RECOLONISATION OF THE ROBBERG PENINSULA BY THE CAPE FUR SEAL *Arctocephalus pusillus pusillus* AND ITS PREY PREFERENCES

by

Johan Huisamen

Submitted in fulfilment of the requirements for the degree of

Masters of Technology in Nature Conservation at the

Nelson Mandela Metropolitan University

2012

Supervisor: **Prof. Laurence Watson**

Co-supervisors: **Dr Steve Kirkman** and **Dr Pierre Pistorius**

Declaration

I, Johan Huisamen, student number 201356279, declare that this thesis is my own, original work and that it has not been submitted for a degree to any other university.

Signature: ………………………………….. Date: ………………………………...

Table of Contents

List of figures

List of tables

Abstract

The Cape fur seal *Arctocephalus pusillus pusillus* colony at the Robberg Peninsula, Plettenberg Bay, on the south-east coast of South Africa, was driven to extirpation by indiscriminate harvesting by the late 1800s and seals only began to recolonise this site in the 1990s. This study describes the recolonisation process from 2000 to 2009, exploring within- and between-year variation in the number of seals using the site. Numbers increased over the study period from less than 300 animals to over 3 100. Year and month were important in explaining variability in seal counts, whereas sea condition, time of day and lunar phase had minimal explanatory power. Within-year variation in seal counts decreased during the study period, which may indicate an increasing proportion of resident (as opposed to transient) seals in the colony. However, the colony is currently still in a transition phase with a low ratio of breeding to non-breeding animals and low numbers of pups born on the colony (currently still < 100 per year). The influx of seals to the Robberg area may be associated with an increase in prey availability in the area. The relative protection afforded by the Nature Reserve status of the Robberg Peninsula and the existence of a Marine Protected Area adjacent to it are likely to contribute to the growth of this colony. However, human interference associated with fishing and/or ecotourism on the Peninsula may prevent the colony from developing into a breeding colony. Faecal (scat) sampling was employed to study the diet of this increasing seal population at Robberg. Species composition and size of prey were determined, temporal variation in the diet was explored, and the potential for competition between seals and the fisheries around Plettenberg Bay was investigated. Of the 445 scats collected, 90 % contained hard prey remains. These comprised of 3 127 identified otoliths representing 15 teleost prey species, 25 cephalopod beaks representing three species and three feathers representing two bird species. The seals' most important prey species in terms of numerical abundance and frequency of occurrence in the diet were anchovy, sardine, horse mackerel, sand tongue-fish and shallow-water hake (in decreasing order of importance). The proportion of anchovy in the diet increased during the study period, while sardine decreased. Sardine was the only species that increased significantly in the diet during the upwelling season. Little evidence was found of direct competition between seals and linefisheries in Plettenberg Bay, both in terms of prey species composition and quantities consumed. Scat sampling in seals holds promise as a method to track long-term changes in prey species availability. The conservation and management of this colony are discussed in light of the research findings.

Keywords: *Arctocephalus pusillus pusillus*, breeding, fisheries, Marine Protected Area, pinnipeds, population trend, sardine, scat analysis, Robberg Peninsula

Acknowledgements

I thank my main supervisor, Professor Laurence Watson, for his guidance throughout my study. Thanks for the support from my co-supervisors, Dr Pierre Pistorius and especially to Dr Steve Kirkman – his enthusiasm and knowledge of seals was an inspiration to me. Thanks to CapeNature, especially the Robberg Nature Reserve staff, for assisting with data collection. Thanks to Dr. Vic Cockcroft from the Centre for Dolphin Studies for his ideas with the setting up of the project and to Rebecca Jewell for her comments on earlier drafts, as well as Dr Debbie Young and volunteers from this programme for assisting with data collection and processing. Dr Nick Hanekom and Kyle Smith from Scientific Services, South African National Parks, provided information on the oceanographic and fisheries aspects of this study. Bruce Dyer from Environmental Affairs, branch Oceans and Coasts assisted with identification of bird feathers and Dr Marek Lipinski from Department of Agriculture, Fisheries and Forestry assisted with identification of cephalopod beaks. Tineke Kraaij is thanked for assistance with data analysis and moral support throughout this study. Thanks to my daughters, Lindie and Hanlie, for their encouragement and to my son, Reuben, for helping with data capturing and for bearing with my after hour working. Unpublished data were made available by the South African Weather Service (weather data), Council for Scientific and Industrial Research (wave height data), South African National Parks (sea surface temperature) and Department of Environmental Affairs, branch Oceans and Coasts (pup count data and sea surface temperature). The Fairfield Group and Nelson Mandela Metropolitan University are thanked for funding.

CHAPTER 1. Introduction

1.1 Background

The Cape fur seal, *Arctocephalus pusillus pusillus*, is endemic to southern Africa with a distribution ranging from Algoa Bay in South Africa to Baia dos Tigres in Angola (Kirkman *et al.* 2007a). It feeds exclusively on the continental shelf (Lipinski and David 1990). The west coast contains 93 % of the Cape fur seal population and most work on this species' diet has been done here (Lipinski and David 1990, Balmelli and Wickens 1994, Punt *et al.*1995, Punt and Butterworth 1995).

The Robberg Nature Reserve and Marine Protected Area is situated along the southern Cape coast of South Africa. Until the late 1800s an estimated 3 000 seals formed a colony on Robberg Peninsula (Metelerkamp 1955), but by 1908, this population was eliminated by harvesting (Ross 1971). Since the early 1990s there has been an apparent increase in the number of seals in Plettenberg Bay. Seals proceeded to haul out on the northern shoreline of the Robberg Peninsula. Since a breeding colony did previously exist in Plettenberg Bay it is likely that the foraging in the area was good and that new colonies may establish in the same area. Furthermore the rocky northern shore of Robberg has little human disturbance, potentially providing suitable habitat for seals to establish and/or disperse to/from other areas.

In the past, several fisheries operated out of Plettenberg Bay or its vicinity. These include a hand line fishery for shallow-water hake *Merluccius capensis,* a long line fishery targeting hake and kingklip *Genypterus capensis* and a jigging fishery for chokka squid *Loligo vulgaris reynaudii*. Furthermore, Robberg itself is known for its shore-angling potential (King 2005). The return of Cape fur seals to Robberg has been met with concern by elements of the local fishing community which claims that the increased number of seals has caused a marked decrease in the fish caught in the area due to competitive effects and/or damage to catches by seals (Jewell 2005, Smith 2005). Predictably, there has been a call by fishers to introduce a seal culling programme in the area (O. Glennie, Plett Fisheries, pers. comm.). However, any management intervention aimed at preventing, reducing or mitigating seal-fishery interactions should be based on sound scientific assessments. Critical information in this regard includes characteristics of the diet of the seal population concerned (Murie 1986).

This current study set out to determine the status of the seal population at Robberg, to monitor changes in population numbers over time and to determine their prey base. The data will enable CapeNature, the managing authority of Robberg, to educate fishers by providing information in the form of interpretation signs and newspaper and popular articles. It will furthermore inform management interventions to accommodate the expanding seal colony, as well as what is required to monitor the breeding status of the colony, and suggest whether continued scat sampling would provide a means of monitoring long-term changes in prey species distribution.

The structure of this thesis is as follows:

Chapter 1 gives the background to the study, the thesis structure, a literature review of Cape fur seals, and the objectives of the study;

Chapter 2 gives and account of the historical exploitation of Cape fur seals at Robberg Peninsula and description of the study site;

Chapter 3 describes the recolonisation of the Cape fur seal population on Robberg Peninsula and incidence of breeding;

Chapter 4 explores the diet of Cape fur seals at Robberg, the change in prey species composition over time and possible conflict with fisheries; and

Chapter 5 sums up the general findings of the study, the implications for management and suggestions for future research.

Chapters 3 and 4 were written as independent papers (accounting for some replication), authored by J. Huisamen and various co-authors. Despite this independence, each chapter is a contribution to the central issue of the thesis, i.e. to better understand the population dynamics of a re-establishing seal colony and its prey base.

1.2 Taxonomy

The Cape fur seal *Arctocephalus pusillus pusillus* belongs to the family Otariidae, which includes fur seals (sub-family *Arctocephalinae*) and sea lions (sub-family *Otariinae*) (Bonner 1994). Fur seals are distinguished from sea lions by their abundance of under-fur. There are two fur seal genera, namely the monotypic *Callorhinus* and *Arctocephalus* consisting of eight species, with the Cape fur seal and the Australian fur seal *A. p. doriferus* being subspecies of *A. pusillus* (Bonner 1981). The remaining seven species of *Arctocephalus* are the South American fur seal *A. australis*, the Juan Fernandez fur seal *A. philippi*, the Galapagos fur seal *A. galapagoensis*, the Guadalupe fur seal *A. townsendi*, the New Zealand fur seal *A.*

forsteri, the subantarctic fur seal *A. tropicalis* and the Antarctic fur seal *A. gazella*. All *Arctocephalus* species, with the exception of *A. townsendi*, occur in the southern hemisphere, and are therefore referred to as ‘southern fur seals’ (Bonner 1981).

1.3 General biology

In terms of appearance, social behaviour, reproduction and ecological role, southern fur seal species are very similar (David and Rand 1986, Kirkman 2010). They are all sexually dimorphic in body size (males outweigh females by two- to four-fold, depending on species), and have a polygynous mating system characterised by territorial aggression on the part of adult males (Kirkman 2010). In the Cape fur seal, harem sizes are usually between 10 and 30 females per territorial bull during the breeding season (Wickens and York 1997). Females give birth to a single pup, while twin births are extremely rare (Kirkman 2010). Although seal pups are precocious at birth, weighing 5-6 kg, being fully furred and able to move around within a few hours, a land mammal of similar size does not require 12 months gestation. Therefore delayed implantation has evolved in seals (David 1989). The active gestation period is around 8 months, ensuring that birth is at the traditional season i.e. first week in December. The breeding season spans from November to early January each year, with a peak in births during the first half of December (de Villiers and Roux 1992). The females remain with their pups for a few days after giving birth, during which period they mate, before they depart to sea to feed (David and Rand 1986). From then until weaning, the females intersperse foraging trips to sea with suckling bouts ashore. In the Cape fur seal, the weaning takes place between July and October (Rand 1955, David and Rand 1986).

The natal fur of pups is black or dark brown in colour, in contrast to adults which are dark-grey brown dorsally, shading to lighter beneath (Bonner 1981). Pups are entirely dependant on milk for the first six months and grow quickly, but cannot swim until about six weeks of age (David 1989). In order to maintain an adequate supply of milk, cows leave their pups for three to four days (up to a week) and return to sea to feed. In these times, pups are susceptible to predation by predators, especially on mainland colonies (David 1989). Cows will defend and feed only their own pups and actively reject pups of other females, while bulls play no part in defence of young (David 1989). Weaned pups are strong swimmers, but evidently finding food is not easy as they put on very little weight during their second year. For the next few years juveniles wander from colony to colony forming aggregations of their own age group (Kirkman 2010). Young females become sexually mature at three to four years of age, and have their first pup when they are four to five years old and may give birth each year until death (Wickens and York 1997). Most of them return to their natal colony to give birth (Wickens and York 1997). Young males only become heavy enough for competition for territory when they are 10 to 14 years old (David 1989).

Cape fur seals fulfil the role of top predators in the marine ecosystem that they inhabit. They generally appear to be opportunistic hunters, feeding predominantly on teleost fish, cephalopods or crustaceans (David 1987, Kirkman *et al*. 2000, Mecenero *et al.* 2006). Fur seals in turn are preyed on by killer whales *Orcinus orca* (Newman and Springer 2008, Reisinger *et al*. 2011) and large sharks such as the great white shark *Carcharodon carcharias* (Martin *et al.* 2005). Cape fur seals that breed at mainland locations are also at risk from terrestrial predators, such as brown hyena *Hyaena brunnea* and black-backed jackal *Canis mesomelas* (Oosthuizen *et al*. 1997, Wiesel 2006).

Cape fur seals feed predominantly over the continental shelf of southern Africa (David 1987). The bulk of its diet is comprised of teleost fish, mainly pelagic shoaling fish such as sardine, anchovy, round herring *Etrumeus whiteheadii*, Cape horse mackerel *Trachurus trachurus capensis* and juvenile hake *Merluccius* species. (Shaughnessy 1985, David 1987, Mecenero *et al*. 2006). Cephalopods feature in the diet to a lesser extent, while crustaceans form a relatively minor part of their diet (Lipinski and David 1990, Castley *et al.* 1991, Stewardson 2001, Mecenero *et al.* 2006). Cape fur seals also prey on certain seabird species, with an increasing frequency of attacks having been recorded since the 1980s (David *et al*. 2003, Johnson *et al.* 2006, Makhado *et al.* 2006, Makhado *et al.* 2009). Most dietary studies of Cape fur seals in South Africa have been performed on the west coast (Lipinski and David 1990, Balmelli and Wickens 1994, Punt and Butterworth 1995, Punt *et al.* 1995). However, the studies of David (1987) and Castley *et al.* (1991) have provided an insight into the variation in seal diet between the west and south-east coasts of South Africa, highlighting the need for further studies on seal diet along the south-east coast.

South Africa and Namibia's sardine stocks collapsed in the 1960s and 1970s, respectively, due to over-exploitation, but whereas this species has generally remained in a depleted state in Namibian waters, the South African stock subsequently recovered to record biomass levels in the early 2000s (Griffiths *et al*. 2005, van der Lingen *et al*. 2006). Since the 1990s there has however been marked eastward shifts in the geographical distributions of the sardine (Fairweather *et al.*

2006), anchovy (Roy *et al.* 2007) and west coast rock lobster *Jasus lalandii* (Cockcroft *et al.* 2008) stocks in South Africa, with consequences for commercial fisheries (van der Lingen *et al*. 2006) and for locally breeding seabirds that are dependent on these prey (Crawford *et al*. 2008a, 2008b). It has been speculated that the progressive shifts of these prey stocks away from the west coast of South Africa, where the bulk of the country's seal population occurs (David 1989), may have resulted in nutritional stress to seals in this area (Makhado *et al*. 2006).

The diet of seals can be monitored using an inexpensive and practical method such as analysis of faeces (scats) collected in colonies, which can provide important information on spatial and temporal changes in diet (Tollit and Thompson 1996). The retrieval of hard prey remains (otoliths, cephalopod beaks, krill carapaces and bird feathers) from gastrointestinal contents, scats and regurgitates has been used for diet analysis in pinnipeds (Boyd *et al*. 2010). The benefits of scat analysis as a technique for assessing the diet of pinnipeds, include the fact that it can be obtained relatively easily from seal colonies, the abundance of faecal matter allows for large sample sizes, a high proportion of scat samples contain identifiable hard prey remains, the technique is cheap, is not destructive and non-lethal (Pierce and Boyle 1991). Provided that identifiable prey remains pass through the gut, they will be represented in the same proportion that they were consumed if a large enough sample set of scat is considered. While the technique is subject to numerous biases, it can provide important information on spatial and temporal trends in the relative consumption of the main prey species (Harwood and Croxall 1988).

Otoliths are composed of calcium carbonate and their high density makes them the most digestion resistant structure in teleost fish (Treacy 1981). The position of the otoliths inside the skull of teleost fish offers protection from the process of digestion (Smale *et al.* 1995). Otoliths are species specific, therefore it can be used to identify prey species consumed by piscivores (Jobling and Breidy 1986). Using regression models, the length and mass of prey consumed can be reconstituted from the otolith size.

As cephalopod beaks are resistant to digestion they accumulate in the predator's stomach until they are either regurgitated or pass through the gut (Klages 1996). They can also be identified to species level, while beak size is directly related to total body weight (Clarke 1962) so measurement of beak dimensions (lower rostral length in *Loligo* species and hood length in *Sepia* species) can be used to estimate dorsal mantle length and mass of the cephalopod from regression equations (Gales *et al*. 1993).

Potential problems associated with the use of fish otoliths and cephalopod beaks to estimate the diet composition of piscivores may be encountered. Regarding fish otoliths the following problems may arise: (1) Seals may tear off and discard the heads of large fish before swallowing them (Best 1983, Balmelli and Wickens 1994). This would underestimate the number of larger fish in the diet. However, it is assumed that all species that grow to large sizes are equally affected by this bias. (2) Stomachs of predatory fish may also contain otoliths of their own prey items (David 1987, Punt *et al.* 1995). These secondary otoliths would result in an overestimate of the number, and possibly species diversity, of fish eaten by seals. (3) The occurrence of cartilaginous fish (which lack well defined otoliths) in the diet will be underestimated (Olesiuk *et al.* 1990). (4) Seals may scavenge from trawlers instead of actively foraging and the importance of the target fish of the fishing industry will be overestimated (Punt *et al.* 1995). (5) The digestive fluids of marine mammals are strongly acidic (pH 1.5 to 3.5) (Jobling and Breiby 1986), thereby eroding the otoliths, reducing their size and altering their characteristic features (Smale *et al.* 1995). This makes species identification difficult and will result in underestimates of fish size (Jobling and Breiby 1986, Smale *et al.* 1995). (6) Prey species that have fragile otoliths (especially smaller fragile otoliths) may be completely digested in the gastrointestinal tract, therefore they may be underrepresented in scat and this would lead to biases in the relative importance of prey species in the diet (Jobling 1987).

Use of cephalopod beaks to determine composition of the diet is furthermore potentially biased because: (1) The irregular shape of the beaks makes them prone to retention in the stomach folds, they may therefore be underestimated in the scats. (2) Seals are known to regurgitate both on land and in the water (Gales *et al.* 1993), and beaks are often regurgitated, therefore they may be underestimated in the scats. (3) Smaller beaks may pass through the pylorus of the stomach more easily than larger beaks, therefore larger cephalopods may be underestimated in the faeces (Stewardson 2001). A study on size distribution of hard prey remains in the digestive tract of northern fur seals found a higher occurrence of large cephalopod beaks in the stomach and suggested that their passage to the intestines may be restricted by the diameter of the phyloric sphincter (Yonezaki *et al.* 2003). They concluded that scat analysis alone will fail to provide accurate data on the distribution of prey with large hard parts in the diet. However, it is assumed that seals are consuming both large and small cephalopods and that the species diversity of the diet is unaffected. Stomach content analysis however, may overestimate the importance of species that have parts resistant to digestion, such as cephalopods (Castley *et al.* 1991). No method of diet analysis is entirely free from bias.

To compensate for otolith erosion due to acidic digestive fluids, size-specific correction factors have previously been applied to compensate for erosion. The degree to which any particular otolith is eroded appears to be highly variable, depending on residence time of an otolith in the digestive system of a seal. This will be influenced by factors such as meal size and composition, and the activity of the seal (Jobling and Breidy 1986, Smale *et al.* 1995). One way to compensate for erosion is to grade each otolith individually, by examining its morphological features, assessing how eroded it appears to be and applying correction factors accordingly (Sinclair *et al.* 1994, Reid 1995, Tollit *et al.* 1997). When assessing the effect of size and species of prey on estimating diet composition of captive seals, Tollit *et al.* (1997) found that when correction factors were applied for the different grades of erosion, results were the most accurate.

Seal-fisheries interactions

The increase in abundance of Cape fur seals in recent years has caused increasing conflict between seals and fisheries (Balmelli and Wickens 1994, Butterworth *et al*. 1995). The majority of commercial fishers consider seals as ‘pests’ for disturbing and scattering schooling fish, becoming entangled and damaging fishing gear and stealing catches from nets and long lines. More importantly, seals are accused of competing directly with the fishing industry, consuming large quantities of fish that would otherwise be available to the fishers. Seal-fisheries problems in southern Africa date back to at least the beginning of the twentieth century (David and Wickens 2003). These conflicts between seals and fishers are a common problem and as a result, illegal killing of the seals occurs (Klages 1996). Although the Sea Birds and Seals Protection Act of 1973 prohibits the killing or capture of seals, enforcement of the Act over such a vast expanse of ocean is virtually impossible.

Mankind and seals have been involved for four centuries or more, being killed either for their pelts, oil and meat or because they are perceived as a threat to fishers (David and Wickens 2003). Nevertheless they have managed to co-exist with an increasingly rapacious fishing industry. The South African fishing industry and the seal population have simultaneously shown strong growth since 1948 (David and Wickens 2003). It seems therefore that there are adequate resources to support both the industry and the seals without undue competition between the two (Kirkman 2010). Seals potentially avoid direct competition with the industry by feeding in different areas at different times on different species and on different size classes of fish. This is supported by the fact that the commercial catches of hake are stable and the catches of sardine *Sardinops sagax* have been increasing (David and Wickens 2003). It should also be acknowledged that even though seals may scavenge offal from trawlers, the dead fish eaten are no loss to the industry. This indicates that presently there are adequate fish stocks to support both a burgeoning industry and a healthy seal population (David and Wickens 2003). The two main forms of interaction are operational, that is effects of seals on fishing operations, and biological, that is potential competition between seals and fisheries for common fish recourses (David and Wickens 2003). Despite many complaints from the fishing industry regarding interference with fishing by seals, examination of operational interactions by independent observers in the various sectors of the fishery, showed only minor financial losses to fishers, with the exception of the snoek *Thyrsites atun* fishery (Kirkman 2010). Overall, the fishing industry does not suffer a substantial financial loss as a result of seals, although the loss is possibly severe for particular fisheries in localized areas and at certain times of the year (Wickens *et al*. 1992). Conversely, fishing operations act negatively on seals, both through incidental drowning in nets and through illegal killing by fishers (David and Wickens 2003).

Seals and seabirds are obliged to return to land to breed, but adaptations for locomotion in water often make them considerably less agile on land than most terrestrial animals, and thus more vulnerable to predators (Kirkman 2010). Consequently, both seabirds and seals frequently breed at islands where there are few or no predators. If feeding conditions in the vicinity of these islands can support large populations of birds and seals, there may be competition for space (Kirkman 2010).

The Sea Fisheries Act of 1988 states that there is a need to move towards ecological management to provide for the conservation of the marine ecology and the orderly exploitation, utilisation and protection of certain marine resources (Crawford and Payne 1989). Options to alleviate seal-human conflicts fall into two categories: lethal and non-lethal methods. Lethal methods can include culling at seal colonies or removal of specific individuals (Kirkman 2010). Even if culling were to halve the number of seals found on the fishing grounds, this is unlikely to reduce the magnitude of losses appreciably in the case of snoek fishing, where one or two seals can cause major losses for fishers (Kirkman 2010). Removal of specific animals attending fishing operations is not regarded as effective. To evaluate whether this method is an appropriate management strategy some form of monitoring would be required. The concerns if seals are to be shot at sea are the safety of other fishers in the vicinity, seals are more likely to be injured than killed and it is likely to be unacceptable to the public (Crawford and Payne 1989).

Non-lethal methods include technical solutions such as adaptations of boats and gear or operational solutions such as the use of deterrents to repel seals from fishing areas, conditioning seals to avoid fishing areas or alteration to the specific mode of fishing (David and Wickens 2003). Such solutions are likely to be fairly fishery specific, which makes them potentially appropriate management measures. For example, in the rock lobster hoop-netting fishery it is possible that a change in baiting technique may reduce losses to seals. In terms of operational solutions a number of attempts have been made to find efficient and humane methods of deterring seals from fishing operations. Devices included explosive fire-crackers, electronic pulses, air guns and sounds of killer whales (David and Wickens 2003). An electronic unit emitting random acoustic pulses to deter seals has also been tried but there are various problems with the use of acoustic methods underwater. While many operational solutions have been attempted in the past and possibilities have been explored elsewhere in the world, none has proved consistently successful and some methods are thought by fishers to disturb the fish or would have attracted seals as well (David and Wickens 2003).

Culling of a predator for the possible benefit of fisheries is a multi-species problem because seals are only one among a suite of marine predators. Seals only happen to be the most conspicuous and the one that is often encountered by fishers. They therefore tend to get the blame from the fishing community for poor catches (Kirkman 2010). In reality, predatory fish such as large hake play a far more important role in the system than do seals (David and Wickens 2003). Larger hake tend to live in deeper water than small hake, and large shallow-water hake overlap in distribution with small deep-water hake *Merluccius paradoxus*. Hake is cannibalistic and large shallow-water hake feed extensively on small deep-water hake (Punt *et al.* 1995). The main conclusion of these studies was that the effects of possible future seal culls on the yields and catch rates for both hake species are likely to be small and could even be detrimental. The key mechanism underlying this finding is that fewer seals will eat fewer shallow-water hake, which will leave more of the latter to prey on small deep-water hake. This will lead to fewer deep-water hake and less hake overall. This conclusion assumes that fishing patterns will not change in the future and that the proportion of deep-water hake in the catch would remain as present (David and Wickens 2003).

Seal-seabird interactions

Cape fur seals have recently displaced many seabirds from a number of islands off South Africa (Crawford and Payne 1989). Seals are known to attack and kill endangered seabirds such as African penguins *Spheniscus demersus*, Cape gannets *Morus capensis* and Cape cormorant *Phalacrocorax capensis*, bank cormorant *P. neglectus* and crowned cormorant *P. coronatus* (David *et al.* 2003, du Toit *et al*. 2004). These species breed only in South Africa, Namibia and southern

Angola and all are classified in terms of the World Conservation Union (IUCN) as Threatened or Near Threatened (Barnes 2000). The penguin population declined by 90 % since 1910, gannet by 30 % between 1956 and 1996 and bank cormorant by 44 % since 1980 (Crawford *et al.* 1999). The South African government (Oceans and Coasts) implemented a seal culling program in 1993 to protect Cape gannets, by shooting specific seals which are seen to attack birds during the gannet fledging season (David and Wickens 2003). One of the objectives was to investigate whether seabird mortality could be reduced by removing the offending seals (Kirkman 2010). A reduced kill rate was observed, which would indicate that specific individuals had learnt to prey on seabirds (David *et al.* 2003). Seals culled were juvenile or sub-adult males aged two to ten years (David *et al.* 2003). The explanation for this could be that most mature females have a dependant pup and must make regular feeding trips to sea alternating with visits to the colony to feed their pup. Therefore, females are more focussed in their foraging efforts than males (Kirkman 2010).

