

**The comparative foraging ecology of Royal *Eudyptes schlegeli* and
Rockhopper *E. chrysocome* Penguins**

by

Cindy Lee Hull

BEd, BSc (Hons.)


A thesis submitted in fulfilment of the requirements for the degree of Doctor of
Philosophy in the Science Faculty, Zoology Department

UNIVERSITY OF TASMANIA

July, 1997

Declaration

This thesis contains no material which has been accepted for a degree or diploma by the University or any other institution, and to the best of my knowledge and belief no material previously published or written by another person except where due acknowledgment is made in the text of the thesis.

A handwritten signature in cursive script, reading "Cindy Hull".

Cindy Hull

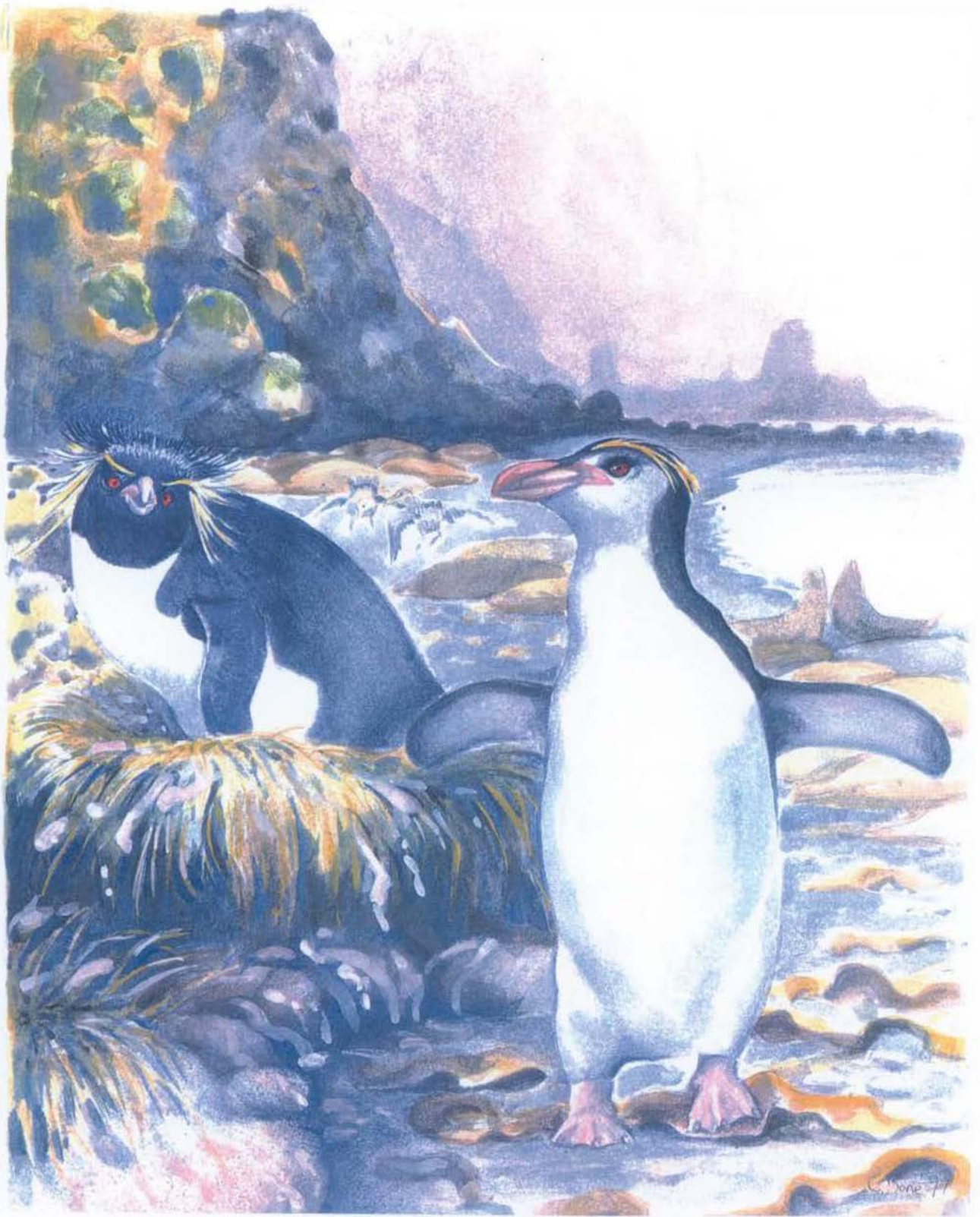
Authority

This thesis may be made available for loan. Copying of any part of this thesis is prohibited for two years from the date this statement was signed; after that time limited copying is permitted in accordance with the *Copyright Act 1968*.

