

Delayed breeding in Little Penguins – evidence of climate change?

Lynda E. Chambers

Bureau of Meteorology Research Centre, Australia

(Manuscript received July 2003; revised November 2003)

Recently there has been renewed interest in the use of natural systems in providing evidence for climate change. Continuous biological datasets, covering a number of decades, are rare in Australia, however, data does exist on the timing of commencement of breeding of Little Penguins in Victoria. Climate affects marine ecosystems, particularly through sea surface temperatures. For a burrowing seabird, such as the Little Penguin, with strong ties to the land during the breeding season, there may also be an air/land temperature influence. The mean laying date of the penguins of Phillip Island, Victoria, has become progressively later over time and the question is raised whether this can be interpreted as a climate change signal.

Introduction

In the past few years there has been a resurgence of interest in the possibility of detecting climate change using natural systems (see, for example, Crick and Sparks 1999; Sparks and Menzel 2002; Hughes 2003; Parmesan and Yohe 2003; Root et al. 2003). The study of recurring natural (or biological) events, often in relation to climate, is known as phenology. These studies typically record events such as the arrival of migratory birds, first egg-laying or the commencement of flowering (e.g. Crick and Sparks 1999; Keatley et al. 2002; Root et al. 2003).

Early studies of meteorology were strongly linked with phenology, with the timings of events in nature being used, for example, by the British Royal Meteorological Society (RMS), as measures of variations in climate (Sparks et al. 2002; Sparks and Smithers 2002). The RMS used a phenological network to study the timing of the seasons from 1875 to 1947, when the last coordinator retired (Sparks and Smithers 2002). During the same period many other countries in the northern hemisphere also had phenological schemes. In the subsequent 40 years phenology became less popular with meteorological agencies in many countries, often being regarded as not

- ‘real science’ (Keatley et al. 2002; Sparks and Menzel, 2002). This image of phenology has largely been altered by growing concerns over global warming and its potential impact on natural ecosystems. Sparks and Smithers (2002), summarise why phenology is now seen by many governments as important:
- (a) ‘The growing consensus that greenhouse-gas emissions are causing global climate change.’
 - (b) ‘The realisation that phenological events can be very sensitive to climate fluctuations.’
 - (c) ‘Phenological events are cheap and easy to record.’
 - (d) ‘Phenology can motivate and enthuse a large body of committed recorders.’
 - (e) ‘Phenological events are excellent vehicles through which to demonstrate a changing climate to the general public.’

Most of the phenological studies published so far are limited to results for the northern hemisphere. Within Australia there has not been a coordinated approach to phenological records and the extent and availability of such records is largely unknown (Keatley et al. 2002; Hughes 2003). Long-term datasets, of greater than 20 years, with relatively consistent collection and recording methods, are rare. One such dataset is that collected on breeding in the Little Penguin on Phillip Island, in Victoria, to which this paper is dedicated.

Corresponding author address: L. Chambers, Bureau of Meteorology Research Centre, GPO Box 1289K, Melbourne, Vic. 3001, Australia.
email: l.chambers@bom.gov.au

Climate affects marine ecosystems, particularly through sea-surface temperatures (Stenseth et al. 2002; Chambers 2003). For a burrowing seabird, with strong ties to land during the breeding season, there may also be an air/land temperature influence.

Little Penguins feed predominantly on small fish, such as pilchard (*Sardinops sagax*), anchovy (*Engraulis australis*), red cod (*Pseudophycis bachus*), barracouta (*Thyrsites atun*) and blue warehou (*Serirolella brama*), and on cephalopods (mainly squid) and crustaceans (most frequently krill, *Nyctiphanes australis*) (Chiardadia et al. 2003). Such species are known to be highly sensitive to environmental variability (Stenseth et al. 2002). Given that climate fluctuations can impact on the prey items of seabirds, it would not be surprising if delayed effects of climate were felt by marine species, such as the Little Penguin.

