TEMPORAL AND SPATIAL VARIATION IN BREEDING SUCCESS OF THE LITTLE PENGUIN *EUDYPTULA MINOR* ON THE EAST COAST OF AUSTRALIA

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SUMMARY

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A 10-year study of the Little Penguin *Eudyptula minor* on Bowen Island has revealed comparatively high breeding success for this large colony towards the northern limit of the species' range. Similarly high success has been found at nearby Lion Island. The colony is prone to episodic broad-scale changes of ocean and climate, including the global-scale El Nino Southern Oscillation (ENSO). These climatic changes influence to varying degrees the breeding success of colonies on the east coast of Australia. The mean breeding success for first broods of the Bowen colony was 1.23 chicks/pair. This is the highest recorded for the species, and 20% of pairs lay second broods in the same season. Lion and Bowen Islands are characterised by distinctive native vegetation assemblages which provide high quality, formally protected, nesting habitat for penguins, and a marine environment predominantly influenced by the East Australia Current, contributing to higher breeding success. Reduced foraging range of Bowen Island penguins during critical stages of the breeding cycle compared with other colonies in the south suggest regional oceanographic characteristics may influence distribution of major diet items. There appears to be an inverse relationship between breeding success and latitude of breeding colonies. This study is continuing, and early results are presented.

INTRODUCTION

The breeding success of the Little Penguin *Eudyptula minor* in Australia varies considerably. Understanding the causes of variation, particularly sudden breeding failure and long-term decline in breeding success, is of considerable and increasing interest and vital to managing penguin populations. Data collected over many years from colonies across the range of the Little Penguin are required both to recognise trends and to understand mechanisms. These data are only just becoming available. In this paper I compare some aspects of the terrestrial and marine habitat of the Little Penguin within and between Australian east coast colonies.

Bowen Island in Jervis Bay National Park is the largest northern penguin breeding colony in Australia, and has been classified as a scientific reference area because of high breeding success compared to other colonies, unique and relatively intact woodland nesting habitat, and because it is situated in a pristine bay formally protected by National Park status (Fortescue 1995, Fortescue & Kristo 1995, Dann *et al*. 1996). The breeding range and in some instances the success of the Little Penguin has declined in other locations (Fortescue 1995), particularly in Victoria, and a range of studies to examine causes of declines is continuing. The Bowen Island colony provides a valuable opportunity to compare ecological attributes of this relatively pristine colony with other colonies.

In 1987 I commenced long-term studies into the breeding biology of the Little Penguin on Bowen Island. Initially the study compared breeding success in a range of vegetation assemblages between 1987 and 1990 and found higher breeding success in mature woodland compared with early successional vegetation assemblages, namely tussock scrubland (Fortescue 1995). Whereas it seems that differences in quality of nesting habitat are important factors in high breeding success, it is unlikely that these alone account for the higher breeding success compared with southern colonies.

In the 1995 summer breeding season I commenced a study of foraging behaviour. Little Penguins were first tracked using radio telemetry techniques by Weavers (1992) between 1986 and 1988 over an 18-month period on Phillip Island, Victoria. He described two travelling patterns; short-term single day trips, typically during the breeding season; and long-term trips of more than several days, sometimes hundreds of kilometres away from the breeding colony during the non-breeding period. Early in 1991, Taronga Zoo commenced a radio telemetry pilot study on Little Penguins breeding on Lion Island, in the mouth of the Hawkesbury River, Sydney. Palmer (in Cunningham *et al*. 1993) found that, due to the rugged topography of Broken Bay, effective tracking would require at least three fixed towers and two mobile antennae, as well as aerial survey. Three penguins only were tracked. Two of the three remained in the outer Pittwater, within approximately 5 km of Lion Is. Due to site problems the study was not continued. Also in 1991, Collins *et al*. (1994) commenced a radio telemetry study aimed at determining the foraging locations of Little Penguins from Phillip Island during different breeding stages, and relating foraging patterns to breeding success. They found that the birds commitment during the different stages of breeding determined the foraging range, with birds committed to feeding chicks having the shorter foraging trips. Birds forced to feed over greater distances during chick raising had lower fledging success.

Bowen Island lies 300 m offshore of Governor Head on Bherwerre Peninsula within the Commonwealth Territory of

Jervis Bay, about 200 km south of Sydney. It is 51 ha in area and composed of Permian sandstone capped by Quaternary sand (Albani *et al*. 1972). Extensive, steep fore-dunes fringe the western shoreline. Many islands have only skeletal soils, and this dune development may be particularly important for determining distribution of unique vegetation assemblages on Bowen Island, and supporting the highest density of burrows recorded for the Little Penguin (Dann *et al*. 1996). The underlying sandstone dips westward resulting in spectacular cliffs to 30 m along the island's eastern coastline and gently sloping rock platforms and beaches along the western shoreline (Albani *et al.* 1970). Hence access by penguins to the nesting areas is from the inshore western side of the island.

The 1995 breeding season was a particularly poor season for the Little Penguin on Bowen Island. Breeding failure was reported for other east coast colonies (Lion Island, E. Walraven pers. comm.; Montague Island, N. Klomp pers. comm.; Phillip Island, J.M. Cullen pers. comm.). Initial results on foraging behaviour, although based on limited data in a poor season, suggest some interesting differences compared to southern colonies.

