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Breeding success and conservation of little penguins *Eudyptula minor* in Boronia Beach colony, southeast Tasmania

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Breeding success and conservation of little penguins *Eudyptula minor* at Boronia Beach colony, southeast Tasmania

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Abstract

Offshore islands are main sites for breeding for little penguins *Eudyptula minor*, but several colonies exists on mainland New Zealand and Australia, including Tasmania. A mainland colony of little penguins at Boronia Beach, southeast Tasmania, was monitored over three consecutive breeding seasons (from 2011/2012 to 2013/2014) by the Derwent Estuary Penguin Program. Information on nest types and habitat for this study was collected from February to May 2014. The number of breeding pairs in the colony ranged from 32 to 53 per annum, showing a declining trend. The mean breeding success of 0.62 at Boronia Beach was within the range and above the average reported at other little penguin colonies in Australia and New Zealand. Variation in both annual and seasonal breeding success was, however, observed throughout study period. In addition, 26 to 46 nests per annum were used for occupancy other than breeding, such as moulting and resting. Of the 140 nests included in the study, natural nests located in cliff caves in proximity to the shoreline reached the highest rate of occupancy as well as breeding success. This research provides a basis for further conservation efforts at Boronia Beach little penguin colony. Understanding the health and threats facing the survival and success of the colony is of pivotal importance in effective conservation of little penguins and their habitat at Boronia Beach and in other mainland colonies in Australia and New Zealand impacted by increasing human disturbance and predation by introduced mammals.

Keywords

Breeding success, Derwent estuary, *Eudyptula minor*, little penguin, nest occupancy, nest type, seabird conservation

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1 INTRODUCTION

1.1 Introduction to little penguins and their habitats

1.1.1 Little penguins

The little penguin, *Eudyptula minor*, or “good little diver”, is the smallest species of penguin (family Spheniscidae) standing 30 centimeters tall and endemic to southern Australia and New Zealand, where it is known as the blue penguin or kororā (Stahel and Gales 1987; Reilly 1994). The species is long-lived, generally starting to breed at the age two or three and reaching an age of over 20 years (Dann & Cullen 1990) with records of an individual breeding at an impressive 21 years of age (Reilly 1977). In general, however, there is a decline in reproductive success upon reaching 8 years of age (Nisbet and Dann 2009). Up to six subspecies have been suggested, of which the single Australian little penguin would be *Eudyptula minor novaehollandiae* (Kinsky and Falla 1976) having white feathers on the rear edge of flippers and on its tail.

Figure 1.1. Little penguins are easily identified by their blue and white colouration and small size.

Little penguins normally produce a clutch of two eggs and breed once per year. Considerable inter-annual and spatial variation exists in the length and timing of breeding in little penguins across their range (Stahel and Gales 1987). Seasonality in marine productivity, and hence food resources, influences the timing of breeding, and the duration of breeding is dependent on whether a pair engages in single or multiple breeding attempts within one season (Fortescue 1999). Double brooding of little penguins occurs throughout their entire range of distribution. In Tasmania the breeding season typically spans from September to February, with double brooding occurring from July to September. Rearing of two successive clutches in one breeding cycle is thought to be unique for little penguins as no other penguin species has been observed to engage in double brooding (Gales 1984; Stahel and Gales 1987). Breeding is followed by moulting, during which old feathers are replaced by new ones providing better insulation. In penguins this is sometimes referred to as a catastrophic moult because these birds moult all their feathers at once and need to remain on land for the whole period of moulting. Little penguins may use a breeding burrow for molting but are known to moult in crevices between boulders and in understory, not always returning to moult to the breeding colony (Reilly and Cullen 1983).

1.1.2 Little penguin habitats and nests

As a seabird, little penguins are highly adapted to life in temperate marine waters, feeding on small schooling fish, krill and squid with a foraging range extending to its maximum during non-breeding (Stahel and Gales 1987). For breeding and moulting as well as resting little penguins are required to come ashore and do this generally after dusk to avoid predators on land. Nest sites used by little penguins are highly variable in their characteristics, from underground burrows, to crude shelters under a bush, and under artificial structures (for example buildings and steel barrels). Nest site characteristics affect the reproductive fitness and survival of both adults and chicks by influencing the degree of shelter and hence microclimate in the nest, as well as providing concealment from predators on land (Burger and Gochfeld 1988; Clark and Shutler 1999; Stokes and Boersma 1998). Therefore, breeding habitats constitute a critical resource for little penguins among other birds during the breeding season (Gandini *et al*. 1999).

Selection of breeding site in sea birds follows from the concept of central-place foraging influenced by the abundance and distribution of prey and the need to return to colony to dependent eggs and chicks (Burke and Montevecchi 2009). Disproportionate use of nests from all nests freely available suggests that a degree of nest-site selection is occurring in little penguins. For mainland little penguins as flightless birds finding suitable habitat minimizing the risk of predation constitutes an additional challenge. The question of which nests are selected for and make up a successful site for breeding and survival is essential for the reproductive success and survival of an individual as well as a colony.

The size of little penguin colonies range from less than ten pairs to thousands of pairs (Waas 1990), with larger colonies found predominately on off-shore islands. Like most other penguin species of temperate seas, little penguins are loosely colonial, nesting typically five to ten metres apart from other pairs (Stahel & Gales 1987; Williams 1995). As an exception, however, nests in cave colonies are commonly found less than two metres apart (Waas 1990). Nest densities, then, are highly variable both between and within colonies. As a species highly adapted to the marine environment and requiring access to sea, the little penguin nests on rocky and steep coastal areas of off-shore islands and mainland headlands (Beruldsen 1980). Near human settlement they are sometimes seen to nest under buildings or other man-made structures.

Natural nests are burrows scratched out into soft soil, under grasses and other vegetation, or crevices between rocks and boulders. Hollows beneath dense ground-covering vegetation (Beruldsen 2003), such as creeper, are also used as nests on islands where terrestrial predation is minimal. In addition, burrows previously used by *Puffinus* spp. (shearwaters) or *Pterodroma* spp. (petrels) are sometimes used (Beruldsen 1980). Due to human disturbance and habitat degradation, man-made nests are a commonly used tool in little penguin colony restoration. These artificial nests are either wooden nest-boxes or concrete igloos. A number of natural elements in the form of rocks, logs and vegetation are often added in the proximity of artificial nests. In addition, boulder or cliff nest reinforced with concrete constitutes a combination of natural and artificial nests.