Data

Breeding data from Little Penguins were obtained from birds nesting at one site at the 'Penguin Parade' on the Summerland Peninsula (38°31'S, 145°08'E) on Phillip Island (Victoria) in southeastern Australia from 1968 to 1998. General procedures have been described by Reilly and Cullen (1979, 1981) and Dann and Cullen (1990). Fifty-five burrows (mostly artificial) were checked during the day as well as at night after the birds had returned from the sea. Visits were made at weekly intervals for the first three years and then at intervals of four weeks in subsequent years. Laying dates, if laying was actually not observed, were inferred retrospectively from hatching dates or the age of young chicks. Mean laying date was calculated by averaging the dates of egg laying for each pair's first nesting attempt. The minimum number of observations in any year was 11 (1981/82), and only three years had less than 20 observations. The typical standard error of the mean laying date was around seven days.

Temperature (monthly mean maximum and monthly mean minimum) data were extracted from the Commonwealth Bureau of Meteorology's climate database for sites close to the Phillip Island Penguin Reserve (now known as Phillip Island Nature Park). In March 1981 the Phillip Island Penguin Reserve (site number 086354) began daily weather observations. However, these records were patchy, with temperature recorded on very few occasions.

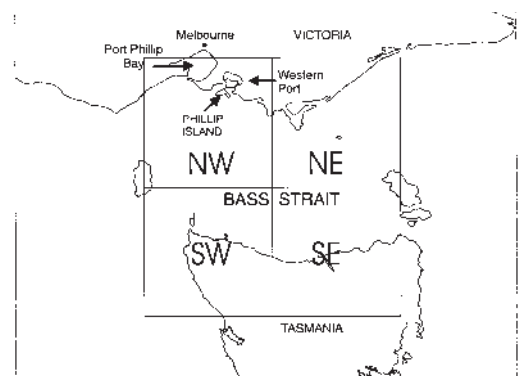
Alternatives to the station temperature records are the Bureau's gridded temperature datasets (based on high-quality station data, as described in Jones 1999). These datasets have a 0.25 degree spatial resolution,

with the grid-point encompassing the Phillip Island Penguin Reserve being used in the analyses.

The sea-surface temperature (SST) dataset used is the US National Centers for Environmental Prediction (NCEP) reconstruction of historical SSTs. These NCEP data use optimum interpolation analysis and are available, in a monthly format, from January 1950 to the present. However, since data on the Little Penguin breeding commence in 1968, SST data post-1967 were used. The spatial resolution of the data is 2° x 2° with global coverage. The foraging range of the Little Penguin is restricted to the coastal waters of Bass Strait, Western Port and Port Phillip Bay, particularly during the breeding season (Collins et al. 1999). Therefore, a subset, of four SST grid boxes, each with one data point, covering the region 38°S to 42°S and 144°E to 148°E was used to represent the local SSTs (see Fig. 1). Weekly SST data, on a 1° x 1° resolution, was only available from November 1981.

Changes in sea-surface temperatures are unlikely to initiate an immediate response from penguin populations, unless they affect fish distribution and abundance. For regions in the eastern equatorial Pacific Ocean it is hypothesised that 'reduced advection and upwelling would have led to both increased sea-surface temperatures and reduced supply of nutrients, which would have in turn resulted in smaller phytoplankton. The effects of reduced phytoplankton would eventually be translated to birds via reduced zooplankton populations' (Veit et al. 1996). If this, or a similar, hypothesis holds in southern temperate regions, then we would expect a time lag in the response by birds to changes in sea temperature and, hence, may need to consider SSTs in seasons earlier than the expected breeding season.

Fig. 1 Location of Phillip Island and the 2° x 2° local sea-surface temperature boxes.



Results

Little Penguin breeding success on Phillip Island, in Victoria, varies from year to year (Reilly and Cullen 1981; Dann and Cullen 1990; Chambers 2004). In general, when the breeding season starts early the number of chicks raised per pair and the weight of the chicks are both high, indicating a successful breeding season (Reilly and Cullen 1981; Chambers 2004). Conversely, when the breeding season start date is delayed the weight of the chicks is generally low and the number raised per pair low (Chambers 2004).

Over time there has been a significant (linear) positive trend in the mean laying date of penguins on Phillip Island ($p = 0.003$) (Fig. 2). Despite considerable interannual variability in the mean laying date, egg laying in the Phillip Island birds generally occurs in the southern hemisphere spring (September-October-November).