A handwritten signature in cursive script, reading "Cindy Hull".

Cindy Hull

24/7/97



Frontispiece

Watercolour inspired by Royal and Rockhopper Penguins at Macquarie Island.

Catherine Bone, May 1997

Abstract

Penguins are well adapted to the marine environment, spending the majority of their time at sea. Whilst their ecology is intrinsically linked to this environment, details of how they interact with biotic and abiotic aspects of it are not well known for most species. The majority of penguins have a limited breeding season, and commitments at the nest necessitate that their foraging ranges are restricted, presumably placing pressure on prey resources around nesting colonies. Sympatrically breeding species are thought to compete for these resources, and their co-existence is thought possible by the segregation of aspects of their ecologies, in particular foraging zones, diet or the asynchrony in breeding timetables. Royal and Rockhopper Penguins both belong to the *Eudyptes* genus, are ecologically very similar, and breed sympatrically on Macquarie Island. This similarity provides the opportunity to explore the issue of ecological segregation in these two species. The purpose of this study was to describe the foraging ecology of Royal and Rockhopper Penguins and to determine the degree of overlap in resource use. It was undertaken over three years (1993/4, 1994/5 and 1995/6) to examine inter-annual variability.

The thesis is divided into two parts, the first dealing with methodological aspects. Morphometric indices were determined for externally sexing birds in the field. Bill length and depth were found to be reliable measures for sexing individuals of both species. Experiments assessing the impact of investigators on breeding success found no significant effects, provided care was taken when working in the colony. The

deployment of external devices (transmitters and Time Depth Recorders, TDRs) was an integral part of data collection in the study, and the impact of these on Royal Penguins was examined. No effects were found in birds carrying the small, streamlined VHF transmitters, but the attachment of the larger, unstreamlined TDRs decreased the likelihood that penguins would return from a foraging trip, increased foraging trip duration, increased water influx rates, and decreased accumulated fat levels. The different impacts of the devices was related to their size and streamlining most likely affecting drag. Some aspects of the foraging ecology of penguins carrying TDRs were therefore not entirely representative of unencumbered birds.

The second part of the thesis examined the foraging ecology and degree of overlap in resource use in Royal and Rockhopper Penguins. Aspects examined were: foraging zones (using satellite telemetry, TDRs which estimated positions using geolocation, sea surface temperature, and foraging trip durations); diving behaviour; diet; and breeding biology.

Both species foraged offshore, to the southeast of Macquarie Island in the polar frontal zone, further than had previously been estimated (Royal Penguins 600 km and Rockhopper Penguins 480 km). Foraging zones changed with stage in the breeding season, with their extent being related to foraging trip durations, determined by commitments at the nest. The sea surface temperatures in which both species travelled were the same (6.8 - 10.8° C), and constant between years and stages in the breeding season. The position of the polar frontal zone changed during this period, suggesting

that the species targeted a specific part of the zone.

Royal and Rockhopper Penguins were predominantly diurnal foragers, with most diving between the hours of 04:00 and 21:00. They spent 38.9% and 36.6% of a 24 hour period respectively, diving. Both species were capable of diving to over 100 m, but spent the majority of their time at depths less than 60 m in dives of less than 2 minutes duration. This emphasis on shallow, short dives probably maximised foraging efficiency by reducing the degree of anaerobic metabolism, with its associated cost of removing respiratory byproducts, and reduced time spent descending and ascending in the water column, which is presumably less profitable foraging time.