Seals are also known to displace seabirds when they recolonise islands (Kirkman 2009). This has occurred on a number of islands along the southern African coast, including Seal Island in Mossel Bay. In some of these cases, management practice was to chase the seals off the island because of the serious consequences for threatened seabirds of encroachment into their breeding colonies (Crawford *et al.* 1989). Where humans have disrupted the natural functioning of marine ecosystems by, for example, providing additional habitat for some species to breed and decreasing the food available for others through overexploitation of fish stocks, it is no longer adequate to view interactions between seals and seabirds simply as natural processes. CapeNature, as the authority responsible for the management of

Bird Island, a Provincial Nature Reserve off Lambert's Bay, is therefore required to implement active and ongoing intervention. Selective culling of those seals identified as seabird predators (Wolfaardt and Williams 2006) is undertaken, given that Bird Island is one of only six localities in the world where Cape gannets breed. The 11 000 pairs at the island represent 7 % of the global population of this species, which is listed as 'Vulnerable' to extinction. Retaining this breeding locality is therefore critical to the survival of the species (Kirkman 2010).

1.4 Distribution and spatio-temporal changes

Cape fur seals are the only species of pinniped resident on the coast of southern Africa (Shaughnessy 1985) where they currently breed at 24 island and 16 mainland locations. The species is distributed along 3 000 km of coastline from East London in the south-eastern part of South Africa to southern Angola in the north-west (Kirkman 2010). Its current geographical distribution ranges from Algoa Bay in South Africa to Baia dos Tigres in Angola (Figure 1.1). The greater part of the Cape fur seal population (> 90 %) occurs along the coast of Namibia and the west coast of South Africa (David 1989) (Figure 1.1). This region corresponds with the cold, nutrient-rich Benguela Current Ecosystem, also referred to as the Benguela Upwelling System. Only two of the 40 existing breeding colonies in this range occur to the east of Cape Agulhas (Kirkman *et al.* 2007b, Kirkman 2010, see Figure 1.1). These are Seal Island near Mossel Bay and Black Rocks near Port Elizabeth.

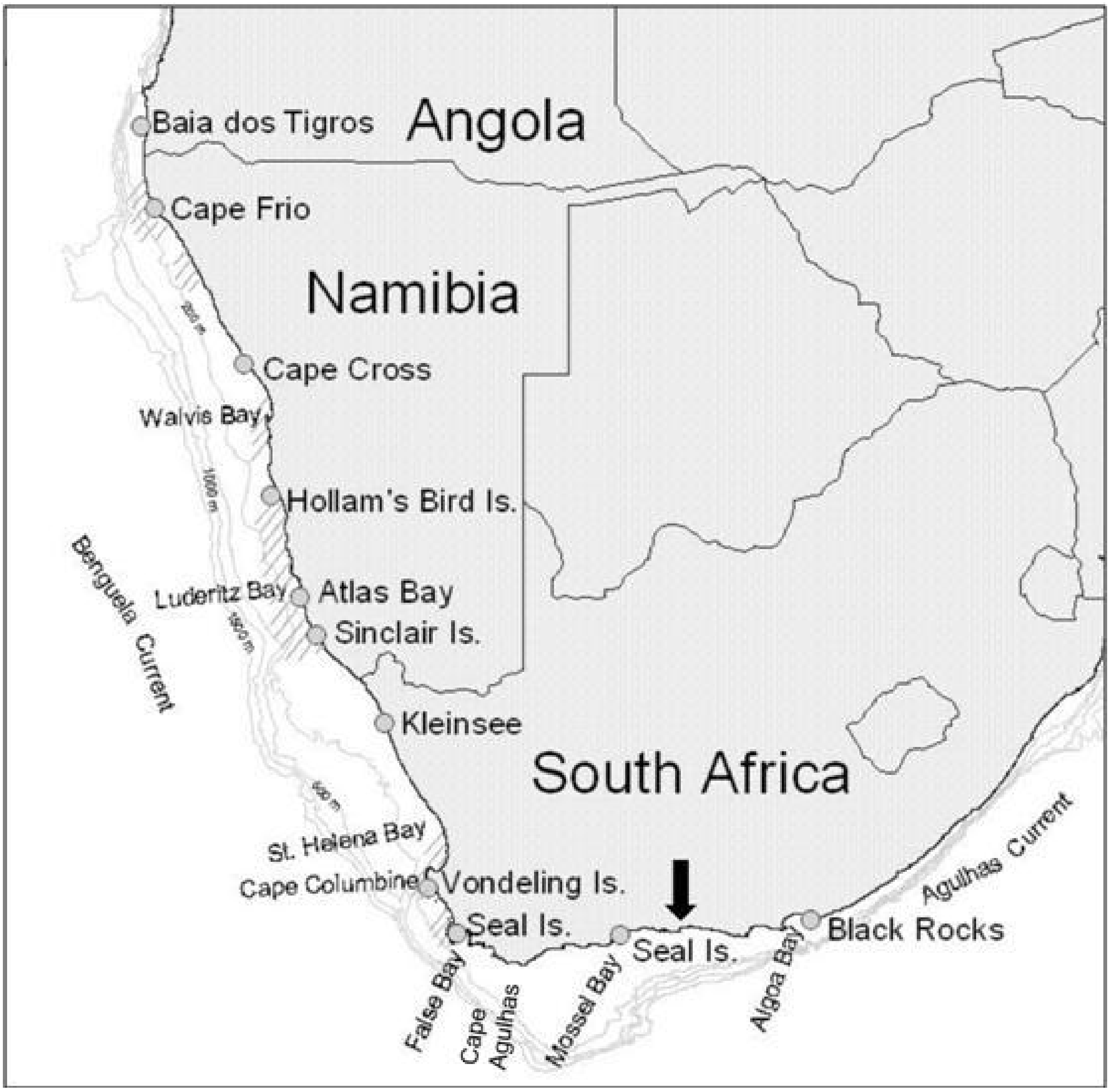

Figure 1.1 Cape fur seal breeding range from Black Rocks on the Agulhas current to Baia dos Tigres on the Benguela current with selected breeding colonies indicated. The arrow shows the location of Plettenberg Bay.

The current geographical distribution of the population differs considerably from its former distribution, as reconstructed from the records or anecdotes of seal hunters and other travellers in past centuries (Rand 1972, Shaughnessy 1982, Shaughnessy 1984), before several seal colonies were destroyed by large-scale, uncontrolled seal hunting (Rand 1972, Best and Shaughnessy 1979, Shaughnessy 1982, 1984, David and van Sittert 2008).

The increase in population size during the past century is a normal response of a species recovering from over exploitation (David 1989). Roux (1987) classified the process of recolonisation of the Amsterdam Islands by the subantarctic fur seal *A. tropicalis*, following depletive human exploitation, into four phases: (1) a 'survival' phase extending from the cessation of exploitation to the initiation of breeding, whereby surviving individuals ensured that a remnant population persisted at isolated and remote sites; (2) an 'establishment' phase during which breeding was restricted to a few founding colonies; (3) a 'recolonisation' phase during which numbers increased and new colonies arose in response to a shortage of space in the founding colonies; (4) a 'maturity' phase in which the rate of increase declined, caused by density-dependent factors such as an absolute shortage of space ashore or food at sea. Kirkman (2010) has shown that patterns of expansion of other otariid populations recovering from over-exploitation, including subantarctic fur seals at Marion Island (Hofmeyr *et al*. 2006), New Zealand fur seals *A. forsteri* on the Otago Peninsula (Bradshaw *et al*. 2000) and South American sea lions *Otaria flavescens* in Patagonia (Grandi *et al*. 2008) seem applicable to the expansion of the Cape fur seal population since the early 20th century when sealing was placed under legal controls, (Shaughnessy 1984), although the 'recolonisation' phase appears to have been considerably influenced by factors that were not density dependent.

At mainland seal colonies, breeding space does not appear to be a limiting factor (Wickens *et al*. 1991, Kirkman 2010); however, all seal colonies that were in existence in the 1970s were on small islands (3 ha in area or less) and typically are extremely crowded, especially during the breeding season (Rand 1967, Crawford and Best 1990). Therefore, limited breeding space was a probable mechanism of density dependent regulation at these island locations, most of which have shown little or no sustained growth (Kirkman 2010).

Cape fur seal females generally show fidelity to their natal and breeding sites (Rand 1967), behaviour that is typical among pinniped species (Gentry 1998, Pomeroy *et al.* 2000, Raum-Suryan *et al*. 2002). Matthiopoulos *et al.* (2005) suggested that such fidelity can slow down colonisation of new areas by seals and prevent populations from utilising all available habitats in their range, despite conditions of resource limitation. The population of northern fur seals *Callorhinus ursinus*, for example, colonised only two new locations in 200 years (Gentry 1998). The seal population in Algoa Bay is currently limited to Black Rocks, a group of four exposed rocks, the largest of which has a surface area of less than 1 ha and which is used for breeding (Rand 1972). This colony was thought to have survived sealing operations of previous centuries only on account of its inaccessibility (Stewardson 1999). Nearby in the same island group are two larger islands, Seal Island (6.5 ha) and Stag Island (*c*. 1.1 ha), where seal colonies existed until they were completely destroyed in the 19^{th} or early 20^{th} century (Shaughnessy 1984, Stewardson 1999). Despite the availability of these two islands that are not inhabited by humans, there has been no growth at Black Rocks, and seals have yet to recolonise these islands.

While density-dependent factors are known to influence seal population dynamics, several authors have emphasised the importance of environmental variability as a density independent influence on the population dynamics of seals (Trillmich 1993, Gerber and Hilborn 2001, Reid and Forcada 2005, Forcada *et al.* 2005, Matthee *et al.* 2006).

South Africa's marine environment, including prey resources, is considered to have been generally stable in recent years (Cury and Shannon 2004, van der Lingen *et al.* 2006). Nevertheless, wide-scale shifts in the distributions of certain species such as adult sardines and the abrupt eastward shift in the stock of adult Cape anchovy *Engraulis encrasicolus* in this period have occurred (Roy *et al.* 2007). The distributions of several seabird top predator species in South Africa that prey on sardine and anchovy (for example Cape gannet, Cape cormorant, bank cormorant *P. neglectus*, swift tern *Sterna bergii*), as well as several other seabird species that do not (for example crowned cormorant *P. coronatus*, Hartlaub's gull *Larus hartlaubii*), have also shifted eastward during the study period (Crawford *et al.* 2008a, 2008b). Considering the congruency in their timing and direction, Crawford *et al.* (2008b) proposed that these shifts may have been influenced by environmental factors, possibly forced by climate changes. Climate-induced shifts in prey species distributions may have implications for seal population dynamics.

Accessibility and extent of human activity along the south coast likely provide less opportunity for seals to establish breeding colonies on the mainland compared to the more restricted or reserved coastlines of Namibia and the north of South Africa's west coast (Shaughnessy 1982), where the potential for human interference is lower (Shaughnessy 1982). Likewise, fewer new breeding colonies have established along the relatively more developed South African coastline of the southern Benguela Current Ecosystem compared to the Namibian coastline (Kirkman 2010). Despite range expansion and the development and growth of new colonies, the overall size of the Cape fur seal population appears to have been stable since the 1990s (Kirkman 2010).

Short term fluctuations in seal numbers at a haulout site may be influenced by several bio-physical factors. These include time of day as there are likely to be more seals on land when it is cool; this is early morning and late afternoon (Rand 1959). At night, some seal species also avoid feeding when the moon is bright due to decreased foraging efficiency resulting from vertical migration of prey (Trillmich and Mohren 1981). Under these conditions more seals would be present ashore during early morning than under dark moon conditions. Previous studies in False Bay, South Africa, suggest that majority of Cape fur seals traverse to and from their colonies at night, when it is believed that there is low shark activity (Hammerschlag *et al*. 2006, Laroche *et al*. 2008). Differences in weather conditions may also influence numbers of hauled out seals (Hofmeyr *et al.* 2006). For example, during high sea conditions at Robberg, seals ashore are forced higher up the ledge, which limits the space available at the haulout site (J.H. pers. obs.). The topography of the site where the seals haul out could also influence access to these sites. Pups may, for example, struggle to negotiate steep rock faces. Understanding of the drivers of seal population dynamics (including distinguishing between human- and climate-related effects on trends in population size and distribution) requires region-wide monitoring of population parameters to complement aerial census data (Kirkman 2010).

1.5 Study objectives

The Cape fur seal has an important role as top predator in the marine environment, and with expansion of seal numbers at Robberg near the eastern end of the species' distribution range, the population trends and whether it will become a breeding population need to be investigated. Furthermore, fewer diet studies of this species have been carried out to the east of Cape Agulhas than along the west coast of South Africa or Namibia. Obtaining this information will enable the determination of trends in diet composition to compare with other areas, and ascertain the extent of competition between seals and the local fishing industry.

The objectives of this study therefore were:

1. to assess the numerical trends in Cape fur seals at Robberg between 2000 and 2009;
2. to investigate within-year variability in seal counts and attempt to explain this variability;
3. to assess the extent of breeding at the Robberg colony and changes therein over the study period;
4. to determine the species composition and size of prey in the diet of Cape fur seals at Robberg;
5. to explore intra- and inter-annual variation in the diet;
6. to investigate the potential for competition between seals and the fisheries in Plettenberg Bay.

1.6 References

Balmelli M, Wickens PA. 1994. Estimates of daily ration for the South African (Cape) fur seal. *South African Journal of Marine Science* 14: 151-157.

Barnes KN. 2000. *The Eskom Red Data Book of birds of South Africa, Lesotho and Swaziland*. Johannesburg. Birdlife, South Africa.

Beckley LE, van Ballegooyen RC. 1992. Oceanographic conditions during three ichthyoplankton surveys of the Agulhas current in 1990/91. *South African Journal of Marine Science* 12: 83-93.

Best PB. 1983. Management of Cape fur seals. Unpublished Report, Sea Fisheries Research Institute of South Africa.

Best PB, Shaughnessy PD. 1979. An independent account of Captain Benjamin Morrell's sealing voyage to the south-west coast of Africa in the Antarctic, 1928/29. *Fisheries Bulletin of South Africa* 12: 1-19.

Bonner WN, 1981. Southern fur seals. In: Ridgway SH, Harrison RJ (eds), *Handbook of Marine Mammals Vol. 1. The Walrus, Sea Lions, Fur Seals and Sea Otter.* Academic Press, London, pp 161-218.

Bonner WN, 1994. *Seals and Sea Lions of the World*. Blandford, London.

Boyd IL, Bowen WD, Iverson SJ. 2010. *Marine Mammal Ecology and Conservation: A Handbook of Techniques*. Oxford University Press, Oxford.

Bradshaw CJA, Lalas C, Thompson CM. 2000. Clustering of colonies in an expanding population of New Zealand fur seals (*Arctocephalus forsteri*). *Journal of Zoology, London* 250: 105-112.

Butterworth DS, Punt AE, Oosthuizen WH, Wickens PA. 1995. The effects of future consumption by the Cape fur seal on catches and catch rates of the Cape hakes. 3. Modelling the dynamics of the Cape fur seal *Arctocephalus pusillus pusillus. South African Journal of Maritime Science* 16: 161-183.

Castley JG, Cockcroft VG, Kerley GIH. 1991. A note on the stomach contents of fur seals *Arctocephalus pusillus pusillus* beached on the south-east coast of South Africa. *South African Journal of Maritime Science* 11: 573-577.

Clarke MR. 1962. The identification of cephalopod 'beaks' and the relationship between beak size and total body weight. *Bulletin of the British Museum (Natural History) Zoology* 8: 419-480.

Cockcroft AC, van Zyl D, Hutchings L. 2008. Large-scale changes in the spatial distribution of South African West Coast rock lobsters: an overview. *African Journal of Marine Science* 30: 149-159.

Crawford RJM, Best PB. 1990. On the former abundance of South African fur seals off Namibia. Working paper, Benguela Ecology Programme workshop on seal-fishery biological interaction, BEP/SW91/A6, 4 pp.

Crawford RJM, Payne AIL. 1989. Southern Africa's ocean ecosystems. In: Payne AIL, Crawford RJM (eds), *Oceans of Life*. Vlaeberg Publishers, Cape Town, pp 347-359.

Crawford RJM, David JHM, Williams AJ, Dyer B. 1989. Competition for space – recolonizing seals displace endangered, endemic seabirds off Namibia. *Biological Conservation* 48: 59-72.

Crawford RJM, Dyer BM, Cordes I, Williams AJ. 1999. Seasonal pattern of breeding, population trend and conservation status of bank cormorants *Phalacrocorax neglectus* off south western Africa. *Biological Conservation* 87: 49-58.

Crawford RJM, Sabarros PS, Fairweather T, Underhill LG, Wolfaardt AC. 2008a. Implications for seabirds off South Africa of a long-term change in the distribution of sardine. *African Journal of Marine Science* 30: 177-184.

Crawford RJM, Tree AJ, Whittington PA, Visagie J, Upfold L, Roxburg KJ, Martin AP, Dyer BM. 2008b. Recent distributional changes of seabirds in South Africa: is climate having an impact? *African Journal of Marine Science* 30: 189-193.

Cury P, Shannon LJ. 2004. Regime shifts in upwelling ecosystems: observed changes and possible mechanisms in the northern and southern Benguela. *Progress in Oceanography* 60: 223-243.

David JHM. 1987. Diet of the South African fur seal (1974-1985) and an assessment of competition with fisheries in southern Africa. *South African Journal of Marine Science* 5: 693-713.

David JHM. 1989. Seals. In: Payne AIL, Crawford RJM (eds), *Oceans of Life*. Vlaeberg Publishers, Cape Town, pp 288-302.

David JHM, Rand RW. 1986. Attendance behaviour of South African fur seals. In: Gentry RL, Kooyman GL (eds), *Fur Seals: Maternal Strategies on Land and at Sea*. Princeton, Princeton University Press, pp 126-141.

David JHM, van Sittert L. 2008. A reconstruction of the Cape (South African) fur seal harvest 1653-1899 and a comparison with the 20th century harvest. *South African Journal of Science* 104: 107-110.

David JHM, Wickens PA. 2003. Management of Cape fur seals and fisheries in South Africa. In: Gales N, Hindell M, Kirkwood R (eds), *Marine mammals: fisheries, tourism and management issues*. Australia: CSIRO Publishing. pp 116-135.

David JHM, Cury P, Crawford RJM, Randall RM, Underhill LG, Meÿer MA. 2003. Assessing conservation priorities in the Benguela ecosystem, South Africa: analysing predation by seals on threatened seabirds. *Biological Conservation* 114: 289-292.

De Villiers DJ, Roux J-P. 1992. Mortality of newborn pups of the South African fur seal *Arctocephalus pusillus pusillus* in Namibia. *South African Journal of Marine Science* 12: 881-889.

du Toit M, Bartlett PA, Bester MN Roux J-P. 2004. Seabird predation by individual seals at Ichaboe Island, Namibia. *African Journal of Wildlife Research* 34:45-54.

Fairweather TP, van der Lingen CD, Booth AJ, Drapeau L, van der Westhuizen JJ. 2006. Indicators of sustainable fishing for South African sardine *Sardinops sagax* and anchovy *Engraulis encrasicolus*. *African Journal of Marine Science* 28: 661-680.

Forcada J, Trathan PN, Reid K, Murphy EJ. 2005. The effects of global climate variability in pup production of Antarctic fur seals. *Ecology* 86: 2408-2417.

Gales R, Pemberton D, Lu CC, Clarke MR. 1993. Cephalopod diet of the Australian Fur seal; variation due to location, season and sample type. *Australian Journal of Marine and Freshwater Research* 44: 657-671.

Gentry R. 1998. *Behavior and Ecology of the Northern Fur Seal.* Princeton University Press, Princeton.

Gentry RL, Kooyman GL (eds). 1986. *Fur Seals: Maternal Strategies on Land and at Sea*. Princeton University Press, Princeton.

Gerber LH, Hilborn H. 2001. Catastrophic events and recovery from low densities in populations of otariids: implications for risk of extinction. *Mammal Review* 31: 131-150.

Glennie OH. 81 Longships Dr, Plettenberg Bay. Cell 0733456330.

Grandi MF, Dans SL, Crespo EA. 2008. Social composition and spatial distribution of colonies in an expanding population of South American sea lions. *Journal of Mammalogy* 89: 1218-1228.

Griffiths CL, van Sittert L, Best PB, Brown AC, Clark BM, Cook PA, Crawford RJM, David JHM, Davies B, Griffiths MH, Hutchings K, Jerardino A, Kruger N., Lamberth S, Leslie RW, Melville-Smith R, Tarr R, van der Lingen CD. 2005. Impacts of human activities on marine animal life in the Benguela: a historical overview. *Oceanography and Marine Biology: an Annual Review* 42: 303-392.

Hammerschlag N, Martin RA, Fallows C. 2006. Effects of environmental conditions on predator-prey interactions between white sharks (*Carcharodon carcharias*) and Cape fur seal (*Arctocephalus pusillus pusillus*) at Seal Island, South Africa. *Environmental Biology of Fishes* 76: 341-350.

Harwood J, Croxall JP. 1988. The assessment of competition between seals and commercial fisheries in the North Sea and the Antarctic. *Marine Mammal Science* 4: 13-33.

Hofmeyr GJG, Bester MN, Makhado AB, Pistorius PA. 2006. Population changes in Subantarctic and Antarctic fur seals at Marion Island. *South African Journal of Wildlife Research* 36: 55-68.

Jewell R. 2005. A study of the diet of Cape fur seals, *Arctocephalus pusillus pusillus*, in Plettenberg Bay, South Africa. Report submitted in partial fulfillment for MSc degree. University of Plymouth, England.

Jobling M. 1987. Marine mammal faeces samples as indicators of prey importance-a source of error in bioenergetics studies. *Sarsia* 72: 255-260.

Jobling M, Breiby A. 1986. The use and abuse of fish otoliths in studies of feeding habits of marine piscivores. *Sarsia* 71: 265-274.

Johnson RL, Venter A, Bester MN, Oosthuizen WH. 2006. Seabird predation by white shark (*Carcharodon carcharias*) and Cape fur seal (*Arctocephalus pusillus pusillus*) at Dyer Island. *South African Journal of Wildlife Research* 36: 23-32.

King CM. 2005. Towards a new approach for coastal Governance with an assessment of the Plettenberg bay shore-based linefishery. MSc thesis Rhodes University, South Africa.

Kirkman SP. 2009. Evaluating seal-seabird interactions in southern Africa: a critical review. *African Journal of Marine Science.* 31: 1-18.

Kirkman SP. 2010. The Cape fur seal: monitoring and management in the Benguela Current Ecosystem. PhD thesis. Animal Demography Unit, Department of Zoology, University of Cape Town, South Africa.

Kirkman SP, Wilson W, Klages NTW, Bester MN, Isaksen K. 2000. Diet and estimated food consumption of Antarctic fur seals at Bouvetoya during summer. *Polar Biology* 23: 745-752.

Kirkman SP, Oosthuizen WH, Meÿer MA, Kotze PGH, Boucher M, Underhill LG. 2007a. Ecological responses of Cape fur seals to temporal shifts in pelagic prey availability. In: Kirkman SP (ed.) *Final Report of the BCLME (Benguela Current Large Marine Ecosystem) Project on Top Predators as Biological Indicators of Ecosystem Change in the BCLME*. Cape Town: Avian Demography Unit, University of Cape Town. pp 53-65.

Kirkman SP, Oosthuizen WH, Meÿer MA, Kotze PGH, Roux J-P, Underhill LG. 2007b. Making sense of censuses and dealing with missing data: trends in pup counts of Cape fur seal *Arctocephalus pusillus pusillus* for the period 1972-2004. *African Journal of Marine Science* 29: 161-176.

Klages NTW. 1996. Cephalopods as prey. II. Seals. *Philosophical Transactions of the Royal Society of London, B Biological Sciences* 351: 1045-1052.

Laroche RK, Kock AA, Dill LM, Oosthuizen WH. 2008. Running the gauntlet: a predator-prey game between sharks and two age classes of seals. *Animal Behaviour* 76: 1901-1917.

Lipinski MR, David JHM. 1990. Cephalopods in the diet of the South African fur seal (*Arctocephalus pusillus pusillus*). *Journal of Zoology, London* 221: 359-374.

Makhado AB, Crawford RJM, Underhill LG. 2006. Impact of predation by Cape fur seals *Arctocephalus pusillus pusillus* on Cape gannets *Morus capensis* at Malgas Island, Western Cape, South Africa. *African Journal of Marine Science* 28: 681-687.

Makhado AB, Meÿer MA, Crawford RJM, Underhill LG, Wilke C. 2009. The efficacy of culling seals seen preying on seabirds as a means of reducing seabird mortality. *African Journal of Ecology* 47: 335-340.

Martin RA, Hammerschlag N, Collier RS, Fallows C. 2005. Predatory behaviour of white sharks (*Carcharodon carcharias*) at Seal Island, South Africa. *Journal of the Marine Biological Association of the United Kingdom* 85:1121-1135.

Matthee CA, Fourie F, Oosthuizen WH, Meÿer MA, Tolley KA. 2006. Mitochondrial DNA sequence data of the Cape fur seal (*Arctocephalus pusillus pusillus*) suggest that population numbers may be affected by climatic shifts. *Marine Biology* 148: 899-905.

Matthiopoulos J, Harwood J, Thomas L. 2005. Metapopulation consequences of site fidelity for colonially breeding mammals and birds. *Journal of Animal Ecology* 74: 716-727.

Mecenero S, Roux J-P, Underhill LG, Kirkman SP, Bester MN. 2006. Diet of Cape fur seals *Arctocephalus pusillus pusillus* at three mainland breeding colonies in Namibia. 2. Temporal variation. *African Journal of Marine Science* 28: 73-88.

Metelerkamp S. 1955. *George Rex of Knysna*. Cape Town, Timmins pp 308.

Murie DJ. 1986. Interpretations of otoliths in stomach content analyses of phocid seals: quantifying fish consumption. *Canadian Journal of Zoology* 64: 1152-1157.

Newman K, Springer AM. 2008. Nocturnal activity by mammal-eating killer whales at a predation hot spot in the Bering Sea. *Marine Mammal Science* 24: 990-999.

Olesiuk PF, Bigg MA, Ellis GM, Crockford SJ, Wigen RG. 1990. An assessment of the feeding habits of harbour seals (*Phoca vitulina*) in the Strait of Georgia, British Columbia, based on scat analysis. *Canadian Technical Report of Fisheries and Aquatic Sciences*, No. 1730.