METHODS

Breeding success

Breeding success in a range of vegetation assemblages was determined in accordance with methods described in Fortescue (1995) for the years 1987 to 1995 (see also Cullen & Dann 1993, 1994). In response to difficulties encountered in 1992 and 1993 in obtaining adequate replicates across vegetation assemblages and the risk of bias toward shallow burrows inherent with manual checking, non-invasive techniques of burrow inspection were developed. A miniature Sony XC–999 CCD Colour Video Camera Module ('lipstick' camera), measuring 150 × 25 × 25mm with 1:1.4 6 mm lens was coupled to a 12 v gel cell battery and high-resolution colour television monitor was used to observe burrow contents. The camera was encapsulated and attached to a skid on a 5-m flexible bilge hose. Lighting was provided by two miniature 12 v bulbs mounted on the skid. Where burrows were accessible, traditional techniques of removing the contents by hand were used (Fortescue 1991). Eggs were weighed and measured, and birds were weighed, beak measurements taken, age of chicks determined from state of plumage development, and, if older than six weeks, the young birds were banded. A chick was deemed to have fledged if it disappeared after reaching a mass of approximately 800 g or greater (determined by weighing or visual assessment), and was fully feathered.

When possible, mean laying date, the number of eggs, hatching success, fledging success (Fortescue 1995), breeding success (the number of chicks fledged per pair, Reilly & Cullen 1981) and percentage of double broods were determined. A total of 4916 birds was banded or retrapped from 500 burrows between 1987 and 1996.

Radio telemetry

The study concentrated on the foraging behaviour of Little Penguins during their breeding season. Birds were selected for fitting with transmitters on the basis that they bred in the range of vegetation assemblages previously categorised (Fortescue 1991), were actively breeding, were accessible with minimal disturbance, and were in healthy condition (over 1000 g). Transmitters were glued with Loctite®401 to the feathers on the lower back (Collins *et al.* 1994). Band numbers of birds were recorded, and birds were weighed before application of the transmitters, and on subsequent encounters. Eggs, chicks, and mate were recorded on every occasion the burrows were inspected. Ten birds were selected from the habitat types *Banksia* Woodland, *Casuarina* forest, and *Lomandra* tussock scrubland.

The two stage transmitters, manufactured by Sirtrack Tracking and Telemetry Systems, New Zealand measured 23 × 38 × 11 mm and were powered by a LTC3PN 3.6-v lithium cell. The transmitter and battery were cast in a tapered mould to ensure good hydrodynamics. The total package weighed 9 g. The transmitter pulses at 80 ppm with an 18-ms pulse width, and has a life of 67 days. The antenna is a 1-mm stainless steel whip approximately 220 mm long.

Telonics TR–4 light weight receivers assigned frequencies 150.000 to 150.990 MHz in increments of 0.010 (corresponding to 99 channels) were used.

Signals from the transmitters were received from 6 m and 12 m fixed point, phased harness receiving towers manufactured by Bio-Telemetry Systems, South Australia. The towers were located at elevated points and were checked for signal strength and coverage using transmitters in known locations. Towers were located at the Beecroft Peninsula Lighthouse at Point Perpendicular, central Bowen Island, and Huskisson Trig. Station (Fig. 4). The towers at Point Perpendicular and Bowen Island had clear line of site coverage over the entire Bay, and out to sea eastwards and southwards. Line of site coverage to the north was obstructed by Long Nose Point. Tests prior to fixing transmitters to birds confirmed the range of the transmitters exceeded 15 km, and gave good coverage of the Bay from fixed receiving towers. Test transmitters were placed at Bowen Island, the lighthouse at Beecroft Peninsula, Captains Point Navigation Marker at the surveyed boundary intersection of NSW waters and Commonwealth waters, and at Greenpoint in the far northern limit of the Bay. All locations gave clear signals, although significant interference (radar, etc.) was encountered when Naval ships entered the Bay.

Before each tracking session, the antennae were calibrated using the fixed transmitter at Captains Point. The direction of a transmitter was recorded as a compass bearing, and the location determined as the intersection of at least two bearing lines.

On some occasions, the birds were tracked from a boat using a hand held Yagi antenna to validate general accuracy of fixed-point locations, to gain an understanding of Little Penguin behaviour, and to determine any possible behavioural anomalies of birds equipped with transmitters.

Data from the fixed towers were transformed from bearing to grid reference data, and processed in a home range statistical analysis program (Ackerman *et al*. 1990).

RESULTS

Breeding success

Breeding data are drawn from 500 burrows and 4916 birds monitored through eight breeding seasons between 1987 and 1995 on Bowen Island. Breeding success of the Bowen Island

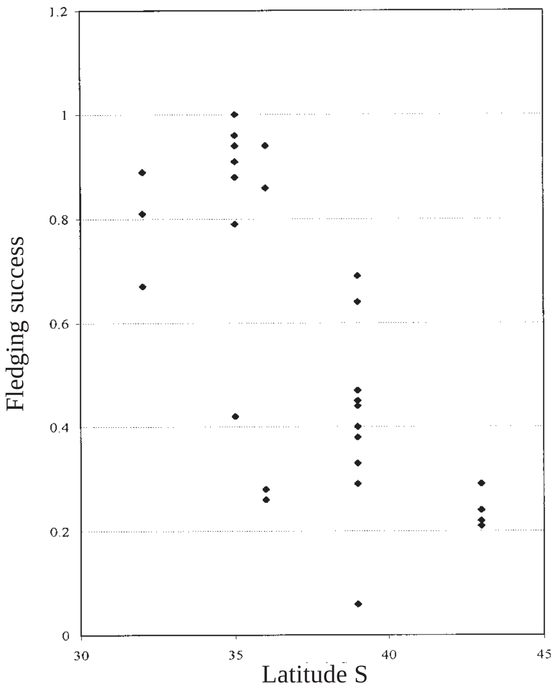

Fig. 1. *Fledging success of Little Penguins with increasing latitude. Latitude and fledging success are negatively correlated (*r *= –0.71, df = 29,* P *< 0.001).*

colony is relatively high compared to other studied Little Penguin colonies (Table 1), and similar to that of the nearest monitored colony at Lion Island in the Hawkesbury River, Sydney.

