

**THE FORAGING ECOLOGY OF THE SHORT-TAILED
SHEARWATER PUFFINUS TENUIROSTRIS**

A thesis submitted for the degree of
Doctor of Philosophy
Adelaide University

May 2009

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Declaration

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ABSTRACT

The short-tailed shearwater *Puffinus tenuirostris* is one of the world's most abundant seabirds, with a population of around 23 million breeding birds. Despite this abundance we have a limited understanding of their role in the marine ecosystem. This is largely due to the many uncertainties surrounding the trophic interactions, resource requirements and foraging ecology of this wide ranging pelagic seabird. I studied the movement of adults during the short trip (ST) and long trip (LT) component of their dual foraging strategy to determine how they use their marine habitat. ST were primarily confined to neritic (continental shelf) waters 30 to 100 km from their colony, and maximum depth gauges revealed that birds reached a depth of 21 ± 13 m (SD). Analysis of the time spent in area by 39 individuals performing ST revealed that 18 birds employed area restricted searches within circles of a diameter of 14 ± 3 km (SE). Prey returns from area restricted search flights were predominated by bony fish, whereas prey diversity increased for non-area restricted search flights, with more krill and cephalopods. Thus, direct flights were performed when birds were exploiting prey patches dominated by fish, in contrast to the more varied diet returned when birds covered greater distances. LT flights were highly variable ranging from 11 - 32 days duration, and reaching 912 – 6,952 km from the colony. Foraging trips of extended duration enabled birds to exploit temperate waters further away from the colony, as well as sub Antarctic and Antarctic waters. A wider range of search patterns were performed on LT, as birds either: (1) showed no signs of area restricted search; (2) concentrated area restricted search directly at small scales of within circles of 33 ± 11 km (SE) diameter; or, (3) adopted a hierarchical mode of foraging, where large scales of area restricted search are first performed, followed by nested searches at smaller scales. This variation in foraging behaviour indicates that a range of foraging tactics are employed by the short-tailed shearwater. LT to sub Antarctic and Antarctic waters commonly involved a period of commuting travel to regions with elevated chlorophyll *a* associated with ocean fronts, where search effort was increased.

How adults allocated time and energy during the entire chick-rearing period was investigated via the simultaneous assessment of adult attendance, adult mass change, the rate of energy delivery to chicks, and chick survival. Adults who reared chicks to good condition spent 80 % of the 90 day chick rearing period performing five - six LT of 13 ± 3 days (SE)

duration. The remaining 20 % of time involved 14 ± 3 ST (SE) of one to three days duration. Comparison with chicks of moderate and poor condition revealed that, despite extensive variation in the day to day rate of provisioning, a small change in the proportion of time spent performing ST and LT over the entire chick rearing period can spell the difference between breeding success and failure. By allocating all of the food collected on ST to chicks birds depleted stored energy reserves, which were replenished on LT. Of the total energy required by chicks from hatching to adult abandonment 75 % was delivered from LT in the form of energy rich stomach oil, with the remainder being supplied in ST meals of raw prey. The advantages of the dual foraging strategy to both adult and chick was demonstrated by considering the daily food requirements of chicks and the likely energy flow from alternate feeding regimes. Under regimes of all ST or all LT, energy flow to chicks could not meet chick energy requirements. This highlights that LT of more than seven days duration are required to accumulate stomach oil. Oil boosts the energy value of meals beyond that achievable in continuous ST foraging. Under continuous ST the estimated rate of food consumption achieved by adults would not sustain both adult and chick requirements. Therefore the dual strategy enables short-tailed shearwaters to overcome many of the constraints of central-place foraging.