Oosthuizen WH, Meÿer MA, David JHM, Summers NM, Kotze PGH, Swanson SW, Shaughnessy PD. 1997. Variation in jackal numbers at the van Reenen Bay seal colony with comment on likely importance of jackals as predators. *South African Journal of Wildlife Research* 27: 26-29.

Pierce GJ, Boyle PR. 1991. Review of methods for diet analysis in piscivorous marine mammals. *Oceanographic Marine Biology* 29: 409-486.

Pomeroy PP, Twiss SD, Duck CD. 2000. Expansion of a grey seal (*Halichoerus grypus*) breeding colony: changes in pupping site use at the Isle of May, Scotland. *Journal of Zoology* 250: 1-12.

Punt AE, Butterworth DS. 1995. The effects of future consumption by the Cape fur seal on catches and catch rates of Cape Hakes. 4. Modelling the biological interaction between Cape fur seals *Arctocephalus pusillus pusillus* and the Cape Hakes, *Merluccius capensis* and *M. paradoxus*. *South African Journal of Maritime Science* 16: 255-285.

Punt AE, David JHM, Leslie RW. 1995. The effects of future consumption by the Cape fur seal on catches and catch rates of the Cape hakes. 2. Feeding and diet of the Cape fur seal *Arctocephalus pusillus pusillus*. *South African Journal of Maritime Science* 16: 85-99.

Rand RW. 1955. Reproduction in the female Cape fur seal, *Arctocephalus pusillus*. *Proceedings of the Zoological Society of London* 124: 717-740.

Rand RW. 1959. The Cape fur seal (*Arctocephalus pusillus pusillus*). Distribution, abundance and feeding habits off the southwestern coast of the Cape Province. Investigational Report Sea Fisheries South Africa 34: 1-75.

Rand RW. 1967. The Cape fur seal (*Arctocephalus pusillus pusillus*). 3. General behaviour on land and at sea. Investigational Report, Division Sea Fisheries, South Africa 60: 1-39.

Rand RW. 1972. The Cape fur seal *Arctocephalus pusillus*. 4. Estimates of population size. Investigational Report Sea Fisheries South Africa 89: 1-28.

Raum-Suryan KL, Pitcher KW, Calkins DG, Sease JL, Loughlin TR. 2002. Dispersal, rookery fidelity, and metapopulation structure of Steller sea lions (*Eumetopias jubatus*) in an increasing and a decreasing population in Alaska. *Marine Mammal Science* 18: 746-764.

Reid K. 1995. The diet of Antarctic fur seals *(Arctocephalus gazella* Peters 1875) during winter at South Georgia. *Antarctic Science* 7: 241-249.

Reid K, Forcada J. 2005. Causes of offspring mortality in the Antarctic fur seal, *Arctocephalus gazella*: the interaction of density dependence and ecosystem variability. *Canadian Journal of Zoology* 83: 604-609.

Reisinger RR, de Bruyn pjn, Bester MN. 2011. Predatory impact of killer whales on pinniped and penguin populations at the Subantarctic Prince Edwards Islands: fact and fiction. *Journal of Zoology (London)* 285: 1-10.

Ross GJB. 1971. Notes on seals and sealing in the Eastern Cape. *The Eastern Cape Naturalist* 44: 6-8.

Roux J-P. 1987. Recolonization processes in the Subanctarctic fur seal, *Arctocephalus tropicalis*, on Amsterdam Island. In: Croxall JP, Gentry RL (eds), *Status, Biology, and Ecology of Fur Seals: Proceedings of an International Symposium and Workshop, Cambridge, England, 23-27 April 1984*. NOAA Technical Report NMFS 51, Seattle, Washington, pp 189-194.

Roy C, van der Lingen CD, Coetzee JC, Lutjeharms JRE. 2007. Abrupt environmental shift associated with changes in the distribution of Cape anchovy *Engraulis encrasicolus* spawners in the southern Benguela. *African Journal of Marine Science* 29: 309-319.

Shaughnessy PD. 1982. The status of seals in South Africa and South West Africa. *Mammals of the seas. FAO Fisheries Series* 5: 383-410.

Shaughnessy PD. 1984. Historical population levels of seals and seabirds on islands off southern Africa, with special reference to Seal Island, False Bay. Investigational Report of the Sea Fisheries Research Institute, South Africa 127: 61pp.

Shaughnessy PD. 1985. Interactions between fisheries and Cape fur seals in southern Africa. In: J.R. Beddington. R.J.H. Beverton, and D.M. Lavigne. (eds), *Marine Mammals and Fisheries* George, Allen and Unwin: London.

Sinclair E., Loughlin T. Pearcy W. 1994. Prey selection by northern fur seals (*Callorhinus ursinus*) in the eastern Bering Sea. *Fishery Bulletin* 92: 144-156.

Smale MJ, Watson G, Hecht T. 1995. *Otolith atlas of Southern African Marine Fishes*. Ichthyological Monographs. J.L.B. Smith Institute of Ichthyology, Grahamstown, South Africa.

Smith MKS. 2005. Towards a new approach for coastal governance with an assessment of the Plettenberg Bay nearshore linefisheries. MSc thesis Rhodes University, South Africa.

Stewardson CL. 1999. The impact of the fur seal industry on the distribution and abundance of Cape fur seals *Arctocephalus pusillus pusillus* on the Eastern Cape coast of South Africa. *Transactions of the Royal Society of South Africa* 54: 217-245.

Stewardson CL. 2001. Biology and conservation of the Cape (South African) fur seal. PhD thesis, Australian National University, Canberra, Australia.

Tollit DJ, Thompson PM. 1996. Seasonal and between- year variations in the diet of harbour seals in the Moray Firth, Scotland. *Canadian Journal of Zoology* 74: 1110-1121.

Tollit DJ, Steward MJ, Thompson PM, Pierce GJ, Santos MB, Hughes S. 1997. Species and size differences in the digestion of otoliths and beaks: implications for estimates of pinniped diet composition. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 105-119.

Treacy SD. 1981. Retrieval of otoliths and statoliths from gastrointestinal contents and scats of marine mammals. *Journal of Wildlife Management* 45: 990-993.

Trillmich F. 1993. Influence of rare ecological events on pinniped social structure and population dynamics. In: Boyd IL (ed.) *Marine Mammals: Advances in Behavioural and Population Biology.* Proceedings of a Symposium held at The Zoological Society of London on 9th and 10th April 1992. Symposia of the Zoological Society of London 66: 95-114.

Trillmich F and Mohren W. 1981. Effects of the lunar cycle on the Galapagos fur seal, *Arctocephalus galapagoensis*. *Oecologia* 48:85-92.

van der Lingen CD, Shannon LJ, Cury P, Kreiner A, Moloney CL, Roux J-P, Vaz-Velho F. 2006. Resource and ecosystem variability, including regime shifts, in the Benguela Current System. In: Shannon V, Hempel G, Malanotte-Rizzoli P, Moloney CL, Woods J (eds), *Benguela: Predicting a Large Marine Ecosystem*. Elsevier, Amsterdam, pp 147-185.

Wickens PA, York AE. 1997. Comparative population dynamics of fur seals. *Marine Mammal Science* 13: 241-292.

Wickens PA, David JHM, Shelton PA, Field JG. 1991. Trends in harvests and pup numbers of the South African fur seal: implications for management. *South African Journal of Marine Science* 11: 307-326.

Wickens PA, Japp DW, Shelton PA, Kriel F, Goosen PC, Rose B, Augustyn CJ, Bross CAR, Penney AJ, Krohn RG. 1992. Seals and fisheries in South Africa – competition and conflict. In: Payne AIL, Brink KH, Mann KH, Hilborn R (eds), *Benguela trophic functioning. South African Journal of Marine Science* 12: 773-789.

Wiesel I. 2006. Predatory and foraging behaviour of brown hyenas *Hyaena brunnea brunnea* (Thunberg, 1820) at Cape fur seal *Arctocephalus pusillus pusillus* (Schreber, 1776) colonies. PhD thesis, Biozentrum Grindel und Zoologisches Museum, Universität Hamburg, Germany.

Wolfaardt A, Williams T. 2006. Sealed off. Predation threatens seabirds and tourism. *Africa Birds and Birding* 11: 60-67.

Yonezaki S, Kiyota M, Baba N, Koido T, Takemura A. 2003. Size distribution of the hard remains of prey in the digestive tract of the northern fur seal (*Callorhinus ursinus*) and related biases in diet estimation by scat analysis. *Mammal Study* 28: 97-102.

CHAPTER 2. Historical exploitation of Cape fur seals at Robberg Peninsula and description of the study site

2.1 History

Seals have been harvested for their skin, meat and blubber from the 17th to the 19th centuries by Dutch, French, American and British sealers (Punt *et al*. 1995). It was thought that historically, breeding colonies of this sub-species occurred almost exclusively at island locations, with terrestrial predators including early hunter-gatherers generally preventing viable breeding colonies from occurring on the mainland (Rand 1972). However, uncontrolled seal harvesting (sealing) that took place between the 17th and 19th centuries following the arrival of Europeans in the region led to the extirpation of seal breeding colonies at several islands (Rand 1952, 1972, Shaughnessy 1984, David and van Sittert 2008).

At least nine seal colonies were known to exist to the east of Cape Agulhas prior to the 20th century (Shaughnessy 1982, Stewardson 1999). The colonies in this area that were hunted to extirpation included at least five colonies in Algoa Bay and another two in Plettenberg Bay. At Plettenberg Bay, seals historically occurred at Beacon Island (which has since been developed and joined to the mainland) and also at 'Seal Point' on Robberg (Figure 2.1). In 1833, a government official estimated that there were 3 000 seals on Robberg, although figures reported by other sources were much lower (Stewardson 1999). The only available record of seal numbers taken at Robberg was of 146 seals during one season around the same time. These were all males therefore it has been inferred that this may have been a non-breeding colony (Metelerkamp 1955). In 1857, tenders were sent out for the harvesting of seals at Robberg by the Civil Commissioner of George, but details of these hunts were not recorded (Rand 1982). According to Ross (1971), it is likely that the Robberg rookery had ceased to exist by 1890.

By the beginning of the 20th century when the species' population was probably at its most reduced level, numbers are thought to have been less than 100 000 individuals (Shaughnessy and Butterworth 1981) and breeding colonies had disappeared from at least 23 coastal islands (Best and Shaughnessy 1979, Shaughnessy 1982). The remaining seals were generally restricted to small islands and rocky outcrops not utilised by guano-producing birds, and not easily accessible to seal hunters (Rand 1952). Despite the introduction of control measures on sealing around the beginning of the 20th century, recolonisation of many of their former island breeding colonies was inhibited by human activities, mostly related to the exploitation of seabird products (for example guano, eggs) (Shaughnessy 1984). However, around the middle of the 20th century, new breeding colonies were established at mainland locations, including at Kleinsee in South Africa and at Atlas Bay and Wolf Bay in Namibia (Rand 1972). The growth in seal numbers at these colonies and at Cape Cross, a mainland colony in Namibia which existed before the 20th century, largely accounted for a recovery in seal numbers during the 20th century, with numbers estimated at 1.7 million animals (excluding pups of the year) in 1992 (Butterworth *et al*. 1995). There has been speculation as to whether the current size of the seal population exceeds the pre-sealing population size, which is unknown (Makhado *et al.* 2006).

Sealing operations reduced the Cape fur seal population to approximately 200 000 animals by 1920 (Punt and Butterworth 1995). Sealing operations continued up until the Sea Birds and Seals Protection Act of 1973 was introduced to prohibit sealing. Thereafter the numbers increased to 1.7 million by 1993 (Punt and Butterworth 1995). However, for the majority of the south east coast colonies, including those on Robberg and Beacon Isle in Plettenberg Bay, the legislation came too late. Only two seal colonies, the Black Rocks colony in Algoa Bay and the Seal Island colony in Mossel Bay, survived on the south-east coast of southern Africa.

2.2 Study area

The study area is located along the south coast of South Africa to the east of Cape Agulhas. The major oceanographic feature along this coast is the Agulhas Current (Beckley and van Ballegooyen 1992) which flows in a south westerly direction along the edge of the continental shelf (Figure 1.1), but moves offshore in the East London area which reduces its influence on the south coast (Schumann *et al*. 1982). Wind has a strong effect on the oceanography of the region and wind is experienced throughout the year. In winter the prevailing wind direction is northwest which swings to south-east during summer (CSIR 1984) causing numerous upwelling events.

In Plettenberg Bay the fast flowing Agulhas current intermittently causes inshore counter-currents and upwelling of colder water (Lutjeharms and Ansorge 2001) associated with prominent capes (Schumann *et al.* 1982). Rough sea conditions are generally associated with westerly cold fronts in winter (Duvenage and Morant 1984). The average water temperature off-shore of Plettenberg Bay ranges between a monthly average of 15.9 ºC in August and 19.4 ºC in January (N. Hanekom unpubl.

data). However, upwelling associated with periods of south-easterly winds of which 80 % occurs between November and April (Hanekom *et al.* 1989) may decrease water temperatures by 10 ºC (Schumann *et al.* 1988). The climate is mild (average daily maximum temperature of 24 ºC in February and average daily minimum temperature of 10 ºC in August) while rainfall occurs year-round (Figure 2.2, South African Weather Service).

The Robberg Peninsula lies 7 km south of the town of Plettenberg Bay and forms the south-western extremity of Plettenberg Bay (Figure. 2.1). The Peninsula is a proclaimed Provincial Nature Reserve, the Robberg Nature Reserve (Government Notice No. 1 of 1980), while the surrounding sea is proclaimed as a Marine Protected Area (Marine Living Resources Act No. 18 of 1998). The terrestrial portion of the Reserve is 174 ha in extent, while the Marine Protected Area covers an area of 2 241 ha. Robberg Peninsula consists of a rocky headland, 3.9 km in length and 0.9 km at its widest point. The shoreline rises steeply from the high water mark, especially on the northern side of the Peninsula, with the highest point at 148.5 m. A number of sandy beaches and well known archaeological features occur mainly on the southern side of the Peninsula. No bait collection, spear-fishing or angling from a boat is permitted but rock and surf angling is allowed (Robberg Marine Protected Area Management Plan 2005) and Robberg has been a popular game-fish angling destination. Other activities and facilities available at the Robberg Nature Reserve include hiking trails and interpretation centres, attracting approximately 30 000 visitors per annum (Robberg Nature Reserve Management Plan 2010).

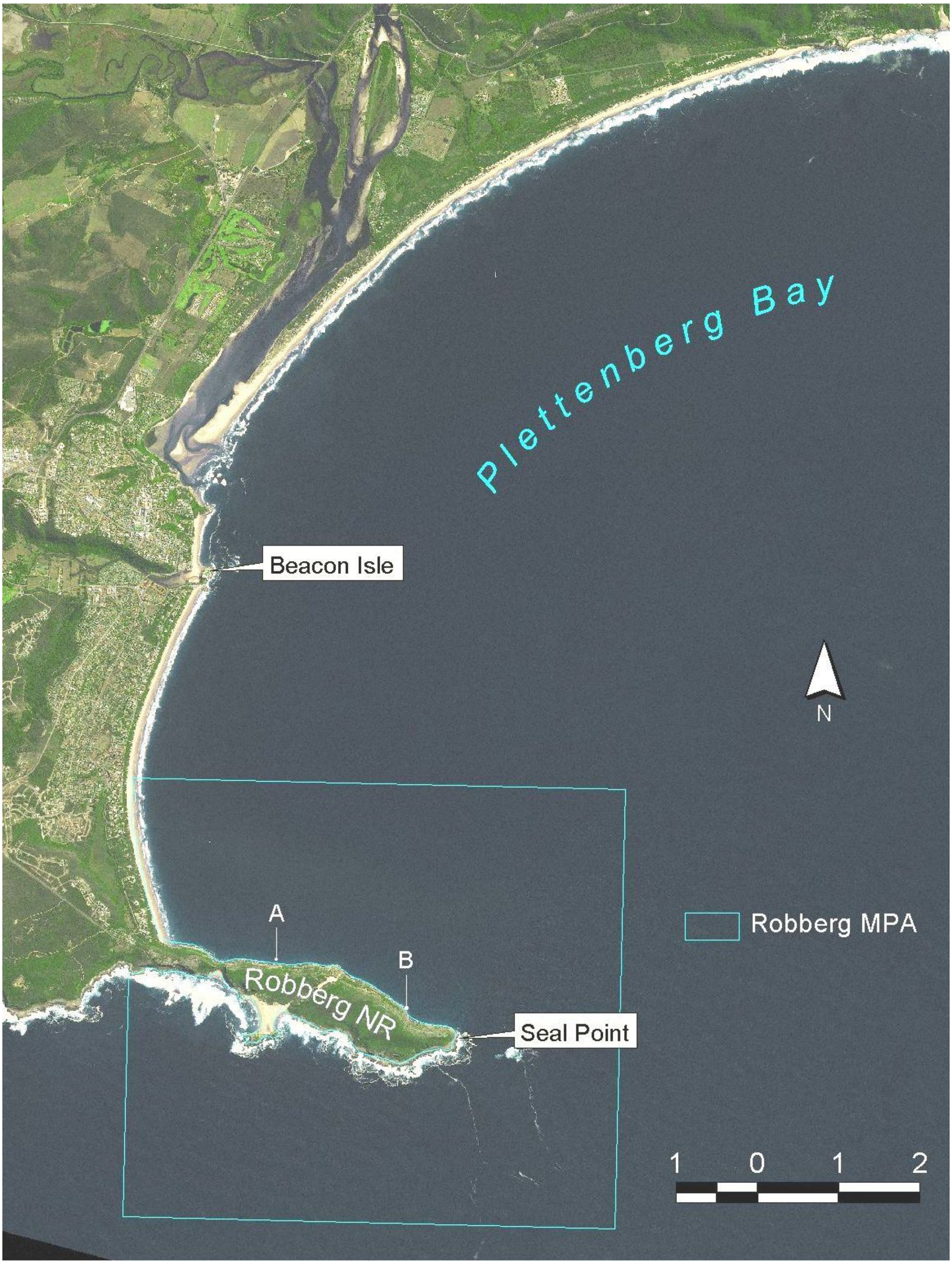

Figure 2.1 Location of the study site at Robberg Nature Reserve (NR), Plettenberg Bay. Seal Point, where seals hauled out historically, is indicated as well as the current recolonisation site between A and B. (Scale bar in kilometres.)

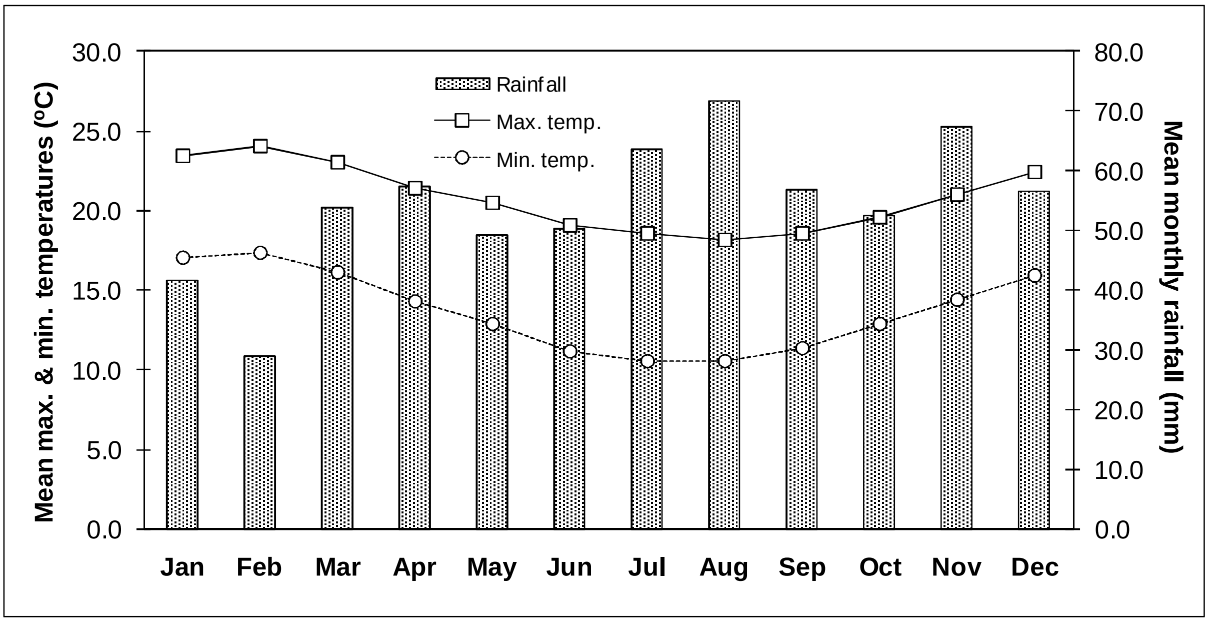

Figure 2.2 Mean monthly rainfall and mean daily maximum and minimum temperatures for Plettenberg Bay airport for the period 2000 to 2008 (South African Weather Service).

After the population of an estimated 3 000 seals at Seal Point on Robberg Peninsula (Metelerkamp 1955) was eliminated by harvesting by 1908 (Ross 1971), seals started to haul out on the northern shoreline of the Robberg Peninsula in about 1993. Numbers subsequently increased (Stewardson 2001) and a few newborn pups were first observed in 1996/97 (M Brett, Western Cape Nature Conservation, pers. comm.). This led to speculation that the colony could eventually fulfil the function of a breeding colony (Stewardson 1999, Kirkman 2010). Since a breeding colony did previously exist in Plettenberg Bay it is likely that the foraging in the area was good and that new colonies may establish in the same area. Furthermore the rocky northern shore of Robberg has little human disturbance, potentially providing suitable habitat for seals to establish and/or disperse to from other areas. The *c.* 400 km stretch of coastline between Seal Island in Mossel Bay and Black Rocks in Algoa Bay, the only breeding colonies to the east of Cape Agulhas (Figure. 1.1), is by far the longest stretch of coastline within the current breeding range of Cape fur seals that was devoid of a seal colony (Kirkman 2010). Apart from other the islands in Algoa Bay that are currently uninhabited by seals, no other islands occur along this 400 km stretch of coastline (Kirkman 2010).

2.3 References

Best PB, Shaughnessy PD. 1979. An independent account of Captain Benjamin Morrell's sealing voyage to the south-west coast of Africa in the Antarctic, 1928/29. *Fisheries Bulletin of South Africa* 12: 1-19.

Beckley LE, van Ballegooyen RC. 1992. Oceanographic conditions during three ichthyoplankton surveys of the Agulhas current in 1990/91. *South African Journal of Marine Science* 12: 83-93.

Butterworth DS, Punt AE, Oosthuizen WH, Wickens PA. 1995. The effects of future consumption by the Cape fur seal on catches and catch rates of the Cape hakes. 3. Modelling the dynamics of the Cape fur seal *Arctocephalus pusillus pusillus. South African Journal of Maritime Science* 16: 161-183.

David JHM, van Sittert L. 2008. A reconstruction of the Cape (South African) fur seal harvest 1653-1899 and a comparison with the 20th century harvest. *South African Journal of Science* 104: 107-110.

Duvenage IR, Morant PD. 1984. CSIR Research report. Estuaries of the Cape. Part 2. Synopsis of available information on individual systems. Report Number 31. Keurbooms System (CMS 19). Piesang (CMS 18). Stellenbosch.

Hanekom N, Hutchings L, Joubert PA, van der Byl PCN. 1989. Sea temperature variations in the Tsitsikamma Coastal National Park, South Africa, with notes on the effect of cold conditions on some fish populations. *South African Journal of Marine Science* 8: 145-153.

Kirkman SP. 2010. The Cape fur seal: monitoring and management in the Benguela Current Ecosystem. PhD thesis. Animal Demography Unit, Department of Zoology, University of Cape Town, South Africa.

Lutjeharms JRE, Ansorge IJ. 2001. The Agulhas return current. *Journal of Marine Systems* 30: 115-138.

Makhado AB, Crawford RJM, Underhill LG. 2006. Impact of predation by Cape fur seals *Arctocephalus pusillus pusillus* on Cape gannets *Morus capensis* at Malgas Island, Western Cape, South Africa. *African Journal of Marine Science* 28: 681-687.

Metelerkamp S. 1955. *George Rex of Knysna*. Cape Town, Timmins pp 308.

Punt AE, Butterworth DS. 1995. The effects of future consumption by the Cape fur seal on catches and catch rates of Cape Hakes. 4. Modelling the biological interaction between cape fur seals *Arctocephalus pusillus pusillus* and the Cape Hakes, *Merluccius capensis* and *M. paradoxus*. *South African Journal of Maritime Science* 16: 255-285.

Punt AE, David JHM, Leslie RW. 1995. The effects of future consumption by the Cape fur seal on catches and catch rates of the Cape Hakes. 2. Feeding and diet of the Cape fur seal *Arctocephalus pusillus pusillus*. *South African Journal of Maritime Science* 16: 85-99.

Rand RW. 1952. Fur seals: research and management. *Commerce and Industry* 11: 35-40.

Rand RW. 1972. The Cape fur-seal *Arctocephalus pusillus*. 4. Estimates of population size. Investigational Report Sea Fisheries South Africa 89: 1-28.

Rand RW. 1982. Die Kaapse pelsrob *Arctocephalus pusillus*. 4. Ramings van bevolkingsgrootte. Afdeling Seevisserye. Ondersoekverslag. 89: 1-28.

Ross GJB. 1971. Notes on seals and sealing in the Eastern Cape. *The Eastern Cape Naturalist* 44: 6-8.

Schumann EH, Perrins LA, Hunter IT. 1982. Upwelling along the South Coast of the Cape Province, South Africa. *South African Journal of Science* 78: 238-242.

Schumann EH, Ross GJB, Goschen WS. 1988. Cold water events in Algoa Bay and along the Cape south coast, South Africa, in March/April 1987. *South African Journal of Science* 84: 579-584.

Shaughnessy PD. 1982. The status of seals in South Africa and South West Africa. *Mammals of the seas. FAO Fisheries Series* 5: 383-410.

