

**The population status, breeding success and foraging ecology  
of *Phoebetria* albatrosses on Marion Island**

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**Dissertation presented for the degree of Master of Science  
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**August 2015**

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## **Acknowledgements**

I thank God for the opportunity to undertake this project and seeing it through to the end. I would also like thank my supervisor, Prof. Peter Ryan, for enabling me to spend a year on Marion Island and for the opportunity to undertake this research project. Also for all the guidance, mentoring and useful comments during the development and final stages of the project. Thanks also go to Kim Stevens, Ben Dilley, Delia Davies, Maëlle Connan, Alexis Osborne and Vonica Perold for all the long hours spent in the field. I appreciate the help from all M70 expedition members that spent time with me collecting data in the field (especially Carson McAfee).

Further I thank everyone at the Percy FitzPatrick Institute that helped in any small way to make this project a reality, you are a great bunch of people. I appreciate all the help with data analysis from Petra Sumasgutner (linear modelling), Otto Whitehead (GPS data), Jaimie Cleeland (GLS data) and Maëlle Connan (isotope analysis). On the admin side Hilary Buchanan was a great help in making everything go smoothly.

The Department of Environmental Affairs provided logistic support during my stay on Marion Island. The Percy FitzPatrick Centre of Excellence and South African National Antarctic Programme, through the National Research Fund that funds this project. Thanks to all friends and family for their support and advice. Lastly, I give thanks to my loving wife Janine for all your support, numerous cups of coffee and enduring all the late nights of typing.

## Abstract

Seabird populations breeding within the Southern Ocean have experienced various threats over the past few decades. Albatrosses are particularly at risk due to several factors, *inter alia*, accidental bycatch on fishing gear, ingestion of polluted marine debris, invasive predatory species at breeding sites, as well as climate change-induced alterations to ocean circulation patterns. The recent decline in many albatross populations is mainly attributed to incidental fishing mortality, which decreases adult as well as juvenile survival rates and is thus detrimental to these long-lived, low fecundity birds. Recently, changes in fishing regulations to require the use of various mitigation measures have reduced the number of seabirds killed by fishing vessels. However fisheries may still impact seabirds either by direct competition for the same prey, or through ecosystem cascades arising from the removal of predatory fish and squid. Sub-Antarctic islands are important breeding grounds for many seabirds, including albatrosses. Monitoring of seabirds breeding on sub-Antarctic islands is important to detect changes in population dynamics to be able to implement timely conservation measures.

Marion Island, the larger of the two Prince Edward Islands, some 2000 km southeast of South Africa, is a breeding site for four albatross species including the sooty (*Phoebastria fusca*) and light-mantled albatrosses (*P. palpebrata*). The Prince Edward and Crozet Islands are the only places where both *Phoebastria* albatrosses breed sympatrically in substantial numbers. Both archipelagos are 46°-47°S, at the southern and northern limit for sooty and light-mantled albatrosses, respectively. At-sea observations and diet studies suggest that sooty albatrosses forage mainly in sub-tropical waters to the north and light-mantled albatross in Antarctic or sub-Antarctic waters to the south. The sooty albatross is listed as Endangered due to recent global population declines whereas the light-mantled albatross is Near-threatened. The only comprehensive study of these species at the Prince Edward Islands was conducted during the late 1970s but annual estimates of breeding populations have been made from 1996 onwards. The previous analysis of these counts, up to 2008, suggested that the sooty albatross population on Marion Island decreased from 1996 to 2008, whereas numbers of light-mantled albatrosses increased over this period. Extending the count series to 2014, trends for both species were reversed, with sooty albatrosses recently increasing and light-mantled albatrosses decreasing. However, the timing of sooty albatross counts is in question as these were done towards the end of the incubation period when many nest failures have already occurred. Breeding success of both *Phoebastria* albatrosses was estimated during 2013/14 and 2014/15. The success of sooty albatrosses (51% overall) was higher than estimated at Marion Island in the 1970s (19%), but it was still lower than that of a neighbouring colony on Possession Island, Crozet archipelago (65%). The sooty albatross success was however skewed by a sub-colony with a very low

breeding success; excluding this sub-colony the breeding success is similar to that of the Crozets. Light-mantled albatross breeding success was the same as past estimates and lower than colonies at Macquarie and Possession Islands. Additional monitoring of a sub-sample of nests within the monitoring colonies was done to determine incubation and brood guard (light-mantled albatross only) shift lengths for both species. The shift lengths and distributions were not significantly different from previous data on Marion Island or other breeding sites.

No tracking data have been published for sooty or light-mantled albatrosses from Marion Island. Established breeders from both species were tracked with GPS loggers during the 2013 and 2014 breeding seasons, while GLS loggers were used to track birds during the non-breeding periods during 2012 and 2013. Tracking data from the GLS loggers were supplemented with isotope analysis of feather samples collected during retrieval of the GLS loggers. All three techniques showed similar results during breeding and non-breeding periods, with sooty albatrosses occurring mainly within the sub-Antarctic and sub-tropical zones, whereas light-mantled albatrosses ranged further south in the sub-Antarctic and Antarctic zones. Foraging grounds of sooty albatrosses during the breeding season was associated with meso-scale eddies, especially close to the Sub-Tropical Front. Sooty albatross distribution during the breeding period showed a large amount (70% of points) of overlap with long-lining fishing effort in the southern Indian Ocean, whereas light-mantled albatrosses showed negligible levels of overlap with fisheries as all points were in areas with annual catches lower than 10 tons. This study suggests that the differing conservation status of these closely related albatross species may be linked to their distribution in the Southern Ocean.

This study provides direct observations supporting previous distribution estimates of spatial segregation between sooty and light-mantled albatrosses. The population trends observed for light-mantled and sooty albatrosses in the past were contrary to expectations as poleward movement of major fronts in the Southern Ocean is expected to favour birds foraging north of the Antarctic Polar Front (APF) and have a negative effect on birds that forage to the south as the distance between breeding and foraging grounds is increased. However, these counts were done towards the end of the incubation period reducing the accuracy of the counts as many nest failures are not accounted for. The breeding success of *Phoebastria* albatrosses on Marion Island may be linked to climate changes in the southern Indian Ocean with sooty albatrosses being positively and light-mantled albatrosses negatively influenced. Although sooty albatrosses are not affected by fishing operations close to Marion Island, 30-74 birds were killed on long-line fishing gear in the high seas of the southern Indian Ocean by Taiwanese fishing vessels alone between 2004 and 2007. Fishery-related mortality was thought to be the main reason for recent sooty albatross declines on Marion Island. However, recent increases in sooty

albatross population sizes on Marion Island suggest that fishery related mortalities in the southern Indian Ocean might be decreasing for these birds. More accurate counts are needed to determine if the sooty albatross population size is actually increasing on Marion Island and methods for doing this is discussed. This study is the first comprehensive study of *Phoebetria* albatrosses on Marion Island since the 1970s addressing a range of questions regarding the status and at-sea distribution of these birds.

## Chapter 1: Introduction and study design

Amongst marine animals, seabirds are some of the best studied species, making them particularly useful in studying the effects of threats within their ecosystems (Croxall et al. 2012). Albatrosses are wide ranging pelagic birds when not breeding, but they function as central place foragers during the breeding period (Tickell 2000) when they return to land and are easily accessible to study (Nel et al. 2002a) making them good indicators of ecosystem quality (Boyd et al. 2006, Frederiksen et al. 2007). Pelagic species are one of the most threatened groups of birds, especially albatrosses and petrels (Croxall et al. 2012). Of the 22 albatross species 15 are Threatened while the remaining species are Near-threatened (ACAP 2015a, IUCN 2015), however accurate population trends are known for only a few of these species (Croxall et al. 2012). The available habitat for wide-ranging seabirds is a vast space with a range of different variables shaping it, while mesoscale oceanographic features play an important role regarding their foraging grounds (Bost et al. 2009). It is therefore important to study a wide range of species when using these top predators to monitor and predict the effects of a changing environment (Frederiksen et al. 2007).

Within the genus *Phoebastria*, the sooty albatross (*P. fusca*) is listed as Endangered (ACAP 2015b, IUCN 2015) while the light-mantled albatross (*P. palpebrata*) is listed as Near-threatened (ACAP 2015c, IUCN 2015). The poor conservation status of the sooty albatross is the result of a population decline within several breeding colonies (Delord et al. 2008), including at the Prince Edward Islands (Ryan et al. 2009). Changes in population trends and breeding success of *Phoebastria* albatrosses have been linked to changes in environmental conditions and anthropogenic pressures such as fisheries related mortalities (Inchausti et al. 2003, Delord et al. 2008, Rolland et al. 2010)

It is widely accepted that our climate is currently changing at a faster rate than in the past 1000 years (Walther et al. 2002, Weimerskirch et al. 2003, Barbraud & Weimerskirch 2006, Pendlebury & Barnes-Keoghan 2007, Møller et al. 2008, le Roux & McGeoch 2008). Climate changes may not be as simple as gradual increases in sea surface temperature, as extreme events such as El Niño Southern Oscillation (ENSO) may cause localised changes for the duration of the event (Walther et al. 2002, Crawford et al. 2003b), while different species might react differently to these events (Rolland et al. 2010). Changes in climate at breeding grounds may provide suitable environments for previously absent pathogens or parasites (Walther et al. 2002), which has been documented on sub-Antarctic islands where avian cholera resulted in mass mortality of seabirds (Cooper et al. 2009) or increased mortality of chicks (Bergstro et al. 1999). Warming of higher latitude climates may also increase the chance breeding seabirds



reaching their upper temperature limits (Walther et al. 2002), especially chicks that might not be able to move far from their nests.

Other threats to seabirds include mortality from fisheries bycatch (Gales et al. 1998) and habitat degradation or mortality due to introduced species (Sekercioglu 2006, Croxall et al. 2012) or more subtle threats like build up from pollutants such as heavy metals or plastics (Goutte et al. 2014, Jiménez et al. 2015). Long-term datasets are crucial for conservation of long lived seabirds such as albatrosses as lag periods of population change may be several years (Weimerskirch et al. 2003). Numerous studies have used such long-term datasets to show population changes in response to different environmental and anthropogenic influences (Nel et al. 2002a, Croxall et al. 2002, Weimerskirch et al. 2003, Barbraud & Weimerskirch 2006, Delord et al. 2008). The last estimate of *Phoebetria* albatross population trends on Marion Island was for the period 1996-2008 (Ryan et al. 2009) while breeding success was last estimated in the 1970s (Berruti 1979). This highlights the need for an update on the population trends and breeding success of both species on Marion Island.

## **Study species**

Among *Phoebetria* albatrosses the sooty albatross mainly occurs between 30° S and 50° S and only breeds at islands in the Indian and Atlantic Oceans north of the Antarctic Polar Front (APF), whereas the light-mantled albatross breeds mainly south of the APF with a circumpolar distribution mainly south of 40° (Table 1.1; Berruti 1979, Tickell 2000, ACAP 2015b, 2015c). Marion Island, at 47° S, is located where these species overlap, lying at the southern and northern breeding limits for sooty and light-mantled albatrosses, respectively. Sooty albatrosses have the larger (~1400 annual breeding pairs) population of the two species on Marion Island (~600 annual light-mantled albatross pairs; Ryan et al. 2009). The Prince Edward Islands provide breeding grounds for 23% and 4% of the global sooty and light-mantled albatross population, respectively (Table 1.1; Ryan & Bester 2008, ACAP 2015b, 2015c).

The global population trend of light-mantled albatrosses are either stable or increasing (ACAP 2015c, Delord et al. 2008), and the Marion Island population increased from 1996 to 2008 (Ryan et al. 2009). Studies on *Phoebetria* albatrosses are limited in literature as these cliff nesting species are hard to work with (Ryan & Bester 2008, Ryan et al. 2009) and little information has been published on their movements, especially for sooty albatrosses (Weimerskirch & Robertson 1994, BirdLife International 2004, Phillips et al. 2005a, Phalan et al. 2007, Lawton et al. 2008, Phillips et al. 2008, Cherel et al. 2013, ACAP 2015b, 2015c). On Marion Island both species have been tracked with satellite transmitters (PTTs), but none of these tracks have been published in peer-reviewed journals.

Berruti (1979) undertook the first comprehensive study on *Phoebastria* spp. on Marion Island. He described the breeding biology of the birds, estimated their breeding success and inferred their foraging ecology by examining diet samples from chicks. He studied both species, however during the 1970s the light-mantled albatross population was very small on Marion Island and thus his sample sizes were very small ( $n = 16$ ). Results from Berruti's (1979) work and more recent publications (Cooper & Klages 1995, Connan et al. 2014) suggest that sooty albatrosses from Marion Island feed mainly north of the APF and light-mantled albatross feed towards the south during the breeding period. During winter (and summer non-breeding periods), stable isotope data from Marion Island (Cherel et al. 2013, Connan et al. 2014), Gough, Amsterdam and Kerguelen Islands (Cherel et al. 2013), the Crozet Islands (Jaeger et al. 2010a, Cherel et al. 2013) and Bird Island, South Georgia (Phillips et al. 2009, Cherel et al. 2013) suggest sooty albatross feed mainly north of the Sub-Tropical Front (STF) in sub-tropical waters and light-mantled albatrosses mainly stay within sub-Antarctic waters (Jaeger et al. 2010a, Cherel et al. 2013, Connan et al. 2014) which is similar to birds breeding on Possession Island, Crozet archipelago (Jaeger et al. 2010a). All sooty albatross populations seem to follow a similar distribution during the non-breeding period staying within sub-tropical waters, except birds from Gough Island that prefer sub-Antarctic waters (Cherel et al. 2013), while all light-mantled albatross populations seem to stay within Antarctic and sub-Antarctic waters for most of the non-breeding period (Phillips et al. 2009, Cherel et al. 2013).

At the Prince Edward Islands, sooty albatrosses lay eggs in October, which hatch in mid-December, and their chicks fledge in May (Berruti 1979). Light-mantled albatrosses lay about a month later at the end of October and their chicks fledge in June (Berruti 1979). Both species display strong site fidelity with adults normally breeding within the same colony (Berruti 1979). Both species are biennial breeders and do not return to breed in successive years after successfully rearing a chick (Thomas et al. 1983, Tickell 2000, Jouventin & Dobson 2002), however this has not been confirmed with demographic study on Marion Island. The delayed breeding of light-mantled albatrosses, together with spatial and trophic segregation while foraging has been proposed as reasons why these similar species can breed together on the same island (Berruti 1979, Jaeger et al. 2013). Berruti (1979) hypothesised that the two species do not compete for nesting sites on Marion Island. It is important to study these similar species as a changing environment may alter their distribution and phenology, changing when and where they interact with anthropogenic stressors (e.g. fisheries, introduced species) which are particularly relevant for the Endangered sooty albatross.

## Study design

The aims of this study are threefold for both sooty and light-mantled albatrosses breeding on Marion Island. Firstly, to provide an update on both species' population trends and breeding success. Sooty albatrosses are expected to have similar success and trends to neighbouring colonies at the Crozet archipelago. Secondly the at-sea breeding distribution and foraging areas are described. Spatial segregation of the two species is expected during the breeding period with sooty albatrosses to the north and light-mantled albatrosses to the south of the island. Lastly the non-breeding distributions of sooty and light-mantled albatrosses are described. Both species are expected to conform to distribution estimates from stable isotope analysis with sooty albatrosses overwintering in warmer sub-tropical waters and light-mantled albatrosses within the sub-Antarctic.

The first chapter explains why the study of albatrosses is important and provides an outline of the current knowledge of *Phoebetria* albatrosses, focussing on Marion Island. A summary of the genus *Phoebetria* is provided. The second chapter provides current breeding success data from two years of monitoring colony data and explores different reasons for nest failures. Several colonies of both species were monitored during the 2013/14 (referred to as the 2013 season) and 2014/15 (referred to as the 2014 season) breeding seasons. The population trend is also updated from annual counts between 1996 and 2014, while monitoring colony data are used to propose improved count methods. In Chapter 3 data from GPS tracked birds during the breeding season are used to determine distribution and foraging areas during this period. The foraging areas are compared to environmental variables and fishing effort. The last data chapter (Chapter 4) describes the non-breeding distribution of *Phoebetria* albatrosses and data from using GLS loggers and feather stable isotope analyses. The GLS tracks and isotope results are compared to look for possible overlap to estimate moulting areas for individual birds. Finally the fifth chapter summarises the main findings and recommendations for future research.

**Table 1.1: The global breeding locations and population estimates of all sooty and light-mantled albatrosses.**

Location	Species	Population size *	% of Global	Trend
Tristan Archipelago (37°S, 12°W)	SA	3750	26	Unknown
Amsterdam & St. Paul Islands (38°S, 77°E)	SA	488	3.7	Unknown
Gough Island (40°S, 10°W)	SA	5000	35.7	Stable <sup>a</sup>
Crozet Archipelago (46°S, 51°E)	SA	2264	15.8	Decreasing <sup>b</sup>
	LMA	2323	11.2	Increasing <sup>b</sup>
Prince Edward Islands (47°S, 37°E)	SA	2493	18.8	Decreasing <sup>c</sup>
	LMA	657	3.2	Increasing <sup>c</sup>
Kerguelen Islands (49°S, 69°E)	SA	5	< 0.1	Unknown
	LMA	4000	19.6	Unknown
Antipodes Islands (50°S, 179°E)	LMA	250	1.2	Unknown
Auckland Islands (51°S, 166°E)	LMA	5000	24.4	Unknown
Campbell Island (52°S, 169°E)	LMA	1600	7.8	Unknown
Heard & McDonald Islands (53°S, 73°E)	LMA	350	1.7	Unknown
South Georgia (54°S, 38°W)	LMA	5000	24.4	Unknown
Macquarie Island (54°S, 158°E)	LMA	1281	6.3	Stable

\*approximate annual pairs and trends (ACAP 2015b, 2015c). SA: sooty albatross; LMA: light-mantled albatross

*a* - Cuthbert et al. 2014, *b* - Delord et al. 2008, *c* - Ryan et al. 2009

## Chapter 2: Population trends and breeding success of sooty and light-mantled albatrosses on Marion Island

### Abstract

The last assessment of *Phoebastria* albatrosses breeding on Marion Island reported that, since 1996 sooty albatrosses (*P. fusca*) were declining at almost 2% while light-mantled albatrosses (*P. palpebrata*) were increasing at almost 6% per annum up to 2008. During the 2013 and 2014 breeding seasons, the breeding success of sooty and light-mantled albatrosses on Marion Island was calculated at three monitoring colonies for each species. Additional monitoring on a subsample of nests was done to determine the incubation and brood guard shift lengths of both species. Extending the annual counts to 2014 showed a reversal of trends with sooty albatrosses currently increasing with a population size similar to the 1970s while light-mantled albatrosses seem to be decreasing. Breeding success for sooty albatross (mean 51% and 95% confidence interval (CI) 36-61%) increased compared to the 1970s estimate (mean 19% and CI 8-30%), while light-mantled albatrosses stayed the same at 31% for both periods. The increase in breeding success might be linked to climate changes where sooty albatrosses foraging north of the Antarctic Polar Front (APF) may be positively influenced as poleward warming of the Southern Ocean reduces the distance of foraging grounds from their breeding site, while light-mantled albatrosses forage south of the APF and may be negatively influenced as foraging sites move further south. The incubation and brood guard (light-mantled albatross only) shift lengths and distributions were not significantly different from previous recordings at Marion Island and other breeding sites. The increasing population trend of sooty albatrosses may be resulting from mitigation measures implemented in fisheries in the southern Indian Ocean reducing fishery related mortality of adult sooty albatrosses. More data are needed to confirm this however. Confidence in island-wide counts is low due to the cryptic nature of the albatrosses on their largely inaccessible cliff-side nest sites, as well as counts for sooty albatrosses taking place rather late in the incubation period when 10–20% of nests have already failed. Most light-mantled albatrosses breed at low densities inland, making it particularly hard to monitor their population trends. Given the greater conservation concern for the sooty albatross, it is recommended that dedicated annual counts be conducted during the early incubation period, and where possible, be repeated shortly after the chicks hatch and again towards the end of the nestling period, to give a better idea of breeding success. Count zones should be revised to facilitate more accurate counts. Implementing these measures should ensure more reliable estimates of *Phoebastria* albatross population trends at Marion Island.

## Introduction

Long-term data-sets are important to determine the effects of climate change and other threats (e.g. fisheries bycatch and introduced species) on Southern Ocean communities (Weimerskirch et al. 2003, Delord et al. 2008, Cuthbert et al. 2014). This is especially relevant for long-lived species with long generation times as these species may take longer (or be unable) to respond to environmental change and other anthropogenic impacts. Long-term data sets can aid in determining seabird responses to environmental variations, such as El Niño Southern Oscillation (ENSO) events or fishing pressure (Crawford et al. 2003b, Nel et al. 2003, Rolland et al. 2010).

Both *Phoebetria* albatrosses are biennial breeders (Berruti 1979, Weimerskirch et al. 1987, Tickell 2000) and like all albatrosses and petrels have higher adult survival rates, which compensate for their low fecundity (Jouventin & Weimerskirch 1984, Weimerskirch et al. 1987). The survival rates of adult sooty and light-mantled albatrosses are estimated at 95%-96% and 97.3% respectively (Jouventin & Weimerskirch 1984, 1986, Jouventin & Dobson 2002), however survival rates are not known at most breeding locations, including Marion Island (ACAP 2015b, ACAP 2015c). The current trends for *Phoebetria* albatrosses are not well known (Table 1.1; Delord et al. 2008, ACAP 2015b, ACAP 2015c) with a lot of the trends relying on crude estimates (Ryan et al. 2009), which are attributed to these birds nesting in cryptic, often inaccessible areas and high failure rates during early incubation stages (Berruti 1979).

The Prince Edward Islands are important breeding ground for sooty albatrosses as they support ~19% of the global breeding population which is second only to the Tristan-Gough Island group (ACAP 2015b) whereas only ~3% of light-mantled albatrosses breed there (Table 1.1; ACAP 2015c). Sooty albatross population sizes seem to be declining over the last few decades up to 2008 at Crozet (4.2% annual decrease from 1979–2005; Delord et al. 2008) and Marion Island (2% annual decrease from 1996–2008; Ryan et al. 2009) while being stable over the last decade at Gough Island (2000–2011; Cuthbert et al. 2014). Sooty albatross numbers breeding on Ile Possession in the Crozet Islands suffered a great reduction in population size around 1980 (Delord et al. 2008) and similar reductions were inferred on Marion Island around 1998 (Ryan et al. 2009). Light-mantled albatrosses appear to be increasing at their northern breeding sites, Crozet and Prince Edward Islands (Delord et al. 2008, Ryan et al. 2009), while no long-term data are present for South Georgia and the Auckland Islands, which are the largest breeding grounds for these birds (Table 1.1; Poncet et al. 2006, Tickell 2000, ACAP 2015b).