If breeding in Little Penguins is largely triggered by a particular air temperature or SST value then we would expect no (or insignificant) correlations between mean laying date and air temperature/SST values at the time of egg laying. This does not appear to be the case as there were significant (positive) correlations between the mean laying date and the air and sea-surface temperatures, both at the time of laying and in the month prior to laying for air temperature (Table 1, correlations remain significant after applying Bonferroni corrections). These correlations are expected since dates towards the end of spring are generally warmer than those near the start of spring, for both air temperatures and for sea-surface temperatures in Bass Strait. However, it is clear from Fig. 3 that penguin egg laying coincides with times when local SSTs are rising.

When the monthly SST values are standardised, by subtracting the monthly mean and dividing by the monthly standard deviation, there are no longer any significant correlations between the SSTs at the time of laying and the mean laying date (e.g. for the NW box $r = 0.043$, $p = 0.818$). Thus, when the mean laying date occurs later in the year the SSTs in Bass Strait are generally higher (see paragraph above), however, warmer or cooler than normal SSTs in a particular month do not correspond to earlier or later mean laying dates. Figure 4 illustrates the timing of the mean laying date in relation to standardised SST anomalies in the NW box (containing Phillip Island). Compared to the full data period (1968-1998), over the period 1982 to 1998 (the limit of the weekly SST data) the relationship between mean laying date and SSTs at time of laying was weaker (correlation using monthly SST data, $r = 0.138$, $p = 0.597$; using weekly SST data, $r = 0.150$, $p = 0.567$). Using the weekly

Fig. 2 Mean laying date of Little Penguins on Phillip Island, 1968 to 1998. Also shown is the linear trend in mean laying date. (MLD = $0.0397 \text{ Year} - 68.525$; $p = 0.003$)

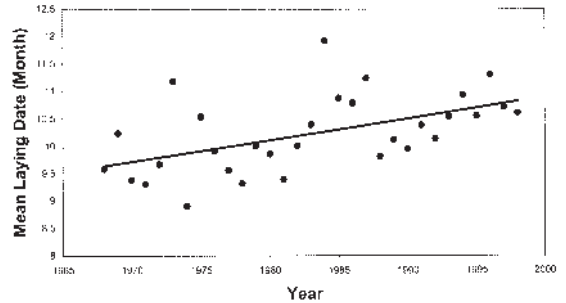


Fig. 3 Time series of sea-surface temperatures in the northwest box. The sea-surface temperatures at mean laying date are indicated by the triangles. Note, these always coincided with periods of warming SSTs. In most cases, when the mean laying date corresponded to a period of relatively high SSTs, such as in 1973, 1975, 1984, 1985, 1987 and 1997, the breeding success of the penguins was also low (see Chambers 2004).

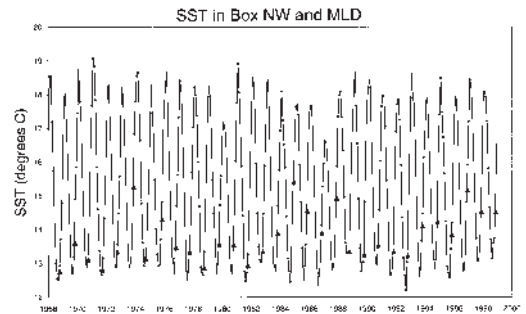
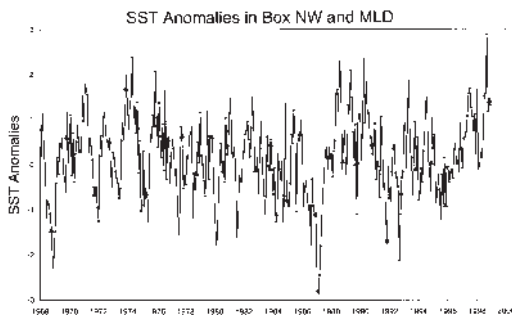


Table 1. Pearson correlation coefficients between mean laying date and air (monthly mean maximum and monthly mean minimum) for a grid-point encompassing Phillip Island) and sea-surface temperatures, 1968-1998. P-values for the correlations are given in brackets. Later laying dates correspond to warmer temperatures but do not imply that warmer temperatures result in later laying dates.