This broad range of both natural and artificial nests at different breeding sites makes little penguins among the most variable of all penguins in terms of choosing their nests as well as their breeding habitat (Braidwood, Kunz and Wilson 2011). In addition to maintaining strong and lasting pair-bonds by exhibiting high degree of social monogamy (Watts 1999), little penguins are highly philopatric towards their nest-site, returning to their natal colony to moult and breed. However, despite site-fidelity, a failed breeding attempt may result in a change of nest site (Johannesen, Steen and Perriman 2002), whereas successful breeders are more likely to return to the same breeding colony in consecutive years (Switzer 1997). This is suggested to reflect the ability of birds to assess habitat quality based on previous reproductive experience (Switzer 1997). In addition, increased disturbance of nest sites is likely to alter the behaviour of little penguins while choosing a breeding site. These factors highlight the need for assessing the breeding success and challenges for conservation of any one colony of little penguins.

1.2 Introduction to conservation of little penguin habitats

It has been estimated that there are nearly 1,000,000 little penguins in Australia (Marchant and Higgins 1990; del Hoyo *et al*. 1992; Williams 1995) and 25 000 – 50 000 in New Zealand (Williams 1995). Owing to the large range in distribution, the IUCN Red List classifies the conservation status of the species of least concern, but with decreasing population trend (Birdlife International 2012). It is important to note, however, that the classification is based on estimates. Several studies as well as anecdotal evidence suggest a decline in little penguin populations throughout mainland Australia and New Zealand but the unavailability of long-term data from a broad range of colonies has made it difficult to confirm whether little penguin populations on the mainland have in fact decreased (Stevenson and Woehler 2007). In recent decades there has been evidence of decline in the number of mainland colonies as well as the size of many of these colonies both in Tasmania and Australia (Hodgson 1975; Barton 1978; Fortescue 1995; Stevenson 2003; Stevenson and Woehler 2007). In the absence of nation- and statewide population monitoring of little penguins, the challenge of estimating population trends extends to both single local populations as well as to mainland little penguin populations.

Within Australia, off-shore islands are main sites for breeding for little penguins, whereas substantially smaller number of little penguins breeds on the Australian mainland, including mainland Tasmania (Priddel, Carlile and Wheeler 2008). Small islands around Tasmania (in particular in the Bass Strait and south coast) are classified as exceptionally important breeding grounds for little penguins (Dutson *et al*. 2009) by providing havens further away from human disturbance and predation by introduced mammals. The significance of off-shore islands in Tasmania is exemplified by the fact that less than 5% of the Tasmanian little penguin population is located on the Tasmanian mainland (Whitehead *et al.* 2010).

In comparison to little penguin colonies on off-shore islands, mainland populations are suggested to be less secure (Priddel, Carlile and Wheeler 2008) and high variability exists between mainland colonies in breeding success and nest-site characteristics across Australia and New Zealand. Mainland colonies close to human settlement face a number of challenges ultimately affecting breeding and survival of breeding pairs, chicks and the colony as a whole.

These urban penguins are highly influenced by anthropogenic effects both on land and in water as well as by increasing susceptibility to mammalian predators. Stevenson and Woehler (2007) identified that all factors influencing population decreases in mainland southeastern Tasmania are anthropogenic in origin. Of terrestrial threats, human disturbance of little penguin habitats takes the form of habitat degradation and modification, noise and light pollution and vandalism. Introduction of mammalian predators and irresponsible dog and cat owners pose a serious threat to little penguins together with increasing levels of human settlement and use of coastal areas. Marine threats of anthropogenic origin include oil and heavy metal pollution as well as by-catch in gill netting (Pryor and Wells 2009).

Because of the multitude of threats faced by little penguins, conservation of this species and its breeding habitats are of paramount importance for the future of mainland colonies associated with human influence. The Derwent Estuary Program (DEP) coordinates the Derwent Estuary Penguin Program (DEPP), a regional partnership between local and state governments, industries and community-groups working to protect and restore little penguin habitats, and to conserve the little penguin breeding population within the Derwent estuary. The conservation efforts include weed removal, revegetation and fencing habitats as well as installing artificial burrows for breeding and moulting. Raising awareness of little penguins among specific stakeholders as well as the general public is also a major focus of the DEPP. Obviously the ideal little penguin nest habitat would be as natural and unmodified as possible. However, due to increased human disturbance and predation by introduced animals, the next best option to conserve a nest site is to restore it by revegetation and weed removal as well as to provide artificial nests for breeding and occupancy.

Despite ten years of conservation efforts with significant restoration of larger breeding colonies, little penguins in the Derwent estuary continue to be adversely affected by a number of threats that are mainly human-induced. DEPP has conducted surveys on the size and number of little penguin colonies in the Derwent estuary since 2004. The estuary-wide survey from 2008/2009 identified around 100 breeding pairs at 13 sites, with Boronia Beach colony being the largest consisting of 60 pairs (Pryor and Wells 2009). The most recent survey from 2013/2014 breeding season found only 49 breeding pairs in the estuary (DEP 2014) and speaks for a decline in the number of breeding pairs in the Derwent estuary.

Introduced predators have contributed to declines and extinctions of numerous little penguin colonies (Dann 1992; Holderness-Roddam 2011). On the mainland of Australia feral dogs (*Canis lupus familiaris)* and red foxes (*Vulpes vulpes*) present the biggest threat to penguins (Braidwood, Kunz and Wilson 2011), where as in Tasmania feral and domestic cats (*Felis catus*) and domestic dogs are responsible for marked declines in bird populations (Stevenson and Woehler 2007). Boronia Beach has been affected by two dog attacks in 2004 resulting in the death of 11 adult penguins and more recently in July 2012, when 25 mature penguins – most of the breeding penguins at the time – were killed in one night. Walking dogs through the colony is prohibited by the local council, and is indicated by fencing and signage (Figure 1.2) at two public access points. These measures have proven insufficient as a tool of conservation in the face of continuing presence of dogs and their attacks on little penguins. Remote cameras and footprint searches have identified cats entering colonies and burrows. Several cat-kills are confirmed each season at Boronia Beach colony, evident from penguin remains, such as a detached head found in April 2014 (Figure 1.3).

Figure 1.2. Dogs prohibited -sign and fencing at the entrance of Boronia Beach.

Figure 1.3. Predation most likely by feral cat resulted in the death of a little penguin just outside Boronia Beach.

1.3 Introduction to the study

The study and understanding of little penguin distribution and trends on mainland are essential for the effective conservation of the smallest species of penguin. Research on mainland little penguin colonies and their conservation is thus vitally important and this research attempts to answer that demand in order to better conserve the species under pressure from human settlement and habitat modification. Boronia Beach little penguin colony, located in the upper Derwent estuary at the heart of Hobart metropolitan area, was chosen as the topic for this study because it represents all the major threats addressed in little penguin conservation. Human settlement and disturbance, habitat modification, predation by dogs and cats, and marine pollution adversely affect the survival and success of the colony.