Long-term monitoring data for *Phoebetria* spp. are mostly comprised of annual breeding population estimates (Crawford et al. 2003a, Cuthbert & Sommer 2004, Delord et al. 2008, Ryan

et al. 2009), however many of the key sites do not have known trends (Delord et al. 2008, ACAP 2015b, 2015c) or estimates are extrapolated from small monitoring areas (Cuthbert & Sommer 2004, Cuthbert et al. 2014). Many studies also rely on outdated or extremely crude data due to the difficulty of accessing these birds (Tickell 2000). This lack of data are often the case with endangered species (Sinclair et al. 2006) such as the sooty albatross increasing the difficulty of implementing effective conservation measures to protect these birds.

Since 1996, annual counts of breeding sooty and light-mantled albatrosses have been conducted at Marion Island, the larger of the two Prince Edward Islands (Ryan et al. 2009). Counts of sooty albatrosses breeding at seldom-visited Prince Edward Island almost doubled from 2001 to 2008, apparently largely due to changes in count protocols (Ryan et al. 2009). This highlights the difficulties in accurately estimating population sizes (and hence trends) in these relatively cryptic, cliff-nesting species. The last estimate of breeding success for *Phoebastria* albatrosses on Marion Island was during the late 1970s (Berruti 1979). This study updates the current status of *Phoebastria* albatrosses on Marion Island, including breeding success and population trend estimates. Recommendations are made for improved monitoring protocols.

## **Materials and Methods**

### **Study site**

Marion Island, together with its smaller counterpart Prince Edward Island, are known as the Prince Edward Islands (46°50' S, 37°50' E, Figure 2.1). They are situated over 2000 km south east of South Africa with the nearest land mass being the Crozet archipelago, 950 km to the east (Lutjeharms & Ansorge 2008). Marion Island (293 km<sup>2</sup>) is a relatively young volcanic island less than one million years old (Boelhouwers et al. 2008). Marion Island is located within the flow of the Antarctic Circumpolar Current (ACC) between the Sub-Antarctic Front (SAF) and the Antarctic Polar Front (APF; Ansorge et al. 2012). The island is situated in a variable oceanic environment because of its downstream relation to the South West Indian Ridge (SWIR) where eddies originate and move towards the Prince Edward Islands (Durgadoo et al. 2010, Ansorge et al. 2012). Over the last few decades Marion Island has shown a 0.3-0.7 °C increase in temperature per decade and a 20% decrease in the amount of rainfall (Walther et al. 2002, Rouault et al. 2005, le Roux & McGeoch 2008).

The island has very few beaches with most of the coastline ending in cliffs of varying heights (Berruti 1979). The low lying areas of the island are mostly covered in vegetation, with vegetation cover diminishing as altitude increases with most vegetation below 600 m (Berruti 1979, Smith & Steenkamp 2001, Gremmen & Smith 2008). Seven habitat complexes have been recognised on Marion Island (Smith & Steenkamp 2001). Marion is breeding grounds for both

*Phoebetria* species in substantial numbers making it a unique site to study these species as only the Crozet archipelago shares this characteristic (ACAP 2015b, 2015c). Sooty albatrosses breed mostly on coastal cliffs with a few inland breeders at Grey-headed Ridge (Figure 2.1; Berruti 1977). Light-mantled albatrosses breed coastally as well as inland (Berruti 1977).

### **Monitoring colonies**

Monitoring colonies (see below) were set up for sooty and light-mantled albatrosses on the eastern side of Marion Island during the summers of 2013/14 and 2014/15 and were monitored throughout the respective breeding seasons. The sooty albatross colonies were at Ship's Cove, Macaroni Bay and Funk Bay with the light-mantled albatross at Ship's Cove, Macaroni Bay, meteorological base to Trypot Beach and the inland site, Piew Crag (Figure 2.1). All nests of breeding sooty and light-mantled albatrosses were monitored within this study area.

At each of these locations a sub-colony of approximately 50 nests (15 nests for light-mantled albatross) were identified and accessible nests were marked with a PVC pole. Nests were deemed inaccessible if access required full support of safety ropes (i.e. observers putting their full weight on an anchored rope). Safety ropes and harnesses were used when accessible nests were on steep slopes or in areas with loose vegetation. *Phoebetria* albatrosses on Marion Island have limited space around their nests and have a propensity to fly off when handled. Thus both partners were banded with a metal and plastic band before laying commenced to reduce the risk of birds abandoning a nest as they have to be restrained for the procedure. Breeding birds within the sub-colony that were not banded before laying (mostly females) were banded with a plastic band only as this could be done without removing the bird from the nest by slipping the band onto the leg of the bird causing minimal disturbance. Adults were sexed through direct observation (i.e. mating) or culmen length measurements with a vernier calliper (accuracy 0.1 mm). Males for both sooty and light-mantled albatross are generally larger than the females, for sooty albatross culmen lengths larger than 112 mm were classified as males and smaller than 110 mm were females (Berruti 1979). Sexing of light-mantled albatross was more difficult and the individual with the larger culmen length within a pair was used together with behavioural cues (i.e. displaying on the nest or mating).

The colonies were checked from the onset of egg laying (beginning October) to fledging of chicks (June) at 15 day intervals with additional opportunistic checks during egg laying and hatching periods. Colony checks included: identifying adults and their activity (incubating, brooding or guarding), checking nests for presence of mice (*Mus musculus*) or nearby giant petrel (*Macronectes* spp.) activity and checking the condition (e.g. presence of wounds/parasites



or anything that could lead to failure) of adults and chicks. Nest failures were recorded and motion detection trophy cameras (Bushnell Trophy Camera, model 119436, Dilley et al. 2013) were used to film randomly selected nests within the colonies to determine reasons for failures. Accessible chicks were banded with a metal band in March.

To determine incubation shift durations of both species a subset of nests was monitored daily from onset of incubation to the end of the hatching period at Macaroni Bay, Grey-headed Ridge and Trypot. Light-mantled albatross nests were monitored up to the end of the brood guard period by visiting the nest or observing from a distance with binoculars (especially during the brood guard period when birds frequently stand up). The sooty albatross nests were monitored through a combination of nest visits and camera traps. The dataset obtained from these observations were compared to previous studies (Berruti 1979, Thomas et al. 1983) to test for changes in shift duration of adults. The 1974 incubation shift table was adjusted as the first shift recorded by Berruti (1979) was the first male shift (which is much longer than the first female shift immediately after laying the egg).

### **Population trends**

Counts of breeding *Phoebastria* albatrosses were made in November/December each year from 1996 to 2014. Annual counts were conducted during the early breeding season of both *Phoebastria* albatrosses, recording adults on nests as assumed incubating birds (see Ryan et al. 2009 for details). The timing of counts ranged from 12 November to 27 December across all years. The island is divided into 20 management zones (Figure 2.1) originally set up to record wandering albatross *Diomedea exulans* breeding pairs. Sooty albatrosses breed in 16 of these zones, mainly along the coast but also inland along Grey-headed Ridge. However, some zones have very few pairs and some zone boundaries straddle contiguous populations, making it hard to standardize allocation of nests to zones across years. Therefore, 15 zones were used to track changes in sooty albatross populations. Light-mantled albatrosses occur in 17 coastal zones, but most of the population breeds at low densities at inland cliffs loosely divided into 12 inland regions. Because of poor weather and difficulty of access, not all inland areas were counted each year, and counts at some coastal sites were compromised by poor visibility.

### **Analysis**

Data were tested for normality through visual inspection of histograms and qq-plots or tested with a Shapiro-Wilk test in R (R Development Core Team 2014). Data that were not normally distributed were transformed (log, square or cube roots) and if normality was still not attained non-parametric tests were performed. Breeding success was calculated as the proportion of eggs that produced a fledging chick within each sub-colony. Differences in breeding success

between colonies as well as breeding success between years (breeding seasons) were tested with a linear mixed effects model (using R package *nlme*) with site and year as fixed and random variables for colony differences and *vice versa* for year. A two-sample Kolmogorov-Smirnov test was used to test for differences in distribution of incubation and brood guard (light-mantled albatross only) shift lengths over time. All analyses were performed in R (R Development Core Team 2014) unless stated otherwise.

Count zones from complete island counts were analysed using the software package TRIM (Pannekoek and van Strien 2005), which imputes counts for areas with missing data, to estimate the number of pairs breeding in each year and the standard error (SE) of the estimate. Guidelines used by Ryan et al. (2009) were applied to exclude 'poor quality' counts, but there were fewer of these in 2009-2014 than was the case prior to 2009. Change points to TRIM models were fitted by eye where there were changes in population trends based on improved fits to regression models. The model used a Poisson error distribution and over dispersion as well as serial correlation was accounted for. For both species, for each zone counted and overall, an estimate of the coefficient of variation (CV) of counts was obtained by computing the mean and standard deviation (SD) of counts during periods when TRIM estimated the overall populations of each species at Marion Island to be stable.

## **Results**

### **Laying dates and adult breeding frequencies**

The first sooty albatross eggs within the monitoring colonies were observed on 3 October and 29 September in 2013 and 2014, respectively. The first laying date for light-mantled albatrosses could not be determined in 2013, but the first egg in 2014 was recorded between 21 and 23 October. Out of the 153 sooty albatross breeding pairs monitored in 2013, 16 pairs and one male returned to breed in 2014 (12% of 141 nests). The 16 pairs were failed breeders in 2013, representing 24% of the failed breeders in 2013 (10 (15%) during the egg stage and 6 (4%) during the early chick stage), while the returning male was a successful breeder in 2013 and bred with a different partner in 2014. Only one pair of the 40 light-mantled albatross pairs monitored in 2013 returned to breed in 2014 (4% of 27 nests), this nest failed during the egg stage and represents 5% of the failed breeders in 2013.

### **Breeding success**

Sooty albatrosses within the monitoring colonies had a higher breeding success (51%, confidence interval (CI) 36-61%) than light-mantled albatrosses (31%) averaged over the two breeding periods, however this varied considerably between colonies (Table 2.1). The hatching success was similar for both species, while the fledging success (proportion of hatched chicks

that fledge) was much higher for sooty albatrosses (Table 2.1). There was a significant difference between the breeding success of the three sooty albatross colonies with SC having a significantly lower breeding success than the other two sites (linear mixed effects model;  $t = -4.3$ ,  $df = 2$ ,  $p < 0.05$ ; Figure 2.2). There was no significant difference between the breeding success in successive years for sooty albatrosses (linear mixed effects model;  $t = -1.3$ ,  $df = 2$ ,  $p = 0.33$ ). The rate of failures was high throughout the incubation period (October – mid-December) for all three monitoring colonies whereafter it flattened out for two colonies (Macaroni Bay and Funk Bay) but displayed a dramatic increase towards the end of December for Ship's Cove (Figure 2.2). Sooty and light-mantled albatrosses had similar distributions of incubation shift lengths and the mean shift length was not significantly different (Figure 2.3, Table 2.2). The incubation period for sooty albatrosses comprised 6-11 shifts and 5-8 shifts for light-mantled albatrosses.

Bushnell trophy camera footage showed a sub-Antarctic skua (*Catharacta antarctica*) attacking an incubating sooty albatross within the Macaroni Bay sub-colony, displacing it from its nest and eating the egg on the 11 of November 2013. This was the only nest failure recorded on camera within the monitoring colonies. However, skua activity around nests was seen shortly before and after failure on three occasions. Two southern giant petrels (*Macronectes giganteus*) were seen killing a light-mantled albatross chick at Storm Petrel Bay (a coastal site outside monitoring colonies) in April 2015. Three light-mantled albatross chicks had heavy tick infestations on their faces in 2013/14 with approximately 50 ticks surrounding the eyes and bill; two of the three chicks did not survive.

### **Population trends**

Counts of sooty albatrosses across the 15 count zones showed little variation between 1996 and 1998 when the population was stable (see below). Inter-annual coefficients of variation (CV) per count zone ranged from 1-80% (mean 34%, Table 2.3), the largest amount of variation included the whole western side of the island which is dominated by steep cliffs and inaccessible beaches. The population of sooty albatrosses breeding on Marion Island was stable between 1996 and 1998 followed by a moderate decline from 1998 to 2006 (regression slope  $0.97 \pm 0.01$  SE,  $p < 0.05$ ) and a moderate increase from 2006 to 2014 (slope  $1.04 \pm 0.01$ ,  $p < 0.05$ ; Figure 2.4). The average incubating bird count over 2012-2014 was  $1640 \pm 174$  (SD). The maximum incubating bird count (1838 pairs), made in 2014, underestimated the total population because a large sub-colony on the north-facing side of a cliff spur in southern Triegaardt Bay was not counted (and probably also was not in most previous counts; D. Green pers. comm.). On 4 May 2015 this cliff had 88 live chicks and 15 recently dead chicks (killed that day by giant petrels *Macronectes* spp.; PG Ryan unpubl. data). There would likely also have been

some prior failure of nests so that the minimum breeding population in 2014/15 was of the order of 1950 pairs.

Inter-annual variation in counts of light-mantled albatrosses (mean CV 66%, Table 2.3) was greater than for sooty albatrosses, at least in part because of the smaller numbers of pairs per count zone. The best fitting TRIM model suggested that the population of light-mantled albatrosses breeding on Marion Island was stable between 1996 and 2003, increased from 2003 to 2006 (slope  $1.20 \pm 0.04$  SE,  $p < 0.05$ ), and then experienced a moderate decline from 2006 to 2014 (regression slope  $0.91 \pm 0.02$  SE,  $p < 0.05$ ; Figure 2.5). The average incubating bird count over the last three years was  $268 \pm 43$ , with only 246 pairs in 2014, compared to 506 pairs in 2009.

## Discussion

The timing of laying for sooty albatrosses was similar to previous studies on Marion Island (Berruti 1979) and light-mantled albatross laying dates were similar to that from South Georgia (Thomas et al. 1983) where laying was during early and late October for sooty and light-mantled albatrosses respectively. *Phoebastria* albatrosses are classified as biennial breeders (Berruti 1979, Tickell 2000) and this seems to be the case for Marion Island as only a small proportion of birds returned to breed in successive breeding seasons. A larger percentage of failed breeders returned to breed in 2014 for sooty albatrosses (~25%) than for light-mantled albatrosses (~5% or one individual). This is much lower than the 83-89% of failed breeders returning on the Crozet Islands (Jouventin & Weimerskirch 1988, Marchant & Higgins 1990), however the Marion Island estimate is only over two years. The one pair of light-mantled albatrosses that returned to breed in 2014 was the first to fail within its sub-colony in 2013 (end November) and such an early failure might give enough time for the birds to recover to breed in the successive season. The lower percentage of light-mantled albatrosses returning might be due to their more distant foraging grounds to the south of the island (see Chapter 3) and their energy expenditure during the breeding season is probably higher than sooty albatrosses as they have to cover a greater area foraging for an unpredictable food source (Weimerskirch 1987). A male sooty albatross was recorded breeding in 2014 after successfully fledging a chick in 2013, to my knowledge, this is the first record of a successful sooty albatross breeding in consecutive years. This behaviour has been documented for grey-headed albatrosses (*Thalassarche chrysostoma*) on Marion Island where males opportunistically breed in successive years while their partners spend a sabbatical period at-sea (Ryan et al 2007).

## Monitoring colonies

The average breeding success of sooty albatrosses on Marion Island during 2013 and 2014 (51%, CI 36-61%) was higher than Berruti's (1979) estimate from the mid-1970s (19%, CI 8-30%). The breeding success was similar to that from Gough Island (48%; Cuthbert et al. 2013) however it was lower than breeding success on the neighbouring Possession Island, Crozet archipelago (65%; Delord et al. 2008b). The breeding success was skewed by one sub-colony (Ship's Cove) having a very low success in successive years. If this sub-colony is excluded from the estimate the breeding success (~63%) is closer to the Possession Island estimate and much higher than the 1970s estimate. However, it has to be noted that Berruti (1979) weighed chicks within the monitoring colonies daily for most of the chick-rearing period and this might have influenced the success of the birds. Even so, the highest estimate of breeding success from Berruti (1979) was 35% which is still lower than the current breeding success and it is not clear how this estimate was calculated as it is based on observation of fewer empty nests in certain areas with no sample sizes reported. The mean and distribution of sooty albatross incubation shifts were not different from birds on the Crozet Islands suggesting that they forage at similar distances from their breeding grounds (see Chapter 3). Thus it is not unexpected that they have similar breeding success as these populations may encounter similar environmental conditions. The similarity of sooty and light-mantled albatross incubation shift lengths is interesting as they forage north and south of the APF respectively (see Chapter 3). The similarity might indicate that they forage at similar distances from Marion Island, or that one of the species travels further in less time, however more data are needed to confirm this. The breeding success of sooty albatrosses on Possession Island increased since the 1980s (~40%; Jouventin & Weimerskirch 1984, Delord et al. 2008b) and this increase might have been due to changes in climate (Delord et al. 2008) as poleward warming of Southern Ocean waters decreases the distance that these birds have to travel to reach foraging grounds of temperature-dependant prey species such as squid (Péron et al. 2010). In a similar way it is possible that the increase in sooty albatross breeding success on Marion Island has occurred over the past few decades as the albatrosses that forage north of the APF are expected to be advantaged (Walther et al. 2002, Inchausti et al. 2003). The average breeding success of light-mantled albatrosses were the same as in the 1970s (31%; Berruti 1979) and lower than the Macquarie (47% ACAP 2015b) and Possession Island average (40%; Delord et al. 2008b), while being higher than the South Georgia average of 15% (ACAP 2015b). Light-mantled albatross populations might have persisted with such a low breeding success if adult survival was extremely high, which is the case for light-mantled albatrosses on Possession Island with a mean adult survival of 97% (Jouventin & Weimerskirch 1988, ACAP 2015b).

Previously ~67% of sooty albatross chick failures were attributed to predation from predators on Marion Island (Berruti 1977). During 2013 and 2014 skuas might have posed a larger threat to sooty albatrosses on Marion Island during incubation and brood guard as they were the only predatory species seen around the nests during these periods, while giant petrels influenced chick survival towards fledging. In 2013 three skuas were observed mobbing a brood guarding northern giant petrel; one individual distracted the adult from the front while the other two snatched the chick from behind (pers. obs). Attacks of northern giant petrels (*Macronectes halli*) on albatross chicks have been inferred from presence of the petrel before a nest failure occurred on South Georgia (Dilley et al. 2013). Giant petrels are probably a larger threat when the chicks are larger as they have been observed killing large sooty albatross chicks on cliff edges (Dilley 2013, Dilley et al. 2013, PG Ryan pers. comm.). Towards the end of the breeding season the invasive house mouse is a significant threat to *Phoebastria* albatross chick survival. The first evidence of mice attacking sooty albatrosses on Marion Island was documented in 2009 where seven out of 19 birds within a small area were seemingly attacked on their heads, necks or backs (Jones & Ryan 2010) and similar on Gough Island (Cuthbert et al. 2013). In 2015 mouse predation on sooty albatrosses was confirmed with photographic evidence where mice attacked sooty albatross chicks. The total proportion of pairs affected was 4.3% and 4% of the sooty and light-mantled albatross populations, respectively (FitzPatrick Institute unpublished data).

### **Population trends**

The population trends of sooty and light-mantled albatrosses on Marion Island have reversed when compared to previous estimates (Ryan et al. 2009). Ryan et al. (2009) suggested a best estimate of 1400 pairs of sooty albatrosses breeding on Marion Island in the early 2000s, with a decrease from 1600-1800 pairs in the 1990s. This continued the apparent decrease from over 2000 pairs in the mid-1970s based on Berruti's (1979) estimate of 2032 pairs. However, Berruti's estimate has to be interpreted with caution as it was derived from maximum counts made between 1974 and 1976 (Berruti 1977), and thus is not directly comparable with more recent annual counts. In addition, for both species of *Phoebastria* albatrosses not all adults breed each year, although 83-89% failed breeders may breed in the following year (Jouventin & Weimerskirch 1988, Marchant & Higgins 1990). The year-by-year counts in Berruti (1977) suggest that the annual breeding population in the mid-1970s was of the order of 1800 pairs. Since 2008, counts of sooty albatrosses have increased and are now similar to those recorded in the 1990s and probably the 1970s, suggesting little long-term change in the Marion Island population. Indeed the 2014 incubating bird count is the highest single-year count on record for Marion Island. Breeding success in the three study colonies in 2013 was not anomalously low

(56% ± 13%), and thus the high count in 2014 was not unduly influenced by a large number of failed birds returning to breed.

The increasing trend of sooty albatrosses on Marion Island is similar to Gough Island where no significant population declines have been observed as both these breeding sites have changed from a declining trend to stable or increasing in recent years (Cuthbert and Sommer 2004, Ryan et al. 2009). However the trend on Gough Island has to be interpreted with caution as it is based on a small proportion of the total population (Cuthbert et al. 2014). The decreasing sooty albatross trend between 1998 and 2006 on Marion Island coincided with a decrease of the same species on Possession Island (Delord et al. 2008). The decrease on Possession Island was attributed to decreased adult survival and recruitment of first breeders to colonies which was probably caused by incidental by-catch mortality from long-line fisheries (Delord et al. 2008). Population declines on Possession Island have been linked to lowered adult survival rates in the past (Weimerskirch et al. 1987). Declines in populations of sooty albatrosses elsewhere have been attributed to mortality associated with fisheries and this is considered the primary threat to *Phoebetria* albatrosses (e.g. Gales et al. 1998, Rolland et al. 2010, Yeh et al. 2013 ACAP 2015b). The only legal fishery operating within waters close to the Prince Edward Islands is a small Patagonian toothfish (*Dissostichus eleginoides*) fishery (Boonzaier et al. 2012), however toothfish fisheries do not cause significant levels of bycatch related mortalities for *Phoebetria* albatrosses (Nel et al. 2002c, Rolland et al. 2010).

Contrasting trends for sooty and light-mantled albatrosses have been observed on Marion Island for the last two decades (Ryan et al. 2009). Numbers of light-mantled albatrosses are currently decreasing on Marion Island which is the first record of such a trend for light-mantled albatrosses, however trends at many breeding locations are unknown (ACAP 2015b). The stable and increasing trends from 1996-2006 (Ryan et al. 2009) are similar to an increase of light-mantled albatrosses on Possession Island over the same time period (Delord et al. 2008). The gradually warming climate offers one possible explanation for this recent decrease, because Marion Island is at the species' northern breeding limit and the island has warmed on average by 0.4°C per decade since the 1960s (le Roux & McGeoch 2008). Rolland et al. (2010) did not find that environmental variation in the Southern Ocean influenced adult survival of sooty albatrosses while it had a significant effect on breeding success.