	Same Month as MLD	Month Prior to MLD
Maximum Temperature	0.789 (<0.001)	0.794 (<0.001)
Minimum Temperature	0.734 (<0.001)	0.686 (<0.001)
SST (NW box)	0.841 (<0.001)	0.263 (0.153)
SST (NE box)	0.856 (<0.001)	0.356 (0.050)
SST (SW box)	0.713 (<0.001)	0.139 (0.456)
SST (SE box)	0.758 (<0.001)	0.169 (0.364)

Fig. 4 Time series of sea-surface temperatures, standardised monthly anomalies, in the northwest box. The sea-surface temperatures at mean laying date are indicated by the triangles.



data it was also possible to explore relationships between the timing of the minimum SST value and the start of egg laying in Little Penguins. At least for this shorter dataset, mean laying date did not appear to be linked to the magnitude of the minimum SST value or to the date when the minimum occurred (correlations $r = 0.200$ ($p = 0.442$) and $r = -0.415$ ($p = 0.098$), respectively). There were no significant (linear) trends in either the date of the minimum SST or the value of the minimum SST.

Although there appeared to be no fixed temperature threshold that initiates breeding in Little Penguins on Phillip Island, though warming SSTs may be an essential cue, land and sea temperatures in the seasons prior to and encompassing the laying period may have an influence on the laying date.

Considering the land temperatures first, delays in the mean laying date generally correspond to cool maximum and minimum temperatures during the summer (December-January-February) prior to breeding and to cool minimum (and to some extent maximum) temperatures during autumn (March-April-May) (Table 2).

Over the period 1968 to 1998, air temperatures in the Phillip Island region have increased (significantly) during the winter period, but not during the other seasons (Table 3). The trend in the winter mean maximum temperature values comes mainly from the June period (trend 0.0332 degrees per year, $p=0.008$), while the strongest monthly mean minimum temperature trends occurred in April (-0.0399 degrees per year, $p = 0.027$) and June (0.0498 degrees per year, $p = 0.002$). April mean minimum monthly temperatures were significantly correlated with mean laying date, even after the linear trend was removed from both variables (raw correlation $r = -0.514$, detrended correlation $r = -0.387$).

Table 2. Pearson correlation coefficients between mean laying date and seasonal air temperatures (averaged monthly mean maximum and monthly mean minimum values) for a grid-point encompassing Phillip Island, 1968-1998. P-values for the correlations are given in brackets.

Season	Maximum Temperature	Minimum Temperature
Summer	-0.418 (0.019)	-0.359 (0.048)
Autumn	-0.343 (0.059)	-0.567 (0.001)
Winter	0.182 (0.327)	-0.075 (0.687)
Spring	0.025 (0.893)	0.179 (0.336)

Table 3. Trends ($^{\circ}\text{C}$ per year) in seasonal air temperature (averaged monthly mean maximum and monthly mean minimum values) for a grid-point encompassing Phillip Island, 1968-1998. P-values for the trends are given in brackets. Trends were determined by linear regression for temperature with explanatory variable year, calculated separately for each season.

Season	Maximum Temperature	Minimum Temperature
Summer	-0.0313 (0.078)	0.0015 (0.935)
Autumn	0.0080 (0.674)	-0.0065 (0.647)
Winter	0.0180 (0.030)	0.0237 (0.026)
Spring	-0.0068 (0.663)	0.0116 (0.294)

Mean laying date was highly correlated with local sea-surface temperatures during the summer and autumn prior to breeding (Table 4), with the strongest correlations being for the northern boxes. Warm ocean conditions in summer and autumn corresponded to an early start to breeding. There were no significant trends in the sea-surface temperatures during the 1968 to 1998 period (Table 5).

Discussion and conclusions

Over the period 1968 to 1998, there was very little evidence of a climate change signal for the region around Phillip Island. There were no statistically significant trends in the (seasonal) ocean temperatures for the four grid boxes close to Phillip Island and the only significant trend in the land temperatures was for winter (monthly mean maximum and monthly mean minimum temperatures).

Table 4. Pearson correlation coefficients between mean laying date and seasonal sea-surface temperatures for the grid boxes shown in Fig. 1, 1968-1998. P-values for the correlations are given in brackets. The autumn correlations remain significant after applying Bonferroni corrections.