Mean fledging success of five east coast colonies is inversely related to latitude ($r = -0.71$, d.f. = 29, $P < 0.001$, Fig. 1). Data used in the analysis are from Lion Island, NSW (Rogers *et al.* 1995), Bowen Island (Fortescue 1991), Montague Island, NSW (Klomp pers. comm.), Phillip Island, Victoria (Reilly & Cullen 1981, R. Jessop pers. comm.), and Bruny Island, Tasmania (Hodgson 1975). Mean annual fledging success varied considerably from year to year within colonies.

The 1995/96 breeding season was poor in eastern Australia. Breeding failure was reported for Lion Island (E. Walraven pers. comm.), Montague Island (hatching success 0.52, breeding success 0.13, n = 479; N. Klomp pers. comm.), and Phillip Island (M. Cullen pers. comm.). A total of 437 birds were banded or retrapped from 120 burrows on Bowen Island. Of the 120 burrows monitored in 1995, birds bred in 97. Hatching success was the lowest recorded since monitoring began in 1987, and failure at the chick stage was considerably higher than usual (Table 1). Regular data collection on breeding birds commenced in September, by which time many birds had eggs, and single birds were in the burrows incubating eggs. Mean date for the onset of laying was 2 September, typical for Bowen Island (Fortescue 1991).

Hatching success (the number of eggs hatched as a proportion of the number of eggs laid), was 0.71 (n = 184), compared to a mean 0.84 (n = 7 seasons, SE = 0.03), and fledging success was 0.79 (n = 131), compared to a mean 0.84 (n = 7 seasons, SE = 0.07), for previous years on Bowen (Table 1). Ninety-seven pairs which were monitored produced 104 chicks in their first attempt, or 1.07 chicks per pair. Double broods were less common, occurring in 8.2% of pairs, compared with a

TABLE 1

Hatching success, fledging success, and first brood chicks fledged per pair in eight Little Penguin studies

Year (location)	Hatching success	Fledging success	Chicks per pair	Reference
Lion Island 32°S				Cunningham
1990	0.87	0.89	1.64	*et al.* 1993
1991	0.76	0.81	1.46	
1992	0.83	0.67	1.13	
Bowen Island 35°S				Fortescue 1991
1987	0.81	1.00	1.69	
1988	0.76	0.88	1.35	
1989	0.90	0.96	1.72	
1992	1.00	0.91	1.83	
1993	0.83	0.42	0.70	
1994	0.90	0.94	1.68	
1995	0.71	0.79	1.13	
Auckland, New Zealand 36° S				Jones 1978
	0.44	–	–	
Montague Island, NSW 36° S				N. Klomp pers.
1994	–	0.28	–	comm.
1995	0.52	0.26	–	
Phillip Island 39° S				Reilly &
1968	0.60	0.40	–	Cullen 1981
1969	0.63	0.29		
1970	0.71	0.47		
1971	0.76	0.44		
1972	0.54	0.69		
1973	0.62	0.29		
1974	0.67	0.64		
1975	0.61	0.33		
1976	0.47	0.06		
1977	0.72	0.45		
1978	0.78	0.38		
1979	0.62	0.65		
1980	0.64	0.61		
1990	–	–	1.54	
1991	–	–	0.74	
1992	–	–	1.21	
1993	–	–	1.10	
1994	–	–	1.21	
1995	–	–	0.32	
Wellington, New Zealand 41° S				Kinsky 1960
1956	0.59	0.86	–	
1957	0.54	0.94	–	
Bruny Island, Tasmania 43° S				Hodgson 1975
1959	0.61	0.29	0.35	
1960	0.71	0.22	0.30	
1961	0.64	0.21	0.27	
1962	0.72	0.24	0.35	
Otago, New Zealand 45° S				Gales 1987
1982	0.63	0.75		

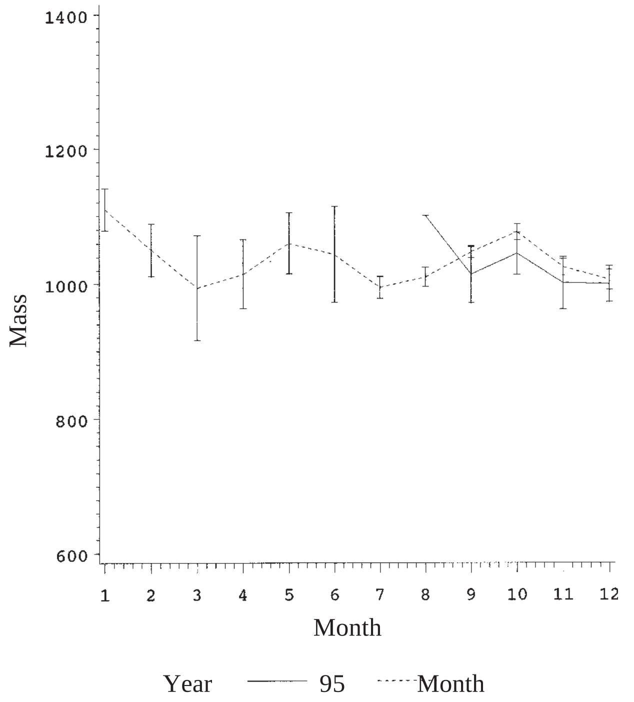

***Fig. 2.** Mean monthly masses of Little Penguins on Bowen Island from 1987 to 1995 combined (dotted line), and from the 1995 season (solid line).*