The diet of both species was dominated by small, gregarious pelagic prey, particularly euphausiids (dominated by *Euphausia vallentini*), and myctophid fish (dominated by *Krefftichthys anderssoni*). Diet varied between years, but was constant across the breeding season, although fewer taxa were consumed before, compared to after, the hatching of chicks.

The breeding biology of both species was similar and synchronous between individuals and years of the study, which is most likely related to the limited temporal window these species have in which to breed. The investment in clutches was low (6.3% in Royal Penguins and 7.0% in Rockhopper Penguins), and breeding success was constant between species and years (on average 53.3% in Royal Penguins and 47.3% in Rockhopper Penguins). Most breeding failures occurred during incubation, with

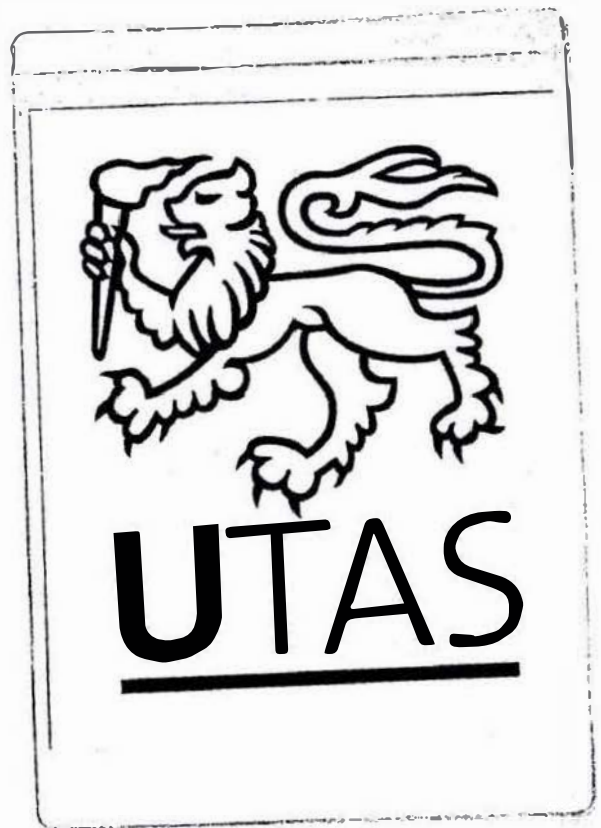
failures in Royal Penguins due to the late return of mates from foraging trips, and in Rockhopper Penguins, predation by skuas. It was speculated that the two species differed in the degree of being "capital" versus "income" breeders.

Inter-annual differences were only found in diet, and Rockhopper Penguin fledging masses, but foraging behaviour of both species was constant, suggesting that prey resources were variable and the species opportunistically consumed those which are encountered. The consistently high breeding success during the study suggests that these years were probably all "good" years in terms of the abundance and accessibility of prey.

Although Royal and Rockhopper Penguins exhibited many similarities in their foraging ecology, the overlap in resource use was not high. The mechanisms (particularly in combination with each other) minimising overlap were differences in: (1) Foraging zones (taking into account the three week asynchrony in the breeding timetables of the two species); (2) Diet, with Royal Penguins consuming larger and more myctophid fish, and fewer euphausiids than Rockhopper Penguins. Further, differences in the degree of digestion of prey suggested that the species foraged on different prey cohorts; (3) Asynchrony in the breeding season, reducing the overlap in peak food demands and the duration of foraging trips (which determined the extent of foraging zones).

This study determined that the foraging ecology of Royal and Rockhopper Penguins was intrinsically linked to the polar frontal zone and regulated by commitments at the nest.

Although these species were similar in aspects of their ecology, the overlap in resource use was less than has been suggested previously.



Acknowledgments

The opportunity to work on Royal and Rockhopper Penguins at Macquarie Island was provided by Mark Hindell, for which I am grateful. Macquarie Island is one of the more fascinating and exciting places in which I have been fortunate to spend considerable amounts of time. The choice of the Sandy Bay site was fortuitous, being arguably one of the more beautiful bays on the east coast. The milder, albeit slightly, climate on the east coast made the long hours working outside easier, and the site abounds with examples of most fauna and flora of the island. Sandy Bay and all Macquarie Island were a constant source of interest as there were also new things to explore and observe. The hut at Sandy Bay was an aircraft engine packing crate established as a field hut in the 1950's. After the initial shock at its small size and basic commodities, and with the help of a number of people to improve the comfort factor, it became home. Its character and charm will always remain with me and it is sad to consider that it is now out of service. Working on Royal and Rockhopper Penguins was another delightful aspect of this project. They are both fascinating and immensely comical species which were a delight to simply observe. Long hours of observation during the project provided the opportunity to watch the antics of these and other species, which provided a great deal of pleasure.

