Investigation of the impact of fur seals on the conservation status of seabirds at islands off South Africa and at the Prince Edward Islands

by

Azwianewi Benedict Makhado

Thesis Presented for the Degree of
DOCTOR OF PHILOSOPHY
in the Department of Zoology
UNIVERSITY OF CAPE TOWN

February 2009

Supervised by

Professor L.G. Underhill
Animal Demography Unit
Department of Zoology
University of Cape Town
Rondebosch 7701
South Africa

Professor R.J.M. Crawford
Department of Environmental Affairs and Tourism
Marine and Coastal Management
Private Bag X2
Roggebaai 8012
Cape Town
South Africa

Professor M.N. Bester
Mammal Research Institute
Department of Zoology and Entomology
University of Pretoria
Pretoria 0002
South Africa

TABLE OF CONTENTS

LAYOUT AND CONTRIBUTIONS OF CO-AUTHORS

This thesis consists of nine chapters, including Chapter 1: Introduction and Chapter 9: Discussion and conclusions. Each of chapters 2-8 has been written as a paper for submission to peer-reviewed journals and should be viewed as self-standing, with its own methods, acknowledgements and references. One paper (Chapter 2) has been published; a second (Chapter 8) has been accepted for publication. References, tables and figures follow the text for each chapter, as would be the case in a paper submitted for publication. I conducted all the field observations, except as otherwise indicated. I was responsible for the analysis of information and the writing of each chapter. My supervisors assisted with selection of appropriate statistical and other methods and with the finalization of the chapters. I am grateful to others for assistance, as acknowledged in the acknowledgements that follow each chapter. PGH Kotze, MA Meÿer and C Wilke culled the seals and undertook measurements on the carcasses of those that were retrieved and identified the prey items in their stomachs.

Chapter 2: AB Makhado, RJM Crawford and LG Underhill (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.

Chapter 3: AB Makhado, RJM Crawford and LG Underhill. An assessment of the impact of predation by Cape fur seals on seabirds at Dyer Island, South Africa.

Chapter 4: AB Makhado, RJM Crawford, MN Bester and LG Underhill. On the predation of seabirds by fur seals *Arctocephalus* spp. at other localities in South Africa and at Marion Island.

Chapter 5: AB Makhado, RJM Crawford, LG Underhill, MA Meÿer and PGH Kotze. Prey, sex and age of Cape fur seals *Arctocephalus pusillus pusillus* collected at Malgas Island, South Africa, during the fledging of Cape gannets *Morus capensis*, 1999–2008.

Chapter 6: AB Makhado, LG Underhill and RJM Crawford. Influence of environmental factors on the predation rate of Cape fur seals on seabirds along the South African coast.

Chapter 7: AB Makhado, RJM Crawford, LG Underhill. The hunting behaviour of Cape fur seals *Arctocephalus pusillus pusillus* preying on seabirds.

Chapter 8: AB Makhado, MA Meÿer, RJM Crawford, LG Underhil and C Wilke (in press) The efficacy of culling seals seen preying on seabirds as a means of reducing seabird mortality. *African Journal of Ecology*.

ABSTRACT

This research project investigated the impact of predation by the Cape fur seals *Arctocephalus pusillus pusillus* on the conservation status of seabirds at islands off the coast of South Africa and at the Prince Edward Islands. At Malgas Island, the impact of predation was investigated over three breeding seasons (2000/01, 2003/04 and 2005/06), and at Dyer Island over two breeding season (2004 and 2006/07). At Marion Island (Prince Edwards Islands) and at other South African islands, such as Dassen Island, Bird Island at Lambert's Bay and Robben Island, observations were collected opportunistically.

Cape fur seals were estimated to have killed some 6 000 Cape gannet *Morus capensis* fledglings around Malgas Island in the 2000/01 breeding season, 11 000 in 2003/04 and 10 000 in 2005/06. This amounted to an estimated 29%, 83% and 57% of the overall production of fledglings at the island in these breeding seasons respectively. Preliminary modelling suggests this predation is not sustainable. There was a 25% reduction in the size of the colony, the second largest of only six extant Cape gannet colonies, between 2001/02 and 2005/06.

At Dyer Island, it was estimated that seals killed up to 7% of African penguin *Spheniscus demersus* adults annually. The present mortality attributable to seals is considered unsustainable. Seals also killed a substantial proportion, 4–8%, of Cape cormorant *Phalacrocorax capensis* fledglings as they left the island. Although this level of mortality may be sustainable for Cape cormorants, this species have also been affected by disease.

Predation on seabirds by Cape fur seals was demonstrated to occur at several other localities in southern Africa but observations were insufficient to enable the effect of such predation to be quantified. Several hundred Cape gannet fledglings were killed annually at Bird Island (Lambert's Bay) and threatened penguins and cormorants were attacked at other localities. At subantarctic Marion Island, Antarctic fur seals *A. gazella* fed on king *Aptenodytes patagonicus* and macaroni *Eudyptes chrysolophus* penguins. However, predation there on seabirds by subantarctic fur seals *A. tropicalis* has not yet been observed. King penguins were mostly killed in winter and macaroni penguins (which are absent from the island in winter) in summer. Predation of seabirds by seals has recently increased in southern Africa and may be doing so at Marion Island. In both regions fur seal populations are expanding.

