

**Feeding and Breeding Ecology of Little Penguins**  
*(Eudyptula minor)*  
**in the Eastern Great Australian Bight**



Submitted by

Annelise S. Wiebkin, BSc (Hons)

A thesis submitted in total fulfilment of the requirements for the degree of  
Doctor of Philosophy

School of Earth and Environmental Sciences,

The University of Adelaide, South Australia,  
Australia

June 2012



## Thesis declaration

This work contains no material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968. I also give permission for the digital version of my thesis to be made available on the web via the University's digital research repository, the Library catalogue, the Australasian Digital Theses Program (ADTP) and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

This thesis is presented as a series of papers that will be submitted following examination. Although I did the significant aspects of data collection, analysis and interpretation of the results I offered co-authorship on papers to B. Page, S.D. Goldsworthy, D.C. Paton, N. Bool and T.M. Ward because they assisted in the pursuit of the research or preparation of the thesis: S.D. Goldsworthy, D.C. Paton and T.M. Ward supervised this project and received grants that funded part of this research.

All research procedures reported in the thesis were approved by the Animal Ethics Committees of the University of Adelaide, Primary Industries and Resources South Australia and the South Australian Department for Environment and Natural Resources (DENR). Permits were granted by DENR.

Annelise S. Wiebkin

..... June 2012





**“Who would believe in penguins  
unless he had seen them?”**

Conor O'Brien, *Across Three Oceans*

## Abstract

This thesis investigated aspects of foraging and reproductive ecology of little penguins *Eudyptula minor* in the eastern Great Australian Bight. Little penguins are permanent residents in this region and the link between their ecology and their local food source is poorly understood in the Great Australian Bight. Most little penguin colonies in South Australia are small in population (< 4000 breeding individuals) and they are almost all found on islands. Despite similarities in breeding seasons and diet among colonies, the foraging ecology of penguins from offshore colonies differed from inshore colonies in the same region. Natural variation in diet and foraging behaviour at eight colonies was attributed to differences in food availability. Inter-colony differences in foraging behaviour and effort, which were consistent between years, were related to differences in penguin morphology, growth and body size. Breeding penguins from the offshore colony travelled up to 3 times further from shore (39 vs. 13-21 km) and for greater durations (3 vs. 1 days), and spent more time diving (56 vs. 37 % of foraging time). Results suggest that food availability is depleted, or not profitable in near colony waters, possibly as a consequence of increased or prolonged predation by the large penguin population. This study also indicated that increased foraging effort at the colony level was reflected in the growth parameters of offspring, because offshore colonies had smaller offspring and adults, and delayed development of sexual size differentiation in bill morphology. Increases in foraging distance and duration were also linked to poorer breeding success.

Little penguins at different colonies exhibited low variation in their diet because juvenile Australian anchovies *Engraulis australis* were mainly targeted as a food source. Dive behaviour was similar among colonies, despite differences in the depths around colonies. The regional availability and abundance of anchovies may be responsible for the unusual pattern of winter breeding that is apparent in South Australia. Little penguin diet, breeding and foraging parameters may provide quantitative indicators of the health of local anchovy stocks, especially if an anchovy fishery develops in South Australia. Baseline information on these penguin parameters may also inform management decisions aimed at conserving penguin populations across the region.

## Acknowledgements

This project would not have been possible or taken the directions it did without the support, knowledge, skills and encouragement of many people. For that I am so very grateful.

Firstly, I thank Brad Page, who although not an official supervisor, contributed hugely to this project and my training. Brad was always there as a mentor for fieldwork, project design, writing, analyses, academic questioning and he provided me with a good dose of 'keep going'. Brad's endless encouragement resulted in more data than I could have hoped for and skills I will have forever. I thank you for all those nights in the field, sitting with me hour after hour, motionless til dawn on cold, rainy beaches waiting for those little satellite trackers to please come home. You gently pushed my limits until I realised that one *can* live on wild parsley and noodles with a ripped tent, wet sleeping bag and smelling of blended sardine for two more weeks. Always with an open door (or inbox), you alleviated my frustrations with R and other analyses. Finally thanks for your true friendship, the fish and all the fruit.