Shaughnessy PD. 1984. Historical population levels of seals and seabirds on islands off southern Africa, with special reference to Seal Island, False Bay. Investigational Report of the Sea Fisheries Research Institute, South Africa 127: 61pp.

Shaughnessy PD, Butterworth DS. 1981. Historical trends in the population size of the Cape fur seal (*Arctocephalus pusillus*). In: Chapman JA Pursley D (eds), *The Worldwide Furbearer Conference Proceedings*. RR Donnelley and Sons Co., Virginia, pp 1305-1327.

Stewardson CL. 1999. The impact of the fur seal industry on the distribution and abundance of Cape fur seals *Arctocephalus pusillus pusillus* on the Eastern Cape coast of South Africa. *Transactions of the Royal Society of South Africa* 54: 217-245.

Stewardson CL. 2001. Biology and conservation of the Cape (South African) fur seal. PhD thesis, Australian National University, Canberra, Australia.

CHAPTER 3. Recolonisation of the Robberg Peninsula by Cape fur seals

Published:

Huisamen J, Kirkman SP, Watson LH, Cockcroft VG, Pistorius PA. 2011. Re-colonisation of the Robberg Peninsula (Plettenberg Bay, South Africa) by Cape fur seals. *African Journal of Marine Science* 33: 453-461.

3.1 Introduction

The Cape fur seal *Arctocephalus pusillus pusillus* is the only resident pinniped on the southern African coastline (Shaughnessy 1985). The current geographical distribution of its breeding population ranges from Algoa Bay in South Africa to Baia dos Tigres in Angola (Kirkman 2010). According to the Oosthuizen and David (1988) definition of a Cape fur seal breeding colony as a location where at least 100 pups per year are born regularly, there are currently 40 breeding colonies in the population (Kirkman 2010). The majority of these are associated with the Benguela Current system located along the west coast of the region, with only two breeding colonies occurring to the east of Cape Agulhas, in the Agulhas Current system (Figure 3.1).

The current geographical distribution of the seal population differs considerably from its historical distribution, as reconstructed from the records or anecdotes of seal hunters and early travellers (e.g. Rand 1972, Shaughnessy 1982, 1984). Historically, at least nine seal colonies occurred to the east of Cape Agulhas, but most of these were hunted to extirpation prior to the 20th century, including at least five colonies in Algoa Bay and another two in Plettenberg Bay (Shaughnessy 1982, Stewardson

1999). In the latter location, seals historically occurred at Beacon Island (which has since been developed and joined to the mainland) and also at Seal Point at Robberg, which forms a Peninsula at the south-western end of the bay. An anecdotal record of an observation from a government official suggests that there were 3 000 seals on Robberg in about 1833 (Ross 1971). During a harvest conducted around this time (the only harvest at this colony for which a record is available) all the seals taken (n = 146) were male (Metelerkamp 1955). For this reason it has been speculated that the colony may have been a non-breeding colony (Metelerkamp 1955, Stewardson 1999), a term for colonies that are typically inhabited by immature or senescent animals, and where few births take place (Oosthuizen and David 1988, de Villiers *et al*. 1997). According to Ross (1971) it is likely that the colony at Robberg was extinct by 1890.

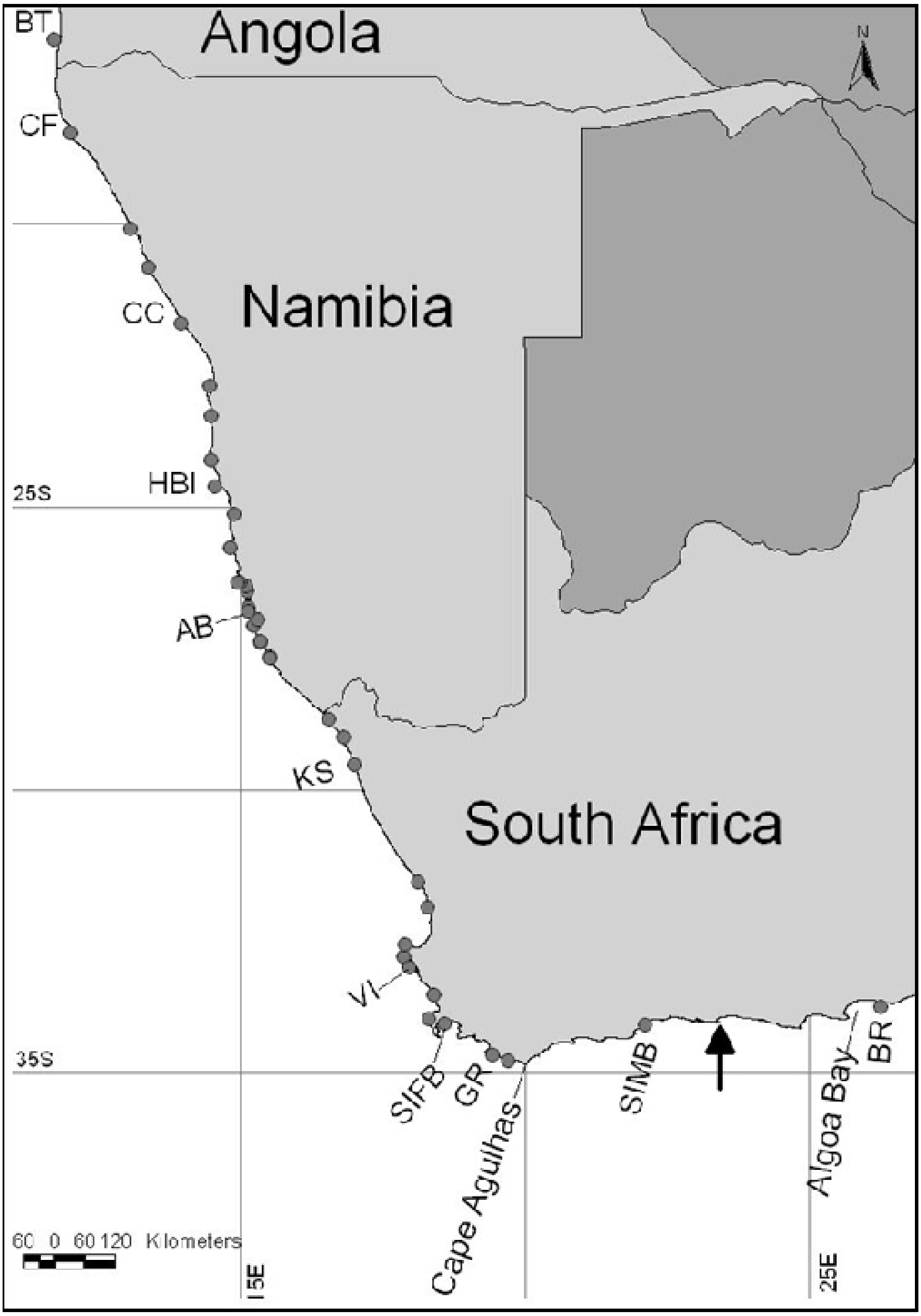

Figure 3.1 Cape fur seal breeding colonies from Black Rocks (BR), Algoa Bay to Baia dos Tigres (BT), southern Angola, with the arrow showing the location of Plettenberg Bay. Selected breeding colonies are indicated including Seal Island in Mossel Bay (SIMB), Geyser Rock (GR), Seal Island in False Bay (SIFB), Vondeling Island (VI), Kleinsee (KS), Atlas Bay (AB), Hollam's Bird Island (HBI), Cape Cross (CC) and Cape Frio (CF).

The Cape fur seal population as a whole was probably at its lowest level around the beginning of the 20th century, when numbers had been reduced to < 100 000 (Shaughnessy and Butterworth 1981). However, following the introduction of protective legislation in 1893 (Best 1973), the population increased during the 20th century, even though it was still subjected to controlled harvests (Wickens *et al.* 1991). Since the commencement of aerial photographic surveys of the population in 1971, considerable increases in the size of the breeding population and its geographical extent have been documented (Butterworth *et al.* 1995, Kirkman *et al.* 2007, Kirkman 2010). These changes predominantly took place on the west coast of southern Africa, where the growth of several mainland colonies accounted for most of the increase in total numbers (Butterworth et al. 1995). The establishment of several new breeding colonies also saw the northernmost extent of the breeding population extend from central Namibia to northern Namibia, and recently to southern Angola. In contrast, the number of extant breeding colonies on the south coast of South Africa, and their population sizes, has remained relatively constant since 1971 (Kirkman 2010). Nevertheless, small numbers of seals returned to the Robberg Peninsula during the 1990s (Stewardson and Brett 2000). Numbers subsequently increased (Stewardson 2001) and a few newborn pups were first observed in 1996/1997 (M Brett, Western Cape Nature Conservation, pers. comm.), leading to speculation that Robberg could eventually become a breeding colony (Stewardson 1999, Kirkman 2010).

The seal colony at Robberg was identified as a monitoring priority by the Robberg management authority (CapeNature), due to the potential for impacts of seals on local fisheries (Wickens *et al*. 1992) and the conservation of certain other marine top predators (Kirkman 2009), as well as the colony's eco-tourism potential. This study is based on intensive monitoring of the size and distribution of the Robberg Cape fur seal colony from 2000 to 2009 and aims to describe the recolonisation process over this period, including between- and within-year temporal patterns in haulout numbers and the extent of breeding. Possible interventions for the conservation management of the colony are discussed.

3.2 Methods

Study site

The Robberg Peninsula is part of the Robberg Nature Reserve (Government Notice No. 1 of 1980) and is adjoined by a Marine Protected Area (MPA), which was established during the late 1990s. The Peninsula forms the south-western extremity of Plettenberg Bay, situated on the south-east coast of South Africa (Figure 3.2). There, the fast-flowing Agulhas Current intermittently causes inshore counter-currents and upwelling of colder water (Lutjeharms and Ansorge 2001) associated with prominent capes (Schumann *et al*. 1982). Rough sea conditions are generally associated with westerly cold fronts in winter (Duvenage and Morant 1984). The climate is mild (average daily maximum air temperature of 24ºC in February and average daily minimum air temperature of 10ºC in August) while rainfall occurs year-round.

Figure 3.2 Google Earth image (http://earth.google.com/) of the Robberg Peninsula showing the extent of the seal colony along the shore-line at the beginning of the study (between A and B) and after 2008 (between C and D). The most easterly extent of the haulout area is currently only 800 m from Seal Point that was historically utilised as a haulout site.

Counting method

Visual counts were conducted from three vantage points on the cliff-tops above the colony. From May 2000 to December 2008 counts were carried out at least monthly (on average every 15 days) except for February 2003 and December 2005 when no counts were conducted due to a lack of manpower. Towards the end of the study period, the colony expanded (Figure 3.2) and it was no longer possible to count all animals from the land-based vantage points. As a result, from February 2009, bi-monthly land-based counts were replaced by boat-based counts conducted every three months at a distance of about 40 m from the high water mark.

Each count was carried out by three observers and the mean was taken to represent the number of seals present in the colony. Only seals present on land were counted, despite the fact that there were often large numbers in the water in close proximity to the haulout sites. Counts were generally carried out between 09:00 and 11:00 (Figure 3.3a). Global Positioning System (GPS) readings to record the extent of the haulout area were taken on 23 June 2000 and again on 13 August 2009. Pups, defined as animals in their first year of life, were distinguished from older animals, based on their small size and the morphometric and colour descriptions of Rand (1956), and were counted separately. No further separation into different age- or sex-classes (e.g. sub-adults or adults, males or females) was made. As from February 2009, counts of pups were not possible because their small size and the oblique angle of the boat-based observations made detecting them difficult.

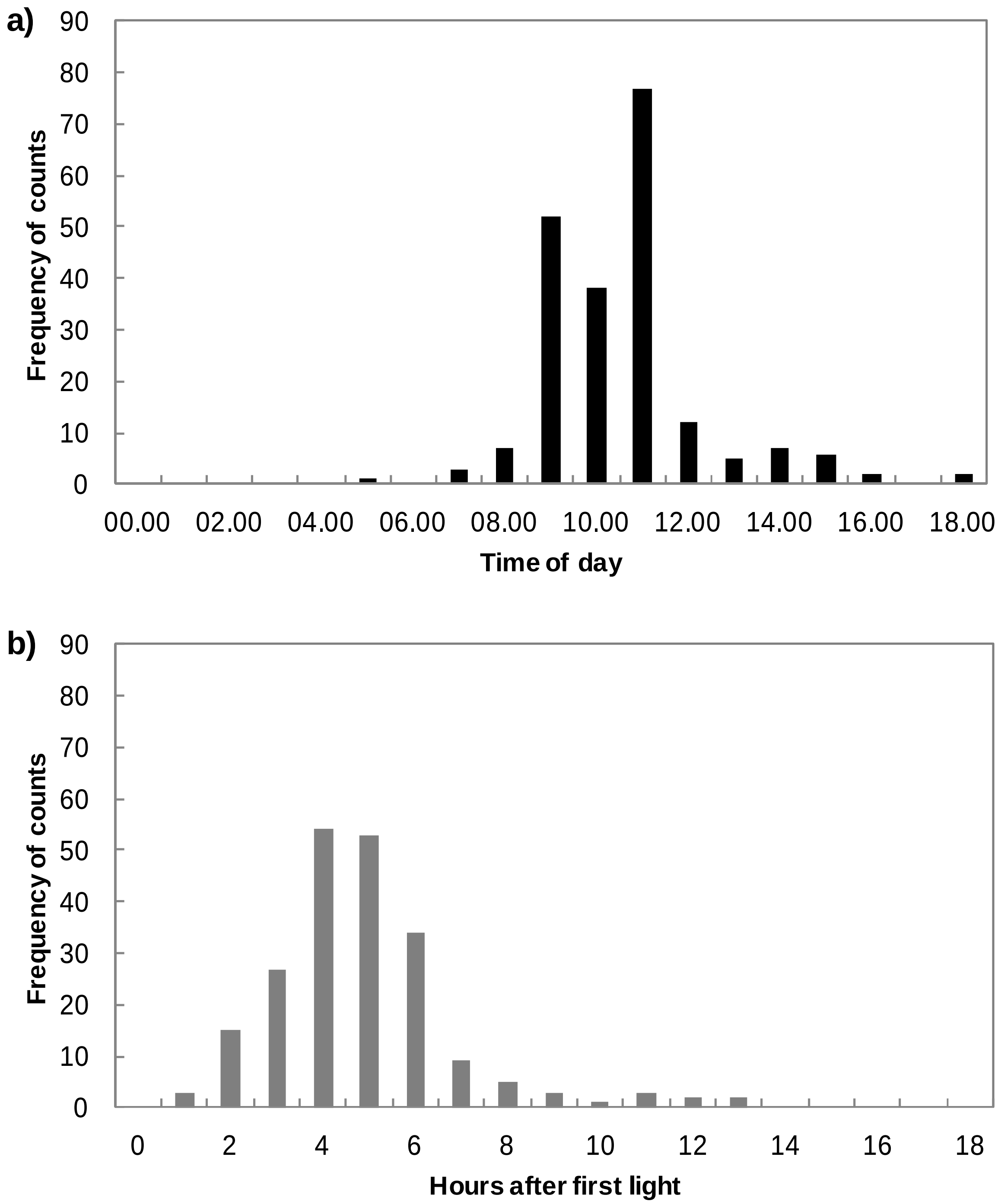

Figure 3.3 Frequency of seal counts carried out at (a) different times of day and (b) times of day converted to number of hours after first light.

Data analysis

Analyses were conducted using Generalised Linear Models (GLMs) in the freely available statistical software package R, version 2.11.0 (R Development Core Team 2009) with the packages 'nlme' (Pinheiro and Bates 2011), 'lmtest' (Hothorn *et al*. 2010) and 'car' (Fox and Weisberg 2011) incorporated. GLMs are an extension of standard linear models in that they allow the response data to follow a distribution from the 'exponential family', which includes normal, binomial, gamma and Poisson distributions. The Poisson distribution, which assumes that the variance is equal to the mean, is often used when modelling count data (McCullagh and Nelder 1989), and such models have frequently been used to estimate the trend and abundance of seal populations (e.g. Frost *et al*. 1999, Small *et al*. 2003, Mathews *et al*. 2011). Therefore, a GLM with a Poisson distribution and a log link function was initially used to describe the relationship between seal numbers at Robberg and several explanatory variables, with the counts as the response variable. Only the land-based count data (2000-2008) were considered in the GLM.

Counts subsequent to 2008 were not included in this analysis to avoid potential bias associated with using different count techniques.The following explanatory variables were considered for inclusion in the model: (1) year; (2) month; (3) time of day (Figure 3.3a) converted to number of hours after first light (Figure 3.3b) to account for variation among seasons; (4) wave height; (5) air temperature; (6) sea surface temperature (SST); and (7) lunar phase. Lunar phase was described using two categories, the bright moon (from first quarter to last quarter) and dark moon (from last quarter to first quarter).

A series of models were run either with year as a continuous or a categorical variable and with time of year represented by one of the following: (a) the four seasons as a categorical variable; (b) the twelve months as a categorical variable; (c) month as a continuous variable; and (d) month transformed to trigonometric functions using a Fourier transformation, so that the variable was independent of year-end and the last month of the year was continuous with the first month of the next year (Underhill *et al*. 1992). Akaike's Information Criterion (AIC) was used to choose the most parsimonious model under the various alternatives for year and time of year. On this basis, year and month were finally included in the model as categorical variables along with variables 3-7. The only interaction term that was considered was year-month.

We examined whether the assumption of equivalence between the variance and the mean held true by specifying a quasipoisson distribution as the error structure in the model. The resulting dispersion parameter was considerably greater than one (ρ = 120). This indicated that the errors were overdispersed and not consistent with the assumption of a Poisson distribution. Therefore a quasipoisson distribution, which assumes that the variance is proportional rather than equal to the mean to account for the overdispersion in model residuals, was specified (Hardin and Hilbe 2003, Faraway 2006).

Comparing AIC scores is not a valid way of choosing between quasipoisson GLMs. Instead automated, backwards stepwise deletion of variables was carried out based on ρ-values of the analysis of variance (ANOVA) tests with the significance level set at 0.05. This was done to eliminate explanatory variables that did not significantly influence the response variable, and to determine the most parsimonious final model. A 'pseudo' R^2, an adjusted R^2 measure for overdispersed Poisson models (Heinzl and Mittlböck 2003), was estimated for the model as

$$\frac{(D_N - D_R)}{D_N}$$

where D_N is the null deviance of the model and D_R is the residual deviance.

3.3 Results

From 2000 to 2009, 212 land-based and three boat-based counts of the seal colony were conducted. There was a clear increasing trend in seal numbers over the study period (Figure 3.4a). Following stepwise deletion of explanatory variables from the full model, only year, month and the interaction between these variables were found to significantly influence the response (Table 3.1). Under this formulation of the model, these variables accounted for 75 % of the variation in the land-based seal counts as indicated by the value of the 'pseudo' R^2 (D_N = 56 429, df = 210; D_R = 14 467, df = 109). The model had the following structure in terms of the response variable:

$$y_{ij} = X_i + W_j + X_i W_j + \text{epsilon}_{ij}$$

$$\varepsilon_{ij} \sim \text{qpois}\left(\mu_{ij}, \rho\mu_{ij}\right)$$

where X_i is the value of the i-th year, W_j is the value of the j-th month and ε is the error, which was assumed to have a quasipoisson distribution. μ is the expected mean value of the response under the model, and ρ is the dispersion parameter.

The fact that the interaction between year and month (Table 3.1) was retained in the model as significant reflects the differences in the trend of monthly seal counts between the years. Plots of the within-year counts fitted with linear trend lines (Figure 3.5), indicate that there was greater stability in the within-year counts towards the end of the land-based count series (2006-2008), compared with earlier years. Seal numbers increased significantly over the time-series (Table 3.1), but it is evident that the increase was not consistent over time (Figure 3.6). Using the land-based count data, the model indicated an initial rapid increase in numbers of around 19 % per year (95 % CI = 12-26 %) between

2000 and 2003, followed by a downward fluctuation (-22 %) in 2004, and a further steady increase of approximately 12 % per year since 2006 (7-17 %).

Corresponding with the overall increase in seal numbers, the number of pups counted in the colony also increased from 1 in 2000 to 36 in 2007, according to the land-based counts. In 2005 and 2008, the land-based counts could be compared with aerial census counts conducted by the former Marine and Coastal Management (MCM), Department of Environmental Affairs and Tourism (now Oceans and Coasts, Department of Environmental Affairs). These counts were carried out near the end of the seal breeding season (ca. 20 December) in those years, as part of MCMs region-wide survey of the seal population (Figure 3.4a). The land-based pup counts in these years were 2 and 19 animals, which were lower than the corresponding aerial census counts by 90 % (n = 21) and 63 % (n = 51) respectively.

Between 2000 and 2007, Cape fur seals hauled out along a limited section of the north-facing shore of Robberg (between points A and B in Figure 3.2) and then expanded east and west in 2007 (between C and D in Figure 3.2). Currently, the length of the colony along the shore of the Peninsula is 1.7 km; at its widest it is approximately 30 m from the high-water mark. After changing to boat-based counts from 2009 onwards, the entire length of the colony could be observed. This, together with continued growth of the colony, is likely to have accounted for the relatively high counts of 2009 (Figure 3.4b). Land-based counts carried out subsequently to the longitudinal expansion of the colony, up until the transition to boat-based counts (December 2007-February 2009), are likely to be an underestimate of the numbers of seals in the colony compared with the early years in the study when the entire colony was visible. However, judging from the upward trend over the entire period (Figure 3.6), the effect of this bias on the model predictions is likely to have been negligible.

Table 3.1 Analysis of variance (Type II) results for explanatory variables in the final Generalised Linear Model, following automated backwards stepwise deletion of insignificant variables.

Variable	Sum of squares	df	*F*	*P*
Year	15 595.0	8	16.0	< 0.001
Month	2 994.8	11	2.2	0.018
Year x Month	20 183.8	82	2.0	< 0.001
Residuals	13 321.4	109		

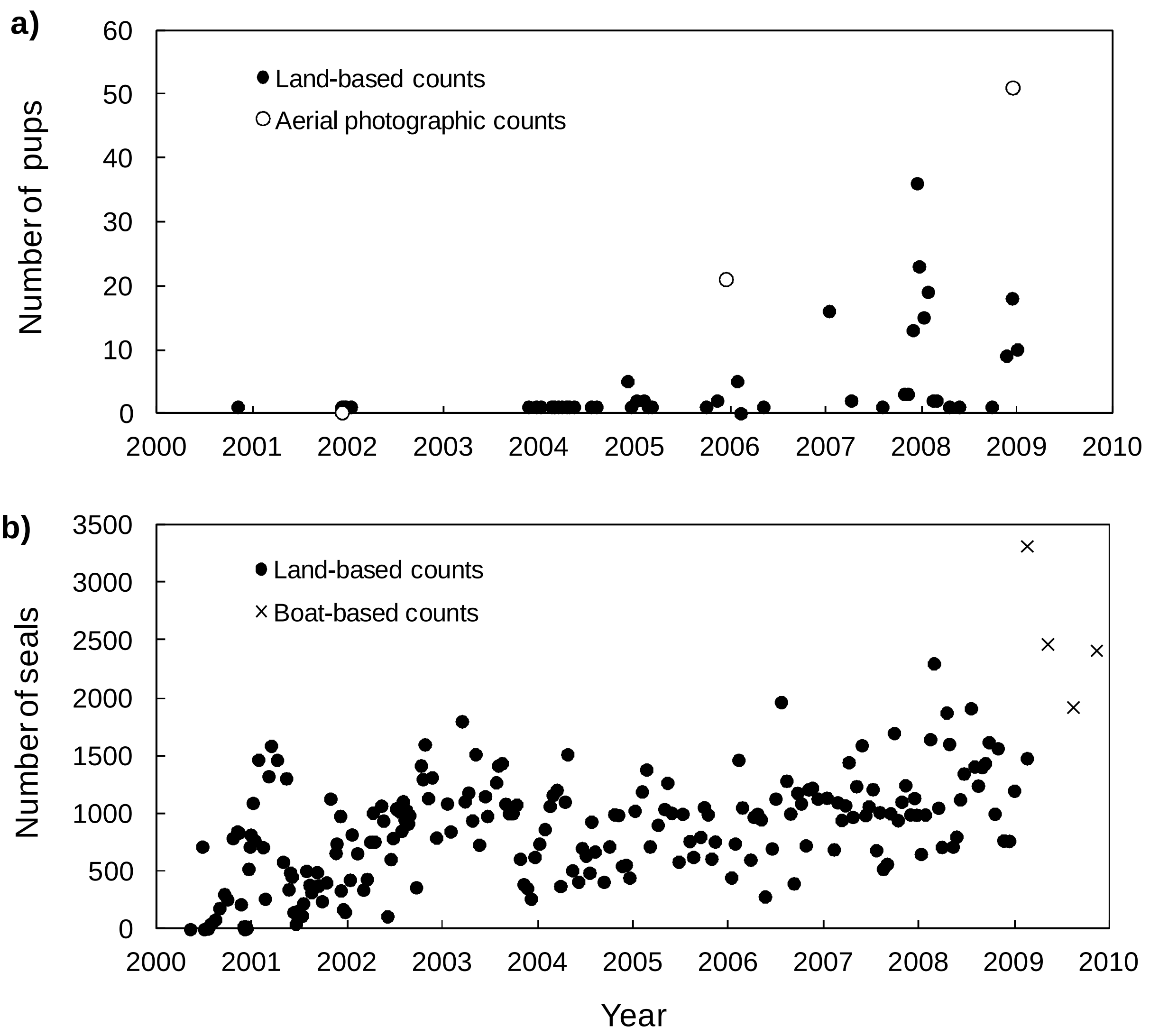

Figure 3.4 Cape fur seal counts at Robberg from 2000 to 2009: (a) seal pups; and (b) seals excluding pups. Solid circles represent land-based counts in both plots, open circles represent aerial photographic pup counts (Oceans and Coasts, unpublished data) in (a) and crosses represent boat-based counts in (b).