This study has two specific aims. Firstly, through measuring the occupancy rate of nests and breeding success of the Boronia Beach colony from data collected by the DEPP from 2011/2012 to 2013/2014, the state of the colony is evaluated in relation to other little penguin colonies in Australia and New Zealand. Here special emphasis is placed to comparing Boronia Beach to other mainland little penguin colonies affected by human settlement. The aim then is to determine whether the colony at Boronia Beach is comparatively successful in terms of breeding. Secondly, this study aims at providing recommendations for future conservation of little penguins in habitats closely associated with human settlement and disturbance. Because effective conservation of little penguins requires a deeper understanding of factors influencing breeding success (Renner and Davis 2001), this thesis intends to bind the observations and findings of this study to effective conservation of little penguins at Boronia Beach and elsewhere.

2 MATERIALS AND METHODS

2.1 Study site

Boronia Beach, 42° 59' S, 147° 19' E, located in southeast Tasmania, 14 km south of Hobart in lower Derwent estuary between Kingston Beach and Blackman´s Bay (Figure 2.1), is home to a little penguin colony of approximately 80 pairs. Number of breeding pairs ranged from 32 to 53 per annum during the study period of last three breeding seasons, from 2011/2012 to 2013/2014. The Boronia Beach colony comprises cliffs, boulders and sand located close to shore as well as vegetated habitat further inland (Figure 2.2).

Figure 2.1. Location of Boronia Beach little penguin colony in southeast Tasmania, Australia.

Figure 2.2. Boronia Beach study site looking northeast across the eastern side of the colony.

Of 13 known colonies in the Derwent estuary, 8 have been found to be active in recent years. The Boronia Beach colony constitutes by far the largest colony in the Derwent estuary in terms of area (4.1 ha) and number of nests and breeding pairs. 60 % of known nests in the Derwent estuary are located at Boronia Beach and half of all known breeding effort (occupied nests and nests used for breeding) takes place at Boronia Beach (DEP 2014). Boronia Beach is the most significant colony remaining in the Derwent estuary in terms of productivity, and size of the colony and number of breeding pairs. For studying breeding success and nest site characteristics Boronia Beach colony provides a good study site as it has 206 nest sites with a wide range of vegetation types and nesting habitat within close proximity.

In terms of vegetation Boronia Beach is a heavily modified habitat following the conservation efforts of the little penguins in the Derwent estuary. In addition to removal of weeds (in particular the introduced and invasive European blackberry *Rubus fruticosus* aggregate), over 1000 native plants have been planted. *Rhagodia* and *Tetragonia* as creeping, or ground-hugging, plants provide shelter to burrows and play a crucial role in concealing the entrance (Figure 2.3) whereas prickly *Bursaria spinosa* and *Acacia verticillata* aid in keeping predators and humans at bay. Some igloos are more exposed in proximity to paths where revegetation efforts are still ongoing (Figure 2.4). Tall *Eucalypt* and pine trees protect from solar radiation (Figure 2.5) except for burrows located in the cliff or boulders close to shoreline (Figure 2.6).

Figure 2.3. Sheltered igloo.

Figure 2.4. Unsheltered igloo.

Figure 2.5. Pine and *Eucalypt* canopy cover.

Figure 2.6. Exposed shoreline.

2.2 Field observations of nests

The Boronia Beach little penguin colony consists of 209 known nests, of which 148 (72%) are artificial and 58 (28%) are natural. The natural nests are mainly located in crevices between or under boulders (Figure 2.7) and in caves under cliffs (Figure 2.8), with a few located under logs.

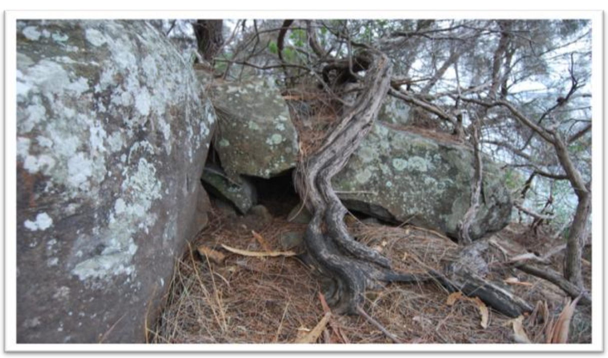

Figure 2.7. Natural nest under boulders.

Figure 2.8. Natural nest in a cliff cave.

Artificial burrows installed at the colony are mainly igloos constructed with concrete and reinforced with wire mesh (Figure 2.9). Wooden nest-boxes are used in other colonies in the Derwent estuary and are commonly used in New Zealand, but are more visible. Igloos are considered a better alternative to nest-boxes in areas of high human traffic to avoid attracting attention from passersby. The more streamlined shape of an igloo and their grey colour allows them to blend in better with their surroundings compared to a box-shaped wooden nest. The low lying shape of igloos and their concrete texture enables vegetation to easily grow over them, providing concealment. Other benefits of igloos are their comparatively smaller entrance, providing protection from large predators, and absence of a lid preventing viewing the nest bowl. Concreted boulders (Figure 2.10) present a novel type of nest combining the characteristics of artificial and natural nests, where natural boulders are reinforced and sealed for protection to create a nest.

Figure 2.9. Artificial nest; concrete igloo.

Figure 2.10. Combination of artificial and natural nests; boulders reinforced with concrete.

2.3 Field observations of nest occupancy and breeding

Nest use was assessed using an infra-red camera attached to a flexible neck and monitoring screen in a portable weather proof box (Figures 2.13 and 2.14). Termed a burrowscope this equipment is commonly used to assess nest occupancy rates for burrowing sea birds, especially when deep and winding nesting chambers make direct observations difficult (Hamilton 2000).

Figure 2.11. Infra-red burrowscope equipped with a camera showing an igloo occupied by a moulting little penguin.

Figure 2.12. The use of infra-red burrowscope suits any type of nest hard to access directly.

Nests were determined to be either empty, empty with signs of past occupancy, occupied by one or two adults, or occupied by one or two eggs or chicks. Presence of whitewash (faecal matter), feathers, mud or scratching at the entrance of or in the nest bowl were used as signs of past occupancy. Nests were considered as occupied when they either contained an adult, or had signs of past occupancy. Breeding was considered successful if it produced a viable fledgling. Failed breeding was determined as a failure to produce a viable fledgling. To avoid disturbance to the penguins, adults incubating eggs or brooding chicks were not touched using the burrowscope. Instead, the presence and number of eggs and chicks were confirmed on the next check. Because none of the little penguins at Boronia Beach have been banded and thus identifying penguin individuals and pairs is not possible, double brooding was left outside the scope of this study. Instead, observations of nests occupied twice during the breeding season were recorded.