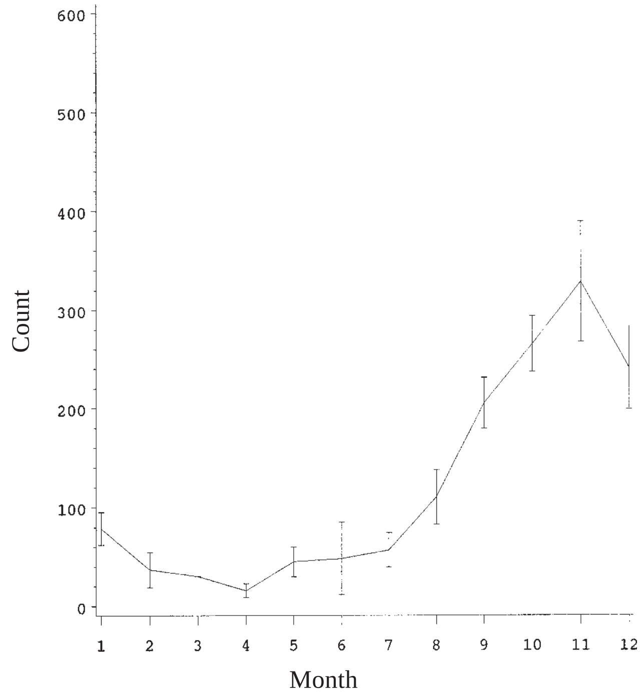

***Fig. 3.** Mean monthly counts and standard error of Little Penguins arriving on Penguin Beach, Bowen island, in the first hour after sunset, 1987 to 1995 combined.*

mean of 13.8% in previous years. Total output for the season was 1.17 chicks per pair, compared to 1.60 for previous years on Bowen Island (Table 1, Fortescue 1995). Whereas the season was poor compared to previous years, breeding success on Bowen is relatively high even in a poor season (Table 1), and similar to the nearest studied colony at Lion Island (a mean of 1.43 chicks per pair over three years, Cunningham *et al*. 1993), suggesting nesting habitat and regional oceanographic characteristics play important roles in determining breeding success. Mean mass at fledging was 1015 g (n = 37, SE = 25.20), a typically high fledging mass for chicks in this area (mean 1011 g over three years, Lion Island, Cunningham *et al*. 1993).

Foraging range

Three tracking sessions were conducted in September, November, and December 1995. These coincide generally with egg laying, chick rearing, and fledging, respectively. These activities overlap considerably, and double brooding is common in November and December.

September: egg laying and incubation

Birds fitted with transmitters left the island well before sunrise (*c*. 04h40) and were generally beyond the range of receiving towers (>20 km) by 07h00.

Burrow attendance in September showed relief periods at the nest site were up to 10 days, much longer than previously encountered on Bowen Island (normally within two days, Fortescue 1991). Mean daily mass loss of birds remaining in burrows during these extended incubation periods was 22.8 g, whereas partners foraging at sea gained 13.3 g per day. Weinecke *et al*. (1995) found penguins incubating eggs usually exchange partners within two days, but that in the poor breeding season of 1989, incubation relief periods increased to five days. Long relief periods are apparently common in Victoria (P. Dann pers. comm.), and presumably reflect increased foraging range and effort.

Mean mass of Little Penguins for September 1995 was 1039±32.56 g, slightly lower but comparable to the previous years since 1987 (1047±4.37 g, 1987–1994 combined, Fig. 2). The rise in mean body mass typically observed over the months of August, September, and October was not observed in 1995.

The mean number of birds arriving on Penguin Beach was 116.2±8.04 (n = 5), usual for this time of the year (Fig. 3). Burrow occupation rate was typically high at 80.8%. Of 120 burrows selected for monitoring, 23 (19%) were abandoned prior to egg laying. Egg success obtained from monitored burrows was 0.56 for the first attempt, compared with a mean of 0.78 in previous years.

There was no attempt made to track birds using techniques other than fixed towers in September. The only hint at where breeding penguins may have been feeding came from reports from professional fishermen who reported seeing penguins on the continental shelf slope approximately 20 km north-east of Jervis Bay.

November: chick rearing

Birds were continuing to travel beyond the range of the fixed towers at the commencement of tracking in early November. Penguins were observed feeding in the bay in the first week of October. On Monday 13 November, towards the end of the second tracking period, birds with transmitters were located close to the island, and continued to forage in close proximity to the island throughout November and December (Fig. 4).

The mean number of birds arriving on Penguin Beach in

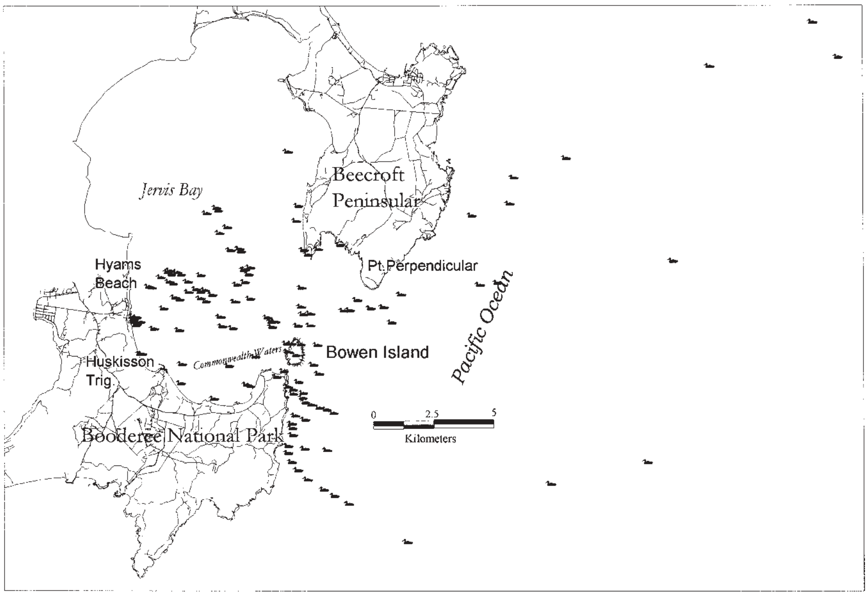

***Fig. 4.** Location of telemetry towers and Little Penguins determined by radio tracking in the 1995 breeding season.*

October had increased to 236 (n = 3), compared to a combined mean of 226±16. By November, counts were 234 (n = 3), somewhat lower than the combined mean of 282±22 (Fig. 3).