Season	NW	NE	SW	SE
Summer	-0.437 (0.014)	-0.473 (0.007)	-0.343 (0.059)	-0.409 (0.022)
Autumn	-0.578 (0.001)	-0.597 (<0.001)	-0.524 (0.002)	-0.575 (0.001)
Winter	-0.078 (0.675)	-0.053 (0.778)	0.058 (0.758)	-0.021 (0.912)
Spring	0.129 (0.448)	0.133 (0.476)	0.261 (0.157)	0.133 (0.476)

Table 5. Trends ($^{\circ}\text{C}$ per year) in seasonal sea surface temperatures for the grid boxes shown in Fig. 1, 1968-1998. The annual trends are based on seasonal anomalies. P-values for the trends are given in brackets. Note, there are no statistically significant trends.

Season	NW	NE	SW	SE
Summer	0.00189 (0.673)	0.00183 (0.703)	0.00218 (0.646)	0.00219 (0.669)
Autumn	-0.00384 (0.608)	-0.00602 (0.467)	-0.00674 (0.444)	-0.00788 (0.384)
Winter	0.00626 (0.166)	0.00635 (0.203)	0.00584 (0.344)	0.00403 (0.493)
Spring	0.00250 (0.562)	0.00215 (0.652)	0.00308 (0.616)	0.00044 (0.936)
Annual	0.00984 (0.265)	0.01030 (0.242)	0.00504 (0.583)	0.00463 (0.600)

An analysis of extreme temperatures, based on a similar time period of 1961 to 1998, also found no statistical significant trends in the frequency of days with maximum/minimum temperatures above the 99th percentile (warm days/nights) for the southeast of mainland Australia (Manton et al. 2001). There were also no statistically significant trends in the frequency of cool days/cold nights (below the 1st percentile). Similar results were found by Collins et al. (2000) for hot days (maximums above 35°C) and relatively warm days/nights (days/nights above the 95th percentile). Using an expanded station list and a longer dataset, generally from 1957 to 1996, Collins et al. (2000) did find some significant trends in the region encompassing Phillip Island (in particular for their closest station to Phillip Island, Laverton, 87031). They found an increase in the annual frequency of hot nights (minimums above 20°C) and decreases in the annual frequency of cold days (maximums below 15°C), cold nights (minimums below 5°C), and relatively cool days and nights (below the 5th percentile).

Regardless of any trends in the air or land temperatures over time, the results suggest that, during the period of this study, the mean laying date in the Little Penguins of Phillip Island is influenced by sea, and to some extent land, temperatures in the summer and autumn prior to breeding. Therefore, changes in temperatures during these seasons are likely to translate into changes in the timing of egg laying in this species.

The importance of ocean temperatures during the summer and autumn prior to breeding may be explained by the lifecycle of the Little Penguin at Phillip Island. During summer the birds are finishing breeding, with the last of the chicks being fed before they leave the nest and their parents' care. Adult Little Penguins will then spend a short time feeding intensively at sea in order to build up adequate fat reserves prior to their annual moult. The moult, lasting two to three weeks, generally occurs during the period February to April (Reilly and Cullen 1981). During this time the birds are unable to feed, as they are restricted to land. Birds that have successfully raised young or that did not breed generally moult earlier than birds whose breeding attempts failed (Reilly and Cullen 1983; Stahel and Gales 1987). A late start to moult may limit the ability to attain the necessary fat reserves needed. Hence, obtaining a good supply of food during the end of the previous breeding season (summer) and prior to and during moult (autumn) places the penguins in a good position for the subsequent breeding season. Interestingly, the weight of penguins at the end of the previous breeding season and during moult has little effect on the bird's survival or breeding success (Dann et al. 1995).

The negative correlations, between the mean date of laying in Little Penguins and the sea-surface temperatures during summer and autumn, suggest that penguins tend to breed earlier when sea temperatures are warm during these periods. Periods of higher water temperatures in Jervis Bay, New South Wales,

have been found to correspond to greater numbers and species of fish (Fortescue 1998). During warm water periods, pilchards, a Little Penguin food source, are known to move into Port Phillip Bay, as seen by increases in commercial catches during these periods (Bunce 2000). The distribution, movement and abundance of other penguin prey items is also likely to be affected by warm water periods in Bass Strait.