Simon Goldsworthy, I could not have landed a more encouraging, understanding supervisor who embraced me into an exciting team that pursued the frontiers of marine predator research. I always left your office more motivated and inspired, and your big picture ecological questions constantly brought my project back into perspective. Thanks for welcoming me into your life and family, and for giving me the subantarctic opportunity of a life-time in the middle of my thesis. David Paton, thank you for your ornithological perspectives, academic guidance and understanding and support with regard to the breaks I took to work. Tim Ward, this project would not have been possible without your foresight and efforts in securing funding and I really appreciate your encouragement and faith in me.

There are so many volunteers who braved the storms of winter and shared my love for wild isolated islands in the pursuit of feathery, flippery secrets. Natalie Bool, thanks for your capable help on many trips, your upbeat and fun personality

brightened the darkest, windiest nights. Girl, you reignited my love of falafels. My dad, Ole Wiebkin, you diligently came along on many occasions, more willing than anyone to work, putting up with tents that were swamped by waves, penguins that latched onto sensitive body-parts, boots that had to be gaffer-tapped and cave walls that pierced your therma-rest. Also, thanks to field workers: Kristian Peters, Al Baylis, Alex Ivey, Richard Saunders, Luke Einoder, Paul Rogers, Lachie McLeay, Derek Hamer, Erica and John Lawley, Caroline Wilson, Georgina Pickerel, Nils Wiebkin, Annika and Adam Felton, Amanda Peucker, Claire Charlton, Richard, Andy Taylor, Jody O'Connor, Robyn, Adam Morrissey, Rachel Stringer, Robin Caines, Greg Johnson and Tony. Thanks for staying out weeks longer than expected, for taking bites and scratches for the team, for keeping the humour up when the tent ripped to shreds and when we were counting out sultanas and Tim Tams to last the remaining days. Thanks also for handling the fleas, for tirelessly plunging your arms into stinking, muddy burrows, and for loving it as much as I did.

Special thanks also to the *Ngerin* crew, to Chris Johnson, Johnny Newton and Matt who transported us to the islands, managed the hairiest of landings and gave me a few rides of my life through Anxious Bay surf break. Sarah Way, for your generous hospitality at Port Lincoln, and to Annika and Adam Felton, for a deluxe bed and dinner-time stories in Canberra, I cannot thank you enough.

Richard Saunders, Paul Van Ruth, Michelle Braley and Kristian Peters, I really found your office companionship so supportive, encouraging and fun, only a PhD student knows how another feels at times. I also thank all the staff at SARDI Aquatic Sciences for the coffees, the beers, the company in the lab, the fish to keep up my omega 3s, the administrative help, the 'free food upstairs' emails and for putting up with the unforgettable smells of diet samples in the wet lab

Nutritional analyses were conducted at Australian National University, Division of Botany and Zoology with the guidance of Ian Wallis, to whom I extend great appreciation. Appreciation is also extended to Paul Jennings (SARDI) who provided fish samples for nutrient analyses. Also thanks to penguin researcher Andre Chiaradia and the Phillip Island Nature Park staff who taught me the ropes



early on, and welcomed me into the penguin research community, keeping me informed on news and research results. I also thank Carlos Teixeira for helping with chlorophyll-*a* data acquisition, and Paul Burch for providing R code for GLMM analyses.

Funding was provided by Fisheries Research and Development Corporation, the South Australian Sardine Fishery (received by Tim Ward), Sea World, Nature Foundation, SARDI Women's Bursary 2005 and Lirabenda Fund (Field Naturalist Society). A Ph.D. scholarship was provided by The University of Adelaide and SARDI Aquatic Sciences.