Of the 209 known nests available to little penguins only 140 had three continuous years of data. Monitoring histories were considered incomplete if nests were difficult to access due to vegetation or their location on a steep cliff or if nests had been overtaken by rabbits. In addition, 10 nests had gaps in their breeding record due to a dog attack killing the resident breeding pair. Monitoring occurred through winter (1 June to 31 August) and spring (1 September to 30 November) and into summer (1 December to 30 February), reflecting the southern hemisphere seasons. The 140 nests were checked five times in the first two years of monitoring (2011/2012 and 2012/2013 breeding seasons) and seven times in the third year of monitoring (2013/2014). Of the 140 nests included in the study majority (97) were artificial igloos and of natural nests 20 were cave nests in cliff, 20 were boulders and 3 were nests under logs and roots.

Ensuring minimal disturbance to the penguins while studying nests the field work was conducted during post-breeding and end of moulting season from March to May 2014, when most penguins were foraging continuously at sea without returning to their burrows. Throughout the three-year survey period on nest occupancy and breeding, great caution was practiced in order to minimize the effect of human disturbance on the breeding success and survival of chicks and adults. Field work was carried out under a permit and supervision of DEP Biodiversity Officer.

3 RESULTS

3.1 Nest occupancy

Nest occupancy was defined as the proportion of used nests of the 140 nests included in the study. Occupied nests then included nests used in both breeding (including both successful and unsuccessful breeding) (Heber 2007) and non-breeding such as moulting and resting. Of the 140 nests in Boronia Beach, the rate of nest occupancy showed a slight decline from 43% (60 nests) to 31% (43 nests) through the three breeding seasons from 2011/2012 to 2013/2014 (Figure 3.1).

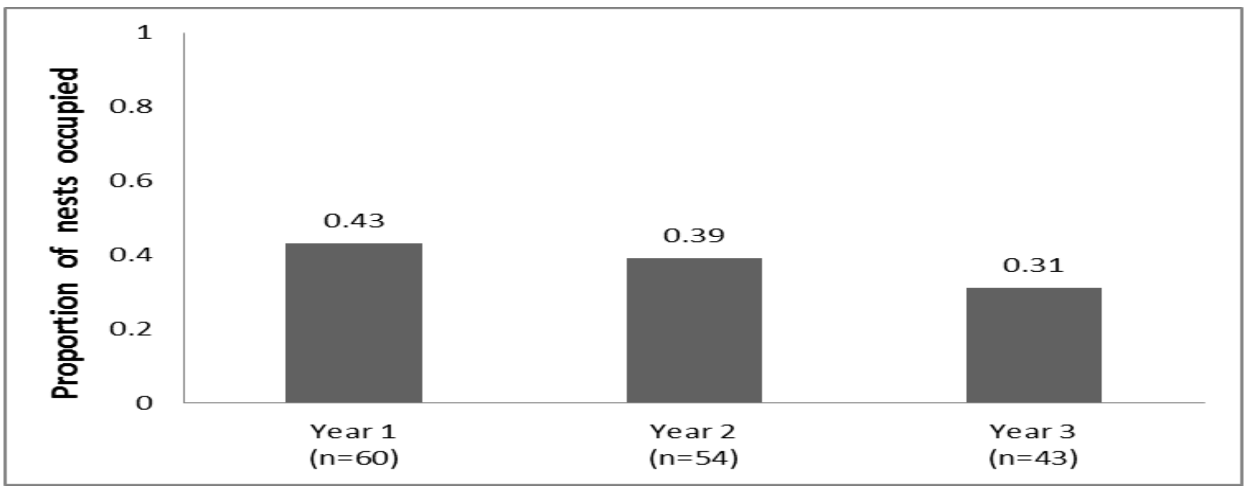

Figure 3.1. Rate of nest occupancy at Boronia Beach colony showing a decline from 2011/2012 (year 1) to 2013/2014 (year 3) (n refers to the total number of number of nests occupied of the total 140 nests studied).

Of all 140 nests available throughout the three years of study, natural nests located in cliffs reached the highest rate of occupancy, with 90% of available cliff nests used for breeding, moulting or resting (Table 3.1). Of artificial igloos, on the other hand, only 39% were used. The highest success rate in breeding (45%) was similarly achieved in cliff nests, whereas igloos had the lowest rate of successful breeding (29%) of all nest types. One third of natural log and root nests included in the study were occupied and successfully bred in but this nest type also achieved the lowest rate of occupancy (67%). Natural boulders reached 40% success rate in breeding but with only 25% occupancy.

TABLE 3.1. Rate of occupancy (black) according to status of occupancy (grey) and nest type (blue).

Status of occupancy	*Nest type*			
	igloo (n=97)	log, root (n=3)	boulder (n=20)	cliff (n=20)
empty	0.39	0.67	0.3	0.1
occupied	0.27	0	0.25	0.35
failed breeding	0.05	0	0.05	0.1
successful breeding	0.29	0.33	0.4	0.45

A small number of nests were used twice for breeding in one breeding season. Four of the eight nests used twice were igloos, whereas three were nests in cliffs and the remaining one was nest under boulder. A decline was observed in the number of nests used twice within one breeding season throughout the three-year period. Whereas during the first year of study all eight nests were used twice, during the second breeding season only three nests were used twice for breeding. In the third season only two nests were used twice and these were both nests in cliff caves, with first breeding attempt successful, followed by failed breeding. Throughout the study period nests reached a higher occupancy rate during the summer than in winter.

3.2 Breeding success

Breeding success was defined as the proportion of fledglings from eggs laid during both summer and winter breeding. Breeding success of Boronia Beach little penguin colony averaged 62% (n=140) in the three years of study. Figure 3.2 shows that the yearly breeding success at Boronia Beach varied from 50% to 78%.