Mean body mass for the month of November was 998±21 g, a little lighter than for the same month in previous years (1023±6 g, n = 453, 1987–1994 combined, Fig. 2), and this trend continued through into December.

December: chick rearing, fledging and second broods

Mean mass of adult birds was 997±13 g, comparable to previous years (1005±7 g, n = 352, 1987–1994 combined, Fig. 2). Mean mass typically declines in the latter part of the breeding season. Penguins were regularly observed feeding in and around the Bay. This coincided with the appearance of large schools of baitfish (pilchard and anchovy) and slimy mackerel in the Bay.

The number of birds arriving on Penguin Beach usually declines in December compared with November, as fledglings leave the island and adults commence pre-moult fattening at sea. The mean number of birds arriving on Penguin Beach was 289±12, considerably higher than the mean 221±29 in previous years (Fig. 3).

Tracking at sea

Once birds were within *c*. 20 km of the towers and able to be tracked, distances travelled from the island were small. Home range analysis (Ackerman *et al*. 1991) on a limited sample of tagged birds showed several centres of activity for the season. The principle core area of activity had its harmonic centre in the Bay 2.7 km north-west of Bowen Island, with other centres of activity located 13 km north-east of the island, in an area of upwelling known as the Banks, and another 6 km due west of the island. Calibration trials suggest the fixed-point towers and transmitters used in this study have a range of *c*. 20 kms. The bivariate normal home range area for the breeding season (95%) was 218.9 km^2 (n = 35, asymptotic SE = 41.1 km^2). However, the analysis is based on a small sample size in an unusually poor season.

On 9 December a bird located by fixed tower telemetry (bearing 91° from Huskisson Trig tower and 141° from the Bowen tower), was tracked from a boat using a hand held Yagi antenna, to confirm general location and behavioural patterns. The location of the bird was determined by GPS (35°7'16.2"S, 150°47'46.2", 1 km east of the island), once visual contact was confirmed. The time elapsed between the fixed-point telemetry fix and visual sighting from the boat was 50 minutes, and the distance between the locations using the two methods was less than 400 m. The bird was actively feeding (diving continuously) with a large number of seabirds including Short-tailed Shearwaters *Puffinus tenuirostris* and Australasian Gannets *Morus serrator*. Moderate sea conditions (3 m southerly swell) hampered detailed observations.

While at sea birds displayed a number of characteristic foraging patterns. No signal could be detected while birds were underwater, so the period of no signal was assumed to represent diving, and the period for which a signal could be received represented time on the surface (Collins *et al*. 1994). Dive times were typically one minute (55.9±2.0 s, n = 80), followed by a shorter rest period on the surface (15.9±1.2 s, n = 100).

DISCUSSION

Geographic variation in breeding success

Few Little Penguin breeding islands in Australia have adequate long term breeding data to ascertain the health of colonies, determine trends, and predict causes of variation. Phillip Island has 30 years of breeding data, Bowen Island has nearly 10 years, and nearby Lion Island has four years. Several other east coast colonies have two to four years of data.

The breeding success of Bowen and Lion Islands are significantly higher than that of Phillip Island. Limited data suggests an inverse relationship between mean fledging success of colonies and latitude of the colony along the Australian east coast (Fig. 1). Lower breeding success at higher latitudes is unexpected, because the stronghold of the Little Penguin is in the southern parts of Australia.

Bass Strait, 800 km south of Bowen Island, supports by far the greatest proportion of breeding seabirds in Australia. Fewer than 1% of seabirds occur in the generally less productive waters of New South Wales. However 11% of breeding Little Penguins in Australia occur on 22 islands off New South Wales (Ross *et al*. 1996). This is because the factors effecting their distribution and success are different to those effecting many other seabirds. Shearwaters breeding on Montague Island recently tracked by satellite telemetry techniques travelled as far as the sub-Antarctic Convergence on foraging trips (N. Klomp pers. comm.), whereas Little Penguins tracked in this study travelled only 3–5 km from their breeding colony. Little Penguins, due to physiological constraints, are less able to exploit highly productive regions such as continental shelf slopes and convergence zones than volant seabirds, and have became comparatively specialised localised foragers adapted to highly variable productivity. Greater foraging distances lead to an energy imbalance and poorer breeding success (Collins *et al*. 1994). The specific oceanographic characteristics of an area are critical to the Little Penguin, more so than highly mobile species.

In 1974, a small penguin colony was discovered 5 km from Melbourne central business district, at St Kilda, within the same bioregion region as the Phillip Island colony. The breeding season of this colony is longer because of earlier laying, fledging masses are heavier, double broods are more common, adult mass are higher, and breeding success is higher than at nearby Phillip Island (Cullen *et al.* 1996). These differences have been attributed to considerably shorter foraging distances to more productive foraging grounds (20 km compared to 100 km, Cullen *et al.* 1996), leading to a favourable energy budget. This example graphically represents the importance of proximity to a reliable food supply.

Oceanographic characteristics of the Jervis Bay region

The range of the Little Penguin on the east coast of Australia incorporates several distinct geological regions and bioregions, characterised by distinctly different oceanographic influences, climate, and biogeographic assemblages (fish, algae, and marine invertebrates) (Ortiz 1992). Gibbs (1992) described the chemical and biological oceanographic characteristics of Bass Strait. He concluded that 'there is still too little understanding of the relationships between oceanographic features, productivity and food for Little Penguins, to relate their variable breeding success or mortality to oceanographic variables affecting Bass Strait'.