### **Count methodology**

Several factors complicate the interpretation of long-term trends in sooty albatrosses at Marion Island. Most of the population breeds on sea cliffs, and with their dark plumage they are often hard to spot (Berruti 1979). At sites where cliffs cannot be scanned from a distance, counts

depend to a large extent on the degree to which observers are willing to descend to the edge of cliffs. Such inter-observer effects can be substantial: the 2-4 fold increase in counts at several sites on Prince Edward Island in 2008 compared to 2001 were attributed to observer differences, as there was little change at sites scanned from a distance (Ryan et al. 2009). Even greater differences can result from changes in survey methods. Again at Prince Edward, there was a 10-fold increase in the estimate of sooty albatrosses breeding on the island's tall southern cliffs when the count was conducted from above the cliffs rather than scanning from below (Ryan et al. 2009). The failure of recent counts to include the north face of the Triegaardt Bay South sub-colony is a case in point. Clearly there is need for greater standardisation in count methods if the aim is to have a reliable index of long-term trends. Subdividing the count zones and moving their boundaries to better reflect the distribution of sooty albatrosses (Figure 2.1) will go some way to improving the repeatability of counts. However, weather also plays a key role; even the same observer is likely to get different estimates when counting on a clear, calm day than on a day of strong winds and indifferent visibility. The western side of the island showed the greatest variation in sooty albatross counts. This variation might be attributed to weather conditions as the dominant wind direction on Marion Island is from the west, with the north-westerly winds being the strongest (le Roux 2008). It is not always safe to descend far down cliffs to carefully scan adjacent valleys for nests with binoculars on very windy days; nor is it always possible to wait for better weather when operating at several days' walk from the scientific station.

An additional problem with the current survey approach is the timing of the annual counts, which have been conducted from mid-November to mid-December (Crawford et al. 2003a, Ryan et al. 2009). This is adequate for light-mantled albatrosses, which lay in late October on Marion Island (Berruti 1979; range 22 October-14 November) but too late for some sooty albatrosses, which mainly lay in early October (Berruti 1979; range 29 September-23 October). By late November, the mid-point of the annual counts conducted between 1996 and 2014, 20% of sooty albatross breeding attempts in monitoring colonies had failed in 2013 and 12% had failed in 2014 (Figure 2.6). Some adults remain on their nests after failing, and so might be counted as incubating birds, but having the counts late in the incubation period of the sooty albatross probably results in some underestimation of the population size of this species. This could be averted by counting incubating sooty albatrosses earlier. Furthermore, more regular monitoring of core breeding areas should provide greater insight on the timing of breeding failures and hence the extent to which island-wide counts may underestimate numbers breeding.

Light-mantled albatrosses are even harder to count than sooty albatrosses at Marion Island. Most birds breed inland at scattered localities, with seldom more than a few birds at any one



site. Also, they select sheltered sites under overhangs or in crevices which are often very hard to detect by scanning from a distance. Counts depend to a large extent on the willingness of observers to explore large areas with very low returns, although known breeding sites should all be surveyed each year. Despite these problems, there is some evidence that the population of light-mantled albatrosses on Marion Island has decreased over the past decade, following an apparent increase from 1996 to 2006 (Ryan et al. 2009). Given that there was no island-wide estimate for the population of this species prior to 1996, it is perhaps debateable whether the increase from 2003 to 2006 reflects a change in the population or simply a better understanding of their inland distribution. At coastal sites, there might also be some competition for nest sites with sooty albatrosses, which start breeding 2-3 weeks before light-mantled albatrosses and hence may have preference to secure favoured nesting sites.

### **Conclusions**

Determining population sizes and trends of long-lived, biennially breeding seabirds is not easy as it is difficult to know which proportion of the population breeds each season (Ryan & Bester 2008). The accuracy of trend estimation can be increased by monitoring a subset of the population during the breeding season and tagging individuals to obtain demographic information (Ryan & Bester 2008). The continued monitoring of *Phoebastria* monitoring colonies is recommended as it will provide the necessary demographic data to estimate population sizes and trends more accurately. There is little evidence of long-term (over four decades) change in numbers of sooty albatrosses breeding on Marion Island. Improved count protocols proposed in this paper will give greater confidence in future trends of this globally important population. Results from this study suggest a possible increase in population size and breeding success of sooty albatrosses, which might indicate a reduction in fisheries related mortalities. Updated trends from neighbouring Prince Edward Island and at other islands are required to determine if this is similar on a local and global scale.

**Table 2.1:** Breeding parameters of sooty and light-mantled albatross monitoring colonies for the 2013/14 and 2014/15 breeding seasons, values are means  $\pm$  SD.

	Sooty albatross			
	Ship's Cove	Macaroni Bay	Funk Bay	Total
<b>Sub-colony size (n)</b>	56 $\pm$ 4	47 $\pm$ 10	44 $\pm$ 3	49 $\pm$ 7
<b>Inaccessible nests (n)</b>	29 $\pm$ 5	16 $\pm$ 2	6	17 $\pm$ 11
<b>Breeding success (%)</b>	31 $\pm$ 15	60 $\pm$ 7	65 $\pm$ 1	52 $\pm$ 18
<b>Hatching success (%)</b>	72 $\pm$ 13	77 $\pm$ 6	76 $\pm$ 7	75 $\pm$ 8
<b>Fledging success (%)</b>	46 $\pm$ 29	78 $\pm$ 3	85 $\pm$ 8	70 $\pm$ 23

	Light-mantled albatross				
	Ship's Cove	Trypot	Macaroni Bay	Piew Crag	Total
<b>Sub-colony size (n)</b>	12 $\pm$ 1	9 $\pm$ 4	3 $\pm$ 2	10 $\pm$ 2	8 $\pm$ 4
<b>Inaccessible nests (n)</b>	5 $\pm$ 3	1 $\pm$ 1	1 $\pm$ 1	0	2 $\pm$ 2
<b>Breeding success (%)</b>	12 $\pm$ 4	54 $\pm$ 53	38 $\pm$ 53	22 $\pm$ 5	31 $\pm$ 33
<b>Hatching success (%)</b>	55 $\pm$ 12	92 $\pm$ 12	100 $\pm$ 0	57 $\pm$ 10	76 $\pm$ 23
<b>Fledging success (%)</b>	24 $\pm$ 13	56 $\pm$ 51	38 $\pm$ 53	39 $\pm$ 15	39 $\pm$ 31

**Table 2.2:** Statistical test performed on incubation and brood guarding shifts for sooty and light-mantled albatross at several breeding grounds or different dates from the same breeding ground.

Species	Stage	Location and date	Test	Statistic	p-value
LMA	Brood	1,2,3,4	ANOVA	F = 0.678	0.41
LMA	Incubation	1,2,3	ANOVA	F = 1.52	0.23
LMA	Incubation	1,2	K-S	D = 0.5417	0.19
LMA	Incubation	1,3	K-S	D = 0.5714	0.14
LMA	Incubation	1,4	K-S	D = 0.3214	0.74
LMA	Brood	1,2	K-S	D = 0.4	0.35
LMA	Brood	1,4	K-S	D = 0.2222	0.98
SA	Incubation	1,2	Wilcox	W = 63	0.88
SA	Incubation	1,2	K-S	D = 0.3182	0.61
SA & LMA	Incubation	1	K-S	D = 0.44	0.29
SA & LMA	Incubation	1	t-test	t <sub>13</sub> = -0.91	0.38

1 = Marion 2013 (present study);

2 = Marion 1974 (Berruti 1979);

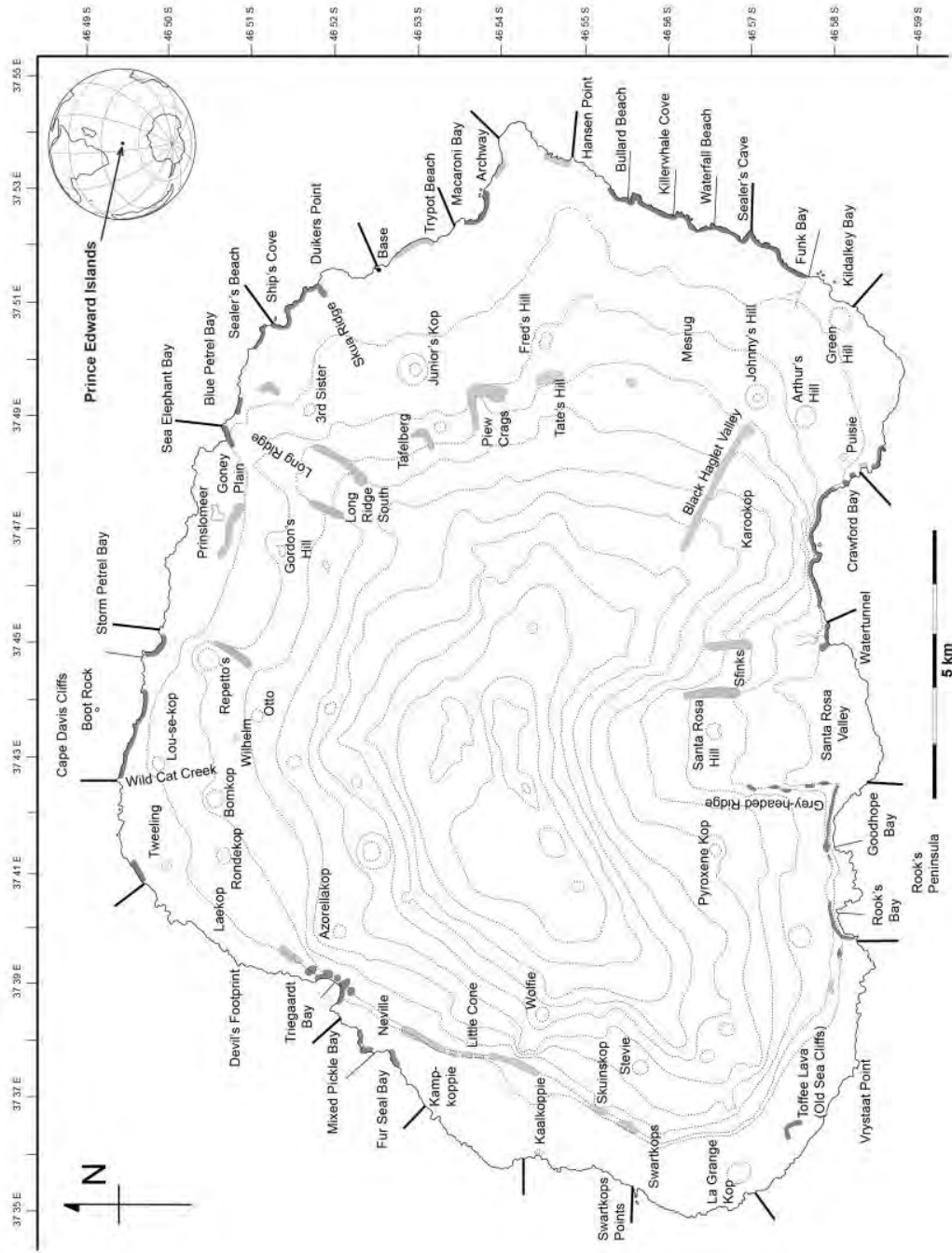
3 = Crozet 1970 (Mougin 1970 from (Berruti 1979));

4 = South Georgia 1983 (Thomas et al. 1983)

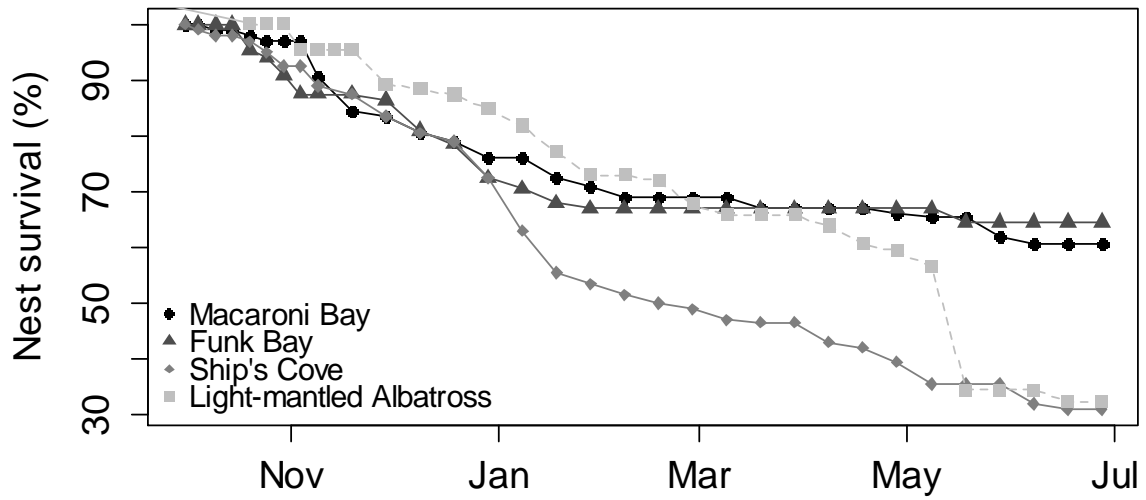
LMA: light-mantled albatross, SA: sooty Albatross

**Table 2.3:** Average ( $\pm$  SD) counts of sooty and light-mantled albatrosses on Marion Island, showing the variation in count CVs among different counting zones for stable periods.

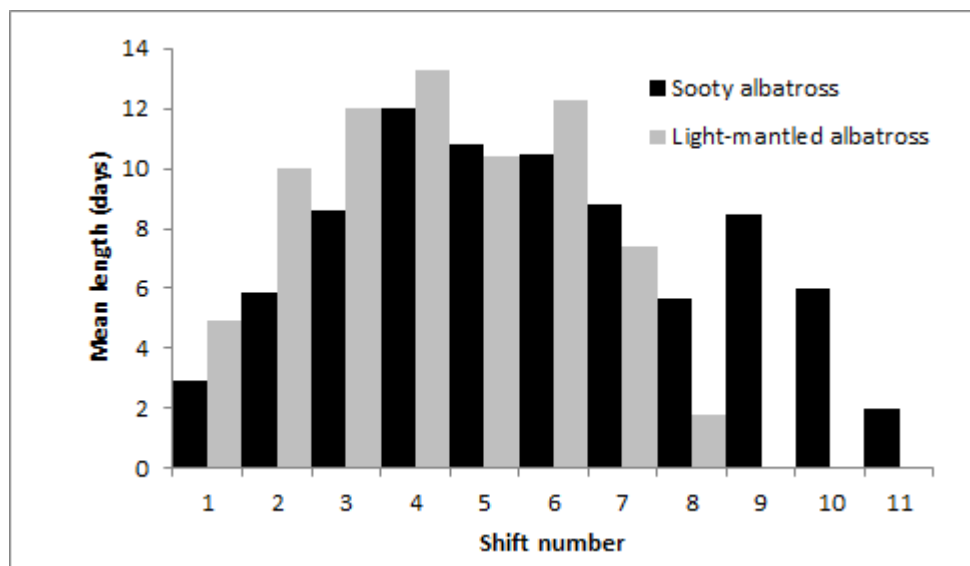
Count zone	Sooty albatross		Light-mantled albatross	
	Mean $\pm$ SD	CV (%)	Mean $\pm$ SD	CV (%)
<b>Coastal</b>				
Base to Hansen Bay	43 $\pm$ 15	5	8 $\pm$ 4	30
Hansen Point to Sealer's Cave	122 $\pm$ 38	1	21 $\pm$ 9	36
Sealer's Cave to Green Hill	91 $\pm$ 31	8	4 $\pm$ 4	118
Green Hill to Puisie	26 $\pm$ 19	58	2 $\pm$ 3	188
Puisie to Watertunnel Stream	53 $\pm$ 37	35	22 $\pm$ 8	37
Watertunnel to Grey-headed Ridge	32 $\pm$ 49	9	2 $\pm$ 4	155
Good Hope Bay to Rooks hut	441 $\pm$ 124	34	92 $\pm$ 45	43
Rooks hut to La Grange Kop	38 $\pm$ 19	78	7 $\pm$ 6	116
Kampkoppie to Mixed Pickle	49 $\pm$ 18	80	6 $\pm$ 7	123
Mixed Pickle to Tweeling	111 $\pm$ 64	74	51 $\pm$ 24	19
Wild Cat Creek to Storm Petrel Bay	225 $\pm$ 61	6	1 $\pm$ 3	245
Storm Petrel Bay to Long Ridge	24 $\pm$ 17	25	0	-
Long Ridge	59 $\pm$ 29	5	6 $\pm$ 7	59
Long Ridge to Ship's Cove	32 $\pm$ 19	62	0	-
Ship's Cove to Base	119 $\pm$ 43	25	19 $\pm$ 8	30
<b>Inland</b>				
Piew Crags			7 $\pm$ 5	0
Between Freds and Tates			1 $\pm$ 1	28
North of Mesrug			1 $\pm$ 1	-
Black Haglet valley			27 $\pm$ 15	27
Sfinx			14 $\pm$ 21	-
Swartkops			9 $\pm$ 5	0
Swartkops to Kaalkop			9 $\pm$ 10	28
Kaalkop to Kampkoppie			19 $\pm$ 11	52
Kampkoppie to Mixed Pickle			7 $\pm$ 4	71
Repettos to Prinsloomeer			18 $\pm$ 8	40
Long Ridge South			26 $\pm$ 10	15
Tafelberg to Junior's Kop			4 $\pm$ 2	64
<b>Total</b>	1465 $\pm$ 259	3	298 $\pm$ 110	49



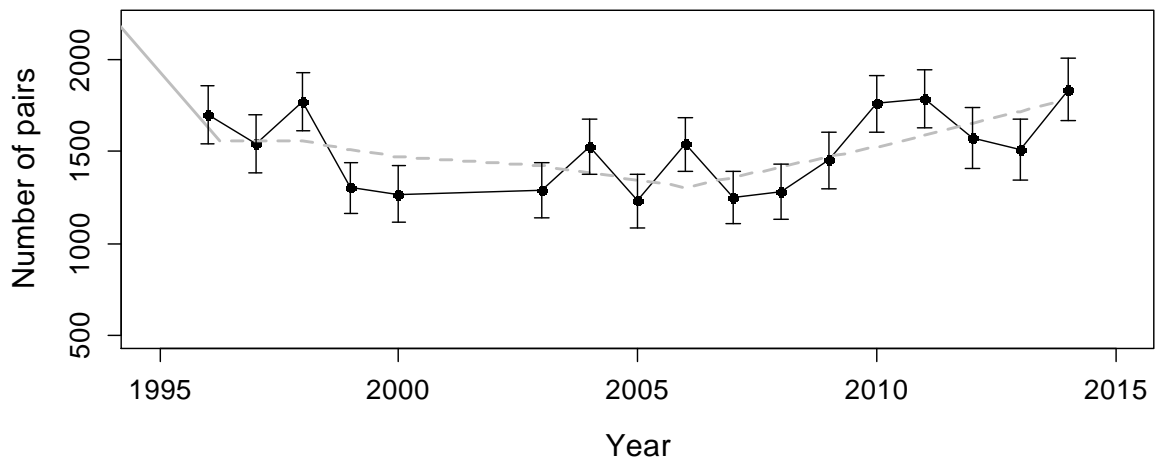
**Figure 2.1:** Marion Island showing the breeding distributions of sooty (dark shade) and light-mantled (light shade) albatrosses in relation to the 20 management count zones (bold lines) and inland sites in (see Table 1.1 for details). Thin lines show suggested revised coastal count zone boundaries to improve count precision and accuracy. Note that light-mantled albatrosses breed with sooty albatrosses in some coastal areas.



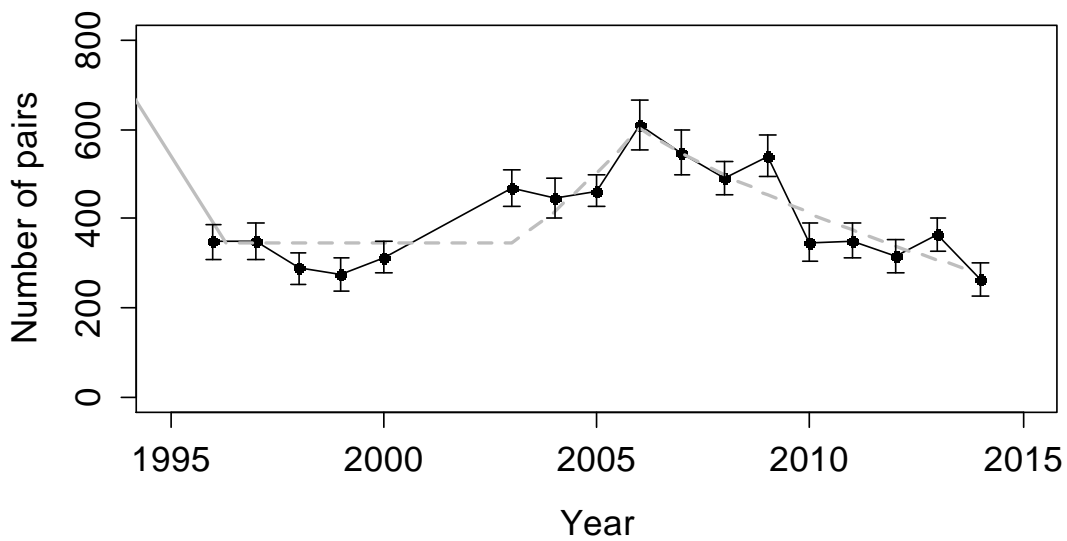
**Figure 2.2:** Nest survival of three sooty albatross (solid lines) colonies and all light-mantled albatrosses (dashed line) in the 2013 and 2014 breeding seasons on Marion Island.



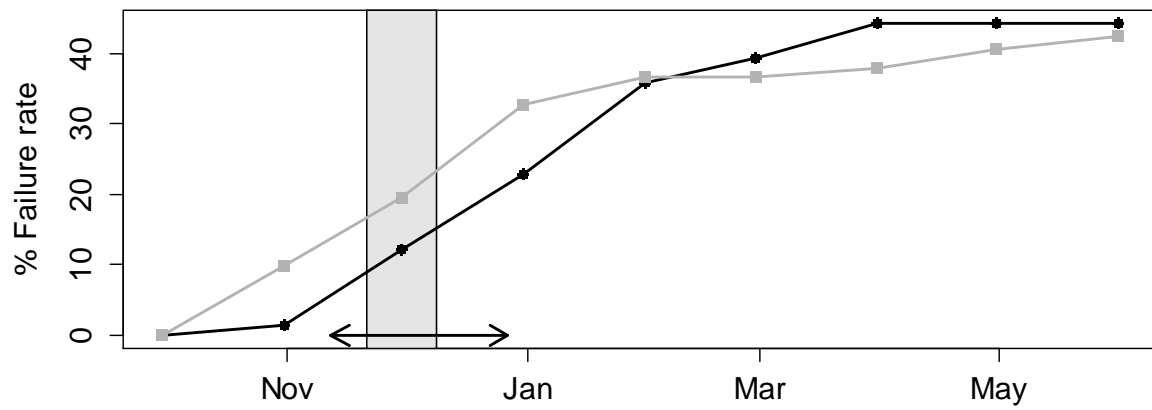
**Figure 2.3:** Incubation shift duration of sooty and light-mantled albatrosses during the 2013 breeding period.