Simulations of future Australian air temperature using climate models, with enhanced levels of greenhouse gases, suggest annual average increases (relative to 1990) of 0.4 to 1.6°C for southern Victoria by the year 2030, and 0.7 to 5.2°C by the year 2070 (CSIRO 2001). For the Phillip Island/central coastal Victorian region the temperature increases are expected to be greatest in summer and least in winter (Whetton et al. 2000; CSIRO 2001).

If sea or air temperatures were to increase during summer or autumn then, based on the results presented here, we would expect the mean laying date to occur earlier, rather than later. Caution needs to be exercised before estimating how much earlier the mean laying date is expected to fall due to the relatively large amount of unexplained variance in the mean laying date (Table 6). Some of the factors that may potentially impact on the temperature – laying date relationships are: commercial fishing pressures (many species commercially fished near Phillip Island are also penguin prey items); and changes in the composition of prey items taken by the Little Penguins (Chiaradia et al. 2003) as different fish species may respond differently to changes in sea-surface temperatures.

The nature and magnitude of the impact that climate change is likely to have on Australian ecosystems is largely unknown. It is therefore important that continuous data is collected on potential (Australian) bio-indicators, such as the Little Penguin. To assist in making limited resources count, a national phenological monitoring program, such as are available in Europe and North America, is needed. The aims of such a program would be to provide datasets with adequate spatial and temporal resolution to allow

regional/local analysis of the impacts of climate change on a selected number of carefully chosen bio-indicator species. For a further discussion of the need for an Australian phenological database and how this might be achieved see Keatley et al. (2002).

Over time the mean laying date of Little Penguins on Phillip Island has tended to become later in the year. Although there were significant correlations between air and sea-surface temperatures and mean laying date, the trend in the laying date was not explainable by corresponding trends in the temperature data. What has caused the tendency for penguins to lay later in the year is largely unknown and warrants further investigation.

Acknowledgments

I would like to acknowledge the Penguin Study Group and the research staff of Phillip Island Nature Park who collected, collated, and provided the Little Penguin breeding data. Valuable comments were made by B. Timbal (Bureau of Meteorology), M. Keatley (University of Melbourne) and P. Dann (Phillip Island Nature Park) as well as by two anonymous reviewers.

References

- Bunce, A. 2000. Population dynamics of Australasian Gannets (*Morus serrator*) breeding in Port Phillip Bay, Victoria: Competition with fisheries and the potential use of seabirds in managing marine resources. Ph.D. Thesis, University of Melbourne.
- Chambers, L.E. 2004. The impact of climate on Little Penguin breeding success. *BMRC Research Report* (in press), Bur. Met., Australia.
- Chiaradia, A., Costalunga, A. and Knowles, K. 2003. The diet of Little Penguins (*Eudyptula minor*) at Phillip Island, Victoria, in the absence of a major prey – Pilchard (*Sardinops sagax*). *Emu*, 103, 43-8.
- Collins, D.A., Della-Marta, P.M., Plummer, N. and Trewin, B.C. 2000. Trends in annual frequencies of extreme temperature events in Australia. *Aust. Met. Mag.*, 49, 277-92.
- Collins, M., Cullen, J.M. and Dann, P. 1999. Seasonal and annual for-

Table 6. Percentage of variance in the mean laying date explained by each of the seasonal temperature variables, 1968-1998.

Season	Sea-surface temperatures			SE	Air temperatures	
	NW	NE	SW		Maximum	Minimum
Summer	19.1	22.4	11.7	16.7	17.5	12.9
Autumn	33.5	35.6	27.5	33.1	11.8	32.1
Winter	0.6	0.3	0.3	<0.1	3.3	0.6
Spring	1.7	1.8	6.8	1.8	0.1	3.2