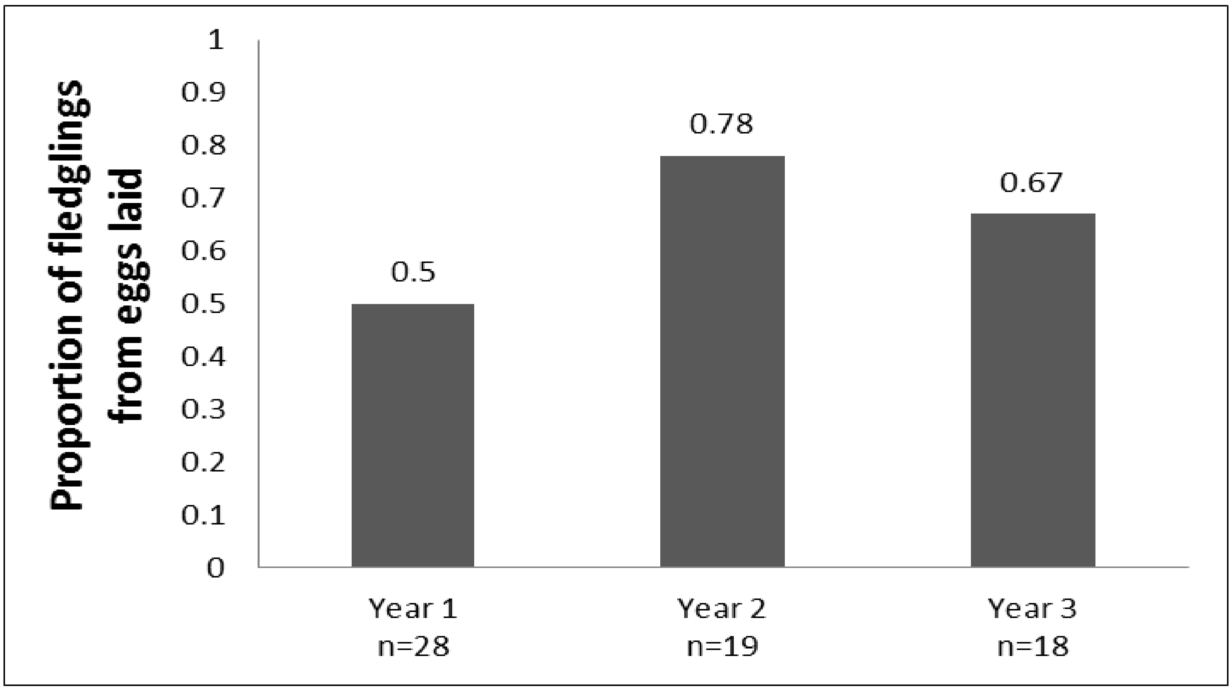

Figure 3.2. Annual breeding success of Boronia Beach little penguin colony over three consecutive breeding seasons, from 2011/2012 to 2013/2014.

In addition to yearly breeding success, variation in winter and summer breeding success needs to be taken into account. Summer breeding in Boronia Beach is more common than winter breeding and the success in summer breeding shows an increase from 40% to 72% throughout the three-year study period. Winter breeding success, on the other hand, experiences a 100% decline from second year to third year but reflects a lower sample size than summer breeding; 5 nests in second year to 2 nests in third year (Figure 3.3).

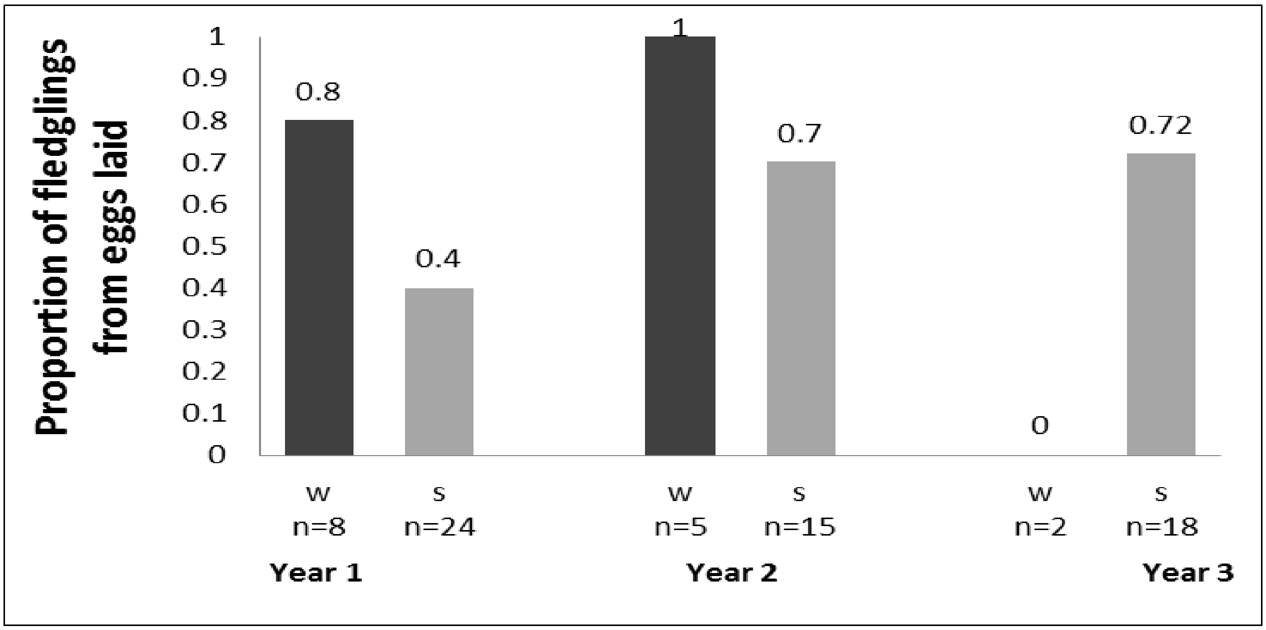

Figure 3.3. Breeding success of little penguin colony at Boronia Beach showing yearly (year 1, year 2 and year 3) and seasonal (w for winter breeding and s for summer breeding) variation (n refers to the number of nests used for breeding of the total 140 nests studied).

4 DISCUSSION

4.1 Nest occupancy

The rate of nest occupancy at Boronia Beach shows a declining trend throughout the study period, from 43% in the first year of study to 31% in the third year of study. This is in line with the broader observation of decreasing populations of little penguins in southeastern Tasmania (Stevenson & Woehler 2007) and in the Derwent estuary (DEP 2014). However, in addition to a general population decrease of little penguins, the Boronia Beach colony may have been affected by changes in prey availability and abundance in the Derwent estuary as well as a more local microclimate. Little penguins at Boronia Beach are relatively sheltered from winds due to the location of the colony in an estuary, but nests in cliffs with no vegetation are more exposed to solar radiation.

In burrow-nesting birds, such as little penguins, there exists both spatial and temporal heterogeneity in burrow occupancy (Sutherland and Dann 2012). In regards to the temporal variability, the results obtained in this study show that during the summer nest occupancy is higher than during winter. Even though the timing of breeding is highly variable (Reilly and Cullen 1981), in Tasmania summer constitutes the main breeding season for little penguins (Gales and Green 1990). It then follows that with increased breeding activity in summer also summer occupancy rates are higher.

Highest rate of occupancy was reached in nests located in cliff caves. These natural nests are then more popular sites for both breeding and moulting than artificial nests. The short distance from the sea to nest may explain why cliff nests are preferred even when more artificial nests further away from the shoreline are available for occupancy. The savings in energy expenditure may be substantial over a lifetime of little penguin since chick rearing accounts for around a third of annual energy budget (Gales and Green 1990). Reaching the dependent chicks faster after foraging at sea may enhance the survival of chicks as well as limit exposure time to predators on land.