Comparisons between years and short-tailed shearwater colonies revealed extensive variation in the dietary composition of meals returned to chicks, as well as the rate of food delivery. A year of increased ST foraging resulted in an increase in feeding frequency, but not provisioning rate, as smaller meals were returned. In this same year ST meals also contained a high % mass of low energy neritic prey (Australian krill *Nyctiphanes australis* and cephalopods). These factors reduced the rate of energy flow to chicks compared to other years where fewer ST meals of increased mass contained mostly higher energy fish (jack mackerel *Trachurus declivis* and anchovy *Engraulis australis*). While the rate of chick growth at different ages varied between years, a similar peak mass was gained in all three years. These findings demonstrate considerable flexibility in the dual foraging strategy of the short-tailed shearwater, providing evidence that adults are able to maintain a suitable rate of energy flow to chicks in years of varied neritic foraging conditions. This is achieved by modifying the time spent performing ST, and the volume of oil returned from LT, likely in response to changing prey availability.

A review of the use of seabirds in fisheries management identified the most commonly used indicators (species and parameters) in environmental, ecological and fisheries management. For the short-tailed shearwater the most useful parameters for identifying the size of pelagic fish stocks in neritic waters include the size and dietary composition of meals returned on ST. The varied importance of pilchard *Sardinops sagax* and anchovy *Engraulis australis* in the diet between years suggest that their occurrence in the diet meals present a potential indicator of the availability of pre-recruits into the South Australian pilchard fishery. The occurrence of Australian Krill in ST meals may also provide a means of investigating the ecological role of upwelling events in neritic waters. The usefulness of provisioning parameters as indicators of prey availability are likely to be limited in this species, due to the extent of flexibility and plasticity in the short-tailed shearwaters provisioning strategy.

Documenting the extent of flexibility in the foraging strategy, and quantifying the value of the ST and LT component of the dual foraging strategy has provided an insight into the habitat utilisation and prey requirements of this species. This demonstrates that despite the various constraints incurred in sourcing and transporting prey over long distances, dual foraging presents the most optimal foraging strategy for the delivery of energy to adult and chick. The sheer abundance of this species is evidence that the separation of their foraging and breeding grounds over 3000 km is a beneficial strategy. An opportunistic diet, and flexibility in foraging suggests that the short-tailed shearwater is more resilient to changes in prey availability than other seabirds in their community. However, we have highlighted that breeding success is sensitive to small changes in the time spent foraging in near and distant waters. Sourcing prey over large spatial scales also exposes birds to feeding conditions over a broader area, increasing their exposure to the potential effects of current and future climate change. For these reasons the short-tailed shearwater presents a valuable indicator species for short and long-term monitoring programs of both neritic and oceanic ecosystems.

ACKNOWLEDGEMENTS

Firstly, thank you to Brad Page for making me realise the beauty of the shearwater, and getting me started on this PhD. Brad has played an absolutely pivotal role in this thesis, from the initial development of concepts and assistance in the field, through to final analysis, and comments on drafts. Thanks also to my primary supervisor Simon Goldsworthy for support throughout the entire PhD. It was a truly great to be in a position where there were very few restrictions or limitations on what we could achieve through this research, and I thank you for making it happen. To David Paton, I thank you for keeping me in check with my university requirements, and also for your encouragement throughout this period. I have very much enjoyed our infrequent but interesting chats over the years. Thanks to all the staff and admin at SARDI –Aquatic Sciences, who made my time there super enjoyable, and assisted with the logistics involved in field work, and making this whole thing possible. Particular thanks to those who have become good friends, you know who you are. I am also very grateful for the efforts and involvement of the staff from DEH-Ceduna, particularly Brett Dalzell and Robbie Sleep. There were some very adventurous island trips of which I will remember for all time. Thanks to my mum for having such a keen interest in this project, for supporting all of my endeavours, and for joining me on the islands on two field trips. To my dad, thanks for many interesting discussions about my research and my findings- I know its never too late for lateral entry into med school, but it never going to happen. And, finally to my wife Cath- You have been an incredibly tolerant and forgiving partner and friend over the years to put up with my extended absences from home through the summer months. Your interest in this work, support, and encouragement over the years has helped me get through, and made it all so much more enjoyable, so thank you.



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