**Figure 2.4:** Trends in the numbers of pairs of sooty albatrosses breeding on Marion Island between 1996 and 2014 (annual counts  $\pm$  SE; trend line derived from TRIM with change points at 1998 and 2006).



**Figure 2.5:** Trends in the numbers of pairs of light-mantled albatrosses breeding on Marion Island between 1996 and 2014 (annual counts  $\pm$  SE; trend line derived from TRIM with change points at 2003 and 2006).



**Figure 2.6:** Count dates of sooty albatrosses in relation to nest failure rates in three study colonies monitored in 2013 (grey) and 2014 (black). The range of count midpoints is shown as a shaded bar with extreme ends indicated by arrows.

## **Chapter 3: Foraging ranges of sooty and light-mantled albatrosses breeding on Marion Island**

### **Abstract**

The differing conservation statuses of *Phoebetria* albatrosses are often attributed to their spatial segregation with the Endangered sooty albatrosses (*P. fusca*) foraging north and Near-threatened light-mantled albatrosses (*P. palpebrata*) south of the Antarctic Polar Front. The poor conservation status of sooty albatrosses is a result of recent population declines mostly linked to fishery related mortality. To determine the spatial overlap that occurs between breeding albatross and fisheries during the breeding season, breeding adults were tracked with GPS loggers during the incubation and brood guard periods. Tracking of sooty albatrosses produced tracks from 24 individuals (out of the 27 recovered loggers recovered) showing 40 foraging trips during incubation and brood guarding. Sample sizes for light-mantled albatrosses were lower with tracks from only nine individuals (out of the 10 recovered loggers) showing 13 foraging trips during incubation and brood guarding. Tracking data supported results from previous studies estimating distributions from dietary, fatty acid or isotope analysis. There was a clear spatial segregation between the two species during incubation, with sooty albatrosses foraging mainly north of the islands towards the Sub-Tropical Front (STF) where they showed a significant amount of overlap with long-line fishing effort, whereas light-mantled albatrosses foraged south of the islands where there is very little fishing effort. During the brood guard period, both species stayed closer to Marion Island with greater spatial overlap between the two species. Sooty albatross foraging was concentrated around the edges of mesoscale eddies especially in areas around the STF. The differing at-sea distributions of *Phoebetria* albatrosses from Marion Island are most probably an underlying cause of their contrasting conservation statuses. This highlights the need for data from fisheries activities within the southern Indian Ocean such as, fishing effort, bycatch rates, use of mitigation and monitoring of compliance to estimate the impact fisheries related mortality may have on sooty albatross survival rates.

### **Introduction**

The global distributions of albatross species are well documented (BirdLife International 2004) and miniature transmitters and loggers have revolutionised our knowledge of individual movement patterns, with some species renowned for their circumpolar migrations (Croxall et al. 2005, Phillips et al. 2008). Technological advances over the past few decades have allowed tracking of large seabirds by deploying various animal-borne tracking devices, *inter alia*, platform terminal transmitter (PTT), global positioning system (GPS) and geolocators (GLS)



(Wilson et al. 2002, Phillips et al. 2008, Lotek 2015) with some of these devices weighing as little as one gram ([www.lotek.com](http://www.lotek.com)).

The global ranges of *Phoebetria* albatrosses are well known from visual observation from ships (Griffiths 1982, Abrams 1983, Marchant & Higgins 1990, Weimerskirch et al. 2000a), augmented by: dietary studies (Berruti 1979, Cooper & Klages 1995, Green et al. 1998, Connan et al. 2014), feather and blood isotope analysis (Cherel et al. 2013, Jaeger et al. 2013, Connan et al. 2014) and fatty acid analysis (Connan et al. 2014). However, the two *Phoebetria* albatrosses have not been studied as extensively as other albatross genera (*Diomedea*, *Thalassarche*, *Phoebastria*) and their finer scale distributions and movements are not well documented, especially non-breeding individuals and juveniles (Phillips et al. 2005b, Weimerskirch 2007). Knowledge of the at-sea distribution of albatrosses is important to determine the amount of overlap that occurs with fishing effort (Phillips et al. 2008). Tracking data have only been published for *Phoebetria* albatrosses breeding on South Georgia, Macquarie, Gough and Crozet Islands (Weimerskirch & Robertson 1994, BirdLife International 2004, Phillips et al. 2005a, Phalan et al. 2007, Phillips et al. 2008, ACAP 2015b, 2015c) using either satellite transmitters or geolocators. These data show that the Endangered sooty albatross (*Phoebetria fusca*) have a northern distribution mainly within sub-Antarctic and sub-tropical waters whereas the Near-threatened light-mantled albatross (*Phoebetria palpebrata*) has a more southern distribution within Antarctic waters while breeding.

Many recent publications surrounding seabird population trends in the Southern Ocean link declining populations with climate change, fisheries impacts or a combination of both factors (Delord et al. 2008, Ryan et al. 2009, Barbraud et al. 2012, Cuthbert et al. 2014). Albatrosses may be killed by long-line fishing vessels when they take hooked bait as it is released into the water drowning the bird, or they can get downed by trawl cables (Weimerskirch et al. 2000a). It has been suggested that fisheries bycatch in the Southern Ocean causes significant sooty albatross mortality (Crawford & Cooper 2003, Huang & Liu 2010). This is in light of the fact that sooty albatrosses show a large degree of overlap with fishing effort in the Southern Ocean (Tuck et al. 2003, 2011, Delord et al. 2008). In the southern Atlantic Ocean, sooty albatrosses have been identified as one of the high priority species for protection from fisheries bycatch (Tuck et al. 2011, Yeh et al. 2013). Although sooty albatrosses are seldom killed by long-liners operating in South African waters (Petersen et al. 2009, Ryan et al. 2009), an average of 48 individuals have been killed annually between 2004 and 2007 in the southern Indian Ocean (high seas) by Taiwanese vessels (Huang & Liu 2010), and this area was recently identified as a hotspot for seabird bycatch (Lewison et al. 2014). Although there have been recent reductions in seabird mortalities in shelf waters under national jurisdictions (e.g. Maree

et al. 2014, Robertson et al. 2014), these have little relevance to sooty albatrosses which remain mostly in oceanic waters (BirdLife International 2004, ACAP 2015b). These areas are subject only to Regional Fisheries Management Organisations (RFMOs) which is generally weaker than national legislation (Delord et al. 2014).

Tracking of individuals may provide a better picture of where these birds move and why their population sizes were declining (Ryan et al. 2009), see Chapter 2. This highlights the need for tracking data from Marion Island, as a major breeding site for sooty albatrosses (ACAP 2015b), to further investigate reasons behind their poor conservation status. Distribution data from all colonies of a particular species are important as even closely neighbouring colonies do not necessarily have the same habitat preference (Catry et al. 2013a). Fisheries management (e.g. compliance with mitigation measures such as bird scaring lines) seems to be the only current measure to protect seabirds in international waters as these far-ranging birds cannot be protected exclusively within country specific exclusive economic zones (EEZs) or marine protected areas (MPAs) (Delord et al. 2014)

Oceanic seabirds often forage around the edges of mesoscale oceanographic features such as eddies or frontal systems as a result of increased productivity induced by up- or downwelling (Hyrenbach et al. 2006, Bost et al. 2009). The areas of increased productivity that are often targeted by seabirds might be equally attractive to fisheries, as is seen with a large degree of overlap between seabirds and fisheries at the Sub-Tropical Front (STF) and in sub-tropical waters (Nel et al. 2002c). Mesoscale oceanographic systems are influenced by various environmental variables (sea surface temperature, bathymetry, etc.) and it is difficult to predict which of these variables (or combinations of variables) drive seabird foraging decisions (Hyrenbach et al. 2006). Not all of the frontal systems in the Southern Ocean display the same characteristics. Although the STF and Antarctic Polar Front (APF) both have high concentrations of macro plankton compared to interfrontal zones, the STF has a uniform high primary productivity whereas the APF shows seasonal changes (Bost et al. 2009). The major Southern Ocean fronts are predictable both spatially and temporally and commuting trips to and from these areas by foraging seabirds indicate that they have a good knowledge regarding the location of the fronts (Weimerskirch 2007, Bost et al. 2009). Many seabirds are associated with areas of complex interactions between currents, frontal systems and bathymetric features (Bost et al. 2009). Such diverse areas occur close to Marion Island when the Antarctic Circumpolar Current encounters bathymetric irregularities at the Andrew Bain fracture zone of the South West Indian Ridge (Durgadoo et al. 2010). This area spawns warm and cold-core eddies that disperse downstream, past Marion Island creating a highly variable oceanographic environment (Durgadoo et al. 2010).

High precision tracking devices allow for detailed studies of seabird movement at finer scales than before (Weimerskirch et al. 2002). This study used archival GPS loggers to track sooty and light-mantled albatrosses on Marion Island to determine their spatial distribution and habitat preference during the breeding season. I hypothesize that breeding sooty albatrosses on Marion Island will show similar distributions to that of birds from the neighbouring Crozet archipelago foraging either close to the island or to the north in sub-tropical waters (BirdLife International 2004, ACAP 2015b), whereas light-mantled albatrosses will forage mainly within Antarctic waters with longer trips on average. I expect to see spatial overlap between sooty and light-mantled albatrosses close to Marion Island with segregation when birds move further away. I also expect to see a greater overlap between sooty albatross distribution and long-line fishing effort in the southern Indian Ocean than light-mantled albatrosses.

## Methods

CatTraQ (Mobile Action Technology, Inc. 2013) GPS loggers (42 mm x 25 mm x 10 mm) were deployed on breeding adult sooty albatrosses during different periods of incubation and during the brood guard period. The loggers were removed from their plastic casing and placed in heat-shrink tubing for waterproofing before they were deployed on the back of the birds between the shoulder-blades (Figure 3.1), as this area least affects the centre of gravity of flying seabirds (Bannasch et al. 1994, Vandenabeele et al. 2014). A single logger was attached to 6-10 body feathers with strips of Tesa® tape which allows safe removal without damage to feathers (Wilson et al. 1997). Deployments were not done during the first two weeks of incubation (beginning of October for sooty and end of October for light-mantled albatross, Berruti 1979) as the birds are more sensitive to disturbance during this period and might abandon the nest. Handling time never exceeded 10 minutes and only one bird (a light-mantled albatross) abandoned its nest after deployment and did not return. The total weight of the logger on the back of the birds was 25-26 g which is approximately 1% of the mean body weight of adult *Phoebastria* spp. (Berruti 1977, 1979), well below the 2-3% maximum recommended by (Phillips et al. 2003). Deployments were done at two locations, Grey-headed Ridge to the south of the island and Skua Ridge in the northeast (see Chapter 2, Figure 2.1).

Early incubation deployments were done before 20 November and late incubation deployments after 20 November for sooty albatrosses where light-mantled albatross deployments were before 10 December for early incubation and after 10 December for late incubation. For sooty albatross, all loggers deployed during early incubation were at Grey-headed Ridge (n = 10), whereas late incubation deployments were split between Grey-headed Ridge (n = 8) and Skua Ridge (n = 3). Deployments on incubating light-mantled albatrosses were at Grey-headed Ridge (n = 5) and Skua Ridge (n = 6). The brood guard period is defined as the

time from hatching to when the chick is left alone for the first time (12 December – 17 January for sooty albatrosses and 25 December – 23 January for light-mantled albatrosses). All brood guard deployments were done at Skua Ridge (eight sooty and four light-mantled albatrosses) except for one sooty albatross deployment at Grey-headed Ridge. Programming and downloading of data from the loggers were done with @trip software (Mobile Action Technology, Inc. 2013). The loggers were programmed to record a GPS location every 60 minutes to maximise the chance of tracking full foraging trips as more frequent intervals reduces the battery life of the logger.

Global location sensing (GLS) loggers were used to track an additional eight breeding sooty albatrosses during the 2011/12 (seven individuals) and 2012/13 (one individual) breeding seasons. For details on the loggers used, method of deployment and estimation of tracks from the loggers, see Chapter 4. The GLS devices were deployed in March 2012 ( $n = 7$ ) in the middle of the chick-rearing period and December 2012 ( $n = 1$ ) just before the brooding period. Thus, only tracks for the chick-rearing period were used. Because of the low accuracy of these tracks, analyses of habitat preference were not performed and the tracks were only used to estimate overlap with fisheries during this period.

### **Analysis**

All GPS tracks were interpolated at 15 km intervals (mean distance between points) and transformed to trajectories using the R package *adehabitatLT* (Calenge 2006). Transforming successive GPS locations into a trajectory provides information such as, *inter alia*, distance between points, turning angles, and squared distances between tracks (Calenge 2006). From here on trajectories are referred to as tracks. The speed for each point was calculated from the time between successive points in  $\text{km}\cdot\text{h}^{-1}$  and obvious outliers were removed from the analysis (e.g. unrealistic speeds above the maximum recorded for albatrosses; Phillips et al. 2008). The duration, distance and speeds (average and maximum) for complete tracks of the three periods (early/late incubation and brood guarding) were tested with an ANOVA to look for significant differences between the periods. A post hoc Tukey HSD analysis was performed to determine which groups differed.

The amount of overlap between the at-sea distribution of breeding birds and the Marion Island Marine Protected Area (MPA) and South African EEZ was determined as the proportion of points within each zone (Thiebot et al. 2014). A multiple null model analysis of the tracks was performed using R package *adehabitatLT* to test for underlying variables that might influence the observed tracks (Calenge 2006). The null model method of analysis provides an estimate of distribution when underlying influences are absent (Gotelli & Graves 1996). Null models were

constructed by randomly rotating individual tracks 300 times within the range of all tracks for a given species within a given period from a fixed starting point (Marion Island). These random rotations were performed while keeping the shape of the track to take into account the internal constraints of the animal as well as autocorrelation of the tracks (Martin et al. 2008). A larger number of random rotations were not possible as this is a computationally demanding process. The null models from all the tracks within a selected period were combined in a multiple null model to allow simultaneous comparison of all the tracks (from a given period) to the multiple null model. Multiple null model analysis was performed for the three breeding periods separately together with the environmental variables explained below.

Data for sea surface temperature (SST) and chlorophyll *a* concentration (chl *a*) were downloaded from <http://coastwatch.pfeg.noaa.gov/erddap/info/index.html>. Monthly chl *a* concentrations were not used, however, because cloud cover caused large data gaps in the maps. Sea surface temperature was a high resolution blended map with a 1 km resolution obtained from satellite as well as in situ measurement from ships and buoys (<http://ouocean.jpl.nasa.gov/SST/>) and was downloaded for each day during the three-month deployment period. Bathymetry data were obtained from NOAA NGDC (<http://www.ngdc.noaa.gov/mgg/global/global.html>) and downloaded as a 1 arc-minute ETOPO1 map. Mean sea level anomalies (MSLA) and mean absolute dynamic topography (MADT) were also downloaded for each day of deployment from Aviso (<http://www.aviso.altimetry.fr/en/data/data-access/gridded-data-extraction-tool.html>). Gradient maps for all these variables were constructed from monthly averaged maps (except for bathymetry where only one map is present). Mean absolute dynamic topography was used to calculate eddy kinetic energy (Jia et al. 2011), which indicates the edges of neighbouring eddies (Tew Kai & Marsac 2010), and was also used to visualise the three main fronts STF, Sub-Antarctic Front (SAF) and APF (Swart et al. 2010). For each environmental variable, the variance from the observed track was compared to the variance of the null model to assess whether the variable had an effect on the observed track. This method allows for modelling the tracks using the total range available for a particular variable as opposed to only modelling the values encountered by an individual bird (Martin et al. 2008).

A hidden Markov model (HMM) was used to determine the state of specific points (Patterson et al. 2008, Jonsen et al. 2013) taking speed and relative turning angle into account (Patterson et al. 2008) while accounting for the large degree of auto-correlation present in tracking data (Patterson et al. 2009). Only two states were used within the HMM and were defined as transit or stationary states. Stationary states could either be resting or foraging; distinguishing between these states was not possible without additional data such as stomach

temperature recorders (Catry et al. 2004) or time-depth recorders (Phillips et al. 2008, Dean et al. 2012). Sooty albatrosses most probably feed by day and mostly rest at night (Weimerskirch & Guionnet 2002, Phalan et al. 2007) and so relatively large turning angles at low speeds during the day should indicate foraging areas (Weimerskirch 2007). Thus, stationary states during the day were treated as foraging states in subsequent analyses. Sunrise and set times were calculated for each coordinate separately using the *maptools* package in R (Bivand & Lewin-Koh 2015) and was used to define nautical dusk and dawn.

The distributions of tracked sooty and light-mantled albatrosses were related to tuna and billfish fishing effort between 2002 and 2012 obtained from the Food and Agriculture Organization (FAO) of the United Nations (<http://www.fao.org/figis/geoserver/tunaatlas/>), which provides a 5° x 5° map of fishing effort with all types of gear. Sooty albatross distribution during the chick rearing period from GLS loggers (see Chapter 4) were also related to fishing effort. Parametric T-tests were performed to test for differences in means for normally distributed data; alternatively a non-parametric Wilcoxon's signed rank test was used. All analyses were performed in R (R Development Core Team 2014). Values are presented as means ± SD unless stated otherwise.

## Results

Twenty-seven GPS loggers were recovered from sooty albatrosses (90%) and 10 from light-mantled albatrosses (67% recovery) during the 2013/14 breeding season. Loggers were lost due to nest failures (n = 1 sooty albatross, 2 light-mantled albatross), adults leaving chick alone (1 sooty and 1 light-mantled albatross) or loss from the bird (1 light-mantled albatross). Of the 10 light-mantled albatross loggers recovered, nine had useable data on eight complete foraging trips (n = 1 incubation and 7 brood guarding) and five partial trips during incubation. The battery on the tenth logger ran out before the bird left its nest. For sooty albatross, 24 out of the 27 loggers contained useable data, comprising 33 (n = 12 incubation and 21 brood guarding) complete foraging trips and seven partial trips (4 incubation and 3 brood guarding).

Incubating adult sooty albatrosses showed similar foraging strategies during both incubation periods, with longer trips than during brood guarding and many over large distances (Table 3.1). The furthest recorded distance from Marion Island was 2260 km with a total trip distance of ~8500 km over 19 days. The total distance travelled, duration of trips and maximum distance from the island was significantly greater for incubating sooty albatrosses than for brood guarding birds (Table 3.1). For sooty albatrosses, the average speed during brood guarding was higher than during early incubation (Table 3.1). Higher average speeds resulted in

larger daily travelling distances (~540 km) during brood guarding than during incubation (~390 km).

The effect of the device and handling of the birds seemed to be negligible as the average trip duration of tracked sooty albatrosses (complete tracks) during the incubation period ( $13.1 \pm 4.3$  days; brood guard shift data were not available) was not significantly different from the average trip duration observed in the monitoring colonies during the same period ( $11.0 \pm 2.3$  days;  $t = 2.18$ ,  $df = 12$ ,  $p = 0.13$ ). Similarly the average trip duration for light-mantled albatrosses during the brood guarding period (2.2 days) was not significantly different from the average trip duration observed within the monitoring colonies ( $2.0 \pm 0.9$  days;  $t = 1.0$ ,  $df = 14.43$ ,  $p > 0.05$ ; see Chapter 2).

Because of the lengthy incubation shifts of light-mantled albatrosses (see Chapter 2) timing of deployments was difficult during incubation and only one of the six incubation tracks was complete. This limited the analyses that could be performed and comparisons with brood guarding tracks. There was a positive correlation between sooty albatross trip duration and both distance travelled (Spearman's rank correlation  $\rho = 0.97$ ,  $df = 31$ ,  $p < 0.05$ ) and maximum distance from the island (Spearman's rank correlation  $\rho = 0.84$ ,  $df = 31$ ,  $p < 0.05$ ) (Figure 3.2). Although no correlation was performed due to incomplete tracks, light-mantled albatrosses seemed to go further in less time (Figure 3.2b). This is probably an artefact of the incomplete tracks during incubation as the only complete track during this period showed the opposite reaching a maximum of 681 km from Marion Island in 19 days (Figure 3.2b). Like sooty albatrosses, light-mantled albatrosses travelled further during incubation (~3500 km) than during brood guarding (~1300 km) with the maximum recorded distance from Marion Island at ~2500 km close to the Antarctic pack ice and (Figure 3.2b).

The average speed of sooty albatrosses at night ( $12.9 \text{ km}\cdot\text{h}^{-1}$ ) was significantly lower than the average speed during the day ( $24.5 \text{ km}\cdot\text{h}^{-1}$ ; Welch Two sample t-test,  $t = 6.3$ ,  $df = 41.6$ ,  $p < 0.01$ ), this was the case across all three breeding periods (Table 3.2). Likewise, the average speed of brood guarding light-mantled albatross at night ( $18.1 \text{ km/h}$ ) was significantly lower than the average speed during the day ( $28.2 \text{ km}\cdot\text{h}^{-1}$ ; Welch Two sample t-test,  $t = 2.6$ ,  $df = 23.5$ ,  $p < 0.05$ ). The maximum speeds (maximum distance covered in an hour) of sooty albatrosses were constant throughout the study period (Table 3.1). There was no significant difference between the average speed of sooty ( $23.3 \text{ km}\cdot\text{h}^{-1}$ ) and light-mantled albatrosses ( $24.0 \text{ km}\cdot\text{h}^{-1}$ ) during the brood guarding period (Welch Two sample t-test  $t = 0.25$ ,  $df = 9.8$ ,  $p = 0.8$ ). This was similar for the incubation period where average speeds did not differ significantly, however only one of the light-mantled tracks was a complete track.

During the incubation period, both sooty and light-mantled albatrosses showed a similar pattern of foraging with foraging trips being either close to the island or commuting trips to distant foraging areas (Figure 3.3). When commuting to distant foraging grounds, sooty albatrosses went far to the north into sub-tropical waters (Figure 3.4a & b) while the light-mantled albatrosses went further south into Antarctic waters (Figure 3.5). Two main foraging areas were identified for both sooty and light-mantled albatrosses using a kernel density analysis with the 50% utilisation distribution of foraging states during the day, one area close to Marion Island for both species and the other to the north of the STF (sooty albatross) or south of the APF near the Antarctic pack ice (light-mantled albatross; Figure 3.6). Overlap between the two species close to Marion Island occurred mainly east of the island (Figure 3.6).