- aging movements of little penguins from Phillip Island, Victoria. *Wildlife Research*, 26, 705-21.
- Crick, H.Q.P. and Sparks, T.H. 1999. Climate change related to egg-laying trends. *Nature*, 399, 423-24.
- CSIRO. 2001. *Climate change projections for Australia*. Climate Impacts Group, CSIRO Atmospheric Research, Melbourne, 8 pp.
- Dann, P. and Cullen, M.J. 1990. Survival, patterns of reproduction, and lifetime reproductive output in Little Blue Penguins (*Eudyptula minor*) on Phillip Island, Victoria, Australia. Pages 63-84, in *Penguin Biology*. Eds Davis, L.S. and Darby, J.T., Academic Press, San Diego.
- Dann, P., Cullen, J.M. and Jessop, R. 1995. Cost of reproduction in Little Penguins. Pages 39-55, in *The Penguins*. Eds Dann, P., Norman, I. and Reilly, P., Surrey Beatty & Sons, Sydney.
- Fortescue, M. 1998. The marine and terrestrial ecology of a northern population of the Little Penguin, *Eudyptula minor*, from Bowen Island, Jervis Bay. Ph.D. Thesis, University of Canberra.
- Hughes, L. 2003. Climate change and Australia: trends, projections and impacts. *Austral Ecology*, 28, 423-43.
- Jones, D.A. 1999. Characteristics of Australian land surface temperature variability. *Theoretical and Applied Climatology*, 63, 11-31.
- Keatley, M.R., Fletcher, T.D., Hudson, I.L. and Ades, P.K. 2002. Phenological studies in Australia: potential application in historical and future climate analysis. *Int. J. Climatol.*, 22, 1769-80.
- Manton, M.J., Della-Marta, P.M., Haylock, M.R., Hennessy, K.J., Nicholls, N., Chambers, L.E., Collins, D.A., Daw, G., Finet, A., Gunawan, D., Inape, K., Isobe, H., Kestin, T.S., Lefale, P., Leyu, C.H., Lwin, T., Maitrepiere, L., Ouprasitwong, N., Page, C.M., Pahalad, J., Plummer, N., Salinger, M.J., Suppiah, R., Tran, V.L., Trewin, B., Tibig, I. and Yee, D. 2001. Trends in extreme daily rainfall and temperature in southeast Asia and the South Pacific: 1961 – 1998. *Int. J. Climatol.*, 21, 269-84.
- Parmesan, C. and Yohe, G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, 421, 37-42.
- Reilly, P.N. and Cullen, J.M. 1979. The Little Penguin *Eudyptula minor* in Victoria. I. Mortality of adults. *Emu*, 79, 97-102.
- Reilly, P.N. and Cullen, J.M. 1981. The Little Penguin *Eudyptula minor* in Victoria. II. Breeding. *Emu*, 81, 1-19.
- Reilly, P.N. and Cullen, J.M. 1983. The Little Penguin *Eudyptula minor* in Victoria. IV. Moulting. *Emu*, 83, 94-8.
- Root, T.L., Price, J.T., Hall, K.R., Schneider, S.H., Rosenzweig, C. and Pounds, J.A. 2003. Fingerprints of global warming on wild animals and plants. *Nature*, 421, 57-60.
- Sparks, T.H., Crick, H., Elkins, N., Moss, R., Moss, S. and Mylne, K. 2002. Birds, weather and climate. *Weather*, 57, 399-410.
- Sparks, T.H. and Menzel, A. 2002. Observed changes in seasons: an overview. *Int. J. Climatol.*, 22, 1715-25.
- Sparks, T.H. and Smithers, R.J. 2002. Is spring getting earlier? *Weather*, 57, 157-66.
- Stahel, C. and Gales, R. 1987. *Little Penguin: Fairy Penguins in Australia*. New South Wales University Press, Sydney.
- Stenseth, N.C., Mysterud, A., Ottersen, G., Hurrell, J.W., Chan, K.-S. and Lima, M. 2002. Ecological effects of climate fluctuations. *Science*, 297, 1292-6.
- Veit, R.R., Pyle, P. and McGowan, J.A. 1996. Ocean warming and long-term change in pelagic bird abundance within the Californian current system. *Marine Ecology Progress Series*, 139, 11-18.
- Whetton, P.H., Hennessy, K.J., Katzfey, J.J., McGregor, J.L., Jones, R.N. and Nguyen, K. 2000. Fine Resolution Assessment of Enhanced Greenhouse Climate Change in Victoria, *Annual Report 1997-1998: Climate averages and variability based on a transient CO₂ simulation*. Consultancy report by CSIRO for the Victorian Department of Natural Resources and Environment.