The East Australia Current (EAC) influences coastal waters in the Jervis Bay region about 50% of the time (Ortiz 1992), and southern Tasmania only four to six times a year (Heaseman *et al*. 1998). The EAC is characterised by warm, tropical, nutrient poor waters. The measurable effects of the EAC on Jervis Bay is a rise in water temperature and salinity. Two EAC events described by Huyer *et al*. (1988) typically separated from the coast north of Newcastle, and were 130 km from the coast by the time they reached Montague Island at 36°S. Their passage took two months, from September to December and November to February, respectively. Most importantly, the EAC is powerful and penetrates to depths greater than 1000 m, thereby promoting upwelling and enriching coastal waters of south east Australia considerably (Tranter *et al*. 1986, Huyer *et al.* 1988). Huyer *et al*. (1988) found water temperatures rose rapidly at the onset of persistent southward currents in late September and fell when the flow ceased, further dropping with northward currents. Frequent slope water intrusions occur mainly from July to February, and particularly in the summer months in Jervis Bay (based on CSIRO data from Port Hacking; Tranter *et al*. 1986, Huyer *et al*. 1988, Blackburn & Creswell 1993, Jacoby 1993, Pritchard *et al*. 1997). This coincides with the Little Penguin's breeding season on Bowen Island. The EAC provides the primary mechanism for nutrient enrichment for NSW coastal waters and in the Jervis Bay area (Jacoby 1992, Blakburn & Creswell 1993).

The resident time of the nutrient-rich water in the semi-enclosed bay is long, greatly increasing algal and general productivity. The period of maximum enrichment coincides with the Little Penguins' breeding season (summer) on Bowen Island. The positive effect of the EAC are reduced at higher latitudes. The productivity of Jervis Bay supports the largest baitfish reserves, particularly pilchard, in New South Wales (Winstanley 1979, Joseph 1981, Leadbitter & Pollard 1987).

The global scale oceanographic phenomenon, the El Nino Southern Oscillation (ENSO), may depress the EAC and upwelling, providing an important mechanism for variability in productivity and Little Penguin breeding success for northern colonies. El Nino similarly depresses upwelling in the eastern Pacific with deleterious affects on Galapagos Penguins (Boersma 1978). Whereas ENSO signatures are not well understood in the Australian region, identified signatures include sea-surface temperature decreases around eastern Australia (Hsieh & Hamon 1991), a weakening of the East Australia Current, onshore transport, downwelling, deepening of the pycnocline, and decreased stream flow (Allan & d'Arrigo 1999).

Nesting habitat

Two of three known colonies with vegetation assemblages nearing climax communities are Bowen and Lion Islands, both with exceptionally high breeding success (Rogers *et al.* 1993, Dann *et al*. 1996, Fortescue 1996). On Bowen, penguins nesting in climax *Banksia* woodland habitat have the higher breeding success compared with an early successional community, tussock scrubland. The succession to mature woodland on Bowen has taken 25 years. The principal mechanism for disturbance of coastal vegetation in Australia is fire (Pyne 1991). On many islands weed invasion, particularly by exotic invasive grasses such as Kikuyu, inhibit or halt natural succession (e.g. Big Island, Five Islands group and Montague Island). Many seabird breeding islands in Australia are characterised by structurally simple early seral vegetation similar to tussock scrubland. Such vegetation structures do not favour the Little Penguin, especially towards the northern limit of its distribution.

Pollutants

Gibbs (1995) compared the tissues and eggs of Little Penguins from Lion, Bowen, and Phillip Islands and found higher concentrations of some contaminants, especially dieldrin, DDT, and chlordane, in the tissue of Phillip Island birds. Eggs from Phillip Island also had significantly thinner shells compared with those from Montague, Bowen, and Five Islands, island which are situated away from major urban or industrial development. The Phillip Island colony is situated in an old housing estate, and catchments of their feeding areas are urbanised and industrialised. Chlordane has been used widely in Australia to control termites in houses. The concentrations of chlordane in Sydney and Phillip Island birds showed significant contamination of the penguins' habitat. Cunningham *et* *al*. (1993) believed the maximum concentrations of contaminants in all tissues were below those considered to cause physiological effects. However they concluded that high concentrations of DDT and chlordane in Sydney and Phillip Island and dieldrin at Phillip Island clearly showed that improved control of pesticides to the environment was essential to penguin health. Jervis Bay has a small catchment and receives little freshwater input. This is a major factor contributing to the clarity of its waters and low levels of pollutants (Cunningham *et al*. 1993).

Poor breeding seasons

Widespread breeding failure was recorded for penguins in the 1995 season. The season was the poorest recorded for Bowen Island since monitoring commenced in 1987, although fledging success is relatively high compared to other locations. The return rate of penguins was very low and adult mortality due to starvation was high at the commencement of breeding at Phillip Island and Kangaroo Island. At Phillip Island, breeding for the 1995 season failed, and an unprecedented decline in attendance by adult birds at the colony was experienced (J. M. Cullen pers. comm.). Poor breeding success was reported for Montague Island (N. Klomp pers. comm.) and Lion Island (E. Walraven pers. comm.).

The greatest component of breeding failure on Bowen in 1995 was egg success at 0.56, compared with a mean of 0.78 for previous years. The season was the last of an extraordinary persistent ENSO event which lasted five years, and which coincided with the most severe drought and bushfires in eastern Australia in recent history. The 1995 season improved when the ENSO warm event ended late in 1995.

In March 1995, a major episode of pilchard deaths commenced in South Australia, and by July had spread throughout its range. A high percentage of adult pilchards were killed, from Western Australia, Bass Strait, Tasmania, the east coast, and North and South Islands of New Zealand. The cause of death was asphyxiation due to damage to the gills. Only pilchards over 12 cm in length died. Death occurred in both spawning and non-spawning fish, and has been linked tentatively to a herpes virus (N. Bax, CSIRO Fisheries pers. comm.). No other fish species were known to have been affected.