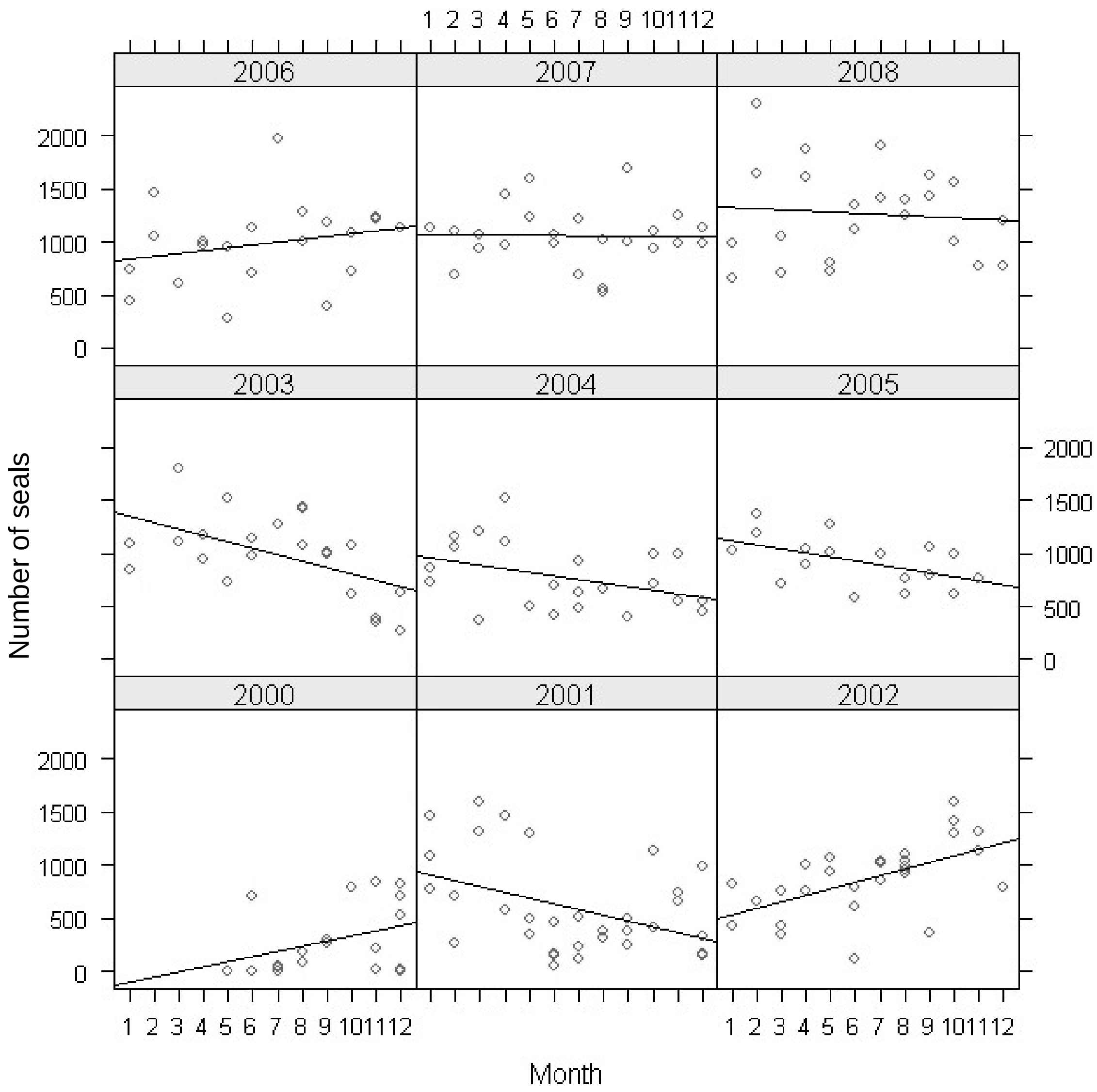

Figure 3.5 Numbers of seals counted throughout each year (months 1-12) from 2000 to 2008 (land-based counts only). Linear trend lines are included to illustrate the different numerical patterns between years.

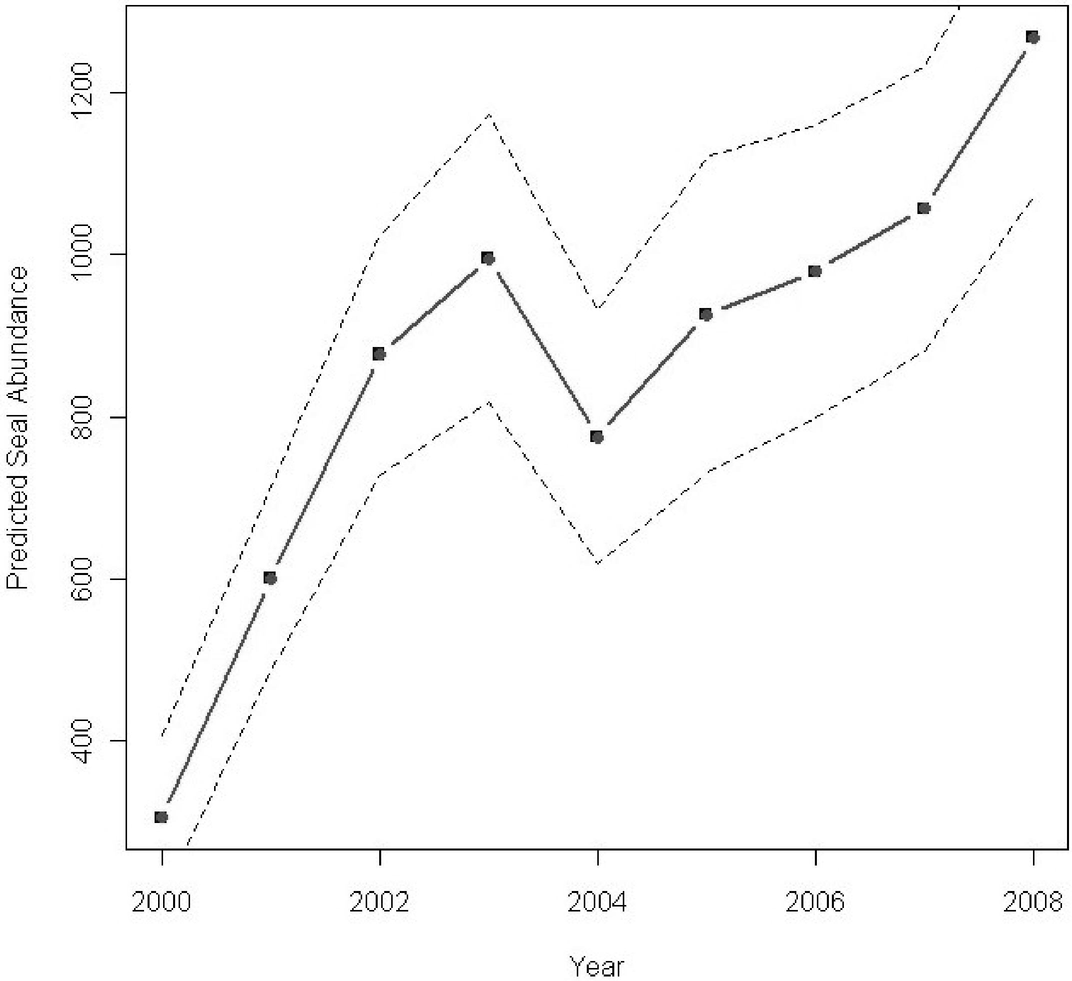

Figure 3.6 Yearly mean numbers of seals at the Robberg seal colony between 2000 and 2008 (land-based counts only) as predicted by the Generalised Linear Model. Dashed lines show 95 % confidence intervals.

3.4 Discussion

This study described the process of recolonisation of the Robberg Peninsula by Cape fur seals between 2000 and 2009, exploring both between- and within-year count data of seals and the extent of breeding at the site. The counts only represent seals on land with an unknown number of animals at sea during these counts. Therefore, the trends that are reported are relative and cannot be used to assess absolute abundance of seals on this colony.

A comparison of the land-based counts of seal pups in the Robberg colony in 2005 and 2008, and the aerial photographic census counts conducted by MCM in these years (Figure 3.4a), suggests that pups are under-represented in land-based counts. The aerial photographic count is expected to be the more accurate because it is easier to count numbers of animals in a photographic snapshot than to count live animals in a seal colony (Kirkman 2007). Moreover, the entire colony would have been covered from a near-vertical angle during the aerial census, whereas during the land-based counts, the areas of the colony farthest from the vantage points were viewed from a relatively oblique angle (approx. 45°). Given their small size after birth, some pups are likely to be hidden from view when performing land-based counts by larger animals or boulders.

Based on the most recent aerial photographic census count, the colony would not be classified as a breeding colony (100 pups or more; Oosthuizen and David (1988). The non-breeding status of the colony is also highlighted by the very small ratio of pups to older animals at the end of the breeding season (1:44 in 2005 and 1:25 in 2008). An approximately even ratio between pups and adults would be expected if the main function of the colony was breeding, as adult females and their new born pups would make up the bulk of the seal numbers at the colony. Considering that reliable counts of pups cannot be obtained during the boat-based counts, which replaced the land-based counts after 2008, aerial censuses of the colony is recommended for future assessment of the breeding status of the colony.

When compared to the final three years of land-based counts, higher within- and between-year variation was evident in seal numbers during the earlier years of the study period, particularly from 2000 to 2003 (Figure 3.5). We postulate that the greater variation during earlier years was symptomatic of the early developmental stages of the colony. In these years, the composition of the colony at any time is likely to have been characterised by transient seals, with numbers possibly dependent on prey availability in the area. Non-breeding seals are not obligated to return to a central place – unlike lactating females – so it might be expected that their numbers would be more sensitive to fluctuations in local prey availability. In this regard, it is possible that the downward trend in seal numbers between 2003 and 2004 may have been caused by local reductions in prey availability. However, as the colony grows, it would be expected that the number of resident seals in the colony would increase in proportion to temporary visitors, therefore stabilising overall numbers. The small number of pups born at the colony together with the relatively high rates of increase in total seal numbers from 2000 to 2004 (19 % per annum) and again after 2004 (12 % per annum) indicate that continuing immigration is primarily responsible for the colony's growth.

Elsewhere, weather or sea conditions (Hofmeyr *et al*. 2006), lunar phase (Trillmich and Mohren 1981), and time of day (Rand 1959, Gentry 1973) have been shown to affect diurnal or day-to-day variation in numbers of fur seals in colonies. The lack of importance accorded to any of these by the GLM in this study may have been due to the temporal resolution of the land-based counts, which were on average 15 days apart (SD = 8.2

days). However, the broad-scale temporal trends of the colony were well explained by year and month (75 % of variability).

Results of region-wide (South Africa, Namibia and Angola) monitoring of the seal population using aerial photographic surveys since the 1970s has brought to light considerable changes in the distribution and abundance of the wider population (Kirkman 2010). This includes the development of 17 new breeding colonies, all on the west coast of southern Africa. These changes have been linked to the effects of environmental changes on prey availability but also to the lack of human interference on the coastlines of these areas, due to inaccessibility or restrictions on access (e.g. diamond mining areas, national parks), that could otherwise prevent the successful establishment of seal colonies. In comparison, the number of seals and seal colonies on the south coast of South Africa (between Cape Town and Port Elizabeth) has remained stable until now. The colony at Robberg is the first new colony to develop on the south coast since the 1970s. Until the establishment of this colony, the *ca.* 400 km stretch of coastline between Seal Island near Mossel Bay and Black Rocks in Algoa Bay (Figure 3.1) was by far the longest stretch of coastline within the current breeding range of Cape fur seals that was devoid of a seal colony (Kirkman 2010).

Development of non-breeding colonies and their transition to breeding colonies have been shown to be a characteristic of the 'recolonisation' phase (Roux 1987) in otariid populations recovering from past over-exploitation (e.g. Oosthuizen and David 1988, Bradshaw *et al*. 2000, Grandi *et al*. 2008). The establishment has been attributed to saturation of space-at-source breeding colonies (e.g. Bradshaw *et al*. 2000, Grandi *et al*. 2008), but another possible cause includes the convenience of haulout sites with respect to feeding grounds. In the case of Robberg, the well-documented shift in the geographical distribution of certain prey resources such as sardine and anchovy from the west towards the east Agulhas Bank (i.e. east of Cape Agulhas) (e.g. van der Lingen *et al*. 2006) may have increased the availability of prey in the Robberg area and influenced the influx of seals. Southward and eastward shifts in the geographical distribution of some other top predator species (e.g. Cape gannet *Morus capensis*, swift tern *Sterna bergii* and Cape cormorant *Phalacrocorax capensis*) along South Africa's coastline have been associated with these changes (Crawford *et al*. 2008a, 2008b).

Fur seals are gregarious and require groups of conspecific animals for breeding (David 1989, Gentry 1998). Once there is a nucleus of breeding animals at a colony, the size of the colony may grow rapidly, surpassing the maximum intrinsic rate of increase (approximately 17 %, Payne 1977) if the site becomes a focal point for dispersal for breeding age animals from other crowded colonies. An example of a colony that has shown this kind of rapid increase is Vondeling Island (Figure 3.1), a former guano island on the west coast of South Africa that has been recolonised by seals since 2000, at a growth rate of more than 100 % per annum (Kirkman 2010). However, the area of the Robberg Peninsula that is currently inhabited by seals (Figure 3.2) may not be ideally suited for the development of a breeding colony. There is limited space between cliffs and the sea (±30 m at most) as well as limited suitable access points within the current extent of the haulout area where seals can move safely between the sea and land. This would most likely limit the number of territories that can be established there by breeding males, because the prime territories would be established at the access points and movement to other areas behind the prime territories would be difficult due to territorial aggression.

According to historical records (Metelerkamp 1955), seals previously occurred at the rocky shelf at the point of Robberg Peninsula, some 800 m to the east of the current colony, which was duly named Seal Point (Figure 3.2). To date, seals have not recolonised this location, which is more accessible and more spacious than the current colony and appears to be more suitable for breeding. A popular hiking trail traverses this area and it is also a popular recreational fishing area. Therefore human disturbance associated with these activities may until now have affected the choice of habitat by seals on the Peninsula – the current location of the colony is inaccessible to tourists and fishers. Such disturbance is likely to be largely incidental, but in the case of fishers it may also be deliberate, considering the potential for increasing conflict between seals and fishers in the area (JH, unpublished data) because many fishers perceive seals to be competitors (Meÿer *et al*. 1992, Wickens *et al*. 1992). Management interventions that may encourage recolonisation of the point area and further growth of the colony could therefore include re-routing of the hiking trail and declaring the area at the point a no-take area for fishers. The latter is realistic in terms of the zoning policy for MPAs, though it is likely to be met with resistance by fishers whom generally laid the blame for declining linefish catches in the vicinity of Plettenberg Bay area on the increase of seals (King 2005, Smith 2005).

With or without human intervention, the continued growth of the Cape fur seal colony at Robberg Peninsula seems likely, based on the population trajectory over the past decade. This will have repercussions at various levels, ranging from the conservation status of the species in the region through to the socio-economic implications, with ecotourism benefits on the one hand and perceived competition with fisheries on the other. In terms of competition with fisheries, it is important that the degree of overlap between the diet of Cape fur seals at the Robberg colony and fish stocks targeted, both recreationally and commercially, is assessed to ensure the availability of robust data when decisions regarding the management and conservation of this colony need to be made.

3.5 Acknowledgements

We thank the Robberg Nature Reserve staff and volunteers from the Centre for Dolphin Studies for assisting with data collection. Unpublished data were made available by the South African Weather Service (weather data), Council for Scientific and Industrial Research (wave height data), South African National Parks (sea surface temperature) and Department of Environmental Affairs, branch Oceans and Coasts (pup count data and sea surface temperature). Fairfield Group is thanked for funding. We are grateful to Theoni Photopoulou and Ryan Reisinger for constructive comments on an earlier version of the paper.

3.6 References

Best PB. 1973. Seals and sealing in South and South West Africa. *The South African Shipping News and Fishing Industry Review*. 28: 49-57.

Bradshaw CJA, Lalas C, Thompson CM. 2000. Clustering of colonies in an expanding population of New Zealand fur seals (*Arctocephalus forsteri*). *Journal of Zoology, London* 250: 105-112.

Butterworth DS, Punt AE, Oosthuizen WH, Wickens PA. 1995. The effects of future consumption by the Cape fur seal on catches and catch rates of the Cape hakes. 3. Modelling the dynamics of the Cape fur seal *Arctocephalus pusillus pusillus*. *South African Journal of Marine Science* 16: 161-183.

Crawford RJM, Sabarros PS, Fairweather T, Underhill LG, Wolfaardt AC. 2008a. Implications for seabirds off South Africa of a long-term change in the distribution of sardine. *African Journal of Marine Science* 30: 177-184.

Crawford RJM, Tree AJ, Whittington PA, Visagie J, Upfold L, Roxburg KJ, Martin AP, Dyer BM. 2008b. Recent distributional changes of seabirds in South Africa: is climate having an impact? *African Journal of Marine Science* 30: 189-193.

David JHM. 1989. Seals. In: Payne AIL, Crawford RJM (eds), *Oceans of life*. Cape Town: Vlaeberg Publishers. pp 288-302.

De Villiers DJ, Oosthuizen WH, Roux J-P, Kotze PGH. 1997. Population structure of a non-breeding colony of the Cape fur seal *Arctocephalus pusillus pusillus* at Cape Frio, Namibia. *South African Journal of Marine Science* 18: 295-298.

Duvenage IR, Morant PD. 1984. CSIR Research report. Estuaries of the Cape. Part 2. Synopsis of available information on individual systems. Report Number 31. Keurbooms System (CMS 19). Piesang (CMS 18). Stellenbosch.

Faraway RJJ. 2006. Extending the Linear Model. Taylor and Francis, New York. 302 pp.

Fox J, Weisberg S. 2011. Car: companion to applied regression. R package version 2.0-10. URL: http://CRAN.R-project.org/package = car [accessed on 20 April 2011].

Frost KJ, Lowry LF, Ver Hoef JM. 1999. Monitoring the trend of harbour seals in Prince William Sound, Alaska, after the Exxon Valdez oil spill. *Marine Mammal Science* 15: 494-506.

Gentry RL. 1973. Thermoregulatory behaviour of eared seals. *Behaviour* 46: 73-93.

Gentry R. 1998. *Behaviour and ecology of the northern fur seal*. Princeton: Princeton University Press.

Grandi MF, Dans SL, Crespo EA. 2008. Social composition and spatial distribution of colonies in an expanding population of South American sea lions. *Journal of Mammalogy* 89: 1218-1228.

Hardin JW, Hilbe JM. 2003. *Generalized Estimating Equations*. Chapman and Hall/CRC. New York. 222 pp.

Heinzl H, Mittlböck M. 2003. Pseudo R-squared measures for Poisson regression models with over- or underdispersion. *Computational Statistics and Data Analysis* 44: 253-271.

Hofmeyr GJG, Bester MN, Makhado AB, Pistorius PA. 2006. Population changes in Subantarctic and Antarctic fur seals at Marion Island. *South African Journal of Wildlife Research* 36: 55-68.

Hothorn T, Zeileis A, Millo G, Mitchell D. 2010. lmtest: testing linear regression models. R package version 0.9-27. URL: http://CRAN.R-project.org/ package = lmtest [accessed on 20 April 2011].

King CM. 2005. Towards a new approach for coastal governance with an assessment of the Plettenberg bay shore-based linefishery. MSc thesis, Rhodes University, South Africa.

Kirkman SP. 2007. Recommendations for a regional monitoring programme for Cape fur seals in the BCLME. In: Kirkman SP (ed.), *Final report of the BCLME (Benguela Current Large Marine Ecosystem) Project on top predators as biological indicators of ecosystem change in the BCLME.* Cape Town: Avian Demography Unit, University of Cape Town. pp 367-371.

Kirkman SP. 2009. Evaluating seal-seabird interactions in southern Africa: a critical review. *African Journal of Marine Science* 31: 1-18.

Kirkman SP. 2010. The Cape fur seal: monitoring and management in the Benguela Current Ecosystem. PhD thesis. University of Cape Town, South Africa.

Kirkman SP, Oosthuizen WH, Meÿer MA, Kotze PGH, Roux J-P, Underhill LG. 2007. Making sense of censuses and dealing with missing data: trends in pup counts of Cape fur seal *Arctocephalus pusillus pusillus* for the period 1972-2004. *African Journal of Marine Science* 29: 161-176.

Lutjeharms JRE, Ansorge IJ. 2001. The Agulhas return current. *Journal of Marine Systems* 30: 115-138.

McCullagh P, Nelder JA (eds). 1989. *Generalized linear models*. London, UK: Chapman and Hall.

Mathews EA, Womble JN, Pendleton GW, Jemison LA, Maniscalco JM, Streveler G. 2011. Population growth and colonization of Steller sea lions in the Glacier Bay region of southeastern Alaska: 1970s-2009. *Marine Mammal Science* DOI: 10.1111/j.1748-7692.2010.00455.x

Metelerkamp S (ed.). 1955. *George Rex of Knysna*. Timmins, Cape Town.

Meÿer MA, Kotze PGH, Brill GW. 1992. Consumption of catch and interference with linefishing by South-African (Cape) fur seals *Arctocephalus pusillus pusillus*. In: Payne AIL, Brink KH, Mann KH, Hilborn R (eds), *South African Journal of Marine Science* 12: 835-842.

Oosthuizen WH, David JHM. 1988. Non-breeding colonies of the South African (Cape) fur seal in southern Africa. Investigational Report Sea Fisheries South Africa 132: 1-17.

Payne MR. 1977. Growth of a fur seal population. *Philosophical Transactions of the Royal Society of London, B Biological Sciences* 279: 67-79.

Pinheiro J, Bates D. 2011. nlme: linear and nonlinear mixed effects models. R package version 3.1-100. URL: http://CRAN.R-project.org/package = nlme [accessed on 20 April 2011]

R Development Core Team. 2009. R: A language and environment for statistical computing. R. Foundation for Statistical Computing. Vienna, Austria. ISBN 3-900051-07-0. URL: http://www.R-project.org [accessed on 15 December 2009].

Rand RW. 1956. The Cape fur seal *Arctocephalus pusillus* (Schreber). Its general characteristics and moult. Investigational Report, Division of Sea Fisheries, South Africa 21: 1-52.

Rand RW. 1959. The Cape fur seal (*Arctocephalus pusillus pusillus*). Distribution, abundance and feeding habits off the southwestern coast of the Cape Province. Investigational Report Sea Fisheries, South Africa 34: 1-75.

Rand RW. 1972. The Cape fur seal *Arctocephalus pusillus*. 4. Estimates of population size. Investigational Report, Division of Sea Fisheries, South Africa 89: 1-28.

Ross GJB. 1971. Notes on seals and sealing in the Eastern Cape. *The Eastern Cape Naturalist* 44: 6-8.

Roux J-P. 1987. Recolonisation processes in the Subantarctic fur seal, *Arctocephalus tropicalis*, on Amsterdam Island. In: Croxall JP, Gentry RL (eds), *Status, biology, and ecology of fur seals*: proceedings of an international symposium and workshop, Cambridge, England, 23-27 April 1984. NOAA Technical Report NMFS 51, Seattle, Washington. pp 189-194.

Schumann EH, Perrins LA, Hunter IT. 1982. Upwelling along the South Coast of the Cape Province, South Africa. *South African Journal of Science* 78: 238-242.

Shaughnessy PD. 1982. The status of seals in South Africa and South West Africa. *Mammals of the seas*. *FAO Fisheries Series* 5: 383-410.

Shaughnessy PD. 1984. Historical population levels of seals and seabirds on islands off southern Africa, with special reference to Seal Island, False Bay. Investigational Report of the Sea Fisheries Research Institute, South Africa 127.

Shaughnessy PD. 1985. Interactions between fisheries and Cape fur seals in southern Africa. In: Beddington JR, Beverton RJH, Lavigne DM (eds), *Marine mammals and fisheries*. London: George Allen and Unwin.

Shaughnessy PD, Butterworth DS. 1981. Historical trends in the population size of the Cape fur seal (*Arctocephalus pusillus*). In: Chapman JA, Pursley D (eds), *The worldwide furbearer conference proceedings*. Virginia: RR Donnelley and Sons Co. pp 1305-1327.

Small RJ, Pendleton GW, Pitcher KW. 2003. Trends in abundance of Alaska harbor seals, 1983-2002. *Marine Mammal Science* 19: 344-362.

Smith MKS. 2005. Towards a new approach for coastal governance with an assessment of the Plettenberg Bay nearshore linefisheries. MSc thesis Rhodes University, South Africa.

Stewardson CL. 1999. The impact of the fur seal industry on the distribution and abundance of Cape fur seals *Arctocephalus pusillus pusillus* on the Eastern Cape coast of South Africa. *Transactions of the Royal Society of South Africa* 54: 217-245.

Stewardson CL. 2001. Biology and conservation of the Cape (South African) fur seal. PhD thesis, Australian National University, Canberra, Australia.

Stewardson CL, Brett M. 2000. Aggressive behaviour of an adult male Cape fur seal (*Arctocephalus pusillus pusillus*) towards a great white shark (*Carcharodon carcharias*). *African Zoology* 35: 147-150.

Trillmich F, Mohren W. 1981. Effects of the lunar cycle on the Galapagos fur seal, *Arctocephalus galapagoensis*. *Oecologia* 48: 85-92.

Underhill LG, Prys-Jones RP, Harrison JA, Martinez P.1992. Seasonal patterns of occurrence of Palaearctic migrants in southern Africa using atlas data. *Ibis* 134: 99-108.

van der Lingen CD, Shannon LJ, Cury P, Kreiner A, Moloney CL, Roux J-P, Vaz-Velho F. 2006. Resource and ecosystem variability, including regime shifts, in the Benguela Current System. In: Shannon V, Hempel G, Malanotte-Rizzoli P, Moloney CL, Woods J (eds), *Benguela: predicting a Large Marine Ecosystem*. Amsterdam: Elsevier.

Wickens PA, David JHM, Shelton PA, Field JG. 1991. Trends in harvests and pup numbers of the South African fur seal: implications for management. *South African Journal of Marine Science* 11: 307-326.

Wickens PA, Japp DW, Shelton PA, Kriel F, Goosen PC, Rose B, Augustyn CJ, Bross CAR, Penney AJ, Krohn RG. 1992. Seals and fisheries in South Africa – competition and conflict. In: Payne AIL, Brink KH, Mann KH, Hilborn R (eds), *Benguela trophic functioning. South African Journal of Marine Science* 12: 773-789.