Whilst I have made specific acknowledgments at the end of each chapter, there are some I wish to reiterate. Field assistance during the three years of the project was provided by Mary-Anne Lea, Jane Wilson, Kirsten Le Mar and Paul Scofield. I am grateful to

each of these people who spent extended times at Macquarie Island, being dragged out on those unbearably windy and wild days that Macquarie is capable of. They all showed great tenacity and tolerance. I would particularly like to thank Jane Wilson who spent one and a half seasons on the island for the project. She was great support during the numerous equipment breakdowns and glitches in the project, a great friend and constant source of fun and entertainment.

A number of people assisted in a myriad of ways, from helping carry back the copious quantities of penguin vomit that I collected, to bringing emergency supplies of food, assisting with observations, or fixing things in the hut. I thank the following: Don (Scone face) Hudspeth who will carry anything if bribed with enough cakes, Lance (Larnce) Biddle who can lift anything, Noel Carmichael who will pack anything in a plastic bag, Terry Reid, Scobie Pye, Peter Mantel (Elwood), Catherine Bone, Joan Russell, Sue Robinson, Louise Wynen, Alan Wiltshire, Ken Barrett, Richard Warner, Matt Brading and Graham MacKenzie (Kiwi).

a number of the pieces of technology that ceased to work during field work were ably fixed by Roger Hansworth or Dale Main. Al Rooke as communications officer was a great source of assistance when needing to communicate with places outside Macquarie Island. His interest in the satellite tracking was wonderful and it enabled us to receive daily updates of the location of penguins whilst being in the field. Joan Russell (1994 Station Leader) brought a rare understanding to the community about some of the difficulties of station life for minority groups. Her enthusiasm for science, in particular

biological projects, instilled an interest in all the community which made for a cohesive and co-operative summer station. I am grateful to them all for their help and enthusiasm.

A number of people in Tasmania assisted with parts of the program which I greatly appreciate. Rod Ledingham from the Australian Antarctic Division always had great ideas for solving some of the logistic difficulties and was always generous and helpful when lending equipment. Don Reid was forever helpful and supportive, as was Warren Papworth. Assistance with identifications was provided by Steve Nichol, Graham Hosie, Dick Williams and Dave Slip, all of whom I thank.

From the Zoology Department, University of Tasmania, Richard Holmes adeptly built a number of pieces of equipment including the nets and some of the dummy packs, and Barry Rumbold handled the purchasing and management of accounts. Alan Dumphy was always helpful when finding and lending microscopes and various other pieces of laboratory equipment, and Sherrin Bowden was her usual incredibly efficient, helpful and reliable self in the department. Kit Williams was a wonderful source of help preparing electronic equipment for the vagaries of the Macquarie Island climate, and repairing numerous things after each field season. He also rescued me on a number of occasions from computers and programs that seized, for which I am grateful. Thanks to them all.

I would like to thank a number people who provided advice or assistance on aspects of

biological projects, instilled an interest in all the community which made for a cohesive and co-operative summer station. I am grateful to them all for their help and enthusiasm.

A number of people in Tasmania assisted with parts of the program which I greatly appreciate. Rod Ledingham from the Australian Antarctic Division always had great ideas for solving some of the logistic difficulties and was always generous and helpful when lending equipment. Don Reid was forever helpful and supportive, as was Warren Papworth. Assistance with identifications was provided by Steve Nichol, Graham Hosie, Dick Williams and Dave Slip, all of whom I thank.