Love and appreciation to my wonderful parents, Sue and Ole, who gave me continual support and who fed and cared for me so often in the final writing phases when the funds ran out. I will one day repay the phone bill for all those late-night internet downloads to update us on progress of penguins carrying satellite trackers, giving us hope to wait another few hours. Also, thanks to my dear friend Alison Derry who kept me going the last six months with encouragement and red wine.

Finally I am so incredibly lucky to have you, Ioane Vakaci. You were my very best field volunteer, always willing to catch that last penguin on the beach, to stay up late covered in mushy sardine, to comfort me when the data logging equipment would not work and to dig a trench to China. Thank you for driving that monotonous desert road when I was exhausted, for being my packhorse across the slippery slopes of Pearson Island, for catching fresh fish when we were sick of pasta again, and for never ever grumbling. You were always there with support and faith in me when I had concerns and uncertainties, and you shared in my excitement when things went brilliantly. 'C'mon, you can do it!'. No one says that quite like you do!

## Table of Contents

<b>Thesis declaration .....</b>	<b>2</b>
<b>Abstract .....</b>	<b>5</b>
<b>Acknowledgements .....</b>	<b>6</b>
<b>Table of Contents .....</b>	<b>9</b>
<b>List of Figures .....</b>	<b>12</b>
<b>List of Tables.....</b>	<b>14</b>
<b>Chapter 1: General Introduction .....</b>	<b>18</b>
Central-place foragers.....	18
Impact of population size at the central-place .....	20
Balancing foraging strategies with reproductive output.....	21
Ashmole’s halo .....	22
Feeding strategies .....	23
Growth strategies .....	24
Seabirds as model species .....	25
Eastern Great Australian Bight.....	27
General Objective and Aims of this Study .....	29
Chapters and Organisation of this Thesis .....	33
References .....	34
<b>Chapter 2: Determining the sex of little penguins from South Australia using discriminant functions based on bill morphology .....</b>	<b>44</b>
Abstract.....	45
Introduction .....	46
Methods.....	47
Results.....	50
Developing discriminant functions to predict sex .....	50
Testing discriminant functions to predict sex .....	54
Using DF in other nearby colonies .....	54
Comparing the use of published DF .....	55
Bill depth and surrounding water depth.....	56
Discussion .....	57
Bill depth and bathymetry.....	59
References .....	60
<b>Chapter 3: Do inter-colony differences in the morphology of little penguins result from differences in food availability?....</b>	<b>62</b>
Abstract.....	63
Introduction .....	64

Methods .....	67
Measures that describe food availability and foraging effort .....	68
Results .....	70
Inter-colony variation in adult bill morphology .....	70
Inter-colony variation in fledgling morphology .....	72
Inter-colony variation in body size, food and foraging variables .....	72
Discussion .....	73
References .....	78
<b>Chapter 4: The diets of little penguins <i>Eudyptula minor</i> and their reliance on Australian anchovy <i>Engraulis australis</i> in South Australia. ....</b>	<b>82</b>
Abstract.....	83
Introduction .....	84
Methods .....	86
Study sites.....	86
Sample collection .....	87
Sample processing.....	89
Analyses of measures .....	91
Other correlations.....	92
Nutritional value of prey.....	93
Results .....	94
Discussion .....	104
A reliance on anchovies .....	104
Meal masses .....	106
Specialist strategies.....	107
Competition with fisheries and implications of ecological change .....	109
References .....	110
<b>Chapter 5: Does the diving behaviour of little penguins differ at sites where their primary prey can access different depths? .....</b>	<b>116</b>
Abstract.....	117
Introduction .....	118
Methods .....	120
Data analyses .....	121
Results .....	123
Discussion .....	128
References .....	133
<b>Chapter 6: Why are some little penguins so little: an effect of Ashmole’s halo on foraging behaviour? .....</b>	<b>136</b>
Abstract.....	137
Introduction .....	138
Methods .....	140