CHAPTER 4. Diet of the Cape fur seal in Plettenberg Bay and the implications for the local fisheries

In press:

Huisamen J, Kirkman SP, Watson LH, Cockcroft VG, Jewell R, Pistorius PA, van der Lingen CD. 2012. Diet of the Cape fur seal *Arctocephalus pusillus pusillus* in Plettenberg Bay, South Africa, and the implications for the local fisheries. *African Journal of Marine Science*

4.1 Introduction

The Cape fur seal *Arctocephalus pusillus pusillus* is the only pinniped resident on the southern African coastline (Shaughnessy 1985). Its current distribution ranges from Baia dos Tigres in Angola to Algoa Bay in South Africa (Figure 3.1) and includes 40 breeding colonies (Kirkman 2010), defined as locations where at least 100 pups per year are born regularly (Oosthuizen and David 1988). Geographically, only two of these colonies, Seal Island (Mossel Bay) and Black Rocks (Algoa Bay), occur to the east of Cape Agulhas, the southern tip of Africa (Figure 3.1). Between the 17th and early 20th century, seven colonies in this part of their range were hunted to extirpation (Rand 1972, Stewardson 1999). Historically, there were five colonies in Algoa Bay and two in Plettenberg Bay. The colonies at Plettenberg Bay occurred on Beacon Island, which has subsequently been developed and is now joined to the mainland, and on the Robberg Peninsula, which currently forms part of the Robberg Nature Reserve and Marine Protected Area (Marine Living Resources Act No. 18 of 1998). In the early 1990s, seals returned to the Robberg Peninsula in small numbers (Stewardson 2001). The seal colony subsequently grew to over 3 000 largely non-breeding individuals in 2009, with numbers increasing at approximately 12 % per annum in recent years (since 2006).

Plettenberg Bay, including Robberg Peninsula, is recognised for its shore-angling potential (King 2005). Several commercial fisheries also recently operated in the area, including a hand line fishery for shallow-water hake *Merluccius capensis* (hereafter 'hake'), a long line fishery targeting hake and kingklip *Genypterus capensis* and a jigging fishery for chokka *Loligo vulgaris reynaudii*. The return of seals to Robberg was met with concern by the local fishing community, as Cape fur seals may interfere with fisheries, either directly through gear or catch damage or indirectly through resource competition (Wickens *et al*. 1992). Local fisheries attributed a marked decrease in the fish caught in the area from 2003 - 2005 to the impacts of seals (King 2005, Smith 2005) and called for the introduction of a seal culling programme in the area (O. Glennie, Plett Fisheries, pers. comm.). The present study was initially motivated by the need for information on the relationship between seals and local fisheries. For such an assessment, data on fish prey species, their size and the quantity that are consumed by the seals are required (Murie 1986). However, knowledge of what the seals eat is also key to an understanding of their role in the ecosystem, while changes in diet over time can provide a useful indication of environmental variability (Boyd *et al*. 2010).

The diet of Cape fur seals along the south-eastern coast of South Africa (east of Cape Agulhas) has been relatively poorly studied. This is partly due to the fact that relatively few seals were encountered in this area during past pelagic surveys during which seals were shot at sea and sampled for diet (David 1987). The present study is based on the sampling of scats from the seal colony over a period of six years (March 2003 to December 2008). The retrieval of hard prey remains (otoliths, cephalopod beaks, feathers etc.) from scats (or from gastrointestinal contents or regurgitates) of seals can provide information on the species, size and quantity of prey consumed (de Bruyn *et al.* 2003, Mecenero *et al.* 2006).

Scats have previously been used to describe the diet of seals at Robberg in 1993-1995 (Stewardson 2001), but subsequently there have been changes both in the availability of prey stocks (van der Lingen *et al.* 2006) and in the size of the seal colony. This study addresses the following objectives: (1) to determine the species composition and size of prey in the diet of Cape fur seals at Robberg; (2) to explore inter-annual and seasonal variation in the diet; and (3) to investigate the potential for competition between seals and the fisheries around Plettenberg Bay.

4.2 Methods

Study area

The study site is situated on the Robberg Peninsula, which forms the south-western extreme of Plettenberg Bay, on the south-east coast of South Africa (Figure 3.1). The continental shelf is approximately 110 km wide here and forms part of the Agulhas Bank, where oceanographic conditions increase biological productivity (Lutjeharms 2007). The fast-flowing Agulhas Current intermittently causes inshore counter-currents, warm plumes and upwelling of colder water (Lutjeharms and Ansorge 2001, Lutjeharms 2007). Upwelling events, associated with prominent capes such as Robberg, occur from December to May on the south-east coast of South Africa (Schumann *et al*. 1982). Hereafter this period will be referred to as the ‘upwelling season’ and the rest of the year as the ‘non-upwelling season’.

Collection and processing of scat samples

Scat samples were collected at the Robberg colony during 60 of the 70 months between March 2003 and December 2008, and an average of 6 samples were collected per month (Appendix 4.1). Sampling effort was reduced during the breeding season (November to January) to minimise disturbance. Sampling generally occurred between 09h00 and

11h00, and each scat sample was stored individually until it could be processed. Hard prey remains were extracted by washing each scat through a 0.5 mm mesh sieve. Otoliths were identified to the lowest possible taxonomic group using Smale *et al*. (1995) while specialists assisted with the identification of cephalopod beaks and bird feathers.

For each scat sample, the minimum number of individuals of each prey species was calculated. Otoliths were recorded as being left- or right-sided and the side with the highest number was taken to represent the minimum number of individuals consumed. Similarly, cephalopod beaks were identified as upper or lower beaks (Clarke 1962) and the highest number was taken to represent the minimum number of individuals (Clarke 1986, Smale *et al*. 1993). Otoliths were measured across their greatest diameter to the nearest 0.1 mm using a dissection microscope fitted with an eyepiece micrometer. No size measurements were taken of other types of prey parts, including cephalopod beaks and bird feathers, as these were found in very low numbers.

Despite being the structure most resistant to digestion in teleost fish (Treacy 1981) otoliths are still eroded during digestion (Jobling and Breiby 1986). Modal otolith reductions of 10-30 % have been reported from captive feeding trials of pinnipeds (Harvey 1989, Tollit *et al*. 1997). Uncorrected, this would result in underestimates of reconstituted prey sizes (Smale *et al.* 1995). Therefore each otolith was visually assessed for signs of erosion and assigned to one of four erosion categories: (1) minimal or no sign of erosion; (2) medial relief and margins of the otolith smoothed by erosion; (3) heavily eroded but still identifiable, with partial or complete loss of medial relief and margin sculpturing; and (4) eroded to the degree of being unidentifiable with complete loss of characteristic medial and marginal features. Erosion correction factors of 0, 10 and 30 % were applied to otoliths in groups 1, 2 and 3 respectively (*cf*. Reid 1995), while category 4 otoliths were excluded from the analysis. Reconstituted mass and total length of teleost prey items were calculated from established size relationships (Smale *et al.* 1995).

Dietary analysis

Three diet descriptors were used to explore dietary composition, namely: (1) the proportional numerical abundance (*NA*) calculated as the percentage of the total number of prey individuals represented by each prey species; (2) the proportional frequency of occurrence (*FO*) calculated as the percentage of scat samples that contained a given species; and (3) the proportional mass (*M*) of each prey species calculated as the percentage of the summed reconstituted mass of all prey individuals. Calculation of *M* was confined to teleost prey.

For analyses of annual and seasonal changes in the above diet descriptors, samples were pooled per month for each of the 60 months within which samples were collected. The five most important prey species (determined for the entire study period) were considered individually while the remaining teleost species were pooled. Exploratory analysis of variation in diet composition between years and between seasons (upwelling vs non-upwelling) was conducted using Principal Components Analysis (PCA) (Figure 4.1). Further analyses were performed using non-parametric tests because the data were not normally distributed. These included Kruskal-Wallis and Mann-Whitney U tests to test for significant variation in diet between years and between seasons, respectively. Spearman rank correlation analysis was used to further explore directional trends in the relative importance of prey species' from 2003 to 2008, or (in the case of sardine and anchovy only) in relation to estimated acoustic biomass of these species using data of Coetzee *et al*. (2008). All statistical procedures were performed using the statistical software programme Statgraphics Centurion XV (Statpoint, Herndon).

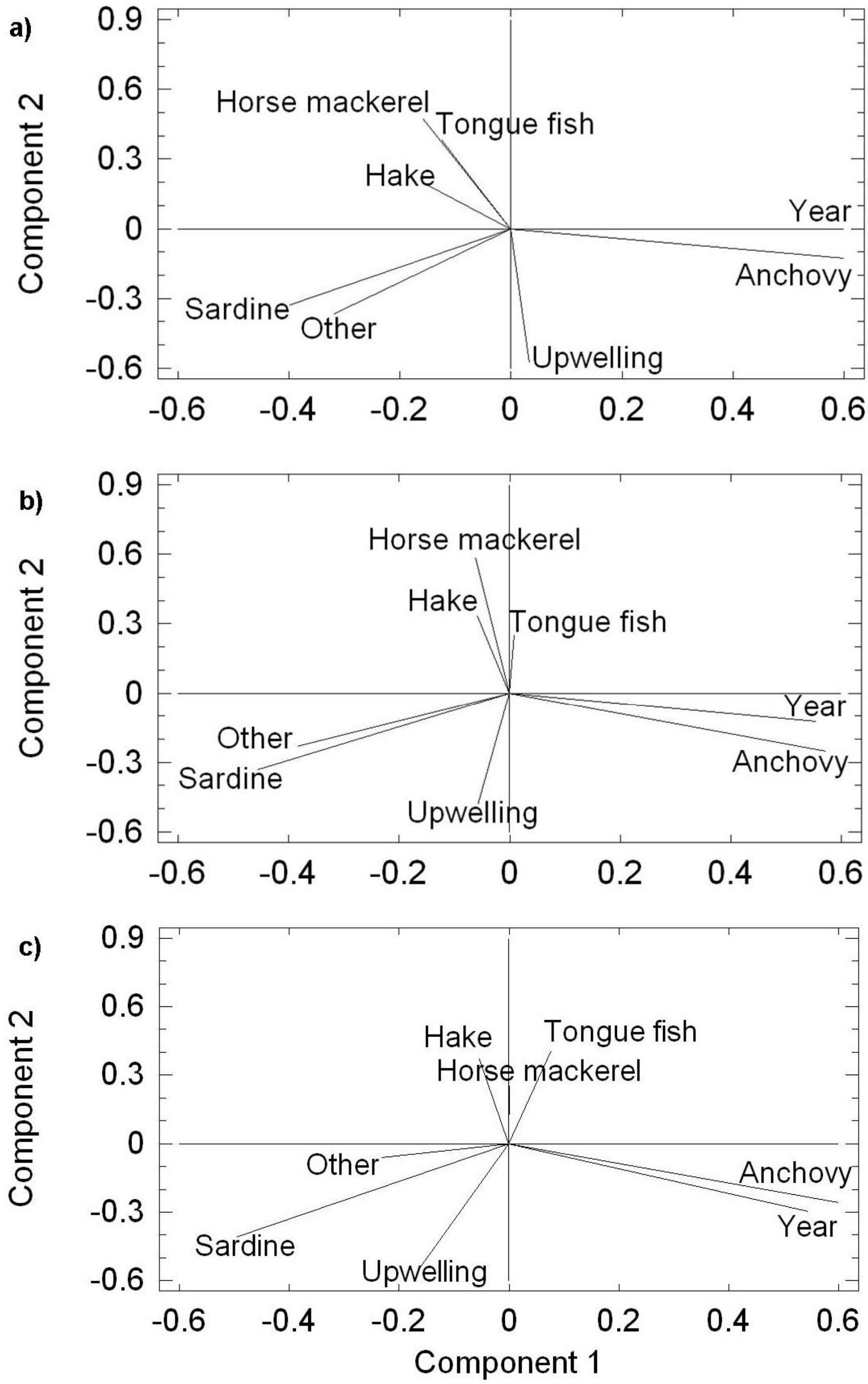

Figure 4.1 Principal components analysis of Cape fur seal diet composition at Robberg Peninsula, Plettenberg Bay from 2003 to 2008 based on scat analysis and using three alternative descriptors of diet (a) Numerical abundance, (b) Frequency of occurrence and (c) Mass per year and season. The five most important prey species were considered individually while the remaining teleost species (‘Other’) were pooled.

Relationship with prey resources and fisheries

To investigate the potential for competition between seals and fisheries, we compared the estimated seal consumption between March 2003 and February 2004 with the catches of species targeted by various local linefisheries namely: commercial hake and recreational ski-boat and shore-based linefisheries. Commercial hake hand line and recreational ski-boat catch data from vessels operating out of Plettenberg Bay between March 2003 and February 2004 (Smith 2005) were used as well as catch data obtained on the recreational shore-based anglers between September 2003 and August 2004 (King 2005). Although the hake hand line fishery targets the shallow-water hake, incidental by-catch of traditional linefish species does occur and contributes to their total annual teleost catches. We used general estimates of daily food consumption (i.e. 8 % of body weight; David 1987) and body weight (i.e. 50 kg; Shaughnessy 1985) for Cape fur seals, population counts of the Robberg colony, and the proportional contributions of the respective prey species to seal diet determined in this study to estimate the biomass of different prey consumed per year.

4.3 Results

Of the 445 scat samples collected between March 2003 and December 2008, 393 contained identifiable hard prey remains. In total, 385 samples (98.0 %) contained teleost fish remains (i.e. otoliths), 14 samples (3.6 %) contained cephalopod remains, and three samples (0.8 %) contained feathers. A total of 3127 otoliths (comprising 15 teleost prey species), 25 cephalopod beaks (three species) and three bird feathers (two species) were extracted (Table 4.1). Two cephalopod beaks and 138 otoliths were unidentifiable and excluded from the analyses. Together, the three cephalopod species accounted for less than 1 % of the total number of prey consumed. The bird species were identified as African penguin *Spheniscus demersus* and Cape cormorant *Phalacrocorax capensis*. The median number of prey species per scat sample was 1.0 and the range 1-4.

Exploratory data analysis

Two components were extracted (eigenvalue ≥ 1.0) for the PCA model based on each dietary descriptor. These components together accounted for 30 % and 19 %, 29 % and 18 %, and 24 % and 20 % of the variance in the *NA*, *FO* and *M* models, respectively. All three PCAs indicated that Cape anchovy was most prevalent in the diet towards the end of the study period (increasing year number), while South African sardine showed an opposite trend (Figure 4.1). The PCAs based on *FO* and *M* also indicated that sardine became more abundant during the upwelling season, with no seasonal pattern apparent for the other teleost species (Figure 4.1).

Diet composition and trends (teleosts only)

Given the similarity in the temporal patterns between the PCA models of the three diet descriptors, further results from *FO* are not presented. *NA* is presented for comparison with previous studies (Stewardson 2001) and *M* to enable comparison with fisheries catch data (Smith 2005).

The most important teleost prey species in the diet, based on *NA* were anchovy, sardine, Cape horse mackerel *Trachurus trachurus capensis,* and sand tongue-fish *Cynoglossus capensis*; these formed 92.5 % of the diet (Table 4.1). The low mean body mass of anchovy (mean = 10 g) resulted in this species ranking lower than sardine and horse mackerel in terms of *M*. Hake, although not numerically abundant in the diet (1.8 %), contributed substantially to *M* (11.5 %) and, together with the other four most important species, made up 90.2 % of biomass consumed. Small shoaling pelagic fish (sardine, horse mackerel, anchovy and Cape roundherring *Etrumeus whiteheadi*) comprised 65.8 %

of the total mass of prey in the diet. Otoliths of a further nine teleost species were found, although each of these species occurred in ≤1.4 % of the scat samples (Table 4.1).

In terms of *NA*, significant inter-annual differences in the diet were observed in the two most important prey species, anchovy ($H_{5,54} = 30.2$, $p < 0.001$) and sardine ($H_{5,54} = 18.2$, $p < 0.01$, Figure 4.2), while *M* differed significantly among years in anchovy only (Table 4.2). There was an increase during the study period in anchovy consumption in terms of *NA* ($r_s = 0.65$, $p < 0.001$, $n = 60$) and *M* ($r_s = 0.66$, $p < 0.001$, $n = 60$) and a concurrent decrease in sardine consumption in terms of *NA* ($r_s = -0.54$, $p < 0.001$, $n = 60$) and *M* ($r_s = -0.39$, $p < 0.01$, $n = 60$) (Figure 4.2). The decrease in sardine over time was particularly apparent outside of the upwelling season (Figure 4.3).

The decrease in sardine consumption (*M*) by seals over time was correlated with decreases in estimated acoustic biomass per year of this species in South Africa ($r_s = 0.94$, $p = 0.04$, $n = 6$) and the correlation approached significance in terms of survey strata east of Mossel Bay only ($r_s = 0.83$, $p = 0.06$, $n = 6$) during the study period (Figure 4.4a). On the other hand, the increase in anchovy consumption (*M*) by seals during the study period was not correlated with the estimated acoustic biomass per year of this species in South Africa ($r_s = 0.26$, $p = 0.57$, $n = 6$) or for the survey strata east of Mossel Bay ($r_s = 0.14$, $p = 0.75$, $n = 6$) (Figure 4.4b). No significant differences between years were evident in any of the other prey species (Figure 4.2; Table 4.2). Similarly no significant differences were evident between the upwelling and non-upwelling seasons, except for sardine, which contributed a significantly higher percentage of mass to diet of seals during the upwelling season (Table 4.2). No significant differences were observed between seasons in terms of *NA*.

Competition with fisheries

The only species targeted by off-shore commercial linefisheries in and around Plettenberg Bay and detected in the diet of Cape fur seals at Robberg was hake. Carpenter *Argyrozona argyrozona*, which is often caught as by-catch in the hake fishery, was also consumed by seals during the study period. Both these species were also caught by off-shore recreational fisheries (Smith 2005). Hake comprised 12.7 % and carpenter 0.3 % of the dietary weight consumed from March 2003 to February 2004 (period corresponding to that of fisheries data during the study period; Appendix 4.3). For the shore-based linefishery, red tjor-tjor *Pagellus bellotii natalensis* and sand steenbras *Lithognathus mormyrus* overlapped with seal diet (King 2005). Over the entire study period (2003-2008) these species comprised 0.3 % and 0.2 % of seal diet at Robberg respectively, though neither was encountered in the seal diet during the period for which fishery data was available (March 2003 to February 2004; King 2005).

Table 4.1 Prey species of Cape fur seals at Robberg Peninsula from March 2003 to December 2008 and their contributions to the diet, expressed as numerical abundance (*NA*), frequency of occurrence (*FO*) and percentage mass (*M*). Mean for reconstructed length and mass (± standard error) are shown as well as the habitat of each prey species and whether they are locally harvested. *M* could not be calculated for cephalopods and birds as size measurements were not taken.

	Species	Common name	*NA*	*FO*	*M*	Mean Mass (g) ± SE	Mean Length (mm) ± SE	Habitat	Locally harvested
Teleost fish	*Engraulis encrasicolus*	Cape anchovy	55.4	31.2	15.1	10.2 ± 0.1	115.8 ± 0.4	Pelagic	
	Sardinops sagax	South African sardine	16.4	26.9	29.7	66.5 ± 1.4	198.6 ± 1.5	Pelagic	Commercial
	Trachurus trachurus capensis	Cape horse mackerel	10.8	13.1	19.6	73.7 ± 5.0	188.1 ± 3.0	Pelagic	
	Cynoglossus capensis	Sand tongue-fish	9.9	12.6	14.3	50.0 ± 2.4	183.2 ± 3.2	Benthic	
	Merluccius capensis	Shallow-water hake	1.8	4.7	11.5	243.1 ± 74.8	229.5 ± 22.5	Benthic	Commercial
	Etrumeus whiteheadi	Cape roundherring	1.3	3.3	1.4	39.6 ± 3.0	172.4 ± 4.7	Pelagic	
	Argyrozona argyrozona	Carpenter	0.9	1.4	2.5	129.1 ± 56.6	165.3 ± 25.8	Benthic	By-catch
	Helicolenus dactylopterus	Jacopever	0.6	1.0	1.7	106.9 ± 18.2	179.7 ± 10.9	Benthic	
	Genypterus capensis	Kingklip	0.5	0.5	1.7	250.2 ± 122.9	323.0 ± 55.7	Benthic	
	Epinephelus andersoni	Spotted rockcod	0.3	1.0	1.0	239.0 ± 89.1	261.1 ± 34.0	Benthic	
	Pagellus bellotii natalensis	Red tjor-tjor	0.3	0.5	0.3	30.9 ± 14.6	110.7 ± 19.6	Benthic	Recreational
	Pomadasys olivaceum	Piggy	0.3	0.3	0.1	8.0 ± 1.5	79.7 ± 19.6	Benthic	
	Austroglossus pectoralis	East coast sole	0.2	0.3	0.4	48.3 ± 11.9	203.8 ± 14.8	Benthic	
	Liza richardsonii	Southern mullet	0.1	0.2	0.5	172.6 ± 73.0	252.8 ± 36.0	Benthic	
	Lithognathus mormyrus	Sand steenbras	0.1	0.2	0.2	131.0	206.7	Benthic	Recreational
Cephalopods	*Loligo vulgaris reynaudii*	Chokka	0.6	1.4	-			Pelagic	Commercial
	Octopus spp.	Octopus	0.3	0.7	-			Benthic	
	Sepia sp.	Cuttlefish	0.1	0.2	-			Pelagic	
Birds	*Spheniscus demersus*	African penguin	0.1	0.3	-			Pelagic	
	Phalacrocorax capensis	Cape cormorant	0.1	0.2	-			Pelagic	

Table 4.2 Inter-annual and seasonal differences (mean ± standard deviation of pooled monthly values) in percentage mass shown for the five most important prey species of Cape fur seals at Robberg Peninsula. The remaining teleost prey species are grouped under 'Other'. Kruskal-Wallis was used to test for significant differences among years and Mann-Whitney for significant differences between upwelling ('upw', December to May) and non-upwelling ('non', June to November) seasons. Significance of test statistics is indicated by *p < 0.05, **p < 0.01 and ***p < 0.001.

		n (months, samples)	Ee	Ss	Tt	Cc	Mc	Other
Year	2003	9, 63	0.14 ± 0.29	45.27 ± 33.06	17.33 ± 32.85	15.60 ± 23.3	7.01 ± 19.06	14.65 ± 18.22
	2004	12, 80	1.78 ± 4.15	36.54 ± 25.67	23.65 ± 26.66	14.86 ± 22.77	7.23 ± 15.36	15.93 ± 23.75
	2005	7, 10	20.54 ± 37.14	29.15 ± 40.58	23.27 ± 38.83	17.30 ± 37.30	9.74 ± 25.78	0 ± 0
	2006	10, 88	25.50 ± 21.66	31.74 ± 30.27	20.48 ± 17.50	13.26 ± 14.95	8.00 ± 14.25	1.01 ± 2.01
	2007	12, 107	38.84 ± 29.46	19.98 ± 31.73	10.60 ± 13.76	14.03 ± 9.98	3.72 ± 8.68	12.83 ± 20.21
	2008	10, 37	42.88 ± 36.82	20.19 ± 19.64	19.63 ± 24.24	12.66 ± 30.93	1.20 ± 2.88	3.44 ± 10.22
Kruskal Wallis	*H*		30.89***	7.60	3.58	5.39	1.31	
Season	upw	32, 183	19.93 ± 25.20	40.43 ± 27.24	16.31 ± 17.08	10.32 ± 20.07	2.96 ± 6.94	10.04 ± 17.84
	non	28, 202	23.70 ± 33.21	21.15 ± 30.00	21.07 ± 30.42	18.07 ± 24.40	8.49 ± 18.77	7.51 ± 16.26
Mann-Whitney	*U*		50.0	201.0**	23.0	68.5	2.0	

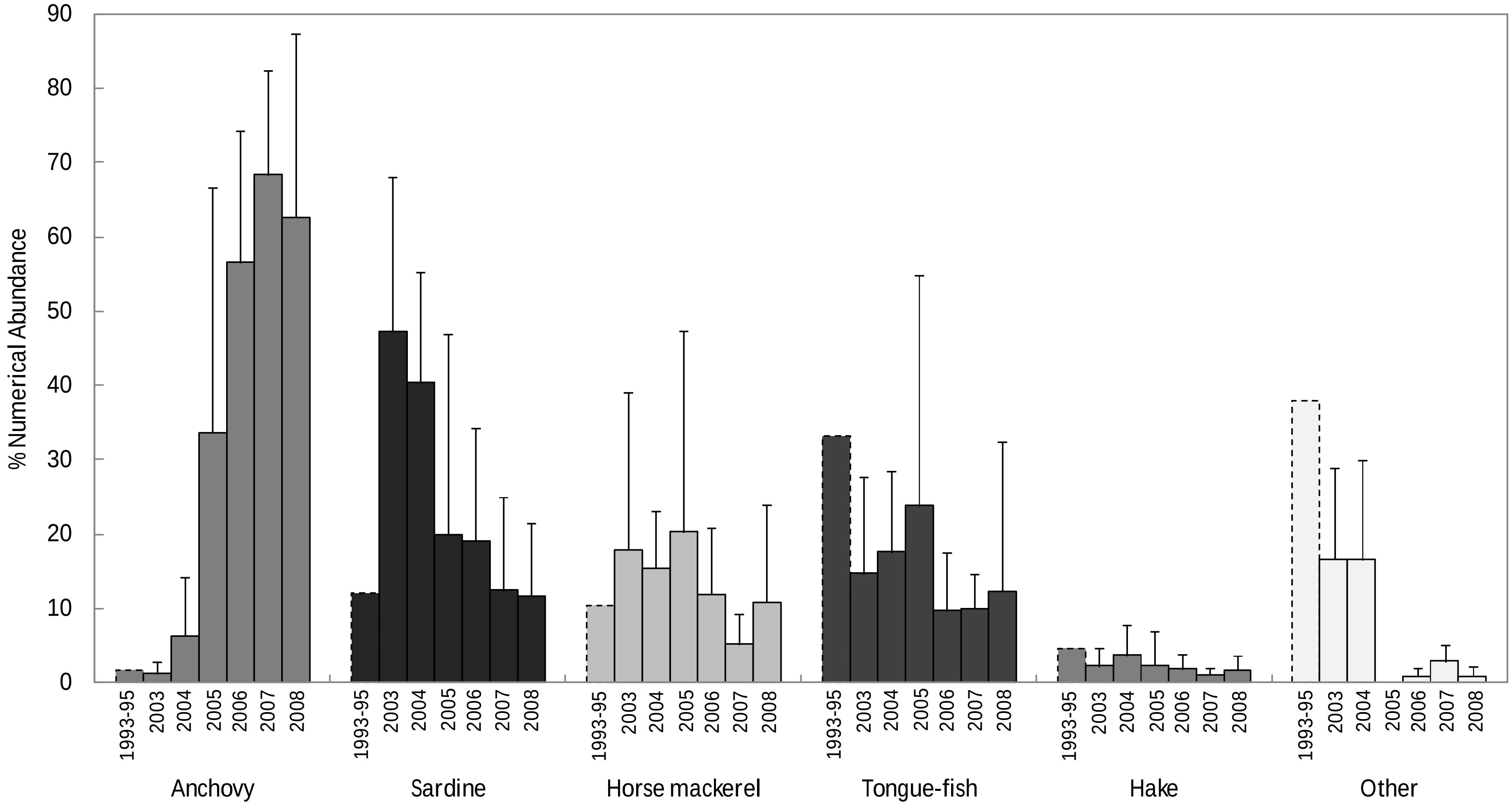

Figure 4.2 Numerical abundance (mean + 95 % confidence intervals) per year (2003-2008) of the five most important teleost prey species in the diet of Cape fur seals at Robberg as determined from scat analyses. The remaining teleost prey species are grouped under 'Other'. Bars with dashed outlines represent data from an earlier study at Robberg in 1993-1995 (Stewardson 2001). The largest part (23.8 %) of the diet composition under ‘Other’ in this study consisted of East coast sole *Austroglossus pectoralis*.