From the Zoology Department, University of Tasmania, Richard Holmes adeptly built a number of pieces of equipment including the nets and some of the dummy packs, and Barry Rumbold handled the purchasing and management of accounts. Alan Dumphy was always helpful when finding and lending microscopes and various other pieces of laboratory equipment, and Sherrin Bowden was her usual incredibly efficient, helpful and reliable self in the department. Kit Williams was a wonderful source of help preparing electronic equipment for the vagaries of the Macquarie Island climate, and repairing numerous things after each field season. He also rescued me on a number of occasions from computers and programs that seized, for which I am grateful. Thanks to them all.

I would like to thank a number people who provided advice or assistance on aspects of

the project. These include Rosemary Gales, Geof Copson, Graham Robertson, Kelvin Michael, Brian Green, Keith Newgrain, Christophe Guinet and Melissa Geise. Di Moyle, Morag Anderson, Roger Kirkwood and Kerrie Swadling assisted with proof reading parts of the thesis and I thank them for their time and pedantry.

My post-graduate colleagues at the University of Tasmania have been a great source of inspiration and enjoyment. In particular I would like to acknowledge April Hedd, Di Moyle, Deb Thiele, Dave Slip, Kerrie Swadling, Sam Lake, Cam Bell and Roger Kirkwood.

Many parts of this project could not have been undertaken if it had not been for the generous support of a number of granting bodies. The following grants were received: Antarctic Scientific Advisory Committee for logistic support and equipment during each year of the project; SeaWorld Research and Rescue Foundation for a postgraduate stipend; the M.A. Ingram Trust for the printer; the Trans-Antarctic Association for VHF transmitters; Charles Lindbergh and Anne Morrow Foundation for satellite transmitters; and the Japanese Penguin Fund for ARGOS time. I am grateful to them all.

Finally, I would like to thank my supervisors Mark Hindell for his input throughout the years, and Leon Barmuta for regular statistical advice. Last, but by far from least, thanks go to Peter Arthur for his support and friendship throughout the project, particularly during those long absences; mum for help during the amendment stage; and to Oigle for being patient! I am eternally grateful.

Table of contents

	<i>Page</i>
Declaration and authority	ii
Frontispiece	iii
Abstract	iv
Acknowledgments	ix
Chapter 1 General introduction	1
1.1 Background	1
Ecological segregation in penguin communities	2
Objectives of the study	4
1.2 The study species and site	5
Royal Penguins	6
Rockhopper Penguins	10
The study site, Macquarie Island	11
Field work	15
1.3 Organisation of the thesis	17
 <u>Section A Methodological aspects</u>	
Chapter 2 Morphometric indices for sexing adult Royal and Rockhopper Penguins at Macquarie Island	19
2.1 Introduction	19
2.2 Materials and methods	20
2.3 Results	22
Sexing penguins by morphometric indices	22
Inter-population comparisons	26
2.4 Discussion	29
Sexing penguins by morphometric indices	29
Inter-population comparisons	31
2.5 Summary	32
2.6 Acknowledgments	33

Chapter 3 The effect of investigators on the breeding success of Royal and Rockhopper Penguins at Macquarie Island	34
3.1 Introduction	34
3.2 Materials and methods	35
3.3 Results and discussion	37
3.4 Summary	41
3.5 Acknowledgments	41
Chapter 4 The effect of carrying devices on breeding Royal Penguins	42
4.1 Introduction	42
4.2 Methods	43
Water flux and body composition	44
4.3 Results	46
Transmitters	48
TDRs	48
4.4 Discussion	50
Effect of tritiated water experiments	50
Effects of devices	51
4.5 Summary	54
4.6 Acknowledgments	55
 <u>Section B Foraging ecology</u>	
Chapter 5 The foraging zones of Royal Penguins during the breeding season, and their association with oceanographic features	56
5.1 Introduction	56
5.2 Materials and methods	58
Deployments	58
Preliminary analysis/filtering	59
Foraging zones	61
Oceanographic influence	62
5.3 Results	63