During incubation, most locations were outside the South African EEZ surrounding Marion Island for both *Phoebastria* species, while most brood guarding period tracks were within the EEZ and more than 50% of locations were within the MPA (Table 3.3). Light-mantled albatross foraging areas did not overlap as much with the Prince Edwards Island MPA and South African EEZ as the sooty albatross with the proportion of points never exceeding 50% for any period (Table 3.3). Sooty and light-mantled albatrosses occasionally overlapped with the French EEZ surrounding the Crozet archipelago and incubating sooty albatrosses occasionally with the South African continental EEZ (Figure 3.6).

Mean sea level anomaly was an important predictor of sooty albatross distribution during both incubation periods, with the strongest prediction for early incubation ( $p < 0.01$ ), second for late incubation ( $p = 0.04$ ; Table 3.4). Eddy kinetic energy also was a strong predictor for both incubation periods ( $p < 0.005$ ) and SST was important during late incubation ( $p = 0.02$ ). During early incubation adult sooty albatrosses appear to follow the edges of eddies (inferred from sea level anomalies) with the main foraging area in the sub-tropics wedged between a cyclonic and anti-cyclonic eddy during early and late incubation (Figure 3.7).

Sooty albatrosses showed a large degree of overlap with tuna and billfish fishing effort between 2002 and 2012 within the southern Indian Ocean, with 70% of all points within areas with an annual catch of more than 10 tons (Figure 3.8). Likewise, a similar overlap with fisheries was observed for sooty albatrosses tracked with GLS loggers during the chick rearing period (Figure 3.9). In contrast light-mantled albatrosses showed little overlap with all points within areas with an annual catch lower than 10 tons (Figure 3.8).

## Discussion

GPS logger recovery was high for sooty albatross with no nest desertions occurring during deployment showing that the current method of deployment is suitable for sooty albatrosses.



The light-mantled albatross deployments were more difficult as the birds seemed to be more stressed than sooty albatrosses with one of the bird deserting the nest after deployment and not returning. A couple of light-mantled albatross loggers could not be recovered due to nest failures. The similarity in foraging trip duration between tracked birds and birds within the monitoring colonies suggests that the weight and position of the loggers did not have a significant effect on the performance of either species (Phillips et al. 2003).

On average, incubating sooty albatrosses conducted longer foraging trips than brood guarding adults, with the longer trips also associated with further distances from Marion Island. Shorter trips were undertaken during the first and last periods of incubation respectively (see Chapter 2, Figure 2.3). The positive correlation between trip duration and both distance travelled and maximum distance from Marion Island for sooty albatrosses show that birds undertaking longer foraging trips typically travelled further from the island in search of food. This is important for monitoring purposes as changes in shift lengths may indicate changes in environmental conditions and food availability (Terauds & Gales 2006). Sooty and light-mantled albatross shift lengths did not change significantly over the last couple of decades (Table 2.2; Berruti 1979), indicating that foraging distances from the island probably haven't changed much for both species. Although sample sizes were too small to test for correlation of light-mantled albatross duration and distances, similar results are expected as this was found for tracked light-mantled albatrosses from South Georgia (Phillips et al. 2005a). The birds from South Georgia often travelled long distances from the breeding ground (mean 941 km) as a result of competition (Phillips et al. 2005a) which is shorter than the  $1519 \text{ km} \pm 685 \text{ km}$  recorded on Marion Island. During the brood guarding period, the newly hatched chicks need constant nutrition and adults have to visit the nest more frequently (Phillips et al. 2004b). Light-mantled albatrosses breeding on South Georgia showed similar behaviour with constant trip durations when rearing chicks (Phillips et al. 2008), as opposed to alternating long and short trips observed in other species such as wandering and yellow-nosed albatrosses (Weimerskirch et al. 1994). Light-mantled albatrosses had similar shift lengths and shift distributions to birds breeding on South Georgia and Possession Island in the Crozet archipelago (Table 2.2). Light-mantled albatrosses spent most of their time in Antarctic waters which is similar to birds breeding on South Georgia and Macquarie Island (Weimerskirch & Robertson 1994, BirdLife International 2004, Phillips et al. 2005a, ACAP 2015c). The similarity of trip lengths for both sooty and light-mantled albatrosses during the incubation and brood guarding period might be indicative that the ocean environment surrounding Marion Island is productive enough to provide adequate food for these adults and their chicks during these periods (Phillips et al. 2008) and that they encounter prey at similar distances from the island. More data are needed

to determine if this is still the case after the brood guarding period when chicks require larger meals (Berruti 1979). Grey-headed albatrosses (*Thalassarche chrysostoma*) on Marion Island showed a bimodal distribution of foraging durations during early chick rearing alternating between longer and shorter trips, however all of these trips were significantly shorter than incubation trips (Nel et al. 2000). Black-browed albatrosses (*Thalassarche melanophris*) breeding on South Georgia forage in different areas at each period of breeding, but remain close to their breeding grounds during chick rearing (Phillips et al. 2004b). Amsterdam albatrosses (*Diomedea amsterdamensis*) on the other hand forage close to their breeding ground during brood guarding and further (in similar areas as incubation) when the chick is left alone (Thiebot et al. 2014) which is similar to wandering albatrosses (*Diomedea exulans*) from Marion Island that exhibit shorter trips during early chick rearing and longer trips during late chick rearing (Nel et al. 2002b).

The distribution of tracked sooty albatrosses mostly support information obtained from dietary studies on Marion Island (Berruti 1979, Cooper & Klages 1995, Connan et al. 2014). Although diet suggests that sooty albatrosses take prey from Antarctic waters, they were rarely tracked within these areas and spent most of their time in sub-Antarctic and sub-tropical waters. This might be due to sample size as breeding sooty albatrosses tracked on Gough and the Crozet Islands did spend a considerable amount of time within Antarctic waters (BirdLife International 2004, ACAP 2015b). However, breeding sooty albatrosses from Gough Island went further from their breeding grounds when travelling south than birds tracked on the Crozet Islands (BirdLife International 2004, ACAP 2015b) and Marion Island. Foraging seabirds typically display one of two broad types of foraging: looping, where the bird searches for unpredictable food sources, or commuting to a predictable food source, returning from the same direction as they set off from (Weimerskirch 2007). Incubating birds displayed commuting trips when the destination was far towards the north (sooty albatross) or south (light-mantled albatross) and looping trips when foraging close to the island, mostly to the south-west. Commuting light-mantled albatrosses went to the Antarctic pack-ice on two occasions (33% of incubation tracks) which is similar to breeding birds tracked from South Georgia (BirdLife International 2004, Phillips et al. 2005a, Phalan et al. 2007, Phillips et al. 2008) and Macquarie Island (Weimerskirch & Robertson 1994, BirdLife International 2004). It is not clear if individual birds would alternate between these two strategies, which is the case for some seabirds (Weimerskirch 2007) or if some other driver, such as sex, dictates where they forage. More tracking data are needed to tease apart such details especially later during the chick rearing stage when tracking data for Marion Island are not available. Sexing is also necessary to determine if sex is an important driver towards sooty albatross distributions. This

is particularly important as some albatross and petrel species show a male bias with regards to fisheries overlap and related mortalities (Ryan & Boix-Hinzen 1999).

For both *Phoebastria* albatross species the average speed during the day was significantly faster than during the night. This shows that most of the commuting trips (trips between foraging areas) are probably done during the day with resting occurring during the night (Weimerskirch & Guionnet 2002, Phalan et al. 2007). It has been suggested that many albatross species mainly feed during the day as a lack of light reduces their ability to catch prey (Phalan et al. 2007, Phillips et al. 2008), however stomach temperature loggers have revealed that grey-headed albatrosses from South Georgia do ingest prey in darkness despite spending a large proportion of the time in the water (Catry et al. 2004). Sooty albatrosses tracked during the breeding season appeared to forage along the edges of eddies, especially during incubation when they travelled further from the island. Many seabirds forage in this habitat, especially where adjacent cyclonic and anti-cyclonic eddies form highly dynamic areas (Tew Kai & Marsac 2010). Grey-headed albatrosses breeding on Marion Island also forage around eddy edges (Nel et al. 2001). Seabird associations with eddies may be due to warmer sea surface temperatures (SST) (Hyrenbach et al. 2006, Bost et al. 2009), but this was not evident in this study. Areas that are hot-spots for seabirds are often areas that are targeted by fisheries as they are also interested in the increased productivity of such areas. When this overlap occurs it produces the concern that seabirds might be killed as bycatch (Gales et al. 1998, Anderson et al. 2011, Tuck et al. 2011). Many recent studies have attributed the decline in albatross populations to such fishing mortalities as is the case for sooty albatrosses (Delord et al. 2008, Ryan et al. 2009, Tuck et al. 2011).

A large proportion of adult movement during the breeding season is close to the island as the birds have to return to the island to share incubation duties or feed their chick. The only legal fishery in the waters around Marion Island is a small Patagonian toothfish (*Dissostichus eleginoides*) fishery that is left after the fish stocks crashed in the late 1990s (Boonzaier et al. 2012). When compared to tuna long-line fisheries, toothfish fisheries are not considered as having major impacts on albatross survival as the incidental bycatch mortality rates are low (Rolland et al. 2010) and even at the height of the fishery very few sooty albatrosses were killed (Nel et al. 2002c). Sooty albatrosses from Marion Island do however forage within the Southern Indian Ocean where their ranges overlap with tuna and billfish fisheries (Tuck et al. 2003, Petersen et al. 2009). Most of the overlap with fisheries occurs during the incubation period and GLS data (see Chapter 4) suggest that chick rearing adults also overlap with fisheries (Figure 3.9). Taiwanese tuna long-liners have been responsible for an average of 48 sooty albatross kills per annum between 2004 and 2007 as a result of incidental bycatch in the Southern Indian

Ocean (Huang and Liu 2010). The southern Indian Ocean is one of the areas with the highest rate of fisheries-related seabird mortalities and is also the most data deficient area in terms of bycatch (Lewison et al. 2014). These areas within international waters are of concern as fisheries are not legally obligated to report bycatch rates, making it difficult to determine the effects that these fisheries have on seabird survival (Delord et al. 2014). Sooty albatrosses from Marion and Crozet Islands forage in similar areas within sub-tropical and sub-Antarctic waters while they do not seem to overlap much with birds from Gough Island during breeding (BirdLife International 2004, ACAP 2015b). Unlike sooty albatrosses on Marion and Crozet Islands (Delord et al. 2008, Ryan et al. 2009), the population on Gough Island does not seem to be decreasing (Cuthbert et al. 2014). This contrast may be linked to differences in their distributions; sooty albatrosses breeding on Gough Island mainly forage within sub-Antarctic and Antarctic waters (BirdLife International 2004) and not much time is spent within the sub-tropical zone where most of the overlap with fishing vessels would occur (Nel et al. 2000, Nel et al. 2002b). However, over the last few years a reversal of sooty and light-mantled albatross trends was observed on Marion Island (see Chapter 2). For the sooty albatrosses this may be attributed to increased mitigation measures implemented within regulated fisheries within the southern Indian Ocean (Anderson et al. 2011). This has been the case where Chilean black-browed albatross populations increased as a result of reduced fishery-related mortality (Robertson et al. 2014). Within the southern Indian Ocean, RFMOs such as the Indian Ocean Tuna Commission (IOTC) and the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), require the installation of bird-scaring lines when fishing below 25° S together with one other mitigation measures (Huang and Liu 2010). The Taiwanese Government requests southern fishing vessels to produce receipts and photographic evidence of installed bird-scaring lines, to ensure compliance (Huang and Liu 2010).

Wide-ranging seabirds often have distributions that overlap with several countries, increasing the difficulty of conservation management (Thiebot et al. 2014). The range of sooty and light-mantled albatrosses overlapped with the Prince Edward Islands MPA and EEZ, South-African continental EEZ (sooty albatross only) and French EEZ surrounding the Crozet archipelago. The proposed Prince Edward Islands MPA (Lombard et al. 2007) was implemented in 2013 (Department of Environmental Affairs, [www.environment.gov.za](http://www.environment.gov.za)) within the South African EEZ around these islands and CCAMLR sections 58.6 and 58.7. One of the main objectives of the MPA is to reduce fisheries-related seabird mortality (Lombard et al. 2007). One of the main foraging areas for sooty albatrosses was between the South African EEZ (Prince Edward Islands) and the French EEZ (Crozet archipelago) just south of the Africana Rise in the vicinity of the Deacon Seamount. The importance of co-management between adjacent EEZs in

the Southern Ocean has been stressed as a measure of effective conservation of species inhabiting these areas (Lombard et al. 2007). Both sooty and light-mantled albatrosses were tracked within the French EEZ during incubation and the proposed MPAs within the French sub-Antarctic EEZ (Delord et al. 2014) will also provide protection for birds breeding on Marion Island.

The contrasting conservation status of sooty and light-mantled albatrosses breeding on Marion Island seems to be linked to their at-sea distribution. Fishery-related mortality within the southern Indian Ocean is the most probable cause of past reductions in sooty albatross population trends. However, the recent increases in the Marion Island population suggest that such mortalities might have decreased. Updated data are needed from neighbouring breeding colonies within the Crozet archipelago to test the generality of these results. More data are also necessary from fisheries within the southern Indian Ocean to determine if there is a reduction in the amount of sooty albatrosses that are killed as a result of incidental bycatch.

**Table 3.1:** Summary of sooty albatross GPS tracking data, significance p-values for ANOVA tests shown with Tukey post-hoc tests. Values are means from complete foraging trips with significant tests indicated in bold.

	Early Incubation (EI, n = 8)	Late Incubation (LI, n = 5)	Brood guard (B, n = 24)	ANOVA	Tukey post hoc
<b>Duration (days) ± SD</b>	13.75 ± 4.89	11.48 ± 4.63	1.82 ± 0.54	<b>F = 79.88, p &lt; 0.001</b>	<b>EI = LI &gt; B</b>
<b>Trip duration (km) ± SD</b>	4978 ± 2346	4711 ± 1466	967 ± 305	<b>F = 53.12, p &lt; 0.001</b>	<b>EI = LI &gt; B</b>
<b>Max distance (km) ± SD</b>	1135 ± 709	1088 ± 149	285 ± 80	<b>F = 26.32, p &lt; 0.001</b>	<b>EI = LI &gt; B</b>
<b>Avg. speed (km/h) ± SD</b>	14.8 ± 3.4	18.0 ± 3.2	22.2 ± 4.8	<b>F = 4.71, p &lt; 0.02</b>	<b>EI = LI; LI = B; EI &lt; B</b>
<b>Max speed (km/h) ± SD</b>	68.3 ± 13.9	72.8 ± 11.9	59.9 ± 9.6	F = 1.08, p = 0.58	EI = LI = B

**Table 3.2:** Differences in travel speeds during day and night for sooty albatrosses at three periods of their breeding cycle.

	Night (km.h <sup>-1</sup> )	Day (km.h <sup>-1</sup> )	Test statistic	p-value
<b>Early Incubation</b>	10.4	21.4	W = 46	< 0.01
<b>Late Incubation</b>	13.3	22.5	t = 4.6, df = 14	< 0.01
<b>Brood guard</b>	14.6	28.3	t = 3.7, df = 14.8	< 0.01

**Table 3.3:** Proportion of sooty and light-mantled albatross points falling within the South African EEZ or MPA surrounding Marion Island or within the French EEZ around the Crozet archipelago during different breeding periods.

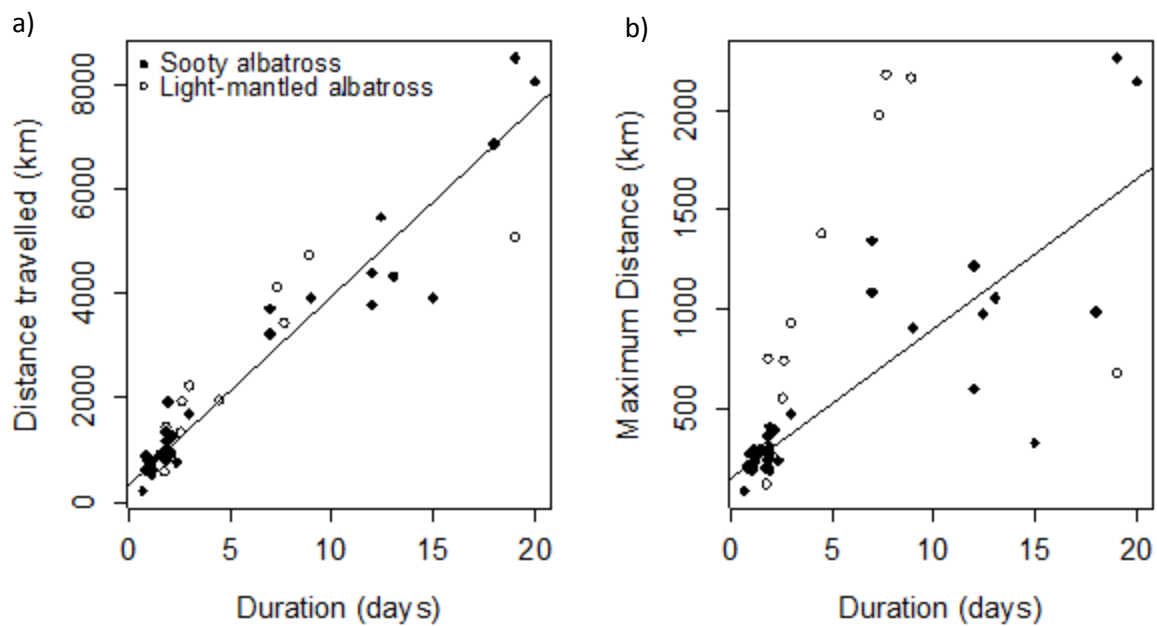
	Prince Edward Is. MPA	South Africa EEZ	France EEZ
<b>Sooty albatross</b>			
<b>Early Incubation</b>	0.15	0.27	0.01
<b>Late Incubation</b>	0.17	0.42	0.03
<b>Brood guarding</b>	0.6	0.98	0.00
<b>Light-mantled albatross</b>			
<b>Early Incubation</b>	0.16	0.42	0.01
<b>Late Incubation</b>	0.03	0.11	0.03
<b>Brood guarding</b>	0.42	0.7	0.00

**Table 3.4:** Multiple null model analysis p-values for sooty albatrosses tracked with GPS loggers compared to environmental variables.

	Early incubation	Late incubation	Brood guard
Bathymetry	0.93	0.81	0.51
Bathymetry gradient	0.8	0.81	0.51
Eddy kinetic energy	<b>&lt; 0.01</b>	<b>&lt; 0.01</b>	0.89
Mean sea-level anomaly	<b>&lt; 0.01</b>	<b>0.04</b>	<b>&lt; 0.01</b>
Sea surface temperature (SST)	0.72	<b>0.02</b>	0.44
SST gradient	0.38	0.07	0.47

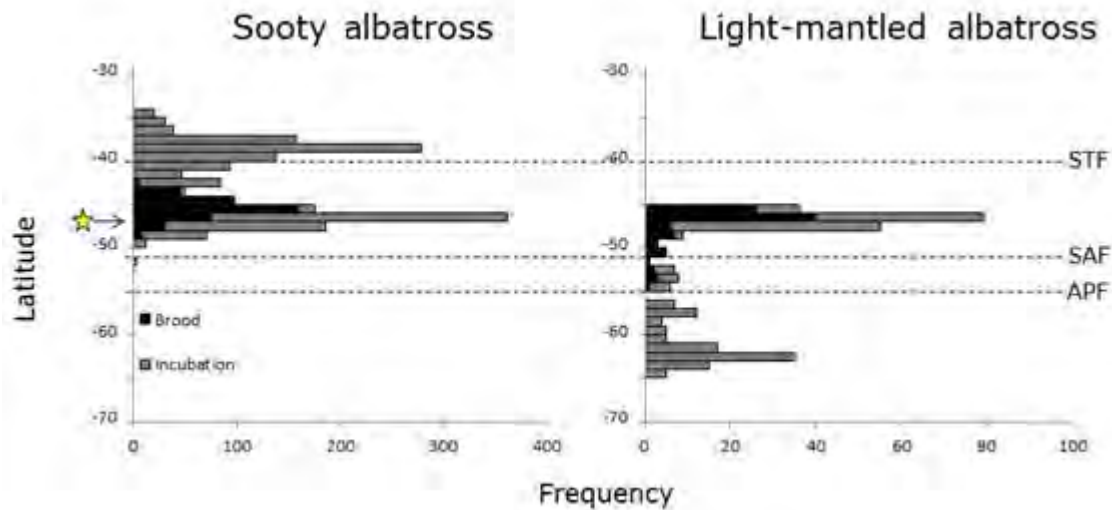


**Figure 3.1:** GPS locator deployed on the back of an incubating sooty albatross

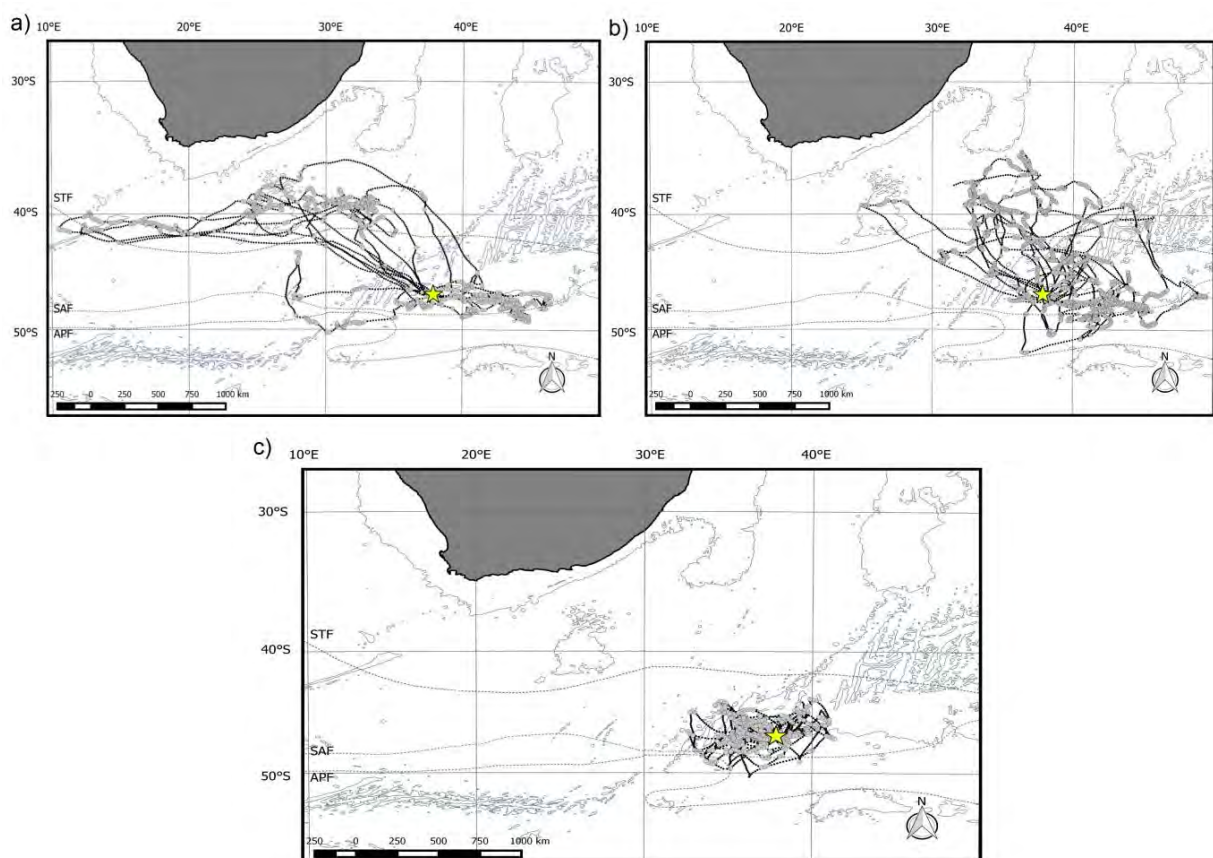


**Figure 3.2:** Correlations between trip duration and a) total distance travelled and b) maximum distance from Marion Island compared to duration of complete sooty albatross trips. Data from all (complete and partial) light-mantled albatross trips are also shown.

