	54	Marchant & Higgins (1990)
Motuara, New Zealand	–	15 ± 1	–	Numata et al. (2004)
Oamaru, New Zealand	–	20 ± 1	–	Numata et al. (2004)
West Coast, New Zealand	33.9	25.6	57.6	this study

occupied by breeding blue penguins in the 2006 season.

DISCUSSION

Breeding cycle

The average incubation period, guard stage, and nestling period determined for this study were all within the ranges found in other studies conducted in New Zealand and Australia (Table 1). The average incubation period (33.9 days) was at the lower end of the range for incubation periods found in all other studies (33–43 days). Conversely, the calculated guard period (25.6 days) was slightly longer than that found in other studies (15–24 days). The extended guard period might reflect favourable feeding conditions, allowing the adults to build up larger fat reserves. However, the small differences in the length of the average incubation and guard periods could also be a result of monitoring frequency, because nests in this study were checked only 3 days a week at the Nile River mouth and once a week at other study sites. The nestling period in this study (57.6 days) also fell within the range of all other studies (49–63 days).

Table 2 shows the hatching, fledging and breeding success, and the number of chicks reared per pair, in this study compared with other New Zealand and Australian studies. Hatching, fledging, and breeding success were considerably higher in this study compared with all other places except at Oamaru on New Zealand's east coast.

The breeding success determined for this study on the West Coast lay toward the upper end of the likely range for all three measured breeding parameters, suggesting that the cause of the suspected population decline of blue penguins in this area is not solely, and possibly not at all related to poor breeding success. No evidence of double-clutching or replacement laying was found in this West Coast study or during a preliminary study carried out in the 2005 breeding season (Blyth et al. 2006). Studies in the Wellington area likewise documented only single clutches (Kinsky 1960; Bull 2000a), suggesting that the West Coast population is not unusual in this regard.

Blue penguin breeding success at Oamaru was 71% in the 2005 breeding season. However, the number of chicks reared per pair in the Oamaru colony was almost twice as high as on the West Coast, largely because 57.5% of the total breeding population present in Oamaru went on to rear a second brood in that breeding season. Blue penguins in Oamaru laid an average of 3.18 eggs per pair (Jones 2006) compared to 1.78 eggs per pair laid on the West Coast during this study. This difference between West Coast and east coast has been observed before: blue penguins at other breeding sites on the east coast frequently lay two clutches a year. For instance, almost half (48%) of the pairs that produced eggs at Taiaroa Head, Otago Peninsula, during the 1993 breeding season laid a second clutch after successfully fledging at least one chick from their first clutch (Perriman & Steen 2000).

At Oamaru, efforts have been made to prevent predation by rats, ferrets (*Mustela furo*), cats (*Felis catus*) and dogs (*Canis familiaris*) since 1993, and the breeding area is protected from human disturbance by a stock fence (Johannesen et al. 2003). Furthermore, in contrast to the northern part of the West Coast, east coast seas are influenced by the Southland Current, which contains nutrient-rich Subtropical Convergence water and an admixture of Australasian Subantarctic water. The Southland Current is often associated with enhanced nutrient availability and hence enhanced oceanic productivity (Kuschel 1975; Field et al. 1998). At Oamaru, the combination of predator control on land and favourable environmental conditions at sea may enable that colony to achieve the maximum breeding success possible for blue penguins.

Potential threats

Table 3 shows that the occupancy rate in this study was about half that in other studies. Since established breeders tend to return to the same nest site in successive seasons (Marchant & Higgins 1990; Bull 2000a), the low occupancy rate might, if all else remains equal, indicate a dramatic population decline over the past decades. However, blue penguins often dig more than one burrow before occupying one (Stahel & Gales 1987; Marchant & Higgins 1990), and often occupy several nest sites before choosing one in which to breed (Dann 1994). Nevertheless, that does not explain these results, since the same behaviour is observed at the other study sites where occupancy rates are considerably higher.

Table 2 Breeding success of blue penguins at various study sites in New Zealand and Australia.

Location	Hatching success (%)	Fledging success (%)	Breeding success (%)	Chicks reared per pair	Reference
Bruny Is., Australia	67	24	16	0.32*	Giese et al. (2000)
Phillip Is., Australia	64	41	26	0.71*	Reilly & Cullen (1981)
Wellington, New Zealand	57	83	47	0.94*	Bull (2000a)
Otago, New Zealand	63	75	47	1.6†	Gales (1984)
Oamaru, New Zealand	73	94	71	2.15†	Jones (2006)
West Coast, New Zealand	79	84	66	1.18†	this study

*These studies do not specify whether the figure represents the number of chicks per pair that laid eggs or for all pairs.
†This figure represents the number of chicks raised per pair that attempted breeding. The number of chicks reared if all pairs are included was 0.95 at Otago and 1.07 on the West Coast. In Oamaru, the number of chicks reared per successful pair and for all pairs is identical as all pairs attempted breeding.