Because predation by introduced mammals as well as by dogs off lead has been extensively documented in causing decrease in numbers of penguins and colonies (Harrigan 1992; Holderness-Roddam 2011), this can directly result in the decline in numbers of little penguins in a colony and thus usage of nests. Continued disturbance may even result in nest abandonment and change in nest-site or even colony, significantly affecting the occupancy rates in the colony. It is possible, however, that moulting and resting occurs in a separate location in Derwent estuary compared to that of breeding. Preferred nest characteristics for breeding and enhancing the survival of chicks may differ from features for moulting or resting. This indicates that a wide variety of nest types in a colony are required to maximize occupancy rates for both breeding and non-breeding activities.

4.2 Breeding success

The average breeding success of 62% for the three years monitored in Boronia Beach was within the range and above the average reported in other little penguin colonies located in Australia and New Zealand (Table 4.1).

Table 4.1. Comparison of breeding success among little penguin colonies in Australia and New Zealand.

Location	Mean breeding success	Years	Source
Australia			
Boronia, TAS	0.62	3	this study
Bowen Island, NSW	0.78	3	Fortescue 1995
Bruny Island, TAS	0.16	4	Hodgson 1975
Lion Island, NSW	0.60	4	Rogers *et al*. 1995
Manly, NSW	0.69	5	DECC 2007
Middle Island, VIC	0.70	1	Overeem and Wallis 2003
North Harbour, NSW	0.70	3	Priddel *et al.* 2008
Penguin Island, WA	0.41	3	Klomp *et al*. 1991
Phillip Island, VIC	0.26	11	Reilly and Cullen 1981
New Zealand			
South Westland, South Island	0.79	2	Braidwood *et al*. 2011
Taiaroa Head, South Island	0.52	7	Perriman & Steen 2000
Wellington, North Island	0.48	2	Bull 2000
West Coast, South Island (Buller)	0.66	1	Heber *et al*. 2008
West Coast, South Island (Buller)	0.63	2	Braidwood *et al*. 2011

Comparison of studies of breeding success of different little penguin colonies shows high variability across Australia and New Zealand. This observation is in line with the general notion that considerable variation between colonies exists in little penguins depending on the location (Stahel and Gales 1987) and availability of prey within foraging range (Perriman *et al.* 2000). Furthermore, the length of each study varies greatly from one year to 11 years with Phillip Island committed to long-term research of little penguins. In fact, 45 years of little penguin research on Phillip Island is one of the longest continuous seabird studies in the world. This inconsistency in the duration of studies inevitably affects the comparability of breeding studies and must be taken into account.

Studies on little penguin breeding success prevalently report on the mean success, often lacking any reference to differences observed between the years studied or seasonal variation within them. Expressing breeding success as a mean comes with a risk of oversimplifying data, as breeding success of little penguins has been shown to fluctuate greatly from year to year as noted above. For this reason, and to present the data at Boronia Beach colony in a comprehensive manner, both yearly and seasonal variation within the three years were seen as an essential component of this study. Annual fluctuations ranging from 50% to 78% show that breeding success at Boronia Beach is not consistent from year to year. The results obtained in this study are in line with the majority of long-term studies conducted on little penguin breeding success both in Australia and New Zealand, which have shown that little penguin colonies exhibit variability in year to year breeding success. Survival of little penguin chicks is suggested to correlate greatly to availability of food (Perriman *et al.* 2000) and thus starvation is the biggest cause of death followed by exposure to rain (Renner and Davis 2001) and heat stress (Ropert-Coudert, Cannell and Kato 2004).

Even though it is well established that the seasonal breeding cycle of little penguins is highly asynchronous (Stahel & Gales 1987), the majority of studies on reproductive success of this species does not report or analyze this key component in measuring reproductive success. Summer breeding is by far the primary breeding season for little penguins (Gales and Green 1990) and the larger number of nests used for breeding in Boronia Beach in summer conforms to this general observation. At Boronia Beach the summer breeding shows an increasing trend in breeding success from 40% to 72% but with fluctuating number of nests used for summer breeding.

The less common winter breeding, however, shows an opposite pattern to that of summer breeding with all breeding attempts resulting in failure. The 100% drop in breeding success from winter of year 2 to winter of year 3 could be explained by the dog predation that resulted in the death of 25 mature penguins following the second year of breeding studied (Day 2014). Even though the colony is rebuilding after the attack and continuing to breed as observed in the third year studied, the long-term consequences especially to winter breeding success are far from clear.

Dogs can influence the survival and reproductive success of a penguin colony either directly with predation or indirectly by spreading disease and leaving a scent and thereby attracting other dogs (Holderness-Roddam 2011). Stevenson and Woehler (2007) identified dog attacks as one of the major causes in the decline of little penguin colonies in southeastern Tasmania and evidence of death resulting from dog predation can be found from Derwent estuary (Day 2014; DEP 2014) as well as Ulverstone in north Tasmania (Webb 2009). For Boronia Beach dog attacks have resulted in considerable declines in both the number of breeding pairs and reproductive success and should be considered currently the biggest single factor threatening the survival and future of the colony. During breeding season and moult both adults and chicks are particularly vulnerable to dog attacks because they are mostly confined to their colony on land. As the scope of this study only extends to the winter breeding immediately following the attack, in order to fully assess the impact of the last dog attack on the colony and its breeding success, continuous monitoring and research on both winter and summer breeding success are critically important. Drastic measures in preventing further dog attacks by fencing and monitoring as well as through more severe fines to dog-walkers entering the colony or letting dogs loose are needed urgently.

Because most mainland colonies of little penguins have declined or gone extinct over recent decades (Stevenson and Woehler 2007; Priddel, Carlile and Wheeler 2008), it is crucial to make comparisons of breeding success in Boronia Beach and other mainland colonies that are affected by human disturbance and predation by introduced mammals on land. The Neck on Bruny Island is highly popular among tourists coming to observe the 400-pair strong little penguin colony. An older study (Hodgson 1975) observed a very low mean breeding success of only 16%. In spite of the presence of viewing platforms and boardwalks, tourists are regularly observed outside these designated areas and thus actively engaging in disturbance of nests and penguins (Stevenson and Woehler 2007).

On the other hand, some colonies located at the heart of human habitation and disturbance score high rates of reproductive success. Colonies located at St. Kilda near Melbourne in Victoria as well as North Harbour and Manly in proximity to Sydney in New South Wales seem to do well despite being surrounded by anthropogenic disturbances. This could be explained by more vigorous and effective conservation efforts or that these urban penguins are have become adapted to continuing human presence and influence (Giling, Reina and Hogg 2008). These explanations, however, do not mean that little penguins thriving in close proximity to human settlement would not be adversely impacted by disturbance by humans and introduced predators as well as vehicles.