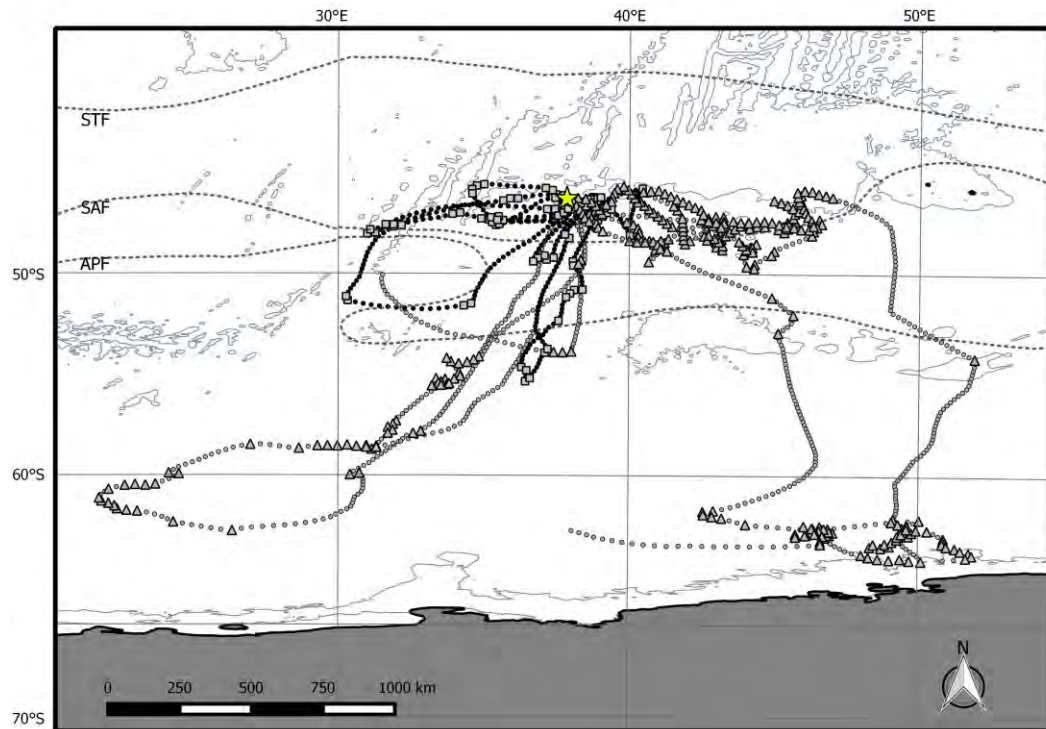




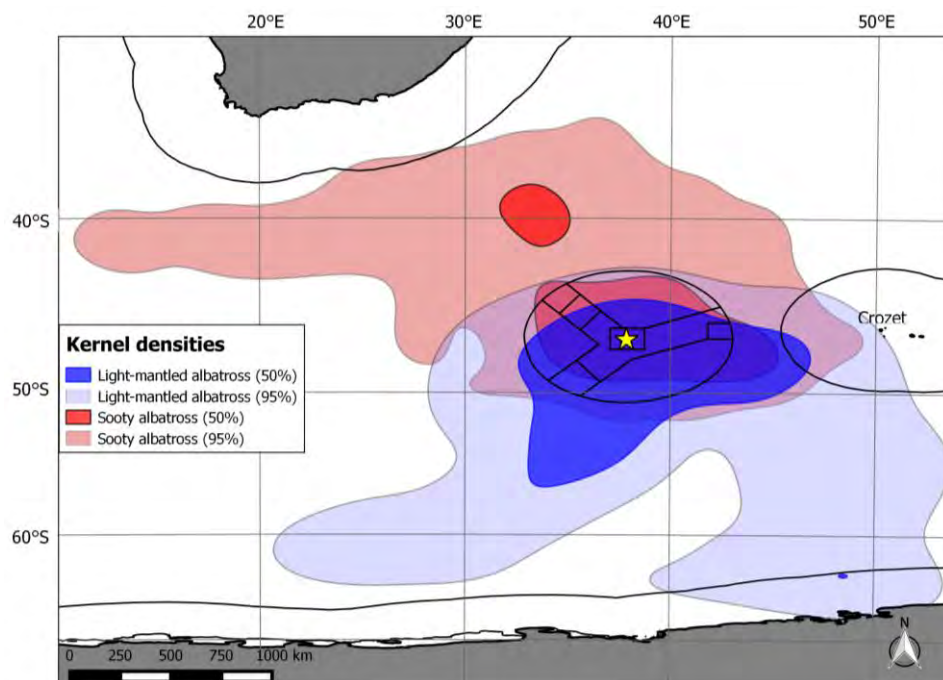
**Figure 3.3:** Frequencies of occurrence for latitudes of possible foraging states revealed by hidden Markov models for sooty and light-mantled albatrosses during incubation and brood guarding. Average latitude of three fronts are shown as determined by (Orsi et al. 1995) with Marion indicated by a star.



**Figure 3.4:** Sooty albatross breeding tracks with probable foraging areas (grey dots) during (a) early incubation, (b) late incubation and (c) brood guarding. Average position of major fronts shown in accordance with (Orsi et al. 1995) with bathymetry at 3000 m and Marion Island is indicated with a star.

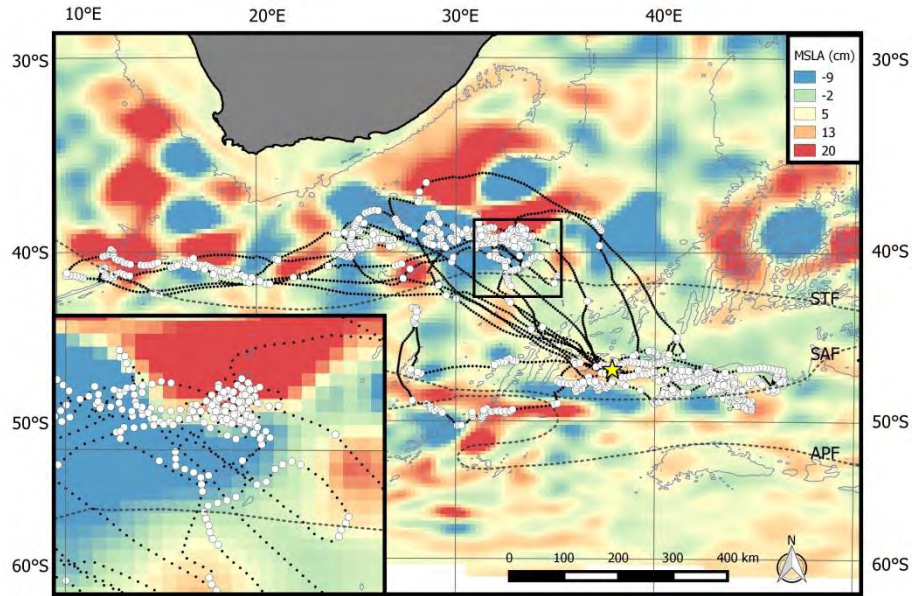


**Figure 3.5:** Light-mantled albatross breeding tracks with probable foraging areas during incubation (triangles) and brood guarding (squares). Conventions as in Figure 3.4.

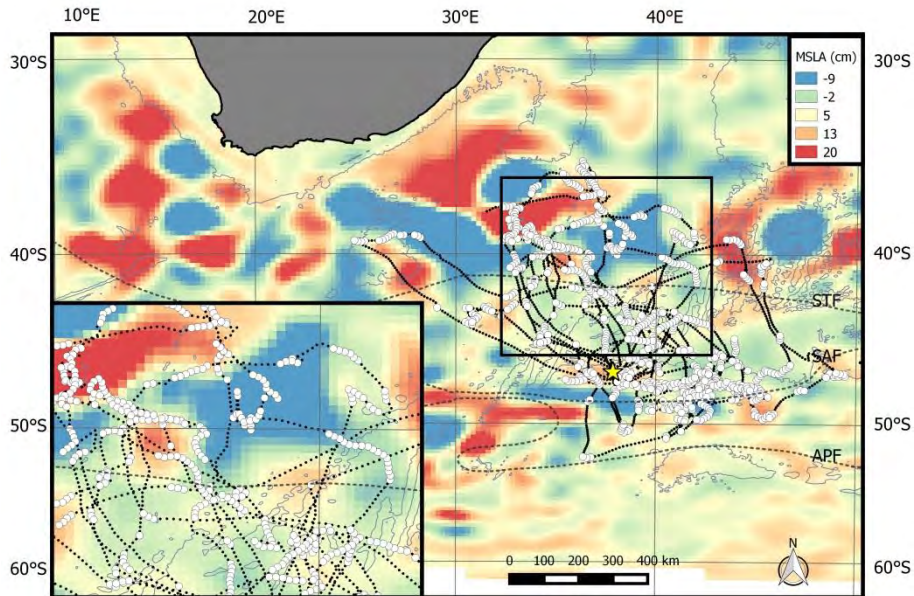


**Figure 3.6:** Sooty and light-mantled albatrosses tracked during the 2013/14 breeding season overlapping with EEZs in the Southern and Indian Ocean, the Y-shape in the EEZ surrounding the Prince Edward Islands represents the Marine Protected Area. Marion Island indicated with a star.

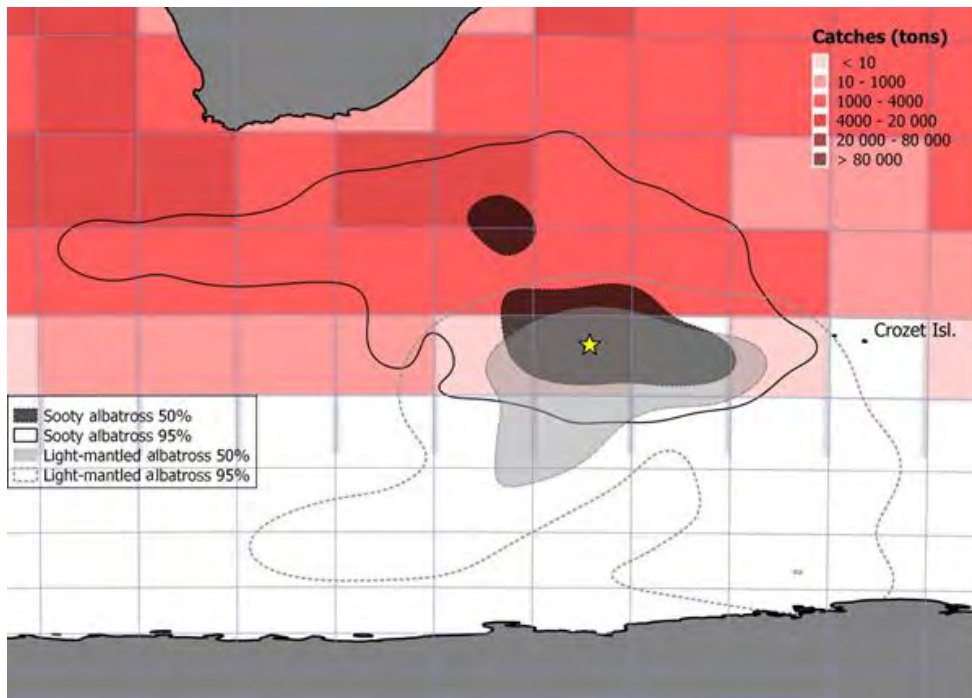
a)



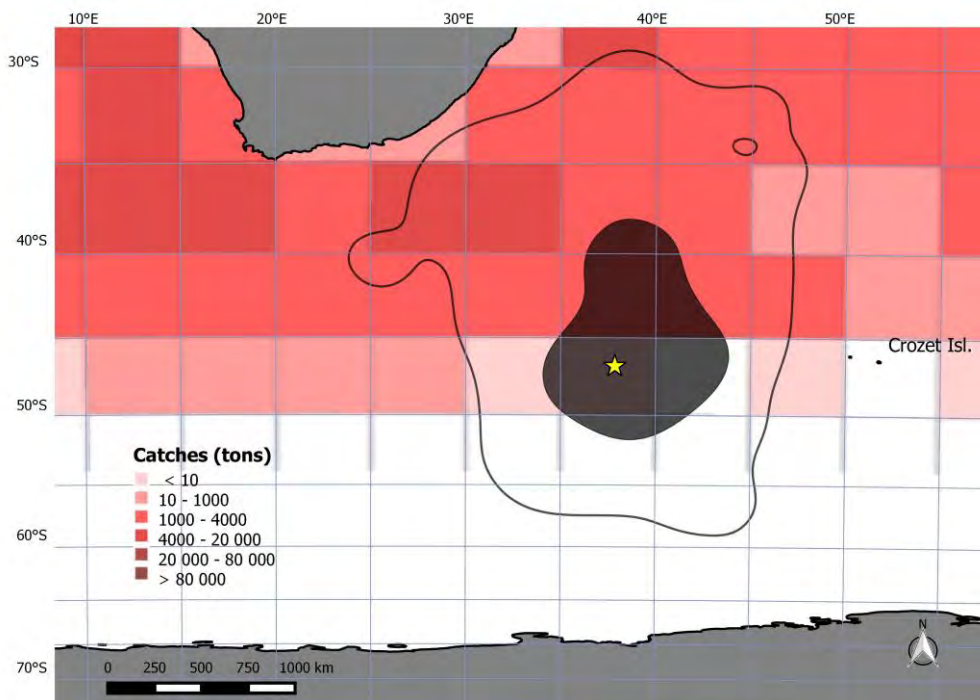
b)



**Figure 3.7:** Sooty albatross foraging locations inferred with a hidden Markov model during (a) early incubation and (b) late incubation displayed on maps of mean sea level height anomalies (MSLA). Insets show association of foraging states with eddies or the edges of eddies. Conventions as in Figure 3.4.



**Figure 3.8:** Kernel density estimates of sooty and light-mantled albatrosses tracked during the 2013/14 breeding season overlapping with tuna and billfish yearly catches between 2002 and 2012. Marion Island indicated with a star.



**Figure 3.9:** Kernel density estimates of sooty albatrosses tracked with GLS loggers from March to May 2012 during the chick rearing period, overlapping with overlapping with tuna and billfish yearly catches. The shaded area shows the 50% density estimate with the 95% estimate shown with a solid line. Conventions as in Figure 3.8.

## **Chapter 4: Non-breeding distributions of sooty and light-mantled albatrosses from Marion Island: comparison of geolocation and stable isotope approaches**

### **Abstract**

The foraging grounds of non-breeding albatrosses are crucial areas to focus conservation efforts as they spend large amounts of time there. Biennially breeding *Phoebastria* albatrosses may spend up to 16 months away from their breeding grounds. The only information on non-breeding distributions of *Phoebastria* albatrosses on Marion Island have been inferred from stable isotope studies, which suggest that sooty albatrosses (*P. fusca*) moult in sub-tropical waters and light-mantled albatrosses (*P. palpebrata*) in sub-Antarctic waters. Established breeders from both species were tracked year round with geolocator (GLS) loggers and feather samples were collected from the tracked birds for stable isotope analysis. Sooty albatrosses mainly foraged within the southern Indian Ocean during the non-breeding period, overlapping with birds from Possession Island (Crozet archipelago) but rarely with birds from Gough Island. Successful breeders had different distributions in consecutive winter periods, spending more time at higher latitudes during the second winter than the first winter period. Isotope analysis showed that moulting mainly occurred in sub-tropical waters north of the Sub-Tropical Front (STF). Tracking data did not show a clear pattern of where moulting occurs, however two periods (sabbatical summer and first winter of successful breeders) had a high proportion of points above the STF. Male and female distributions also varied for successful breeders; males moved further from the island during winter whereas females moved further during their sabbatical summer. Only two light-mantled albatrosses were tracked; both travelled southwest into Antarctic waters of the southern Atlantic Ocean before moving east into lower latitudes in the southern Indian Ocean. One of the birds continued east and circumnavigated the globe during winter, stopping at areas south of Australia for approximately 56 days. Isotope analysis of different feather types showed a difference in  $\delta^{15}\text{N}$  between primary and body feathers, contrary to previous study on albatrosses, however sample sizes were small. Sooty albatrosses overlapped with the Exclusive Economic Zones (EEZs) of several countries although most (79%) of points were in international waters and overlap with areas of high long-line fishing activity during the non-breeding period.

### **Introduction**

During the non-breeding period albatrosses are able to expand their spatial ranges extensively, because they are not constrained to return to their breeding grounds (Tickell 2000, Croxall et al. 2005, Weimerskirch et al. 2015). This can have conservation implications as birds may overlap

with various fisheries (Thiebot et al. 2014). In the past, non-breeding distributions of albatrosses have been inferred from ship observations (Tickell 2000) and more recently from satellite tracking (Jouventin & Weimerskirch 1990, Phillips et al. 2008) or location estimates from GLS loggers (Afanasyev 2004, Phillips et al. 2004a). Tracking over long periods requires satellite transmitting devices (which are very expensive) or data loggers that can stay on the bird for two or more breeding seasons without affecting its fitness. However, for albatrosses, obtaining tracking data in the non-breeding period is particularly hard as the birds do not return to predictable nest sites during this time making logger recovery a daunting task. Long term deployments have created the need for miniaturised devices with long battery life and storage capacity that can stay on the bird for prolonged periods and record data until devices are recovered. Technological advances over the last decade allow for smaller tracking devices with larger storage capacities, such as geolocators (global location sensing, GLS; Afanasyev 2004). Although this method is not as accurate as satellite tracking it is much cheaper and adequate to describe non-breeding movement of wide-ranging birds (Phillips et al. 2004a). The accuracy of this method may be influenced by various factors including animal behaviour, artificial light sources and the inability to predict latitudes around the equinoxes (Phillips et al. 2004a).

To complement the tracking data, stable isotope analysis of feathers are increasingly being used (Cherel et al. 2000, 2013, Jaeger et al. 2013, Connan et al. 2014) as these birds mainly moult when not breeding (Berruti 1979, Jaeger, et al. 2010a). It has been shown that black-browed albatrosses (*Thalassarche melanophris*), breeding on South Georgia and the Falklands respectively, do moult during breeding (Catry et al. 2013b), however no such data are available for *Phoebetria* spp. from Marion Island. Naturally occurring carbon and nitrogen isotopes exist throughout nature and the ratio of these isotopes ( $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , respectively) can be used to infer the origin of a food source or trophic level at which an organism feeds (Hobson 1990, Cherel et al. 2013). This is a valuable tool in the Southern Ocean as  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  decreases with latitude and can be used to infer different characteristics such as the latitude and trophic level within a given time period (Hobson 1990, Cherel et al. 2000, 2013, Jaeger et al. 2010b, Jaeger et al. 2013).

*Phoebetria* albatrosses are biennially breeding birds that typically do not return to breed in consecutive years (Tickell 2000). Identifying their non-breeding distributions is crucial for their conservation as they may be away from the breeding colony for 16 months or more, which is more than double the length of the breeding season (Berruti 1979, Jaeger et al. 2013). Distribution data for *Phoebetria* albatrosses are scarce especially for non-breeding birds, although this is a crucial part of their life cycle (Cherel et al. 2013). There are no published

tracking data for sooty albatrosses from Marion Island, but feather stable isotope analysis from breeding birds suggest that sooty albatrosses (*Phoebastria fusca*) are spatially segregated from light-mantled albatrosses (*Phoebastria palpebrata*) during the non-breeding period and that sooty albatrosses feeds at a higher trophic level (Jaeger et al. 2010a, Cherel et al. 2013, Connan et al. 2014). These studies indicate that sooty albatross mainly moult in sub-tropical waters when they are not breeding, as opposed to their sub-Antarctic breeding grounds and light-mantled albatross mainly moult in sub-Antarctic and Antarctic oceanic waters. Isotope analysis does not give information about longitudinal distribution (Jaeger et al. 2013) and combining tracking data with this method may allow for the inference of specific foraging regions for individual populations (Cherel et al. 2013, Weimerskirch et al. 2014).

This study was done on Marion Island where sooty and light-mantled albatrosses were tracked with GLS loggers and feather samples (collected during logger retrieval) were used for stable isotope analysis. Latitudinal ranges during different time periods are compared to latitudes inferred from stable isotope analysis to identify possible moulting areas. The ranges of sooty albatrosses during the non-breeding period were compared to that of birds from other breeding grounds to determine if overlap occurred. Within-species comparisons were made to determine if sex or breeding success had an effect on their distribution. Trophic and spatial segregation between the two species were expected during the non-breeding period.

## **Materials and Methods**

Global location sensing (GLS; British Antarctic Survey) MK15 loggers (18 mm x 16 mm x 5 mm, 2.5 g) were attached to darvic bands and placed on the legs of breeding adult birds on the north-east coast of Marion Island (from Long Ridge to Macaroni Bay, see Chapter 2, Figure 2.1) in 2012. Individuals that were deployed on during the 2011/12 breeding season were sexed by behavioural observations, culmen length measurements (Berruti 1979). Deployments during the 2012/13 breeding season were on birds that were incubating an egg or brooding a chick. These loggers were deployed and retrieved without restraining the bird to minimise disturbance, consequently culmen length was not measured (Berruti 1979). Such birds could not be sexed unless they were observed mating or with their partner (males assumed to have larger, heavier bills than females (Berruti 1979)). A total of 16 loggers (14 on sooty albatrosses and two on light-mantled albatrosses) were deployed in March 2012 towards the end of the 2011/12 breeding season and a further 24 loggers (17 on sooty albatrosses and seven on light-mantled albatrosses) were deployed towards the end of incubation in December 2012. Colonies where the loggers were deployed were monitored periodically throughout subsequent breeding seasons to look for returning birds. Data from monitoring colonies on Marion Island (Chapter 2) suggests that successful pairs don't breed in successive years. Thus, birds that returned to breed

in successive years were assumed to be unsuccessful breeders during the year of deployment, while successful breeders did not breed during successive years.