It is not known if the pilchard death had a direct impact on penguins. The greater foraging range encountered in the early part of the breeding season on Bowen Island may reflect typical seasonal patterns, as described by Collins *et. al* (1995), or more likely may reflect difficulty the birds were having in obtaining sufficient food close to the colony. This is supported by the considerably higher level of burrow abandonment and egg failure than usual, and long relief periods of 10 days for birds incubating eggs. Birds tracked at Phillip Island early in the 1995 breeding season and in the aftermath of a major oil spill on the east coast of Tasmania travelled beyond the range of fixed towers, and could not be located by aircraft. On Bowen, penguins had lower body masses compared with previous years, and did not gain mass as usually occurs early in the breeding season. It remains unknown how far the birds were foraging from the colony, and subsequent research may indicate the degree of seasonality of this behaviour. The poor breeding season was not reflected in any increase in adult mortality on Bowen Island, which has remained low over the last 10 years.

The higher number of birds than usual arriving on Penguin Beach in December was due to early failure of many pairs. Adult birds which would normally be attending second broods in the burrow had ceased breeding for the season.

Nesting relief periods are particularly revealing. Burrow attendance in September, the incubation and hatching period, showed relief periods at the nest site were up to 10 days, much longer than previously encountered on Bowen Island (normally within two days). Wienecke *et al.* (1995) similarly found penguins incubating eggs usually exchange partners within two days, but that in the poor breeding season of 1989, incubation relief periods increased to five days. Handrich *et al*. (1995) identified the factors of early failure as either (a) the inability to complete the usual shift length, due to poor initial condition or to an unusually rapid drop in body reserves, or (b) the increased duration of the foraging trip of the partner at sea (Croxall *et al*. 1988). Mean daily mass loss during these extended incubation periods on Bowen Island was 22.8 g, while partners foraging at sea gained 13.3 g per day. Collin *et al.* (1994) reported daily mass loss during incubation at Phillip Island as 30 g, and foraging trips during incubation as three to ten days. This varied considerably from year to year. In 1991, 80% of trips during incubation on Phillip Island were greater than 10 days. Relatively long relief periods are not uncommon at Phillip Island (P. Dann pers. comm.).

Foraging patterns

Foraging patterns of Little Penguins from Bowen Island are based on few data, and no aerial tracking was conducted in 1995 when birds were out of range of fixed towers (20 km). Home range analysis on Bowen Island birds showed several centres of activity for the season. Most data are from the chick-rearing period. The principle core area of activity had its harmonic centre in the Bay 2.7 km NW of Bowen Island, with other centres of activity located 13 km NE of the island, in an area of upwelling known as the Banks, and another 6 km due west of the island. Collins *et al*. (1994) found feeding activities in the chick rearing month of December 4 to 6 km southwest of the colony extending to about 15 km. The home range area of Bowen Island penguins for the season was considerably smaller than that at Phillip Island, but no meaningful comparisons can be made at this stage.

REFERENCES

ACKERMAN, B.B., LEBAN, F.A., SAMUEL, M.D. & GARTON, E.O. 1990. User's manual for program home range. Technical Report 15. Forestry, Wildlife and Range Experimentation Station, Moscow: University of Idaho.

ALBANI, A.D., CARTER, A.N. & JOHNSON, B.D. 1972. The bedrock topography of Jervis Bay, New South Wales. In: Fraser, R. (Ed.). Oceanography of the South Pacific. Wellington: New Zealand National Commission for UNESCO. pp. 132–160.

ALLAN, R.J. & D'ARRIGO, R.D. 1999. 'Persistent' ENSO sequences: How unusual was the recent El Nino? *The Holocene* 9: 101–118.

BLACKBURN, S.I. & CRESWELL, G. 1993. A coccolithophorid bloom in Jervis Bay, Australia. *Aust. J. Mar. Freshwater Res*. 44: 253–260.

BOERSMA, P.D. 1978. Breeding patterns of Galapagos Penguins as an indicator of oceanographic conditions. *Science* 300: 1481–1483.

COLLINS, M., CULLEN, M. & DANN, P. 1994. Radio tracking Little Penguins at sea. April 1991–April 1994. Phillip Island Penguin Reserve, August 1994.