Study sites.....	140
Animal capture and transmitter deployment .....	140
Data analyses.....	141
Foraging area fidelity .....	143
Colony comparisons.....	143
Population, body size and foraging correlations .....	144
Effect of environmental variables on foraging.....	144
<b>Results.....</b>	<b>146</b>
Foraging behaviour.....	147
Comparisons in colony foraging behaviour.....	153
Colony foraging and body size correlations.....	155
Environmental influences.....	157
Discussion .....	159
References .....	166
<b>Chapter 7: General Discussion.....</b>	<b>170</b>
Future research.....	178
References .....	182
<b>Publications.....</b>	<b>192</b>

# List of Figures

Page

## Chapter 1: General Introduction.

- Figure 1. Map of southern South Australia showing the eight little penguin colonies where this study was conducted and others mentioned in this thesis.....32

## Chapter 2: Determining the sex of little penguins from South Australia using discriminant functions based on bill morphology.

- Figure 2. Frequency distributions of discriminant scores for male and female little penguins in the Troubridge Island, Pearson Island and combined *reference* data sets using discriminant functions based on *BD* and *BL*...52

## Chapter 3: Do inter-colony differences in the morphology of little penguins result from differences in food availability?

- Figure 2. Frequency distribution of bill depth measurements for male and little penguins from the Troubridge Island and Pearson Island in 0.25 mm size classes.....71

- Figure 3. Frequency histogram of bill depths for fledgling little penguins from Pearson and Troubridge Islands, presented in 0.25 mm size class.....72

## Chapter 4: The diets of little penguins *Eudyptula minor* and their reliance on Australian anchovy *Engraulis australis* in South Australia.

- Figure 2. Frequency distributions of estimated meal biomasses (before digestion) in size categories of 25 g, and the estimated energy consumed for each daily meal size.....95

- Figure 3. The mean otolith length of anchovies and sardines retrieved from diet samples of little penguins at Troubridge Island in 2005 and 2006.....101

## Chapter 5: Does the diving behaviour of little penguins differ at sites where their primary prey can access different depths?

- Figure 2. Example dive profiles of a little penguin from Troubridge Island, showing dive depth and time.....122

- Figure 3. The proportion of foraging area at each 5m-depth interval, and the proportion of dives at each depth for little penguins at Troubridge and Pearson Islands.....125

Figure 4. Cumulative time spent diving during each hour of the day for individual little penguins that were fitted with TDRs, at Troubridge and Pearson Islands.....127

Figure 5. Average dive depths at each hour of the day at Troubridge Island and Pearson Island.....128

## **Chapter 6: Why are some little penguins so little: an effect of Ashmole's halo on foraging behaviour?**

Figure 2. Kernel density plots of little penguin foraging time, at Troubridge Island in the winter breeding seasons of 2004, 2005 and 2006.....148

Figure 3. Kernel density plots of little penguin foraging time at Pearson Island in the winter breeding seasons of 2004 and 2005.....150

Figure 4. Kernel density plots of little penguin foraging time at Olive Island in the winter breeding seasons of 2006.....151

Figure 5. Kernel density plots of little penguin foraging time at Reevesby Island in the winter breeding seasons of 2004.....152

Figure 6. ANOSIM cluster dendrogram of colonies based on similarities in mean foraging parameters from each colony.....154

Figure 7. The mean distance from the colony at which penguins foraged during sequential time periods of their foraging trips.....155

## List of Tables

Page

### **Chapter 2: Determining the sex of little penguins from South Australia using discriminant functions based on bill morphology.**

- Table 1. Means and ranges of bill depths and bill lengths for male and female little penguins in the *reference* and *test* data sets.....51
- Table 2. The discriminant functions used for allocating sex to adult little penguins at Troubridge Island, Pearson Island and at either colony (combined).....52
- Table 3. The percentage of adult little penguins that were correctly sexed by discriminant functions based on *BD* and *BL*, and just *BD* in the reference and test data sets.....52
- Table 4. The mean bill depths and bill lengths of little penguins from Reevesby, Greenly, West Franklin and Olive Islands for each sex as determined by the combined DF based on *BD* and *BL*.....55
- Table 5. The proportions of little penguins in each *reference* data set that were correctly sexed using DF from published studies.....56
- Table 6. The mean *BD* for male and female little penguins at 14 colonies and the mean bathymetric depth of the marine areas within a 20 km radius of each colony.....57