GLS loggers record light levels every 60 seconds but only store the maximum level every 10 minutes in a compressed state, which can be used to estimate longitude and latitude coordinates. Twilight events (sunrise and sunset) are used to determine longitude from local midnight and noon and latitude from day lengths (Afanasyev 2004). In addition to light levels, sea surface temperatures are obtained if the logger is submerged for more than 20 minutes. The GLS loggers were ground-truthed (calibrated) by placing them in an un-shaded area with known coordinates for at least five days before and after deployment.

There is no standardised method for analysing GLS data; several analytical tools exist for this including commercial (MultiTrace; Jensen Software Systems, Germany, Phillips et al. 2004a) and freeware (BASTrak software, R packages such as *GeoLight* and *tripEstimation*). *GeoLight* produces raw locations from twilight events with the option of adding a speed filter, and *tripEstimation* (Sumner et al. 2009, Sumner & Wotherspoon 2015) and *Ukfsst* (Nielsen et al. 2012) use state-space modelling to predict the most likely track from the raw locations (Lam et al. 2008, Thiebot & Pinaud 2010). Accuracy of locations can be further improved by evaluating GLS recorded temperatures against satellite derived sea-surface temperature (SST) to refine latitude estimates, especially around the equinoxes (Shaffer et al. 2005, Lam et al. 2008).

For sooty and light-mantled albatrosses feathers are replaced gradually between breeding events (Warham 1996) and once synthesised the feathers do not change in isotopic composition (Mizutani et al. 1990) and can provide information on non-breeding distribution (Berruti 1979, Jaeger et al. 2013, Connan et al. 2014). During retrieval of GLS loggers, body feathers (from the chest; n = 41 feathers from 16 sooty albatrosses and eight feathers from two light-mantled albatrosses) were collected from all birds. In addition to body feathers, primary feathers of seven sooty albatrosses were sampled by cutting a small piece from the base of the feather (n = 13 feathers from seven birds). The same primary feathers were not sampled for all birds (mixture of primaries 2, 4, 6, 8 and 9 between birds) and moult was not recorded, thus analysis of individual primary feathers between individuals could not be performed. Prior to isotope analysis the feathers were cleaned in a 2:1 chloroform:methanol solution by placing them in an ultrasonic water bath for two minutes, then rinsed in methanol and deionised water separately and oven dried at 50 °C for 24 hours (Connan et al. 2014). Dried feathers were cut into small pieces with stainless steel scissors and subsamples were packaged into small aluminium foil containers for analysis of relative  $^{13}\text{C}/^{12}\text{C}$  and  $^{15}\text{N}/^{14}\text{N}$  ratios (Stable Light Isotope Unit, University of Cape Town), so that the stable isotope ratio of a sample is presented as:



$$\delta X = [(R_{\text{sample}}/R_{\text{standard}}) - 1] \times 1,000$$

where R is the ratio of the isotope (X) in question in the sample and a standard (Vienna PeeDee Belemnite for C and atmospheric air for N).

### **Analysis**

For this study a combination of two software packages were used to analyse the geolocator tracks; raw data were downloaded and decompressed using BASTrack (British Antarctic Survey) and analysed in R (R Development Core Team 2014) using a modified version of *tripEstimation* (J Cleeland et al. pers. comm.) specifically written for GLS data from large Procellariiformes. Calibration from ground-truthed locations were used prior to location estimates to determine the sun elevation angle when the light levels change rapidly during twilight events; this elevation angle is used in subsequent analysis. Unfiltered locations were individually checked to correct obvious outliers that occur partly due to shading of the logger (e.g. when the bird is sitting or flying with its legs tucked in) or during equinox periods. This time-consuming process can take a couple of hours when a lot of locations are present. The modified *tripEstimation* package compensates for shading of the GLS loggers that might result in erroneous locations and uses Bayesian estimation to produce the most likely track from the corrected locations taking variables such as recorded sea temperature and speed into account. The modelling part of the package is similar to the R package *tripEstimation* (R Development Core Team 2014) and uses Markov Chain Monte Carlo (MCMC) simulation methods to estimate tracks (Sumner et al. 2009). The most probable track produced by the model was then interpolated at a time interval of 12 hours (two locations can be estimated per day from light data) and filtered to remove points with speeds larger than 33 km/h (average speed from GPS data, Chapter 3). Average speeds were used as GLS loggers can't give an accurate account of speed because only two locations are available for each day.

Because the accuracy of GLS derived locations is low, with a resolution of 100-200 km (Phillips et al. 2005b), subsequent habitat use was inferred from kernel utilization distribution estimates using the *adehabitat* package in R (Calenge 2006). Geolocator tracks from sooty albatrosses were compared to GPS tracks from breeding birds (see Chapter 3) to determine if they show similar patterns because sample sizes were modest for both approaches. The rest of the analyses were performed on non-breeding tracks (winter and sabbatical summer periods). Winter was defined as 1 June to 31 August as this is when almost all sooty albatrosses are absent from Marion Island (Berruti 1979). Two different feather types were sampled to give a better representation of the whole moulting period and because the data were nested, a linear mixed effects model (R package *nlme*) with individual as a random effect was used to determine

if significant differences of isotopes between feather types were present. Feather isotope data were used to identify areas of non-breeding distribution in relation to oceanic fronts as described by isotopically distinct latitudinal isoscapes in the Southern Ocean (Jaeger et al. 2010b). The  $\delta^{13}\text{C}$  value of each feather was compared to these isoscapes separately to determine in which zone (sub-tropical, sub-Antarctic or Antarctic) the feather was most probably moulted. The proportion of body feathers moulted in different zones for each bird was compared to the proportion of latitudes within each zone from GLS loggers.

## **Results**

Of the 40 loggers deployed in the 2011/12 and 2012/13 breeding seasons, 18 loggers (16 sooty albatross and two light-mantled albatross) were retrieved in October-November 2013 and one sooty albatross logger in November 2014, all from breeding birds. All the loggers could be downloaded and had usable data, however data quality for four of the 19 loggers were too poor to determine locations without large amounts of manual alterations to twilight times and they are not reported here, leaving 15 tracked birds. Recorded light levels from all the downloaded GLS loggers showed a large amount of shading during summer (1 September – 31 May) and to a lesser extent during winter. Thus, accuracy of summer locations is probably lower than winter locations.

Eight sooty albatrosses were successful breeders in the year of deployment and loggers had data for two consecutive winter periods except for one that only had usable data for the first winter period (2012). The remaining five sooty and two light-mantled albatrosses were unsuccessful breeders and loggers had data for only one winter (2013) before the birds returned to breed again.

### **GLS tracking**

The comparison of GLS and GPS tracks (see Chapter 3) during the breeding period showed similar distributions (Figure 4.1) with the 50% distribution kernel of GLS points falling within the 95% distribution of GPS points. The overall distribution of tracked sooty albatrosses during the non-breeding period was mostly located within the southern Indian Ocean and adjacent Antarctic waters between 8° W and 138° E (Figure 4.2). Two core areas were identified during the non-breeding period, a large area surrounding the Prince Edward Islands and smaller area to the east between Amsterdam-Saint Paul Islands and Kerguelen (Figure 4.2). The distribution overlapped with EEZs from several countries including the mainland EEZs of Australia and South Africa, however most (79%) of the tracked locations were in international waters (Figure 4.2). Tracked individuals showed a larger variation in longitude between summer and winter

periods than latitude (Table 4.1), but latitudes must be treated with caution especially towards higher latitudes where accuracy of geolocation decreases.

Both of the light-mantled albatrosses were most likely unsuccessful breeders in the year of deployment as they returned to breed the following breeding season. One bird (ID 24144) circumnavigated the globe within 5 months (March to August 2013). It seemingly failed towards the end of January as it left Marion Island towards the south-west staying within Antarctic waters but close to the Antarctic Polar Front (APF) between 10° W and 10° E and did not return to the island until after winter (Figure 4.3a). During March 2013 it headed southeast to spend the most of the winter (13 May to 8 July 2013) south of Australia between 120° E and 160° E and then returned to Marion Island via the Pacific Ocean covering ~15000 km within 26 days. The second light-mantled albatross (ID 24149) moved away from Marion Island shortly after deployment and did not return to attend its nest until after winter. It spent ~4 months in Antarctic waters south west of Marion between 20° W and 20° E (Figure 4.3b). During April the bird moved east at lower latitudes and overwintered in the sub-Antarctic between 70° E and 100° E before returning to Marion Island to breed. Both birds spent most of the winter in Antarctic waters close to the APF.

Sooty albatrosses that were tracked for two consecutive winters showed a latitudinal shift in distribution (Figure 4.4) spending the second winter at significantly lower latitudes on average (first winter =  $41.8 \pm 2.2$  ° S, second winter =  $46.7 \pm 2.4$  ° S, linear mixed effects model,  $t = -28.6$ ,  $p < 0.01$ ). Although sample sizes were small, males travelled farther east than females during winter, whereas females went farther east during summer when the males were closer to Marion Island (Figure 4.5).

### **Isotope analysis**

There was no significant difference between the  $\delta^{13}\text{C}$  values of the two types of feathers samples ( $t = -0.6$ ,  $df = 43$ ,  $p = 0.5$ ) and  $\delta^{13}\text{C}$  data were pooled across feather types for subsequent analysis. However, the  $\delta^{15}\text{N}$  of primary feathers was significantly lower than that of body feathers ( $t = -3.5$ ,  $df = 43$ ,  $p < 0.01$ ). The mean  $\delta^{13}\text{C}$  value for sooty albatross feathers was similar to that reported in previous studies of birds breeding at Marion Island, while the mean  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values for light-mantled albatross feathers were lower (Table 4.2), however sample the sample size for light-mantled albatrosses was very low. The mean  $\delta^{15}\text{N}$  value for sooty albatross body feathers was similar to previous study; however the mean  $\delta^{15}\text{N}$  value from primary feathers was smaller than body feather values from the present and past studies (Table 4.2).

The mean  $\delta^{13}\text{C}$  value was typical of sub-tropical waters north of the STF for sooty albatrosses and below the APF for light-mantled albatrosses. Most sooty albatross feathers were

grown north of the STF (80%) within the sub-tropical zone (STZ) and the remainder between the STF and the APF within the sub-Antarctic zone (SAZ; 20%); no feathers were moulted below the APF in the Antarctic zone (AAZ) (Figure 4.6). The light-mantled albatross that circumnavigated the globe moulted its feathers mainly north of the APF while the other individual moulted sampled feathers mainly south of the APF (Figure 4.6). Sooty and light-mantled albatrosses tracked during their respective non-breeding summer periods seemed to agree most with the  $\delta^{13}\text{C}$  values from feather samples (Table 4.3).

## Discussion

This study is the first to track sooty albatrosses from Marion Island during the non-breeding period. Direct observations at sea indicate that sooty albatrosses mainly occur within the southern Indian and Atlantic Oceans between 30 – 60° S (Birdlife International 2004, ACAP 2015b). Some of the locations that are reported south of the APF were estimated during equinox periods, which reduces the accuracy of those locations estimates, however they are recorded at latitudes up to 65° S (Marchant & Higgins 1990, Tickell 2000) and dietary studies suggest that sooty albatross may occur in those areas (Cooper & Klages 1995). The tracking data reported here show that sooty albatrosses do occur within sub-Antarctic and Antarctic waters during the non-breeding period. Circumnavigations have been recorded for light-mantled albatrosses from South Georgia (Mackley et al. 2010) as well as other albatross species such as grey-headed albatross (Croxall et al. 2005, Phillips et al. 2008) and wandering albatross (Mackley et al. 2010, Weimerskirch et al. 2014). The latter study proposed that circumnavigations are done to reach the eastern and western Pacific Ocean while avoiding the westerly headwinds, which is probably the case for light-mantled albatrosses from Marion Island as the majority of birds tracked on Bird Island, South Georgia, did not display this behaviour (Mackley et al. 2010). The observed distribution from two light-mantled albatrosses is similar to that of grey-headed albatrosses from Marion Island which also stay either in the Southern Indian and Atlantic Oceans or move east circumnavigating the Southern Ocean (Ryan & Bester 2008).

Sooty albatrosses breeding on Marion Island mainly disperse east during the non-breeding period and individuals that travel west of the island generally did not go further than 10° E. The non-breeding distribution of sooty albatrosses breeding on Gough Island is mainly in the southern Atlantic Ocean with a smaller distribution stretching into the Indian Ocean up to ~35° E (although the 95% kernel distribution estimate only stretches to ~20° E; BirdLife International 2004). This shows that birds breeding on Gough and Marion Island only overlap in a small area to the west of Marion Island (10 – 20° E). Marion and Gough Islands are important breeding sites for sooty albatrosses and this shows that different threats may be applicable for

each breeding site, for example overlap with different fisheries may be applicable (Tuck et al. 2003, 2011, Boonzaier et al. 2012).

There was some evidence for a difference in non-breeding distribution between male and female sooty albatrosses, where males went further east during the winter periods and females going further east during summer. Although the sample size was tiny, spatial segregation between sexes is not uncommon for albatrosses. Female albatrosses tend to stay closer to the breeding grounds than males during their pre-laying exodus or winter periods as has been shown for black-browed albatrosses and grey-headed albatrosses from South Georgia (Croxall et al. 2005, Phillips et al. 2005b). Male grey-headed albatrosses from South Georgia move further away during the non-breeding period, often circumnavigating the globe (Croxall et al. 2005). Closer to Marion Island, wandering albatrosses from Possession Island, Crozet archipelago, also show difference in distribution between sexes during the non-breeding period (Weimerskirch et al. 2014). In most of the above studies males tend to move further than females. The results for sooty albatrosses are interesting because the females move further from the island than males during the non-breeding summer (sabbatical). Females use more energy during breeding as they have to produce an egg and subsequently they may need more time than males to recover. Although albatrosses are monogamous, males might return to their breeding grounds in successive breeding seasons to try and mate with a willing partner or defend a breeding site while the female recovers from breeding (Ryan et al. 2007). This has been observed on Marion Island where a male sooty albatross from a successful breeding pair was breeding with a different female in successive seasons (Chapter 2), however this is just one occurrence.

The only published work on *Phoebetria* albatrosses distribution during non-breeding periods from Marion Island is inferred from feather isotope analysis (Cherel et al. 2013, Connan et al. 2014). These studies suggested that sooty albatrosses occur within the northern sub-Antarctic or sub-tropical waters where they feed at a higher trophic level than light-mantled albatrosses that stay within sub-Antarctic and Antarctic waters. Similar results were found for *Phoebetria* albatrosses breeding on Possession Island, Crozet archipelago (Jaeger et al. 2010a). All of the above mentioned studies only used body feathers for analysis as it has been suggested that the isotopic composition of primary and body feather are not significantly different in albatrosses (Jaeger et al. 2009) and as it does not impair flight ability. The isotopic composition of primary and body feathers may however be different in sooty albatrosses as significantly different  $\delta^{15}\text{N}$  values between feather types showed that individuals foraged at a lower trophic level when primaries were moulted as opposed to when body feathers were moulted. However, these results have to be taken with caution as sample sizes of primary feathers were low and the

age of the feathers were unknown. Between-feather variation of stable isotopes may be observed when individuals move to a different location during moult (Grecian et al. 2015). The  $\delta^{15}\text{N}$  values from primary feathers of sooty albatrosses were similar to that of light-mantled albatross body feathers suggesting a possible overlap in trophic position between the two species. The  $\delta^{13}\text{C}$  did not show a significant difference between feather types of sooty albatrosses and values were similar to the previous studies with a clear spatial segregation between the two *Phoebetria* albatross species. The  $\delta^{13}\text{C}$  value for light-mantled albatrosses from the present study was lower than any of the previous studies on Marion Island. This might be attributed to the small sample size as light-mantled albatrosses from South Georgia showed similar  $\delta^{13}\text{C}$  values (mean  $-21.2 \pm 1.1$  SD; Phillips et al. 2009).

Sooty albatrosses moult most of their feathers during the non-breeding period (Berruti 1979), however not much is known of their moulting patterns (Jaeger et al. 2010a). The comparison of GLS tracks and feather isotope data did not show a clear picture of where moulting occurs, however non-breeding summer periods and the first winter (for successful breeders) showed the highest proportion of latitudes within the sub-tropical zone. A body feather probably takes about three weeks to grow (Jaeger et al. 2010a) and primaries longer than that (Rohwer et al. 2009), however the temporal resolution of stable isotope analysis is limited when compared to the  $\sim 16$  month non-breeding period when a bird had a successful breeding season. The GLS tracking data for sooty albatrosses suggest that successful breeders spend their first winter at significantly lower latitudes than the second winter. It has been hypothesised that birds foraging in more productive areas will recover their body condition faster after breeding (Jaeger et al. 2013). Sooty albatrosses most likely move to productive waters surrounding the STF (Lutjeharms & Ansorge 2008) after breeding to recover body condition and moult. The latitudinal difference between winter periods of successful sooty albatross breeders may be driven by wind patterns (Weimerskirch et al. 2000b, Thiebot et al. 2014). However the mean latitudes for both periods were in areas dominated by westerly winds (Weimerskirch et al. 2012) and it is not clear why this latitudinal difference would occur. The tracking data here spans only two years and more data are required over a longer period to determine if the latitudinal difference during successive sabbatical winter periods is true for sooty albatrosses from Marion Island.

The present study shows that feather isotope analysis and GLS tracking can complement one another in terms of identifying moulting grounds, but without knowledge of moult patterns isotope data cannot be easily ground-truthed (calibrated) with GLS logger data. Moult data for *Phoebetria* albatrosses are needed to determine a time frame from which moulting maps can be constructed, with the aid of tracking data, allowing the tracking of migratory movements from

stable isotope analysis of certain feathers (González-Solís et al. 2011). Identifying moult patterns in body feathers is hard as they are probably moulted periodically throughout the whole non-breeding period (Berruti 1977). According to the present study primary feathers are not similar in  $\delta^{15}\text{N}$  composition when compared to body feathers, however a larger sample size is needed to confirm this. Conservation of Endangered albatrosses is a difficult task as these far-ranging birds may be subject to management from several countries which may be neglected when birds are not breeding within a certain country's EEZ (Thiebot et al. 2014). This is also the case for sooty albatrosses breeding on Marion Island as they overlap with many EEZs apart from South Africa, including French and Australian, however majority of the points were in the high seas where illegal, unregulated and unreported (IUU) fisheries may impact the survival of these birds (Tuck et al. 2003, 2011). With albatrosses being one of the most threatened bird families (Croxall et al. 2012), management of these species require up-to-date information on their distribution to identify areas where conservation action can be implemented. The present study shows the distribution of non-breeding adults, however data from juvenile birds are also necessary to paint the whole picture and future studies should look into this.

**Table 4.1:** Maximum ranges of extent for sooty and light-mantled albatrosses tracked during the non-breeding period.

Bird ID	Species	Sex	Longitude		Latitude	
			Summer	Winter	Summer	Winter
24117	Sooty albatross	F	21° - 127° E	20° - 84° E	35° - 61° S	35° - 54° S
24120	Sooty albatross	M	24° - 131° E	34° - 138° E	30° - 54° S	29° - 53° S
24121	Sooty albatross	M	N/A	75° - 131° E	N/A	31° - 50° S
24123	Sooty albatross	F	6° - 101° E	38° - 98° E	33° - 54° S	32° - 53° S
24127	Sooty albatross	F	22° - 83° E	6° - 50° E	32° - 52° S	34° - 53° S
24130	Sooty albatross	M	23° - 77° E	10° - 66° E	34° - 55° S	32° - 55° S
24133	Sooty albatross	M	26° - 89° E	35° - 100° E	32° - 62° S	36° - 62° S
24128	Sooty albatross	U	25° - 91° E	39° - 92° E	30° - 50° S	34° - 50° S
24137	Sooty albatross	U	8° - 68° E	11° - 84° E	30° - 54° S	31° - 50° S
24142	Sooty albatross	U	23° - 96° E	40° - 98° E	35° - 62° S	34° - 49° S
24143	Sooty albatross	U	9° W - 99° E	70° - 128° E	34° - 59° S	33° - 53° S
24150	Sooty albatross	U	33° - 136° E	40° - 131° E	29° - 55° S	32° - 51° S
24155	Sooty albatross	U	20° - 45° E	19° - 110° E	31° - 58° S	30° - 51° S
24144	Light-mantled albatross	U	15° W - 159° E	174° W - 171° E	36° - 78° S	45° - 67° S
24149	Light-mantled albatross	U	15° W - 82° E	67° - 104° E	45° - 70° S	44° - 55° S

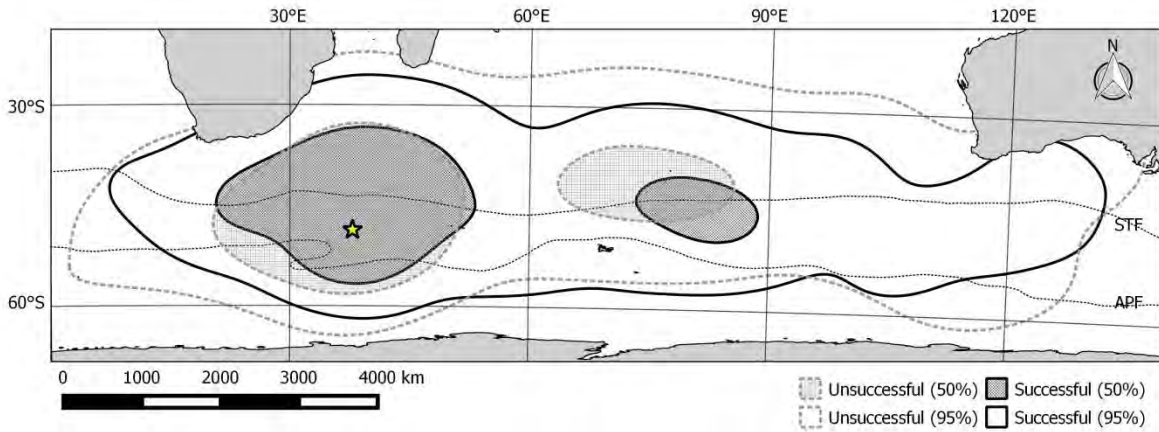
**Table 4.2:** Stable isotope values for carbon and nitrogen from sooty and light-mantled albatrosses breeding on Marion Island.