CULLEN, M., BLAKE, N. & BICKHAM, M. 1996. Urban penguins. *Nature Australia*, Winter 1996: 23–28.
CULLEN, J.M. & DANN, P. 1993. A study of the impact of tourism on penguins at Bowen Island, Jervis Bay National Park. Final Report, Australian National Parks and Wildlife Service, March 1993.
CULLEN, J.M. & DANN, P. 1994. A study of the impact of tourism on penguins at Bowen Island, Jervis Bay National Park. Final Report, Australian National Parks and Wildlife Service, March 1994.
CUNNINGHAM, M., GIGGS, P., ROGERS, T., SPEILMAN, D. & WALRAVEN, E. 1993. Ecology and health of the Little Penguin *Eudyptula minor* near Sydney. A report prepared for the Sydney Water Board, June 1993.
DANN, P., CULLEN, M. & WEIR, I. 1996. National review of the conservation status and management of Australian Little Penguin colonies. Final report prepared for the Australian Nature Conservation Agency, April 1996, Canberra.
FORTESCUE, M.E. 1991. Breeding biology and management of the Little Penguin, *Eudyptula minor* (Forster), 1780, on Bowen Island, Jervis Bay. M.App.Sci. Thesis. Applied Ecology Research Group, University of Canberra.
FORTESCUE, M.E. 1995. Biology of the Little Penguin *Eudyptula minor* on Bowen Island and at other Australian colonies. In: Dann, P., Norman, I. & Reilly, P. (Eds). The penguins: ecology and management. Chipping Norton: Surrey Beatty & Sons. pp. 364–394.
FORTESCUE, M.E., & KRISTO, F. 1995. Jervis Bay National Park. In: Zann, L.P. & Kailola, P. (Eds). The state of the marine environment report for Australia. Technical Annexe: 1. The Marine Environment. Ocean Rescue 2000. Canberra: Department of the Environment, Sport and Territories.
GALES, R.P. 1987. Growth strategies in Blue Penguins *Eudyptula minor minor*. *Emu* 87: 212–219.
GIBBS, P.J. 1995. Heavy metal and organochlorine concentrations in tissues of the Little Penguin *Eudyptula minor*. In: Dann, P., Norman, I. & Reilly, P. (Eds). The penguins: ecology and management. Chipping Norton: Surrey Beatty & Sons. pp. 393–419.
HANDRICH, Y., GENDNER, J.-P. & LE MAHO, Y. 1995. Breeding penguins as indicators of marine resources: a study with minimal human disturbance. In: Dann, P., Norman, I. & Reilly, P. (Eds). The penguins: ecology and management. Chipping Norton: Surrey Beatty & Sons. pp. 73–79.
HARRIS, G., NILSSON, C., CLEMENTSON, L. & THOMAS, D. 1987. The water masses of the east coast of Tasmania: Seasonal interannual variability and the influence on phytoplankton biomass and productivity. *Aust. J. Mar. Freshwater Res.* 38: 569–590.
HEASEMAN, M.P., O'CONNOR, W.A. & FRAZER, A.W.J. 1998. Ontogenetic changes in optimum rearing temperatures for the commercial scallop, *Pecten fumatus* Reeve. *J. Shellfish Res.* 17: 89–95.
HODGSON, A. 1975. Some aspects of the ecology of the Fairy Penguin *Eudyptula minor novaehollandiae* (Forster) in Southern Tasmania. Ph.D. thesis, University of Tasmania, Hobart.
HOLLOWAY, P.E., SYMONDS, G., NUNES VAZ, R. & JEFFREY, M. 1992. Oceanographic measurements in Jervis Bay April 1989 to April 1990. Working Paper 1991/1, Department of Geography and Oceanography, University of New South Wales, Australian Defence Force Academy.
HSEISH, W.H. & HAMON, B.V. 1991. The El Nino-Southern Oscillation in South-eastern Australian waters. *Aust. J. Mar. Freshater Res.* 42: 263–275.
HUYER, A., SMITH, R.L., STABENO, P.J., CHURCH, J.A. & WHITE, N.J. 1988. Currents off South-eastern Australia: results from the Australian coastal experiment. *Aust. J. Mar. Freshwater Res.* 39: 245–288.
JACOBY, C. 1993. Report on the plankton bloom in Jervis Bay, December 1992. An unpublished report to the Australian National Parks and Wildlife Service.
JONES, G. 1978. The Little Blue Penguin (*Eudyptula minor*) on Tiritiri Matangi Island. M.Sc.Thesis Zoology. University of Auckland, Auckland.
JOSEPH, B.D.L. 1981. The pilchard fishery at Jervis Bay – biology, fishery and population dynamics. M.Sc. Thesis. University of New South Wales, Kensington.
KINSKY, F.C. 1960. The yearly cycle of the Northern Blue Penguin (*Eudyptula minor novaehollandiae*) in the Wellington Harbour area. *Rec. Dominion Mus.* 3: 145–218.
LEADBITTER, D., & POLLARD, D.A. 1987. Proposed Jervis Bay aquatic reserve. Sydney: New South Wales Department of Agriculture.
MONTAGUE, T.L. 1982. The food and feeding ecology of the Little Penguin *Eudyptula minor* at Phillip Island, Victoria, Australia. M.Sc. Thesis, Monash University.
NAYLOR, E., & HARTNOLL, R.G. 1978. Cyclic phenomena in marine plants and animal. Proceedings of the 13th European Marine Biology Symposium Isle of Man, 27 September – 4 October 1978. Oxford: Pergamon Press.
ORTIZ, E. & BURCHMORE, J. 1992. The development of a representative system of marine and estuarine protected areas for New South Wales. Report prepared by NSW Fisheries for the Australian National Parks and Wildlife Service, August 1992.
PRITCHARD, T.A., LEE, R.S., & AJANI, P.A. 1997. Oceanic and anthropogenic nutrients and the phytoplankton response: preliminary findings. Pacific Coasts and Ports '97, 7–11 September 1997, Christchurch, New Zealand.
PYNE, S.J. 1991. Burning bush. A fire history of Australia. Sydney: Allen and Unwin.
REILLY, P.N. & CULLEN, J.M. 1981. The Little Penguin *Eudyptula minor* in Victoria II. Breeding. *Emu* 81: 1–19.
ROGERS, T., ELEDERSHAW, G. & WALRAVEN, E. 1995. Reproductive success of the Little Penguin *Eudyptula minor* on Lion Island, NSW. *Wildl. Res.* 22: 707–715.
ROSS, G.J.B., BURBIDGE, A.A., BROTHERS, N., CANTY, P., DANN, P., FULLER, P., KERRY, K.R., MENKHORST, P.W., PEMBERTON, D., SHAUGHNESSY, G., SHAUGHNESSY, P.D., SMITH, G.C., STOKES, T. & TRANTER, J. 1995. The status of Australia's seabirds. In: Zann, L.P. &. Kailola, P. (Eds). The state of the marine environment report for Australia. Technical Annexe: 1. The Marine Environment. Ocean Rescue 2000. Canberra: Department of the Environment, Sport and Territories.
TRANTER, D.J., CARPENTER, D.J. & LEECH, G.S. 1986. The coastal enrichment effect of the East Australian Current eddy field. *Deep Sea Res.* 33: 1705–1728.
WEAVERS, B. 1992. Seasonal foraging ranges and travels at sea of Little Penguins *Eudyptula minor*, determined by radiotracking. *Emu* 91: 302–317.
WIENECKE, B., WOOLLER, R.D. & KLOMP, N. 1995. The ecology and management of Little Penguins on Penguin Island, Western Australia. In: Dann, P., Norman, I. & Reilly, P. (Eds). The penguins: ecology and management. Chipping Norton: Surrey Beatty & Sons. pp. 440–467.
WINSTANLEY, R.H. 1979. Fishery situation report 3 – Pilchard and anchovy. Cronulla: CSIRO Division of Fisheries and Oceanography.