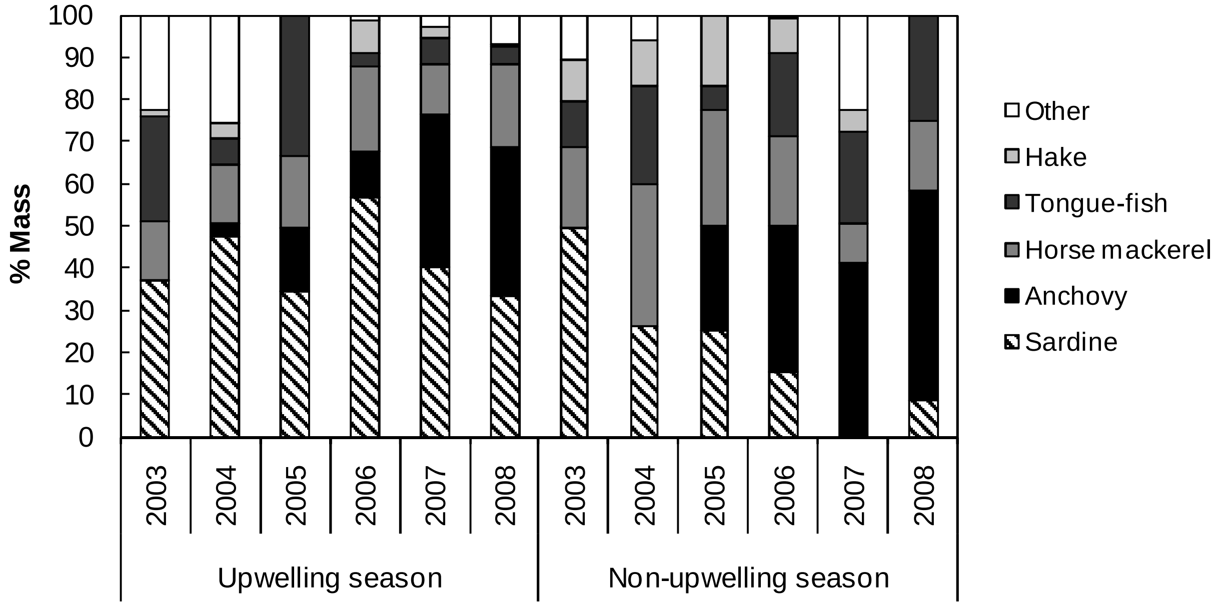

Figure 4.3 The proportional contribution of the five most important prey species to the diet of seals at Robberg, in terms of mass. The remaining teleost fish are grouped under 'Other'.

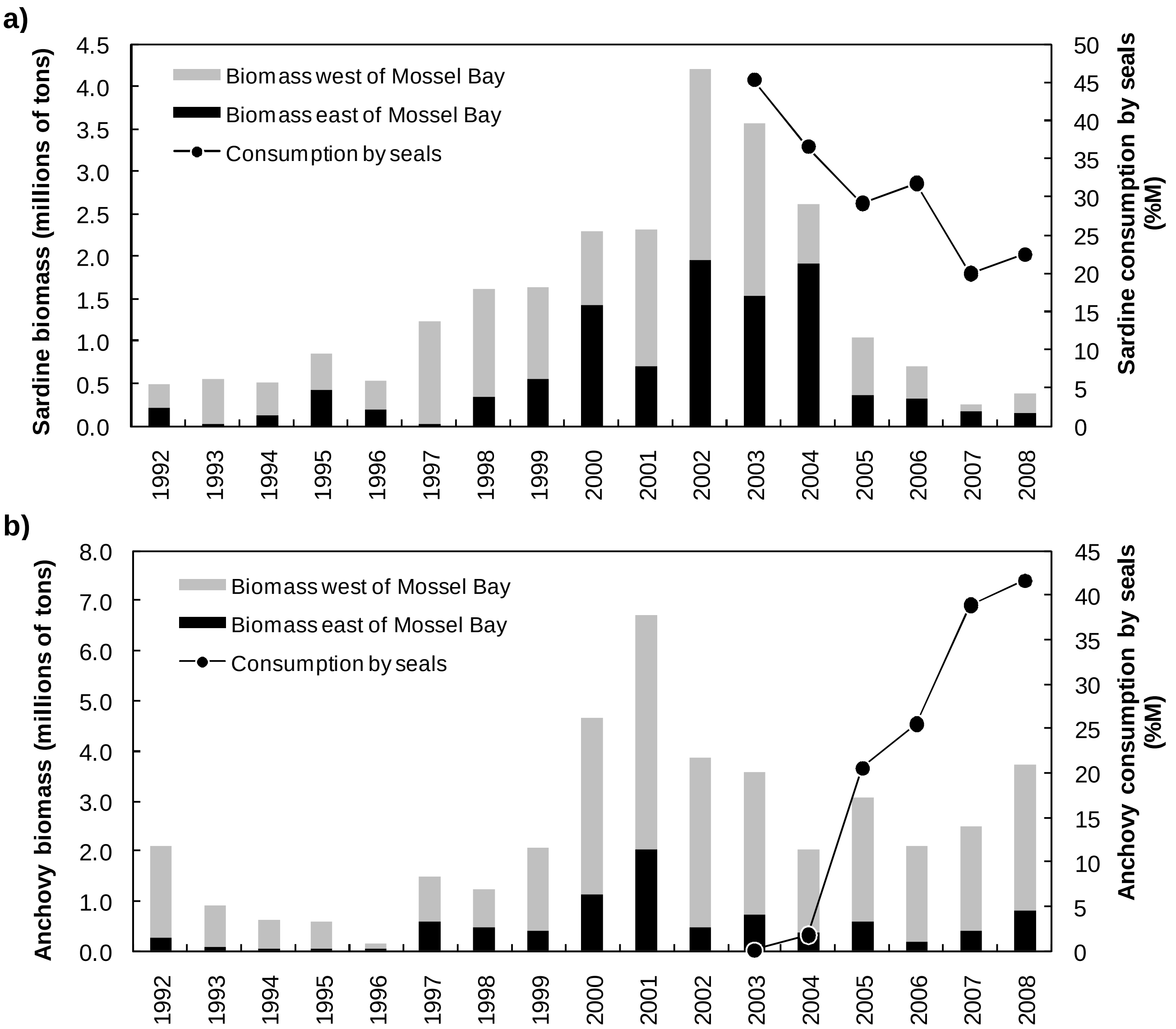

Figure 4.4 The proportion of (a) sardine and (b) anchovy in the diet of Cape fur seal superimposed on the annual acoustic biomass of these species estimated for the survey strata to the east and west of Mossel Bay, respectively. (Data from Coetzee *et al*. 2008 reworked and presented with permission from the authors.)

4.4 Discussion

Cape fur seals travel up to 220 km offshore (Shaughnessy 1985) but the identifiable prey remains in scat samples probably represent prey eaten within 24 hours of seals coming ashore (Pierce and Boyle 1991). Because younger seals forage closer to shore than older seals (Oosthuizen 1991), their scats can be expected to provide more accurate representation of prey consumed locally, subject to several limitations and assumptions of scat analyses (Jobling 1987, Bowen 2000, Yonezaki *et al*. 2003). The population on Robberg Peninsula largely comprises young non-breeding seals (M Meyer, Oceans and Coasts, pers. comm., JH pers. obs.), and it was therefore assumed that the scat samples were largely representative of prey consumed in the general vicinity of Plettenberg Bay.

Fish items in the diet

Scat analysis as a technique for assessing the diet of pinnipeds has several advantages: it is not intrusive and scats are easily obtained from seal colonies; the abundance of faecal matter generally allows for large sample sizes, a large proportion of scat samples contain identifiable hard prey remains; and the technique is inexpensive, non-destructive and non-lethal (Pierce and Boyle 1991, Boyd *et al*. 2010). There are, however, potential problems associated with using this approach to determine the fish composition of seal diet. For example, cartilaginous fish (which lack well defined otoliths) will not be detected in the diet (Olesiuk *et al*. 1990). Seals also do not always eat the heads of large teleost fish (Pierce and Boyle 1991, Balmelli and Wickens 1994) therefore their otoliths are not ingested and their consumption underestimated. Large otoliths may also be regurgitated and would not be represented in scat samples (Gales *et al*. 1993). Furthermore, secondary otoliths, contained in the stomachs of prey consumed by seals, will artificially inflate the number, and possibly species diversity of prey consumed (Punt *et al*. 1995). Despite these biases it has been argued that teleost prey remains will be represented in a similar proportion as that in which they are consumed provided that they pass through the gut at a similar rate and that a large enough sample of scats is collected (Harwood and Croxall 1988). The results presented by Trites and Joy (2005) and Hammond and Rothery (1996) both suggest that a minimum of about 100 scats should be collected for each area/season combination. Although our sample size is adequate for comparison of upwelling and non-upwelling seasons, it does not quite meet this requirement with regards the inter-annual comparison of sample sizes, especially for 2005 and 2008.

In 1993 the prey consumption of Cape fur seals in southern African waters was estimated at approximately 2 million tons per annum (Butterworth *et al.* 1995). This consumption of fisheries resources is partly accountable for the negative attitude harboured by many fishers towards seals (Stewardson 2001). The hake fishery in Plettenberg Bay, before it closed, was effort- rather than quota-controlled; therefore losses to predators such as seals constituted serious losses for the fishery (Wickens *et al.* 1992). Between March 2003 and February 2004 approximately 892 tons of hake were caught from commercial deckboats operating out of Plettenberg Bay using hand lines or long lines, and 1.6 tons of carpenter were caught as by-catch (Smith 2005). The ski-boat sector (recreational and charter fisheries) caught an estimated 2.6 tons of hake and 2.4 tons of carpenter (Smith 2005). During that period, the estimated maximum number of seals on the colony was 1 515 animals, amounting to an estimated total annual prey consumption of 2 212 tons (based on general estimates of daily food consumption; David 1987).

Scat analysis is known to underestimate cephalopod consumption (Yonezaki *et al.* 2003, Gales *et al.* 1993) and cephalopods were assumed to make up 10 % of the dietary weight of Cape fur seals compared to between 5 % and 35 % reported from other south-east coast dietary studies (David 1987, Castley *et al.* 1991, Stewardson 2001). The remaining

90 % (1991 tons) of the diet was allocated to the respective teleost prey species. In this study, hake comprised 12.7 % and carpenter 0.3 % of the dietary weight consumed from March 2003 to February 2004 (period corresponding to that of fisheries data, Smith 2005). This equates to a total estimated consumption by Cape fur seals of 253 tons of hake, less than a third of the quantity of hake caught by fisheries in Plettenberg Bay, while 6 tons of carpenter were estimated to have been consumed between March 2003 and February 2004.

The majority (67 %) of hake caught by commercial fisheries (from March 2003 to February 2004, the period for which fisheries catch data was available) comprised specimens weighing 1-2 kg, while 19 % of the catch consisted of specimens weighing less than 1 kg (Smith 2005). The mean (reconstituted) mass of hake specimens consumed by Cape fur seals during the same period was 326 g (± 639 SD). The hake targeted commercially were therefore considerably larger than those detected in the diet of seals. Similar comparisons could not be made for carpenter, as dimensions of by-catch species were not recorded.

The total mass of fish caught by the shore-based linefishery (recreational and subsistence fishers) from September 2003 to August 2004 in Plettenberg Bay was 13.6 tons, with the only species overlapping with seal diet being red tjor-tjor (12 %) and sand steenbras (10 %) (King 2005). This equates to 1.6 tons of red tjor-tjor and 1.4 tons of sand steenbras. Over the entire study period (2003-2008) red tjor-tjor and sand steenbras comprised 0.3 % and 0.2 % of seal diet, which equates to an estimated annual consumption by Robberg seals of 6.0 and 4.0 tons respectively. However, neither of these species was encountered in the diet at Robberg during September 2003 to August 2004, the period for which fishery data was available.

Sand tongue-fish and East coast sole were both found to be consumed by Cape fur seals in Plettenberg Bay and are both commercially valuable species. East coast sole is targeted by the inshore demersal trawl fishery, operating out of Port Elizabeth and Mossel Bay on the south-east coast. However, these species were not specifically targeted by the fishing vessels which operated from Plettenberg Bay, nor are they mentioned in by-catch records. These two species were the dominant teleost prey items in the diet in 1993-95 (sand tongue-fish 33 %, and east coast sole *Austroglossus pectoralis* 24 %), at which time the contributions of sardine and especially anchovy were relatively low (Stewardson 2001, see Figure 4.2).

Sardine, anchovy and other commercially valuable small shoaling fish (horse mackerel and round herring; Moor and Butterworth 2009) made up over 65 % of the mass of prey in the seal diet in this study. These species are extensively fished on the West coast, but not by vessels that operated out of Plettenberg Bay. Sardine was the most important prey but declined over the study period. This decline was significantly correlated with the decline of sardine availability along the south east coast, based on annual acoustic biomass surveys (Figure 4.4a, Coetzee *et al*. 2008). Consumption of another important prey item, anchovy, increased in the diet as sardine consumption declined, even though the abundance and availability of anchovy stocks are thought to have remained stable (Figure 4.4b, Coetzee *et al*. 2008). According to the results of acoustic biomass surveys (Figure 4.4), the biomass of both sardine and anchovy were relatively low at the time of Stewardson's (2001) sampling period in 1993-95, when sand tongue-fish and east coast sole dominated in the diet.

Top predators such as seals are increasingly being used as indicators of changes in the environment including of prey availability (Kirkman *et al*. 2011). With regard to the latter however, caution is necessary in the case of a generalist predator like the Cape fur seal because consumption of a particular prey item may be influenced by the availability of another. According to our results, diet based on scat analysis appeared to be a potentially useful indicator of sardine abundance but not that of anchovy, the contribution of which to the diet was seemed to be dependent on the availability of sardine. This also supports that the seals may favour sardine over anchovy and possibly other prey.

Other prey items

Loligo sp, which occurred in 1.4 % of the scats collected from Robberg Peninsula, was abundant in Plettenberg Bay in the early 1980s and was targeted by a seasonal squid fishery in Plettenberg Bay (Buxton *et al.* 1984). This fishery has, however, not been operational since. Together, *Loligo* sp. and other cephalopod species accounted for less than 1 % of the total number of prey animals in the diet in this study. This is lower than the 4.7 % that Stewardson (2001) recorded during 1993-95. In contrast to these results from analyses of scats, cephalopods comprised a substantial portion (up to 35 % of total mass consumed) of seal diet determined from stomach content analysis of animals along the south-east coast during the 1980s (Lipinski and David 1990, Castley *et al.* 1991). The stomach content analysis is likely to have overestimated the relative contribution of cephalopods to the diet because hard remains of cephalopods are more likely to be retained in the stomach than those of fish: (1) the passage of large cephalopod beaks to the intestines may be restricted by the diameter of the phyloric sphincter (Yonezaki *et al.* 2003), and (2) the irregular shape of beaks make them prone to retention in the stomach folds. However, it is for these same reasons that scats are likely to underestimate the contribution of cephalopods to the diet of seals (Klages and Bester 1998, Makhado *et al.* 2008), and therefore cephalopods were considered to be underrepresented in our samples.

At some localities within the distribution of Cape fur seals seabirds have been increasingly targeted since the 1980s (David *et al*. 2003, Johnson *et al*. 2006, Kirkman 2009, Makhado *et al*. 2009). Bird remains rarely featured in the scats in our study. A greater consumption of seabirds by seals could have been masked by regurgitation of feathers (Kirkman *et al*. 2000), but very few regurgitates were observed at the study site (JH pers. obs.), in line with the observations of Mecenero *et al.* (2005), and none contained feathers. Although it seems that predation on seabirds is rare for seals using the Robberg colony, it is clear that at least some predation exists.

Conclusions

The results do not support claims of significant interactions between Cape fur seals and the fisheries in Plettenberg Bay. Little similarity was found between seal prey composition and the species targeted by commercial and recreational fisheries, with only two teleost species and one cephalopod species in common with commercial catches and two teleost species in common with recreational catches. Further, seal consumption of the species targeted by recreational fisheries was low. The significant relationship between sardine in the seal diet and the biomass of sardine according to acoustic biomass estimates, and the lack of any such relationship with one of the other main prey items, anchovy, supports that sardine is a favored prey item of the Cape fur seals. It also emphasizes that caution is required when using seal diet as an indicator of prey availability, because the species composition of diet samples is likely to be contingent on prey preferences and the availability of other prey species.

4.5 References

Balmelli M, Wickens PA. 1994. Estimates of daily ration for the South African (Cape) fur seal. *South African Journal of Marine Science* 14: 151-157.

Bowen WD. 2000. Reconstruction of pinniped diets: accounting for complete digestion of otoliths and cephalopod beaks. *Canadian Journal of Fisheries and Aquatic Sciences* 57: 898-905.

Boyd IL, Bowen WD, Iverson SJ. 2010. *Marine Mammal Ecology and Conservation: A Handbook of Techniques*. Oxford University Press, Oxford. 450 pp.

Butterworth DS, Punt AE, Oosthuizen WH, Wickens PA. 1995. The effects of future consumption by the Cape fur seal on catches and catch rates of the Cape hakes. 3. Modelling the dynamics of the Cape fur seal *Arctocephalus pusillus pusillus. South African Journal of Maritime Science* 16: 161-183.

Buxton CD, Smale MJ, Wallace JH, Cockcroft VG. 1984. Inshore small-mesh trawling survey of the Cape south coast. Part 4. Contributions to the biology of some Teleostei and Chondrichthyes. *South African Journal of Zoology* 19: 180-188.

Castley JG, Cockcroft VG, Kerley GIH. 1991. A note on the stomach contents of fur seals *Arctocephalus pusillus pusillus* beached on the south-east coast of South Africa. *South African Journal of Maritime Science* 11: 573-577.

Clarke MR. 1962. The identification of cephalopod 'beaks' and the relationship between beak size and total body weight. *Bulletin of the British Museum (Natural History) Zoology* 8: 419-480.

Clarke MR. 1986. *A handbook for the identification of cephalopod beaks*. Oxford: Clarendon.

Coetzee JC, van der Lingen CD, Hutchins L, Fairweather, TP. 2008. Has the fishery contributed to a major shift in the distribution of South African sardine? *ICES Journal of Marine Science* 65: 1676-1688.

David JHM. 1987. Diet of the South African fur seal (1974-1985) and an assessment of competition with fisheries in southern Africa. *South African Journal of Marine Science* 5: 693-713.

David JHM, Cury P, Crawford RJM, Randall RM, Underhill LG, Meÿer MA. 2003. Assessing conservation priorities in the Benguela ecosystem, South Africa: analysing predation by seals on threatened seabirds. *Biological Conservation* 114: 289-292.

de Bruyn PJN, Bester MN, Mecenero S, Kirkman SP, Roux J-P, Klages NTW. 2003. Temporal variation of cephalopods in the diet of Cape fur seals in Namibia. *South African Journal of Wildlife Research* 33: 85-96.

Gales R, Pemberton D, Lu CC, Clarke MR. 1993. Cephalopod diet of the Australian Fur seal; variation due to location, season and sample type. *Australian Journal of Marine and Freshwater Research* 44: 657-671.

Glennie OH. 81 Longships Dr, Plettenberg Bay. Cell 0733456330.

Hammond PS, Rothery P. 1996. Application of computer sampling in the estimation of seal diet. *Journal of Applied Statistics* 23: 525-534.

Harvey JT. 1989. Assessment of errors associated with harbour seal (*Phoca vitulina*) faecal sampling. *Journal of Zoology, London* 219: 101-111.

Harwood J, Croxall JP. 1988. The assessment of competition between seals and commercial fisheries in the North Sea and the Antarctic. *Marine Mammal Science* 4: 13-33

Jobling M. 1987. Marine mammal faeces samples as indicators of prey importance-a source of error in bioenergetics studies. *Sarsia* 72: 255-260.

Jobling M, Breiby A. 1986. The use and abuse of fish otoliths in studies of feeding habits of marine piscivores. *Sarsia* 71: 265-274.

Johnson RL, Venter A, Bester MN, Oosthuizen WH. 2006. Seabird predation by white shark and Cape fur seal at Dyer Island. *South African Journal of Wildlife Research* 36: 23-32.

King CM. 2005. Towards a new approach for coastal Governance with an assessment of the Plettenberg Bay shore-based linefishery. MSc thesis, Rhodes University, South Africa.

Kirkman SP. 2009. Evaluating seal-seabird interactions in southern Africa: a critical review. *African Journal of Marine Science* 31: 1-18.

Kirkman SP. 2010. The Cape fur seal: monitoring and management in the Benguela Current Ecosystem. PhD thesis, University of Cape Town, South Africa.

Kirkman SP, Wilson W, Klages NTW, Bester MN, Isaksen K. 2000. Diet and estimated food consumption of Antarctic fur seals at Bouvetoya during summer. *Polar Biology* 23: 745-752.

Kirkman SP, Oosthuizen WH, Meÿer MA, Seakamela SM, Underhill LG. 2011. Prioritising range-wide scientific monitoring of the Cape fur seal *Arctocephalus pusillus pusillus* in southern Africa. *African Journal of Marine Science* 33: 495-509.

Klages NTW, Bester MN. 1998. Fish prey of fur seals *Arctocephalus* spp. at subantarctic Marion Island. *Marine Biology* 131: 559-566.

Lipinski MR, David JHM. 1990. Cephalopods in the diet of the South African fur seal (*Arctocephalus pusillus pusillus*). *Journal of Zoology, London* 221: 359-374.

Lutjeharms JRE. 2007. Three decades of research on the greater Agulhas Current. *Ocean Science* 3: 129-147.

Lutjeharms JRE, Ansorge IJ. 2001. The Agulhas return current. *Journal of Marine Systems* 30: 115-138.

Makhado AB, Bester MN, Kirkman SP, Pistorius PA, Ferguson JWH, Klages NTW. 2008. Prey of the Antarctic fur seal *Arctocephalus gazella* at Marion Island. *Polar Biology* 31: 575-581.

Makhado AB, Meÿer MA, Crawford RJM, Underhill LG, Wilke C. 2009. The efficacy of culling seals seen preying on seabirds as a means of reducing seabird mortality and seabird predation. *African Journal of Ecology* 47: 335-340.

Mecenero S, Kirkman SP, Roux J-P. 2005. Seabirds in the diet of Cape fur seals *Arctocephalus pusillus pusillus* at three mainland breeding colonies in Namibia. *African Journal of Marine Science* 27: 509-512.

Mecenero S, Roux J-P, Underhill LG, Kirkman SP, Bester MN. 2006. Diet of Cape fur seals *Arctocephalus pusillus pusillus* at three mainland breeding colonies in Namibia. 2. Temporal variation. *African Journal of Marine Science* 28: 73-88.

Moor CL, Butterworth DS. 2009. The 2004 re-assessment of the South African sardine and anchovy populations to take account of revisions to earlier data and recent record abundances. *African Journal of Marine Science* 31: 333-348.

Murie DJ. 1986. Interpretations of otoliths in stomach content analyses of phocid seals: quantifying fish consumption. *Canadian Journal of Zoology* 64: 1152-1157.

Olesiuk PF, Bigg MA, Ellis GM, Crockford SJ, Wigen RJ. 1990. An assessment of the feeding habits of harbor seals (*Phoca vitulina*) in the Strait of Georgia, British Columbia, based on scat analysis. *Canadian Technical Report of Fisheries and Aquatic Sciences* No. 173

Oosthuizen WH. 1991. General movements of South African (Cape) fur seals *Arctocephalus pusillus pusillus* from analysis of recoveries of tagged animals. *South African Journal of Maritime Science* 11: 21-29.

Oosthuizen WH, David JHM. 1988. Non-breeding colonies of the South African (Cape) fur seal in southern Africa. Investigational Report of the Sea Fisheries Research Institute, South Africa 132: 1-17.

Pierce GJ, Boyle PR. 1991. Review of methods for diet analysis in piscivorous marine mammals. *Oceanographic Marine Biology* 29: 409-486.

Punt AE, David JHM, Leslie RW. 1995. The effects of future consumption by the Cape fur seal on catches and catch rates of the Cape Hakes. 2. Feeding and diet of the Cape fur seal *Arctocephalus pusillus pusillus*. *South African Journal of Maritime Science* 16: 85-99.