Feather type	Species	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	n	Source
Body	Sooty Albatross	-17.2 ± 0.8	14.4 ± 0.9	14	(Cherel et al. 2013)
	Sooty Albatross	-17.3 ± 1.0	14.0 ± 0.6	15	(Connan et al. 2014)
	Sooty Albatross	-17.5 ± 1.0	14.5 ± 1.0	16	Present study
	Light-mantled albatross	-19.9 ± 2.5	12.1 ± 2.0	7	(Cherel et al. 2013)
	Light-mantled albatross	-19.5 ± 1.5	12.5 ± 0.8	8	(Connan et al. 2014)
	Light-mantled albatross	-21.5 ± 2.4	11.1 ± 2.4	2	Present study
Primary	Sooty Albatross	-18.0 ± 1.1	12.1 ± 2.4	7	Present study

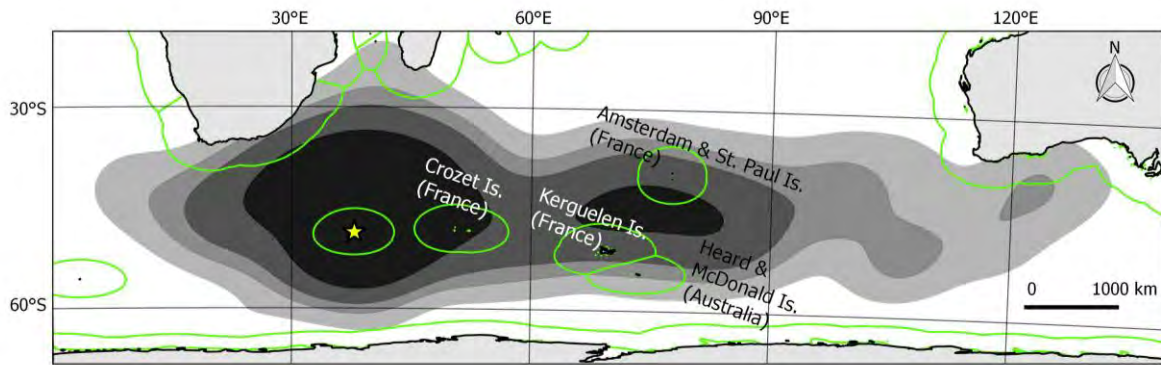


**Table 4.3:** Proportional use of the Southern Ocean (sub-tropical zone (STZ), sub-Antarctic zone (SAZ) and Antarctic zone (AAZ)) during the non-breeding period (and separated between sabbatical winter and summer) for sooty and light-mantled albatrosses tracked with geolocators and from  $\delta^{13}\text{C}$  feather stable isotope analysis. The highest value for each of the periods is shown in bold.

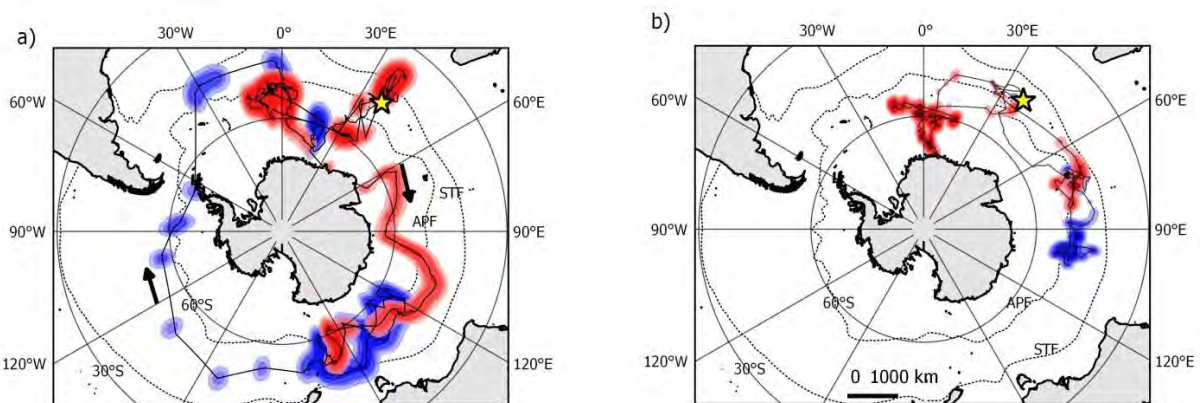
Bird ID	Species	Non-breeding latitudes (%)			Winter latitudes (%)			Summer latitudes (%)			Feathers (%)			
		STZ	SAZ	AAZ	STZ	SAZ	AAZ	STZ	SAZ	AAZ	STZ	SAZ	AAZ	n
24117	SA	26	<b>63</b>	11	10	<b>79</b>	11	30	<b>56</b>	14	<b>50</b>	<b>50</b>	0	2
24120	SA	<b>56</b>	39	5	<b>49</b>	<b>49</b>	2	<b>59</b>	35	6	<b>75</b>	25	0	4
24121	SA	38	<b>62</b>	0	34	<b>66</b>	0	NA	NA	NA	<b>80</b>	20	0	5
24123	SA	<b>49</b>	<b>49</b>	2	35	<b>60</b>	5	<b>51</b>	47	2	<b>100</b>	0	0	3
24127	SA	<b>53</b>	45	2	43	<b>52</b>	5	<b>59</b>	40	1	<b>100</b>	0	0	4
24130	SA	<b>65</b>	27	8	<b>54</b>	32	14	<b>64</b>	31	5	<b>50</b>	<b>50</b>	0	2
24133	SA	26	<b>61</b>	13	10	<b>58</b>	32	33	<b>61</b>	6	<b>67</b>	33	0	3
24128	SA	46	<b>54</b>	0	38	<b>62</b>	0	<b>50</b>	<b>50</b>	0	<b>100</b>	0	0	4
24137	SA	40	<b>59</b>	1	39	<b>61</b>	0	40	<b>58</b>	2	<b>100</b>	0	0	3
24142	SA	<b>54</b>	33	13	<b>74</b>	26	0	<b>43</b>	37	20	<b>100</b>	0	0	4
24143	SA	26	<b>47</b>	27	16	<b>68</b>	16	32	<b>36</b>	32	<b>67</b>	33	0	3
24150	SA	<b>58</b>	31	11	<b>71</b>	29	0	<b>51</b>	31	18	<b>75</b>	25	0	4
24155	SA	37	<b>51</b>	12	NA	<b>72</b>	28	19	<b>63</b>	18	-	-	-	-
24144	LMA	3	48	<b>49</b>	0	47	<b>53</b>	4	<b>49</b>	47	0	<b>75</b>	25	4
24149	LMA	0	36	<b>64</b>	0	<b>68</b>	32	0	19	<b>81</b>	0	25	<b>75</b>	4



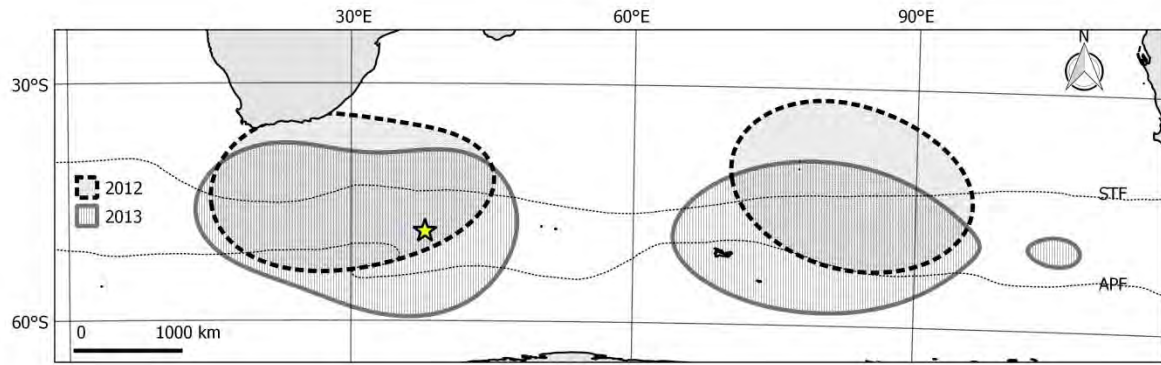
**Figure 4.1:** Kernel density distributions of non-breeding sooty albatrosses in relation to the main fronts (Orsi et al. 1995) shown and Marion Island indicated with a star.



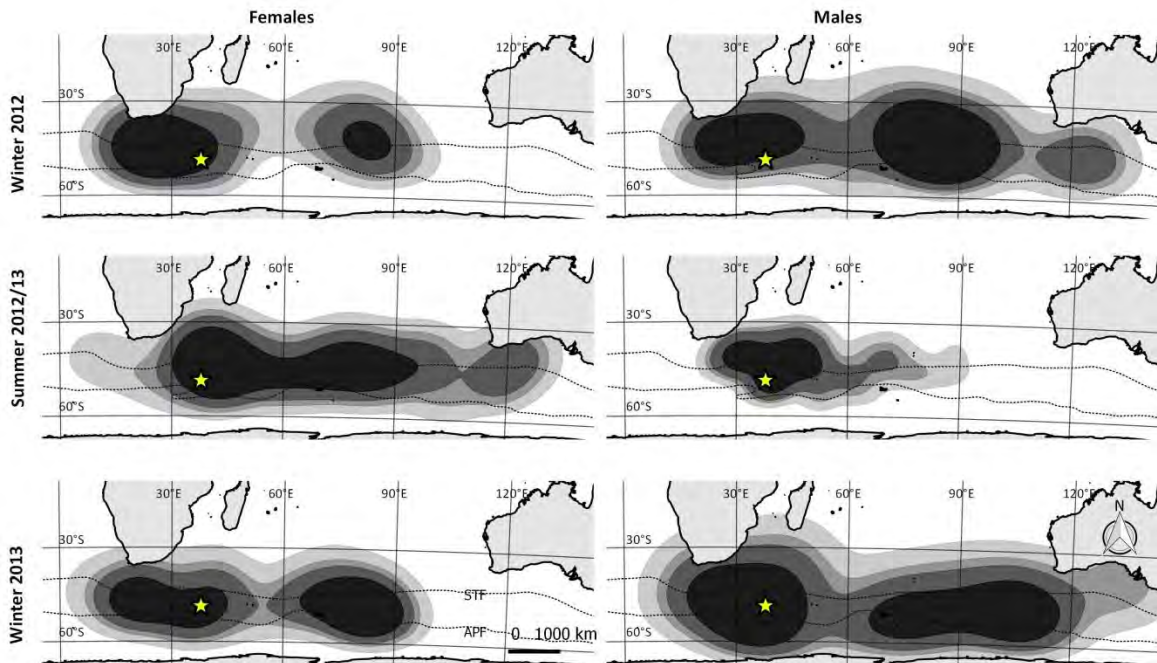
**Figure 4.2:** Kernel utilisation density estimate (increasing darkness of shades are 95%, 85%, 75% and 50% contours) of sooty albatross non-breeding distribution overlapping with several EEZs from different countries. Marion Island is indicated with a star.



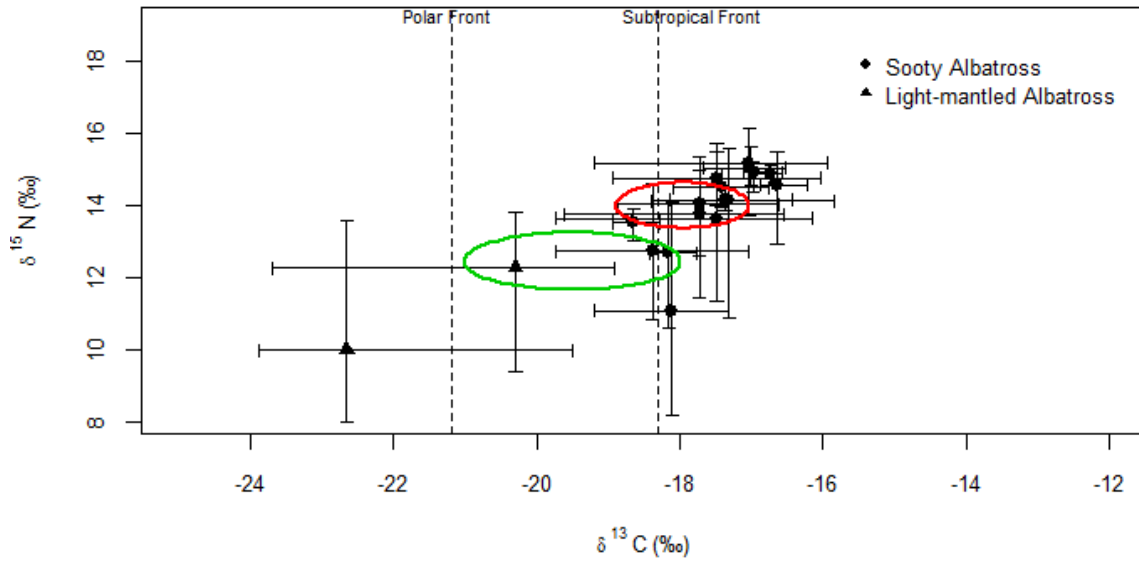
**Figure 4.3:** Two light-mantled albatrosses, a) ID 24144 and b) ID 24149, tracked during the non-breeding period, winter (blue) and summer (red) are shown as kernel utilisation distributions at 95%, 85%, 75% and 50% from light to dark shades. Conventions as Figure 4.1.



**Figure 4.4:** Winter distribution of successful sooty albatross breeders during two winters. Black (dotted) and grey (vertical strips) represent successful breeders during the first (2012) and second (2013) winters, respectively. Distribution is shown as a 50% kernel utilisation distribution identifying core usage areas. Conventions as Figure 4.1.



**Figure 4.5:** Non-breeding distribution of successful sooty albatross breeders during two winters and one summer. Distribution maps are shown for male ( $n = 4$ ) and female ( $n = 3$ ) with kernel utilisation distributions at 95%, 85%, 75% and 50% from light to dark shades. Conventions as Figure 4.1.



**Figure 4.6:** Mean  $\pm$  range of feather stable isotope ratios of carbon to nitrogen for sooty albatrosses (n = 16) and light-mantled albatrosses (n = 2) in relation to isoscapes associated with Southern Ocean fronts (Jackson & Attalla 2010). Ellipses indicate mean  $\pm$  SD ratios for sooty (red) and light mantled albatrosses from Connan et al. (2014).

## Chapter 5: Synthesis and Conclusions

Population declines of sooty albatrosses from around the Southern Ocean have been observed within the last decade leading to its listing as Endangered (Delord et al. 2008, [www.iucnredlist.org](http://www.iucnredlist.org), ACAP 2015a). Light-mantled albatross populations seem to be stable or increasing in size globally (Delord et al. 2008, ACAP 2015b). Similar findings were reported for population trends of sooty and light-mantled albatrosses at the Prince Edward Islands from the 1990s to 2000s (Crawford et al. 2003, Ryan et al. 2003, 2009). With fisheries-related mortality of adults suspected of being the main cause of the declines in all the above mentioned studies and evidence of sooty albatross mortality from Yeh et al. (2013), attention was given to the breeding and non-breeding distributions of both species. Previous work done on Marion Island suggested that sooty and light-mantled albatrosses are latitudinally segregated over a large part of their distribution, with sooty albatrosses foraging to the north of the Antarctic Polar Front (APF) and light-mantled albatrosses to the south (Berruti 1979, Cooper & Klages 1995, Jaeger et al. 2013, Connan et al. 2014). Taking this into account, the observed trends for sooty and light-mantled albatrosses are unexpected when considering recent climate changes. These climate changes are resulting in poleward warming of Southern Ocean water and shifts in major fronts towards the south (Inchausti et al. 2003, McQuaid & Froneman 2008), favouring birds foraging north of the APF while southern species are expected to be at a disadvantage (Inchausti et al. 2003, Bost et al. 2009). With recent mitigation measures recommended in many fisheries (Tuck et al. 2011), populations of seabirds that have not been too severely impacted are expected to show signs of recovery through an increase in population trends if fisheries comply with these measures (e.g. Robertson et al. 2014). This study was performed to give an update on the current numbers and status of *Phoebastria* spp. on Marion Island and to explore possible reasons for these observations from breeding and non-breeding at-sea distributions of the birds.

### Main conclusions

The breeding success of sooty albatrosses has increased over the past few decades with little long term change in population size over the last four decades (Berruti 1979). The current sooty albatross breeding success rate is similar to the Crozet Islands where an increased breeding success has also been seen since the 1980s (Delord et al. 2008). Light-mantled albatross breeding success is much lower, similar to that recorded in 1970s (Berruti 1979), however sample sizes are low. Monitoring colonies showed that a large proportion of nest failures occurred shortly after egg laying was completed and another increase in failures around the time when eggs start to hatch. Sooty albatross numbers seem to have increased since 2006, with the 2014 incubating bird count of 1838 pairs being the highest since 1996 (and it failed to include a sub-colony of more than 100 pairs). The light-mantled albatross trend went from

increasing (1996-2006), to decreasing since 2006. With breeding success and previous population trends on Marion Island being similar to the Crozets (Delord et al. 2008, Ryan et al. 2009). The annual counts of sooty albatrosses most probably underestimate the actual breeding population as the counts are done too late (Ryan et al. 2009) after many failures have already occurred. A revised period of counting and count zone borders should improve the accuracy and precision of future counts. Monitoring of sub-colonies will provide correction factors for previous nests that might have failed before the annual counts are performed.

The breeding distribution was similar to what has been shown through dietary, fatty acid and isotope analyses (Berruti 1979, Cooper & Klages 1995, Jaeger et al. 2013, Connan et al. 2014) on Marion Island, where sooty albatrosses forage predominantly to the north of the APF and light-mantled albatrosses to the south. Both species moved further away from the island during incubation as compared to brooding periods, with sooty albatrosses going north in the vicinity of the Sub-Tropical Front (STF) and light-mantled albatrosses going south as far as the Antarctic pack-ice. Modelling of sooty albatross tracks revealed an association with the edges of eddies, mainly during the incubation period, which is similar to the spatial habitat use by grey-headed albatrosses (*Thalassarche chrysostoma*) from Marion Island (Nel et al. 2001). Both sooty and light-mantled albatrosses also foraged close to Marion Island during incubation and brood guarding periods and an area of overlap between the two species occurred east of Marion Island. Sooty albatrosses show a large degree of overlap with areas of high fishing activity when they move north during incubation and chick rearing (Tuck et al. 2003, Boonzaier et al. 2012). Sooty albatrosses were located within the South African EEZ for a large proportion of the breeding season (up to the brooding period) and both species were mostly within this area during the brooding period. Sooty albatrosses showed a large amount of overlap with long-line fishing effort in the southern Indian Ocean, whereas light-mantled albatrosses did not overlap much with fisheries.

Non-breeding sooty albatrosses were mainly restricted to the southern Indian Ocean. Successful breeders that were tracked for two consecutive winters had a northern distribution mainly within sub-tropical waters during the first winter, which is in accordance with inferences from isotopic studies of feathers (Jaeger et al. 2010a, Cherel et al. 2013, Connan et al. 2014). Isotope analysis of feathers from tracked birds was also in accordance with the above mentioned studies. The second winter period after breeding was spent at higher latitudes, suggesting that birds moult in more productive waters in the vicinity of the STF during the first winter and move south during the second winter. Reasons for this behaviour are unclear but may be linked to wind patterns in the Southern Ocean as poleward shifts of strong westerly winds improve foraging performance of some albatrosses causing a southerly shift in foraging

distribution (Weimerskirch et al. 2000b, 2012). Sexual differences were observed among successful breeders, with males dispersing farther east than females during winter and returning close to the Prince Edward Islands during the non-breeding summer when females travelled east as far as Australian waters. However, sample sizes of sexed birds were small. Sooty albatrosses overlapped with Australian and French EEZs in addition to the South African continental EEZ, however most points (79%) were in the high seas where there is less control over fisheries (Tuck et al. 2003, 2011). Only two non-breeding light-mantled albatrosses were tracked and both foraged in Antarctic waters to the west of Marion Island during the rest of summer after their nests failed in December. In winter, both birds moved north to sub-Antarctic waters to the east of Marion Island with one bird continuing east to eventually circumnavigate the Southern Ocean by the end of winter. Isotope analysis of feathers showed a lower average Carbon isotope ratio value than previous studies (Jaeger et al. 2010a, Cherel et al. 2013, Connan et al. 2014), suggesting that moulting occurred at a higher latitude, however only two birds were sampled. Feathers from sooty albatrosses showed a difference in Nitrogen isotope ratios between two feather types (body vs. primary feathers), which differs from previous findings for wandering albatrosses (Jaeger et al. 2009). As with breeding birds, non-breeding sooty and light-mantled albatrosses are latitudinally segregated during their sabbatical periods with sooty albatrosses at lower latitudes overlapping more with fisheries in the southern Indian Ocean.

The contrasting conservation statuses of *Phoebetria* albatrosses seemed to be linked to their latitudinal segregation (Delord et al. 2008) during both breeding and non-breeding periods on Marion Island. Sooty albatrosses foraging north of Marion Island are in areas close to the Sub-Tropical Front with large amounts of overlap with fisheries activity (Gales et al. 1998, Rolland et al. 2010, Yeh et al. 2013), while light-mantled albatrosses are to the south with less fishery overlap. Fisheries related mortality seem to be the cause behind sooty albatross population declines in the past (Delord et al. 2008, Ryan et al. 2009) and the recent increasing trend on Marion Island may indicate some form of relief from fisheries pressure. This might be due to recent mitigation measures reducing fisheries related mortalities of seabirds on fishing gear, however further investigation is needed to confirm this.

### **Recommendations for future research**

The population trends of *Phoebetria* albatrosses on Marion Island are contrary to previous estimates (Ryan et al. 2009). Albatross population sizes are affected most by adult survival rates (Rolland et al. 2010) and an increase in the sooty albatross population should be linked to a reduction in adult mortality and may be supplemented by an increase in breeding success. Most previous study on sooty albatross trends attribute declines to fishery related mortality of adults (Delord et al. 2008, Ryan et al. 2009) and increasing trends may be an indication that fishery

related mortality of sooty albatrosses have decreased in recent years. This needs to be confirmed with detailed study of sooty albatross and fisheries interaction in the southern Indian Ocean where most of the overlap occurs.

The study colonies established for both sooty and light-mantled albatrosses on Marion Island should be monitored for multiple years to obtain long-term breeding success estimates and information on the demography of these species. Demographic data can provide information regarding the age specific survival rates of *Phoebastria* albatrosses on Marion Island which can be used to estimate the effect of fisheries and climate change on these birds (Rolland et al. 2010). More accurate counts of population sizes are needed on Marion Island and annual counts of sooty albatrosses should be done at the end of October as opposed to the end of November when a large proportion of nests might have already failed.

More tracking data are needed for light-mantled albatross as the sample sizes of the present study are too low to substantiate definitive conclusions and tracks were incomplete during incubation. Accurate sexing should be performed on birds during future tracking studies to determine if any sexual segregation occurs during the breeding season. Data from breeding adults are needed during the chick-rearing period after brooding for both species, as well as tracking data for juveniles.



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