The results in this study show that breeding success at Boronia Beach colony was higher in natural than artificial nests despite the fact that overwhelming majority of nests available at the colony are artificial igloos. These findings are in contrast to several studies indicating that breeding success has been higher in artificial nests, such as in wooden nest-boxes in the study by Perriman & Steen 2000. As the highest rate of occupancy was reached at nests in cliff caves, with these nest being the most successful as well, this suggests that at Boronia Beach nests in cliffs located close to the shoreline are highly favoured nest type of all available nest types. Not only are these nests used for breeding with comparatively high success rate, but they also serve as shelter for moulting, resting and from predation. Even though exposed to solar radiation by lacking overhead shelter, nest bowls located deep in the cliff may offer a cooler microclimate essential to rearing a chick and preventing overheating in hot summer sun during the summer breeding season. The inability of little penguins to withstand heat stress (Stahel and Nicol 1982) sets high requirements of ventilation and temperature inside the nests (Ropert-Coudert, Cannell and Kato 2004). This is of particular importance for the chicks, which need to spend long periods of time confined inside nests. Heat stress has been studied as being one of the leading causes of mortality in young chicks (Stahel and Nicol 1982; Renner and Davis 2001) and choice of nest enhancing survival of offspring may be crucial in determining reproductive success. Furthermore, as these cliff nests at Boronia Beach are located generally within five metres from the high tide line, penguins searching for suitable nest may opt for the nests that are located closest to the shore. By doing this, penguins save energy as well as time being exposed to predation by animals on land.

In conclusion, Boronia Beach little penguin colony is a relatively successful population with chance of survival in the future taken that there is continued efforts in conservation of the habitat and in addressing the issue of increasing disturbance.

4.3 Recommendations for future research

This thesis has provided the first study on the breeding success of little penguins at Boronia Beach and can be used as a baseline for future research. By choosing to study only one colony, Boronia Beach has provided a unique, highly modified study site affected by increasing human disturbance and predation and could potentially be compared to future research of other similar types of mainland little penguin colonies requiring conservation efforts. On the other hand, however, studying several colonies within the same feeding range could have revealed the possible effects of food availability and abundance on breeding success. Small and larger scale fluctuations in the marine environment (such as temperature, climate, marine pollution and availability of prey) and on land (of which temperature and exposure to solar radiation are major factors), have been observed to influence the survival and reproductive performance of little penguins. In addition, parental body condition (measured as body mass divided by flipper length) among other factors may play a role in determining how successful the breeding attempt is (Robinson, Chiaradia and Hindell 2005). Because these variables or other colonies located within the same foraging range were not recorded throughout the three-year period of study, many questions remain unanswered in connection to reproductive success. Broadening the scope of the study would then give a more comprehensive view on the state and reproductive success of the Boronia Beach colony.

Banded individual penguins can give us valuable information about dispersal and survival of little penguins (Reilly and Cullen 1982) and would have enabled to take double brooding, feature unique to little penguins, into account in this study. Age of little penguins through experience in breeding as wells as the strength of pair bond have been observed to affect the reproductive success of these penguins (Nisbet and Dann 2009). In the absence of information identifying individuals and pairs, the age of breeding and non-breeding penguins thus remained unknown and is definitely a drawback of this present study. Furthermore, identifying individual penguins would have made possible to study the link between site-fidelity to the success of breeding in Boronia Beach colony. In summary, the ability to recognize individual penguins and link them to specific nests would have enabled to take individual and pairwise variations into account in this study. As a method of study, however, banding is invasive. Little penguins are banded by their flippers and these bands, by hindering movement on land and in water, potentially lower the breeding probability and chick production of these penguins (Gauthier-Clerc *et al*. 2004). Decision to use banding as a means of study should thus not be taken lightly and as the conservation of little penguins in Boronia Beach colony is grounded on causing the least disturbance to these birds, penguins at the study site have not been banded.

The mean breeding success of 62% in Boronia Beach was obtained from only three years of data and for a more comprehensive result, further studies in breeding success are needed in the future. In addition, monthly monitoring of the colony may have been insufficient as opposed to weekly examination as suggested by Braidwood, Kunz and Wilson (2011). More frequent monitoring would have enabled studies on egg success, hatching success and fledgling success, providing a study of broader scope. In addition, more frequent monitoring could have resulted in a higher accuracy in determining whether a chick had successfully fledged or not. Continuing and more frequent monitoring of predation, disturbance and breeding effort of the colony is essential for the health and survival of the colony as a whole. With more resources and time allocated to allow little penguin research, monitoring and thereby also conservation at Boronia Beach, the future of these penguins would have a better outlook.

Because burrow-nesting birds exhibit both temporal and spatial variability nest-occupancy, Sutherland and Dann (2012) note that using burrow occupancy alone as a measure of breeding numbers potentially underestimates population size across the breeding season. The novel method of mark-recapture is suggested as a means to improve the accuracy of population studies for little penguins (Sutherland and Dann 2012). As a method, however, mark-recapture is far more invasive than using a burrowscope. Furthermore, even though the use of burrowscope has substantially improved the accuracy of breeding and nest occupancy surveys in burrow-nesting birds, eggs incubated or small fledglings are often left unnoticed. Determining nest occupancy by the presence of whitewash alone carries the danger of overestimating nest usage, as little penguins may move around and socialize around nest entrances leaving faecal matter behind but not necessarily entering or occupying the nest.

In addition to environmental (climatic conditions and prey abundance) and individual (breeding experience and age) qualities affecting breeding success, habitat characteristics may also influence breeding success and choice of habitat in colonial seabirds. The following characteristics were measured during February and May 2014: 1) the nest type, 2) the height and width (entrance size) of the nest entrance, 3) the depth of the nest, 4) the degree of entrance concealment, 5) the degree of overhead cover from the roof of the nest to two metres, 6) the degree of canopy cover, 7) type of overhead cover, 8) the orientation of nest entrance and 9) the presence of ventilation. Distance to high tide line and distance to path were measured with Geographic Information System (GIS). The analysis of the effect of these habitat variables would then be the next step in studying the Boronia Beach colony for more effective conservation.

5 RECOMMENDATIONS FOR CONSERVATION OF LITTLE PENGUINS

5.1 Recommendations for conservation at Boronia Beach

Because dogs off lead are the biggest single factor directly affecting the survival of little penguins at Boronia Beach, preventing any further attacks is at the top of the list of conservation priorities. The installing of a taller fence all around the colony, which will keep dogs outside the borders of the colony, is currently in a planning stage by DEPP in cooperation with land-owners at Boronia Beach. To keep walkers with dogs from entering the colony, it is recommended that higher fines are imposed to reflect the responsibility of dog owners to not cause disturbance to wildlife. Instead of the present "Dogs prohibited" –signage at the two entrance gates, a clear statement similar to "No dogs allowed. If you illegally choose to enter this wildlife sensitive area with your dog, you will accept a fine of 5000 dollars". A clear message needs to be sent to owners of domestic animals that they have responsibility to protect native wildlife in their everyday choices.