Rand RW. 1972. The Cape fur-seal *Arctocephalus pusillus*. 4. Estimates of population size. Investigational Report Sea Fisheries South Africa 89: 1-28.

Reid K. 1995. The diet of Antarctic fur seals *(Arctocephalus gazella* Peters 1875) during winter at South Georgia. *Antarctic Science* 7: 241-249.

Schumann EH, Perrins LA, Hunter IT. 1982. Upwelling along the South Coast of the Cape Province, South Africa. *South African Journal of Science* 78: 238-242.

Smale MJ, Clarke MR, Klages NT, Roeleveld MAC. 1993. Octopod beak identification-resolution at a regional level (Cephalopoda, Octopoda: Southern Africa). *South African Journal of Marine Science* 13: 269-293.

Smale MJ, Watson G, Hecht T. 1995. Otolith atlas of Southern African Marine Fishes. *Ichthyological Monographs*. J.L.B. Smith Institute of Ichthyology, Grahamstown, South Africa. 1: 253 pp.

Smith MKS. 2005. Towards a new approach for coastal governance with an assessment of the Plettenberg Bay nearshore linefisheries. MSc thesis, Rhodes University, South Africa.

Shaughnessy PD. 1985. Interactions between fisheries and Cape fur seals in southern Africa. In J.R. Beddington. R.J.H. Beverton, and D.M. Lavigne (eds), *Marine Mammals and Fisheries*. George, Allen and Unwin: London.

Stewardson CL. 1999. The impact of the fur seal industry on the distribution and abundance of Cape fur seals *Arctocephalus pusillus pusillus* on the Eastern Cape coast of South Africa. *Transactions of the Royal Society of South Africa* 54: 217-245.

Stewardson CL. 2001. Biology and conservation of the Cape (South African) fur seal. PhD thesis, Australian National University, Canberra, Australia.

Tollit DJ, Steward MJ, Thompson PM, Pierce GJ, Santos MB, Hughes S. 1997. Species and size differences in the digestion of otoliths and beaks: implications for estimates of pinniped diet composition. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 105-119.

Treacy SD. 1981. Retrieval of otoliths and statoliths from gastrointestinal contents and scats of marine mammals. *Journal of Wildlife Management* 45: 990-993.

Trites AW, Joy R. 2005. Dietary analysis from fecal samples: how many scats are enough? *Journal of Mammalogy* 86: 704-712.

van der Lingen CD, Shannon LJ, Cury P, Kreiner A, Moloney CL, Roux J-P, Vaz-Velho F. 2006. Resource and ecosystem variability, including regime shifts, in the Benguela Current System. In: Shannon V, Hempel G, Malanotte-Rizzoli P, Moloney CL, Woods J (eds), *Benguela: predicting a Large Marine Ecosystem*. Amsterdam: Elsevier, Amsterdam.

Wickens PA, Japp DW, Shelton PA, Kriel F, Goosen PC, Rose B, Augustyn CJ, Bross CAR, Penney AJ, Krohn RG. 1992. Seals and fisheries in South Africa-competition and conflict. In: Payne AIL, Brink KH, Mann KH, Hilborn R (eds), *Benguela Trophic Functioning*. *South African Journal of Marine Science* 12: 773-789.

Yonezaki S, Kiyota M, Baba N, Koido T, Takemura A. 2003. Size distribution of the hard remains of prey in the digestive tract of northern fur seal (*Callorhinus ursinus*) and related biases in diet estimation by scat analysis. *Mammal Study* 28: 97-102.

Appendix 4.1 Numerical abundance pooled per month for each of the five most important prey species with the remaining species pooled as 'Other'. Upwelling season ('upw') is from December to May and non-upwelling ('non') from June to November.

Year	Month	n samples	Season	Anchovy	Sardine	Horse mackerel	Sand tounge-fish	Shallow-water hake	Other
2003	3	3	upw	0.0	33.3	0.0	33.3	0.0	33.3
	4	5	upw	0.0	58.3	8.3	16.7	8.3	8.3
	5	4	upw	0.0	22.2	33.3	11.1	0.0	33.3
	6	15	non	6.1	63.6	3.0	9.1	9.1	9.1
	7	8	non	0.0	40.0	6.7	0.0	0.0	53.3
	8	16	non	4.8	83.3	0.0	2.4	0.0	9.5
	9	1	non	0.0	100.0	0.0	0.0	0.0	0.0
	10	10	non	0.0	25.0	9.4	59.4	3.1	3.1
	11	1	non	0.0	0.0	100.0	0.0	0.0	0.0
	12	5	upw	0.0	66.7	16.7	0.0	0.0	16.7
2004	1	17	upw	26.5	16.3	12.2	18.4	6.1	20.4
	2	10	upw	43.3	30.0	3.3	13.3	0.0	10.0
	3	12	upw	5.6	66.7	0.0	27.8	0.0	0.0
	4	5	upw	0.0	18.2	9.1	0.0	9.1	63.6
	5	4	upw	0.0	16.7	0.0	16.7	0.0	66.7
	6	4	non	0.0	88.2	0.0	0.0	0.0	11.8
	7	9	non	0.0	34.6	19.2	38.5	3.8	3.8
	8	1	non	0.0	66.7	33.3	0.0	0.0	0.0
	9	4	non	0.0	25.0	25.0	50.0	0.0	0.0
	10	3	non	0.0	50.0	25.0	0.0	25.0	0.0
	11	6	non	0.0	5.9	41.2	47.1	0.0	5.9
2005	2	2	upw	85.7	14.3	0.0	0.0	0.0	0.0
	4	1	upw	0.0	0.0	0.0	100.0	0.0	0.0
	5	2	upw	50.0	25.0	25.0	0.0	0.0	0.0
	6	2	non	0.0	0.0	16.7	66.7	16.7	0.0
	8	1	non	100.0	0.0	0.0	0.0	0.0	0.0
	10	1	non	0.0	0.0	100.0	0.0	0.0	0.0
	11	1	non	0.0	100.0	0.0	0.0	0.0	0.0
2006	1	8	upw	20.0	70.0	10.0	0.0	0.0	0.0
	2	5	upw	30.0	60.0	10.0	0.0	0.0	0.0
	4	7	upw	66.7	13.3	3.3	13.3	0.0	3.3
	5	12	upw	31.7	12.7	46.0	4.8	3.2	1.6
	6	14	non	76.2	4.0	18.3	1.6	0.0	0.0
	7	4	non	92.1	0.0	2.6	5.3	0.0	0.0
	8	4	non	77.1	11.4	0.0	2.9	8.6	0.0
	9	10	non	80.0	6.0	2.0	12.0	0.0	0.0
	10	11	non	76.1	4.5	3.0	14.9	1.5	0.0
	11	13	non	15.5	8.5	23.9	42.3	5.6	4.2
	12	5	upw	84.4	2.2	2.2	11.1	0.0	0.0
2007	1	11	upw	24.0	22.0	6.0	32.0	4.0	12.0
	2	9	upw	70.7	8.6	13.8	3.4	1.7	1.7
	3	10	upw	32.6	60.5	0.0	7.0	0.0	0.0
	4	12	upw	35.3	55.9	0.0	2.9	2.9	2.9
	5	5	upw	100.0	0.0	0.0	0.0	0.0	0.0
	6	8	non	81.6	0.0	2.6	13.2	0.0	2.6
	7	9	non	89.6	0.0	0.0	6.6	2.8	0.9
	8	10	non	79.7	0.0	0.0	13.6	0.0	6.8
	9	13	non	60.3	0.0	20.5	11.5	0.0	7.7
	10	6	non	78.9	0.0	15.8	5.3	0.0	0.0
	11	9	non	83.3	0.0	1.5	13.6	1.5	0.0
2008	1	5	upw	33.3	40.7	14.8	7.4	0.0	3.7
	2	6	upw	81.0	6.9	1.7	1.7	3.4	5.2
	3	5	upw	89.1	4.3	6.5	0.0	0.0	0.0
	4	6	upw	73.9	13.0	4.3	4.3	4.3	0.0
	5	6	upw	76.3	18.6	5.2	0.0	0.0	0.0
	6	1	non	0.0	0.0	0.0	100.0	0.0	0.0
	7	1	non	0.0	33.3	66.7	0.0	0.0	0.0
	8	3	non	100.0	0.0	0.0	0.0	0.0	0.0
	9	3	non	100.0	0.0	0.0	0.0	0.0	0.0
	12	1	upw	72.7	0.0	9.1	9.1	9.1	0.0

Appendix 4.2 Frequency of occurrence pooled per month for each of the five most important prey species with the remaining species pooled as 'Other'. Upwelling season ('upw') is from December to May and non-upwelling ('non') from June to November.

Year	Month	n samples	Season	Anchovy	Sardine	Horse mackerel	Sand tounge-fish	Shallow-water hake	Other
2003	3	3	upw	0.0	33.3	0.0	33.3	0.0	33.3
	4	5	upw	0.0	37.5	12.5	25.0	12.5	12.5
	5	4	upw	0.0	40.0	20.0	20.0	0.0	20.0
	6	15	non	4.8	52.4	4.8	9.5	14.3	14.3
	7	8	non	0.0	50.0	8.3	0.0	0.0	41.7
	8	16	non	10.5	73.7	0.0	5.3	0.0	10.5
	9	1	non	0.0	100.0	0.0	0.0	0.0	0.0
	10	10	non	0.0	40.0	13.3	33.3	6.7	6.7
	11	1	non	0.0	0.0	100.0	0.0	0.0	0.0
	12	5	upw	0.0	66.7	16.7	0.0	0.0	16.7
2004	1	17	upw	17.9	21.4	10.7	17.9	10.7	21.4
	2	10	upw	35.3	29.4	5.9	11.8	0.0	17.6
	3	12	upw	7.1	78.6	0.0	14.3	0.0	0.0
	4	5	upw	0.0	33.3	16.7	0.0	16.7	33.3
	5	4	upw	0.0	25.0	0.0	25.0	0.0	50.0
	6	4	non	0.0	75.0	0.0	0.0	0.0	25.0
	7	9	non	0.0	50.0	25.0	8.3	8.3	8.3
	8	1	non	0.0	50.0	50.0	0.0	0.0	0.0
	9	4	non	0.0	25.0	25.0	50.0	0.0	0.0
	10	3	non	0.0	33.3	33.3	0.0	33.3	0.0
	11	6	non	0.0	16.7	33.3	33.3	0.0	16.7
2005	2	2	upw	50.0	50.0	0.0	0.0	0.0	0.0
	4	1	upw	0.0	0.0	0.0	100.0	0.0	0.0
	5	2	upw	33.3	33.3	33.3	0.0	0.0	0.0
	6	2	non	0.0	0.0	25.0	50.0	25.0	0.0
	8	1	non	100.0	0.0	0.0	0.0	0.0	0.0
	10	1	non	0.0	0.0	100.0	0.0	0.0	0.0
	11	1	non	0.0	100.0	0.0	0.0	0.0	0.0
2006	1	8	upw	30.0	60.0	10.0	0.0	0.0	0.0
	2	5	upw	37.5	50.0	12.5	0.0	0.0	0.0
	4	7	upw	45.5	27.3	9.1	9.1	0.0	9.1
	5	12	upw	27.3	22.7	31.8	4.5	9.1	4.5
	6	14	non	52.4	14.3	28.6	4.8	0.0	0.0
	7	4	non	66.7	0.0	16.7	16.7	0.0	0.0
	8	4	non	42.9	28.6	0.0	14.3	14.3	0.0
	9	10	non	64.3	7.1	7.1	21.4	0.0	0.0
	10	11	non	46.7	6.7	13.3	26.7	6.7	0.0
	11	13	non	16.7	8.3	29.2	25.0	8.3	12.5
	12	5	upw	42.9	14.3	14.3	28.6	0.0	0.0
2007	1	11	upw	14.3	33.3	9.5	19.0	4.8	19.0
	2	9	upw	46.7	20.0	13.3	6.7	6.7	6.7
	3	10	upw	26.7	60.0	0.0	13.3	0.0	0.0
	4	12	upw	20.0	60.0	0.0	6.7	6.7	6.7
	5	5	upw	100.0	0.0	0.0	0.0	0.0	0.0
	6	8	non	72.7	0.0	9.1	9.1	0.0	9.1
	7	9	non	56.3	0.0	0.0	25.0	12.5	6.3
	8	10	non	81.8	0.0	0.0	9.1	0.0	9.1
	9	13	non	50.0	0.0	22.7	9.1	0.0	18.2
	10	6	non	75.0	0.0	12.5	12.5	0.0	0.0
	11	9	non	64.3	0.0	7.1	21.4	7.1	0.0
2008	1	5	upw	33.3	25.0	16.7	16.7	0.0	8.3
	2	6	upw	40.0	20.0	10.0	10.0	10.0	10.0
	3	5	upw	71.4	14.3	14.3	0.0	0.0	0.0
	4	6	upw	54.5	18.2	9.1	9.1	9.1	0.0
	5	6	upw	55.6	22.2	22.2	0.0	0.0	0.0
	6	1	non	0.0	0.0	0.0	100.0	0.0	0.0
	7	1	non	0.0	50.0	50.0	0.0	0.0	0.0
	8	3	non	100.0	0.0	0.0	0.0	0.0	0.0
	9	3	non	100.0	0.0	0.0	0.0	0.0	0.0
	12	1	upw	25.0	0.0	25.0	25.0	25.0	0.0

Appendix 4.3 Proportional mass pooled per month for each of the five most important prey species with the remaining species pooled as ‘Other’. Upwelling season (‘upw’) is from December to May and non-upwelling (‘non’) from June to November.

Year	Month	n samples	Season	Anchovy	Sardine	Horse mackerel	Sand tounge-fish	Shallow-water hake	Other
2003	3	3	upw	0.0	38.8	0.0	45.7	0.0	15.5
	4	5	upw	0.0	54.3	7.7	19.3	3.8	14.8
	5	4	upw	0.0	18.2	34.4	9.9	0.0	37.5
	6	15	non	0.4	33.2	1.1	2.1	57.7	5.5
	7	8	non	0.0	44.5	3.9	0.0	0.0	51.6
	8	16	non	0.8	93.2	0.0	0.4	0.0	5.6
	9	1	non	0.0	100.0	0.0	0.0	0.0	0.0
	10	10	non	0.0	25.2	8.8	63.0	1.5	1.4
	11	1	non	0.0	0.0	100.0	0.0	0.0	0.0
	12	5	upw	0.0	63.4	13.2	0.0	0.0	23.3
2004	1	17	upw	6.1	24.1	32.5	10.6	3.1	23.5
	2	10	upw	13.7	64.8	2.9	5.5	0.0	13.2
	3	12	upw	1.6	80.2	0.0	18.1	0.0	0.0
	4	5	upw	0.0	35.9	33.1	0.0	19.0	12.0
	5	4	upw	0.0	14.6	0.0	2.5	0.0	83.0
	6	4	non	0.0	69.4	0.0	0.0	0.0	30.6
	7	9	non	0.0	20.6	5.1	19.6	51.8	2.9
	8	1	non	0.0	28.7	71.3	0.0	0.0	0.0
	9	4	non	0.0	15.1	18.9	66.0	0.0	0.0
	10	3	non	0.0	11.1	76.0	0.0	12.8	0.0
	11	6	non	0.0	10.6	30.7	56.0	0.0	2.7
2005	2	2	upw	33.6	66.4	0.0	0.0	0.0	0.0
	4	1	upw	0.0	0.0	0.0	100.0	0.0	0.0
	5	2	upw	10.2	37.6	52.2	0.0	0.0	0.0
	6	2	non	0.0	0.0	10.7	21.1	68.2	0.0
	8	1	non	100.0	0.0	0.0	0.0	0.0	0.0
	10	1	non	0.0	0.0	100.0	0.0	0.0	0.0
	11	1	non	0.0	100.0	0.0	0.0	0.0	0.0
2006	1	8	upw	4.5	78.1	17.4	0.0	0.0	0.0
	2	5	upw	6.7	90.0	3.2	0.0	0.0	0.0
	4	7	upw	27.9	41.3	18.9	6.4	0.0	5.4
	5	12	upw	6.0	16.6	40.0	7.3	29.6	0.6
	6	14	non	30.7	9.1	56.7	3.6	0.0	0.0
	7	4	non	72.1	0.0	16.0	11.9	0.0	0.0
	8	4	non	23.7	32.4	0.0	5.1	38.9	0.0
	9	10	non	40.3	23.4	7.6	28.7	0.0	0.0
	10	11	non	38.7	20.2	14.2	23.6	3.2	0.0
	11	13	non	4.5	6.2	31.0	46.0	8.3	4.1
	12	5	upw	62.7	9.2	13.9	14.2	0.0	0.0
2007	1	11	upw	6.9	48.3	19.6	17.4	1.0	6.8
	2	9	upw	35.7	23.1	37.3	2.9	0.5	0.6
	3	10	upw	7.4	90.7	0.0	1.9	0.0	0.0
	4	12	upw	6.3	68.5	0.0	0.7	14.0	10.5
	5	5	upw	100.0	0.0	0.0	0.0	0.0	0.0
	6	8	non	22.5	0.0	0.8	23.5	0.0	53.1
	7	9	non	45.8	0.0	0.0	25.7	28.2	0.3
	8	10	non	31.2	0.0	0.0	21.4	0.0	47.4
	9	13	non	19.3	0.0	29.5	15.9	0.0	35.3
	10	6	non	56.3	0.0	24.3	19.5	0.0	0.0
	11	9	non	72.0	0.0	1.8	25.3	0.9	0.0
2008	1	5	upw	4.9	33.9	55.2	4.1	0.0	1.9
	2	6	upw	27.8	21.8	4.7	11.7	1.5	32.5
	3	5	upw	56.4	18.4	25.2	0.0	0.0	0.0
	4	6	upw	44.9	42.8	5.1	5.9	1.2	0.0
	5	6	upw	40.3	50.9	8.8	0.0	0.0	0.0
	6	1	non	0.0	0.0	0.0	100.0	0.0	0.0
	7	1	non	0.0	34.0	66.0	0.0	0.0	0.0
	8	3	non	100.0	0.0	0.0	0.0	0.0	0.0
	9	3	non	100.0	0.0	0.0	0.0	0.0	0.0
	12	1	upw	54.5	0.0	31.4	4.9	9.2	0.0

CHAPTER 5. Conclusions

5.1 Overview

Cape fur seals were harvested to extirpation on the Robberg Peninsula, Plettenberg Bay between the 17th and early 20th centuries. Seals returned to the Robberg Peninsula in small numbers during the early 1990s and their numbers subsequently increased. The colony at Robberg is the first new colony to develop on the coast east of Agulhas since the 1970s. The return of seals to Robberg has been met with concern by the local fishing community, as seals may compete for fish resources. An assessment of the diet of seals was required to determine potential overlap with fishery catches. The diet of Cape fur seals along the south-eastern coast of South Africa has been poorly studied.

This study describes the recolonisation of Robberg by Cape fur seals from 2000 to 2009. Regular counts showed that numbers of seals using the site increased during the study period from less than 300 to over 3 100 animals. The colony is currently still in a transition phase with a low ratio of breeding to non-breeding animals, and low numbers of pups born on the colony (still < 100 per year). Wave height, time of day and lunar phase had minimal explanatory power with respect to variation in seal numbers. Within-year variation in seal counts decreased during the study period, which may indicate an increasing proportion of resident seals in the colony.

Scat analysis of Cape fur seals utilising the colony on Robberg showed that their most important prey species are anchovy, sardine, horse mackerel, sand tongue-fish and hake (in decreasing order of importance). The proportional contribution of anchovy to the diet increased during the study period, while the consumption of sardine decreased. Except for an increase in sardine consumption during the upwelling season (December to May) relative to the rest of the year, no other clear seasonal patterns were observed in seal dietary composition. Little evidence was found for direct competition between seals and fisheries in the Plettenberg Bay area, both in terms of prey species composition and quantities consumed.

Scat collection is biased towards teleost prey as otoliths pass through the digestive system more freely than cephalopod beaks (Jobling and Breiby 1986). The collection of stomach contents of seals shot at sea may be complimentary to scat analysis, providing a more representative sample of the prey base of seals. However the technique is destructive, expensive and undesirable due to ethical considerations. Stomach contents of stranded animals on the south east coast (Castley *et al*. 1991) may provide an indication of cephalopod contribution to seal diet. The assessment of potential competition between seals and fisheries was limited by the lack of fisheries data at a geographically comparable scale. Results, however, clearly indicate that currently Cape fur seals at Robberg Peninsula have a marginal impact on fishing yields, due to the limited overlap in their prey and species targeted by fisheries.

5.2 Implications for management

Ongoing monitoring of seal numbers at developing colonies such as Robberg is key to improving our understanding of the importance of developing colonies in the dynamics of the species (Oosthuizen and David 1988, Kirkman 2007). Spatial expansion of the haulout site at Robberg made continued land-based counts difficult. Boat-based counts are preferred given the slope (viewing angle) and narrow area (proximity) of the haulout site. It is recommended that boat-based counts be continued instead of land-based counts.

Considering that reliable counts of pups cannot be obtained by means of boat-based counts, aerial censuses of the colony will be necessary to assess the breeding status of the colony. To this end, Robberg needs to be included in the aerial pup counts that are routinely done by Department of Environmental Affairs along the Cape coast.

The bi-weekly seal censuses did not yield evidence of the large variation in counts. For a detailed assessment of the effects of environmental variables (e.g. time of day, lunar phase, weather conditions) on numbers of seals hauled out on land, counts will have to be conducted systematically according to a schedule appropriate to the variables in question. For the purpose of monitoring future growth of the colony, quarterly (3 monthly) counts will suffice. Ideally three replicate counts should be performed on every counting occasion to provide an estimate of precision.

In order to encourage recolonisation of the easternmost tip of the Robberg Peninsula ('Seal Point') by seals and further growth of the colony, certain management interventions may be considered. Firstly, the hiking trail along the periphery of the Peninsula may be re-routed away from Seal Point. Secondly, the area at Seal Point may be declared a no-take zone for fishers. The latter is realistic in terms of the zoning policy for MPAs, although it is likely to be met with resistance from fishers.

Scat sampling in Cape fur seals holds promise as a method to track long-term changes in prey species abundance and therefore potentially as indicator of larger-scale environmental change. To this end, the Robberg colony is positioned in a key location for monitoring the observed (Roy *et al*. 2007) eastward shift in sardine abundance. It will therefore be valuable to continue with scat collection to (1) verify whether sardine scat analysis could potentially be a useful indicator of sardine abundance (2) and to document changes over longer time periods and as the colony increase in size. Ongoing collection of scat samples should aim to collect at least 20 samples per month (Kirkman 2010, Kirkman *et al*. 2011).

The simplistic notion adopted by the fishing community that, if seal numbers were reduced, the fish consumed by the seals would at once be available to fishers, cannot be true in the context of an extremely complex marine ecosystem where there are many alternative predator-prey pathways in the food web (David and Wickens 2003). Although seabirds, sharks and game fish also consume fish, and often more so than seals, they are generally perceived as less detrimental to fisheries than seals. Therefore, it is apparent in resource management that the influence of all top predators interacting with a given resource needs to be evaluated without concentrating on the most conspicuous predator. Hand in hand with efforts to manage whole ecosystems should go efforts to engage all stakeholders in order to get their buy-in into these ecosystem concepts, which should ultimately lead towards improved management and conservation practices that benefit all.

5.3 Future research

Future research should consider sex- and age-group dynamics of the seal colony at Robberg to determine the breeding status of the colony. Secondly, the tagging of seals to monitor the movement and exchange of seals between Robberg and other colonies needs to be monitored. Thirdly, exploring the movements of seals between dawn and nightfall in relation to predator avoidance, thermoregulation and foraging could inform the optimal timing for performing seal counts in order to reduce variability that was unaccounted for in this study. Fourthly, in order to establish the utility of seal scat sampling as indicator of teleost prey species abundance, seal diet and fish stocks should be assessed simultaneously to confirm the relationship between fish abundance and the level of consumption by seals.

5.4 References

David JHM, Wickens PA. 2003. Management of Cape fur seals and fisheries in South Africa. In: Gales N, Hindell M, Kirkwood R (eds), *Marine mammals: fisheries, tourism and management issues*. Collingwood: CSIRO Publishing. pp 116-135.

Castley JG, Cockcroft VG, Kerley GIH. 1991. A note on the stomach contents of fur seals *Arctocephalus pusillus pusillus* beached on the south-east coast of South Africa. *South African Journal of Maritime Science* 11: 573-577.

Jobling M, Breiby A. 1986. The use and abuse of fish otoliths in studies of feeding habits of marine piscivores. *Sarsia* 71: 265-274.

King CM. 2005. Towards a new approach for coastal Governance with an assessment of the Plettenberg bay shore-based linefishery. MSc thesis Rhodes University, South Africa.

Kirkman SP. 2007. Recommendations for a regional monitoring programme for Cape fur seals in the BCLME. In: Kirkman SP (ed.), *Final report of the BCLME (Benguela Current Large Marine Ecosystem) Project on top predators as biological indicators of ecosystem change in the BCLME*. Cape Town: Avian Demography Unit, University of Cape Town. pp 367-371.

Kirkman SP. 2010. The Cape fur seal: monitoring and management in the Benguela Current Ecosystem. PhD thesis. Animal Demography Unit, Department of Zoology, University of Cape Town, South Africa.

Kirkman SP, Oosthuizen WH, Meÿer MA, Seakamela SM, Underhill LG. 2011. Prioritising range-wide scientific monitoring of the Cape fur seal *Arctocephalus pusillus pusillus* in southern Africa. *African Journal of Marine Science* 33: 495-509.

Oosthuizen WH, David JHM. 1988. Non-breeding colonies of the South African (Cape) fur seal in southern Africa. Investigational Report of the Sea Fisheries Research Institute, South Africa 132: 1-17.

Roy C, van der Lingen CD, Coetzee JC, Lutjeharms JRE. 2007. Abrupt environmental shift associated with changes in the distribution of Cape anchovy *Engraulis encrasicolus* spawners in the southern Benguela. *African Journal of Marine Science* 29: 309-319.

Smith MKS. 2005. Towards a new approach for coastal governance with an assessment of the Plettenberg Bay nearshore linefisheries. MSc thesis Rhodes University, South Africa.