Satellite tracking data	63
Travelling behaviour	65
Home range analysis	67
Oceanographic influence	76
5.4 Discussion	76
ARGOS data	76
Effects of devices	78
Travelling behaviour	79
Foraging zones and oceanographic influence	80
Conclusion	84
5.5 Summary	84
5.6 Acknowledgments	85
Chapter 6 The foraging zones of breeding Royal and Rockhopper	87
Penguins: a species comparison and assessment of techniques	
6.1 Introduction	87
6.2 Materials and methods	89
Techniques for measuring foraging zones	89
1. VHF telemetry	89
2. Satellite telemetry	90
3. Time Depth Recorders with geolocation (TDRs)	90
4. Sea Surface Temperature (SST)	90
5. Foraging trip durations	91
Deployment of devices	91
Data extraction and analysis	92
6.3 Results	95
1. VHF telemetry	95
2. TDRs	96
Geolocation	96
Errors	96
Locations from geolocation	98

Table of contents

2. Sea surface temperature	99
3. Foraging trip durations	104
Overlap in foraging zones	105
6.4 Discussion	109
Assessment of techniques	109
Geolocation	109
Sea surface temperature	109
Foraging trip durations	110
Foraging zones of Royal and Rockhopper Penguins	111
Overlap in foraging zones between the species	112
6.5 Summary	113
6.6 Acknowledgments	114
Chapter 7 Aspects of the diving behaviour of Royal and Rockhopper	116
Penguins: a comparative examination of the use of the water column	
7.1 Introduction	116
7.2 Materials and methods	117
1. Description of diving behaviour	119
2. Use of water column	121
7.3 Results	121
Foraging trip durations	122
1. Diving behaviour	123
Daily diving activity	123
Rate of diving	123
Time spent submerged	128
Diving depths	128
Diving durations	133
Ascent and descent rates	135
Diving activity across a foraging trip	136
Royal Penguins	136
Rockhopper Penguins	136

Differences between the sexes during creche stage	137
2. Use of the water column	139
7.4 Discussion	143
Effects of devices	143
1. General diving behaviour	144
Diving in relation to prey species	148
Differences in use of the water column by Royal and Rockhopper Penguins	150
Comparisons to Macaroni and Rockhopper Penguins at other sites	151
7.5 Summary	153
7.6 Acknowledgments	154
Chapter 8 The diet of Royal and Rockhopper Penguins during the breeding season: a species and inter-annual comparison	160
8.1 Introduction	160
8.2 Materials and methods	162
Diet sampling	162
Identification of prey items	164
Crustaceans	165
Cephalopods	165
Fish	166
Composition of diet	167
Degree of digestion of samples	168
Statistical analyses	168
8.3 Results	170
Quantity of food brought ashore	170
Diet	172
Degree of digestion	183
Dietary overlap	186
Pre-hatching	186

Post-hatching	186
8.4 Discussion	1891
Effects of stomach flushing	191
The diet of Royal and Rockhopper Penguins	191
Biology of the prey species and penguin foraging	192
Seasonal and inter-annual changes in diet	197
Quantity of food	199
Comparisons to previous studies	200
Overlap in diet	205
8.5 Summary	207
8.6 Acknowledgments	208
Chapter 9 Aspects of the breeding biology of Royal and Rockhopper	228
Penguins: a comparative and inter-annual study	
9.1 Introduction	228
9.2 Materials and methods	230
1. Adult mass change	233
2. Parental attendance	234
3. Nest monitoring: breeding chronology, egg	236
morphometrics, chick growth and fledging mass,	
and breeding success	
Egg morphometrics	237
Chick growth	238
Breeding success	239
9.3 Results	240
Adult masses	240
Pre-hatching	240
Post-hatching	241
Parental attendance and foraging trip duration	247
Breeding chronology	249
Egg morphometrics	250

Table of contents

Chick growth	251
Fledging mass	251
Breeding success	255
9.4 Discussion	259
General breeding biology of Royal and Rockhopper Penguins	260
Differences between the species	264
Inter-annual comparisons	266
9.5 Summary	269
9.6 acknowledgments	270
Chapter 10 General discussion	271
10.1 Objectives of the study	271
10.2 Results of the study	272
Section A Methodological aspects	273
Section B Foraging ecology	275
10.3 Inter-annual comparisons	281
10.4 Overlap in resource use by Royal and Rockhopper Penguins	282
1. Foraging zones	283
2. Diet	283
3. Breeding timetables	284
References	287