Mortality can reduce penguin numbers both on land and at sea. In New Zealand, introduced predators are the main cause for the population decline of many native bird species (Wilson 2004); dogs, mustelids and rats have affected blue penguin populations throughout New Zealand and Australia (Stahel & Gales 1987; Dann 1992; Hocken 2000; Perriman & Steen 2000). On the West Coast, predators did not have the expected negative impact on blue penguin breeding attempts during the 2006 breeding season. Even though 5.6% of all eggs laid and up to 10.7% of all chicks were taken by predators, the consequences of these losses were minimal, and breeding success remained comparatively high in this study area. Few predators were trapped during the course of our study.

Road kills represent another threat to blue penguins (Dann 1992; Harrigan 1992; Hocken 2000; Bull 2000a). Concerns over the high incidence of blue penguin road kills had already been expressed by DOC staff in Paparoa National Park in 1991 after more than 20 road kills were recorded during the 1990 breeding season (Thornton & Rockall 1991). Several of our study sites were close to roads (Fig. 1). By the end of this study, 30 road killed penguins, all from the Buller Region, had been collected by the Westport office of the Department of Conservation (DOC) (J. Reedy pers. comm.). Unfortunately, the time span over which these were accumulated is unknown, since only five of them were labelled; one of them had been collected in the study area in August 2000, while the remaining four had been recovered between September and December 2006. We recorded two additional road kills in August and November 2006, respectively, and eight more were reported by local residents between August and October 2006 (DOC Westport, unpubl. data). This is a total of 15 known road killed adult blue penguins between August and December 2006 in this study area.

Since non-breeding blue penguins spend most of the year at sea (Davis & Renner 2003), they are obviously at greater risk of being killed on the road during the breeding season. Each road killed penguin might be incubating up to two eggs or rearing up to two chicks at the time of death. Since in blue penguins both parents are required to rear the chicks (Davis & Renner 2003; Numata et al. 2004) the death of one penguin on the road can remove up to three more individuals from the population. Furthermore, population size is most significantly affected by changes in adult survival (Dann 1992). These findings suggest that road traffic has been a contributing factor to the decline of the blue penguin population in that area over at least 1 decade.

Other factors that may also affect the West Coast penguin population at times include the following: (1) dogs; in September and November 2003 a single dog killed at least 12 adult penguins at the Nile River mouth colony (H. Chambers pers. comm.); (2) habitat loss (Bull 2000a,b); at Carters Beach, erosion and subdivision and development of housing allotments are damaging the nesting habitat available to the birds; (3) mortality at sea, due to predation by New Zealand fur seals (*Arctocephalus fosteri*) (penguins nesting on the headlands north of Tauranga Bay have to pass close to a large New Zealand fur seal colony at Cape Foulwind in order to come ashore) and rough weather; (4) drowning in fishing nets (but no data are available on blue penguin by-catch or the intensity of set-net fishing on the West Coast).

Seabirds are believed to respond most strongly to changing oceanographic conditions by varying their diet and breeding success rather than their adult and post-fledging survival rates (e.g., Cairns 1987; Russell 1999; Croxall et al. 2002). If this is true of blue penguins on the West Coast, the most effective means of stabilising or increasing their numbers might be to identify and concentrate on the factors reducing adult survival. More emphasis should be put on determining the relative significance of the known factors operating on land. For instance, road kills could be making an important contribution to the population decline, so steps should be taken to identify the most hazardous road crossing points, protect penguins crossing there, and raise public

Table 3 Comparison of blue penguin nest occupancy rates at different locations in New Zealand.

Location	Occupancy rate (%)	Reference
Taieri Island, New Zealand	78	Dann (1994)
Oamaru Quarry, New Zealand	67	Jones (2006)
Oamaru Creek, New Zealand	88	Jones (2006)
West Coast, New Zealand	38	this study

awareness about the danger. Furthermore, monitoring of local populations and breeding success, and a systematic collection of road kill data, are both urgently needed to quantify the effect of road kills on the blue penguin populations and guide future management. Control of adult mortality is the key to recovery of the blue penguin populations on the West Coast, because there is no obvious way to increase their breeding productivity.

ACKNOWLEDGMENTS

Thanks are due to the West Coast Blue Penguin Trust for partial funding and to Lincoln University for the use of field equipment. Research permits and banding permits for this study were issued by the Department of Conservation. Thank you also to the Buller Area Office of the Department of Conservation for support. We thank H. Chambers, J. Cotton, J. Reedy, G. Wood, R. Blyth, R. Bromley and S. Ogilvie for invaluable support during this project.

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