### **Chapter 3: Do inter-colony differences in the morphology of little penguins result from differences in food availability?**

- Table 1. Mean bill depth and bill lengths for male and female little penguins from the Troubridge Island and the Pearson Island samples.....71
- Table 2. Summary table of mean fledging mass, adult mass, meal mass during winter (peak breeding), maximum foraging range, maximum dive depth, length of fishing trips and the number of days on land between fishing trips during the breeding season at Troubridge and Pearson Islands...73
- Table 3. Breeding success of little penguins at Troubridge Island 2004-2006) and Pearson Island 2004-2005.....73

## **Chapter 4: The diets of little penguins *Eudyptula minor* and their reliance on Australian anchovy *Engraulis australis* in South Australia.**

Table 1. The number of little penguins from which diet samples were collected from each colony on multiple occasions, the number of samples used in the biomass analyses and the mean sample wet weights.....	88
Table 2. The numbers of left otoliths and lower beaks measured in each erosion class, the mean otolith and lower beak hood, and percentage decrease in otolith length (from original size) due to erosion.....	91
Table 3. The frequency of occurrence of prey taxa at all colonies and prey taxa consumed across all colonies (standardised for colony) in each season.....	96
Table 4. The numerical abundance of prey taxa consumed at all colonies prey taxa consumed across all colonies (standardised for colony) during each season.....	98
Table 5. The daily frequency of occurrence (FO), mean proportional biomass, mean fish size and mass $\pm$ SE. of anchovies, blue sprat and sardines in little penguin diets at Troubridge Island from 7 <sup>th</sup> -13 <sup>th</sup> July 2004.....	98
Table 6. The estimated relative biomass of identified prey taxa consumed at all colonies and prey taxa consumed across all colonies (standardised for colony) during each season.....	99
Table 7. Summary of fish lengths, masses and ages estimated from measurements of otoliths that were removed from little penguin stomach samples at all colonies.....	100
Table 8. Summary table of numbers and weights of fish samples used for the nutritional analyses.....	103
Table 9. The calorific value of each prey species and the proportional lipid and protein composition.....	103

## **Chapter 5: Does the diving behaviour of little penguins differ at sites where their primary prey can access different depths?**

Table 1. Summary table of the size and biomass of meals, prey, and the bill size, body mass and condition of the penguins from which the diet samples were obtained.....	124
Table 2. Summary table of the body parameters and sex of the birds deployed with TDRs and the dive periods from which data was data was recorded.....	126



Table 3. Average dive behaviour variables calculated for foraging trips at Troubridge and Pearson and the significance of differences between averages using unpaired t-tests.....	127
--	-----

## **Chapter 6: Why are some little penguins so little: an effect of Ashmole’s halo on foraging behaviour?**

Table 1. Mean accuracy error of each class of location determined from 24 days of data collected by a PTT in a known location.....	146
--	-----

Table 2. Summary table of foraging variables at each colony.....	153
--	-----

Table 3. Mean foraging parameters; body mass, bill size, fledging mass and breeding success at seven little penguin colonies.....	156
---	-----

Table 4. The ranges of environmental variables in the cells that penguins visited around each of the four study colonies.....	157
---	-----

Table 5. Results of the best five generalised linear mixed effects models with the effects of chlorophyll-a, sea surface temperature, slope, distance from colony, water depth and year on proportional time spent in area by individual penguins.....	158
--	-----

## **Appendix**

Appendix 1. Summary of body mass, sex and foraging parameters of little penguins deployed with satellite transmitters at four colonies.....	188
---	-----