As results from this study showed, nests located in cliff caves had the highest rates in both the breeding success and occupancy of all nests at Boronia Beach. Despite the previous conservation efforts by installing igloos at the colony, these artificial nest types have not reached the level of efficiency of natural cliff nests. Both natural and artificial nests without a doubt are important tools in enhancing the overall success of the colony and, dependent on colony location, both types of nests have varying rates of occupancy. At Boronia Beach it is recommended that prevention of further disturbance around cliff nests is emphasized in future short- and long term conservation efforts. Ensuring minimal disturbance of nests in cliffs could be achieved by restricting access to cliffs located close to shoreline and creating new cliff nests by reinforcing cliff rocks with concrete. It is important to make sure these nests are high enough in elevation to prevent nests from flooding, a factor that has affected these nests in the past. Conservation efforts involving weeding of introduced invasive species of plants both close to the shoreline and inland needs to be carried out regularly.

Continuing with monitoring pollution sources and loads in the Derwent estuary is vital in maintaining a healthy marine environment for penguins foraging in the Derwent estuary. Point sources in the estuary include sewage treatment plants and zinc smelter. Diffuse sources consist of runoff from land, such as stormwater and catchment inputs, and wastes and oil spills from shipping and ports (Whitehead 2010; DEP 2013). Even though Boronia Beach is located in the generally less polluted lower estuary, contaminants and toxins are not confined to the upper parts of the estuary but impact the estuary at its full length. To further investigate how little penguins in the Derwent estuary are affected by pollution loads, toxicology studies from autopsy samples of dead penguins would be needed.

First and foremost, the impact assessment of any conservation measure or research method needs to take into consideration the extreme vulnerability of seabirds, including little penguins, to human disturbance (Anderson and Keith 1980). Minimizing the effect of investigator activity on little penguins (Andrews-Goff 2003) is vital in ensuring that no further disturbance is caused by conservation itself.

5.2 Recommendations for wider little penguin conservation

The conservation status of seabirds has globally deteriorated over the last decades and Spheniscidae have been identified as one of the most threatened families of seabirds (Croxall *et al.* 2012). The combination of both marine and terrestrial threats presents a challenge for the effective conservation of little penguins and their habitats. Not only are penguins dependent on suitable breeding habitat on coastal areas, but as a central-place forager require abundance of prey distributed within an optimal distance from their colony (Burke and Montevecchi 2009). Prolonged foraging trips in search for prey come with an increased risk of egg desertion (Numata, Davis and Renner 2000).

Further investigations into the conservation of marine habitats are an essential part of little penguin habitat conservation. Because penguins are essentially seabirds and spend most of their life at sea, they are highly vulnerable to changes in their marine environment. Penguins can be regarded as marine sentinels (Boersma 2008), reflecting the state of our oceans. Studying little penguins not only gives us valuable information about the species and their conservation but helps us understand the dynamics of ocean environment.

Even a relatively small amount of oil can have extensive impacts on penguin populations (Goldsworthy *et al.* 2000), possibly wiping out whole colonies and destroying marine and terrestrial habitats for years to come. Thus preventing oil spills by monitoring and regulation of vessel safety and traffic is a highly important component of penguin conservation. Mortality that resulted from accidents of Iron Baron (Goldsworthy *et al.* 2000) in northern Tasmanian and Rena in New Zealand have highlighted the need to be prepared for rapid response in seabird rescue and rehabilitation. A qualified volunteer rescue team, such as the unique WWF Voluntary Oil Spill Response team in Finland equipped with special containers for cleaning oiled seabirds, has the potential to save substantial amounts of seabirds in cooperation with officials. For little penguins across the range of distribution, this idea needs to be developed in cooperation with Australia and New Zealand, enhancing the survival of little penguin colonies.

Little penguins attract considerable tourism both in Australia and New Zealand. Annually the Penguin Parade draws wildlife enthusiasts in their thousands to observe the return of little penguins from the sea to Phillip Island. Unless managed sustainably, the impacts of large crowds can have devastating effects on little penguin colonies and future of tourism revolved around little penguins.

Finally, there is growing concern of the effects of climate change on seabirds. In particular for shallow-diving species, such as the little penguin, changes in surface or near-surface gradients in ocean temperature are likely to impact more on their foraging patterns and prey abundance (Jarvis 2003). Ocean temperatures have been suggested to be the dominant factor in determining breeding success of little penguins (Chambers 2004), because they ultimately influence productivity and thus abundance of prey in the oceans. Little penguins, with a restricted foraging range and thus decreased feeding opportunities, are suggested to be particularly prone to suffer the consequences of food shortages and unavailability (Norman, Cullen and Dann 1992). More research on the influence of changes in climatic patterns and El Niño events are required in the future.

Because little penguins have a long life-span with relatively low lifetime reproductive success, adverse effects of habitat degradation may come to our attention only when it may already be too late to effectively respond with conservation measures. As highlighted in this study, allocating resources into long-term monitoring and investigation of population distribution and status of both offshore and mainland little penguins is of paramount importance in the future conservation of this species. Effective conservation simply cannot rely on population estimates and regulations lacking proper monitoring on ground. Perhaps most importantly, however, no conservation effort will yield results without the involvement and awareness of the wider community of the impact of human activities on the survival of little penguins.

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Glossary of key terms

DEP Derwent Estuary Program; Partnership between state and local governments, industries, scientists and the community to restore and promote the Derwent estuary

DEPP Derwent Estuary Penguin Project; Special program of the Derwent Estuary Program engaging in monitoring, making management recommendations and raise community awareness of little penguins in the Derwent estuary

IBA Important Bird Area; Classification developed by Birdlife International to identify the most important areas on Earth for birds and to assist in conservation efforts. There are in total 314 IBAs in Australia, of which 43 in Tasmania, covering 18% of the island.

IUCN International Union for Conservation of Nature; International organization that publishes the IUCN Red List of Threatened Species, which assesses the conservation status of species

nest occupancy proportion of used nests from all nests; includes nests used in breeding (including both successful and unsuccessful breeding) and non-breeding (such as moulting and resting)

breeding success proportion of fledglings from eggs laid during both summer and winter breeding

moulting process occurring after breeding during which old feathers are replaced by new ones providing better insulation; often referred to as catastrophic moult in penguins because they moult all their feathers at once