The influences of environmental factors on the rate of predation were investigated at both Malgas and Dyer Islands. Of environmental factors considered, time of the day had the most important influence on predation by Cape fur seals on fledglings of Cape gannets and Cape cormorants and adult African penguins. Fledglings of gannets and cormorants were mainly killed between mid morning and late afternoon, coinciding with the time they left the islands and were in the water. Most adult African penguins were killed as they returned in the evening from foraging at sea. Wind speed and direction, sea state and tide had a variable and lesser influence on predation rates. Although these variables might be used to interpolate predation rates through periods when observations are not conducted, their contribution is limited and there will remain considerable uncertainty in the estimate of actual numbers of fledglings killed. Uncertainty will best be decreased by extending the period of observations so as to reduce the amount of days for which predation rates are interpolated.

In six years between 1999 and 2008, 141 Cape fur seals that were feeding on, or thought to be feeding on, Cape gannet fledglings as they left Malgas Island, South Africa, were shot and collected. Examination of the stomachs of 93 of these seals showed that Cape gannets contributed an average of 70% by mass to the diet, and known prey items of Cape gannets, which may have been obtained from the alimentary tract of the fledglings, a further 5%. Hence, when the seals were culled, they were subsisting mainly on the fledglings. Other prey items of the seals included rock lobster *Jasus lalandii* and common octopus *Octopus vulgaris*. All the collected seals were bulls. Their ages were estimated from measures of their total length and previously published information on ages at length. All were 10 years old or less, and their mean age was 4.5 years.

The hunting behaviour of Cape fur seals feeding on seabirds at Malgas and Dyer Islands was investigated in 2003/04 and 2005/06; and 2004 and 2006/07 respectively. At these islands, attacks on seabirds were identified mainly through the presence of other birds overhead and sometimes by the thrashing of a victim in, or throwing of it from, the water. Most attacks occurred beyond the surf zone at distances of 20–100 m from the island. Seals hunted in groups or solitarily and usually attacked birds from underneath or behind. Usually most, or a substantial portion of the carcass was utilized but some surplus killing was observed. On average, attacks lasted 11 min for both Cape gannets and Cape cormorants and 16 min for African penguins.

Due to the increase in seal predation, interventive management such as culling individual fur seals seen preying on seabirds was implemented at Malgas Island. It was anticipated that removal of the small number of individual seals which target seabirds would reduce mortality on the seabirds because this is a learned behaviour. In the 2006/07 breeding season of Cape gannets at Malgas Island, the removal of 61 Cape fur seals that preyed on gannet fledglings when they left to sea significantly reduced the mortality rate of these fledglings in the short term. However, because seals learned to avoid the boat used for their removal, it was not possible to remove all the seals that killed gannet fledglings and some mortality continued. There was a decrease over time in both the maximum and the mean age of seals culled. Sustained removal of these animals may reduce this feeding behaviour.

ACKNOWLEDGMENTS

I am thankful to Department of Environmental Affairs and Tourism, National Research Foundation (SEACHANGE and SANAP programmes), and WWF-SA for supporting this research. The Department of Environmental Affairs and Tourism (South Africa), SANParks, Navy and CapeNature also provided logistical support.

I thank my supervisors Professor LG Underhill, Professor RJM Crawford, Professor MN Bester for their guidance, support and encouragement throughout my study. I have benefited greatly from their expertise. I am most grateful to my supervisor and mentor, Professor RJM Crawford for his unwavering dedication and for input that was unfailingly insightful, broad in perspective and cheerful. I am most indebted to Rob for his continued support, advice, encouragement and trust throughout my study and commenting on drafts of my chapters. I am grateful to Professor Les Underhill for his advice, encouragement, sharing of ideas and commenting on drafts of my chapters. His statistical expertise was very helpful and much appreciated. I thank Professor MN Bester for his encouragement, sharing of ideas and comments on drafts of my chapters. Among them, they have empowered me and helped me develop skills and expertise that will be of use in future. Thank you.

Finally, I am deeply grateful to my wife Mashuvho Makhado and my son Mukonazwothe. Mashuvho has loved, encouraged and supported me throughout my studies. Their unfailing love and courage has kept me going day and night. I also thank my parents for their support and care throughout my life.

CHAPTER 1

General Introduction

General Introduction

During the 20th century, population sizes of fur seals *Arctocephalus* spp. increased at both the Prince Edward Islands and off southern Africa following centuries of over-harvesting (Bester *et al*. 2003, David *et al*. 2003). Conversely, the population sizes of many seabird species in these two regions decreased, leading to concerns about their conservation status (Barnes 2000, BirdLife International 2000, Crawford and Cooper 2003). This thesis examines the impact (especially predation) of fur seals on seabirds in these two regions.

The Benguela current large marine ecosystem

The Benguela current large marine ecosystem (BCLME) is associated with the Benguela current and characterized by distinct bathymetry, hydrography, productivity and trophically-dependent populations (Benguela Current Commission: interim agreement 2006). The BCLME is limited to the north by the latitude 5°S, to the south by a boundary 200 nautical miles south of the baseline of South Africa mainland (in accordance with the 1982 United Nations convention on the law of the sea), to the east by meridian 27°E and to the west by 0°E meridian (Benguela Current Commission 2006).

The Benguela current is the broad northward flow of surface water adjacent to south western Africa, forming the eastern limb of the south Atlantic subtropical gyre and is located between the African coast and the Walvis ridge (Garzoli and Gordon 1996). The cold, nutrient-rich Benguela system is one of four major upwelling systems in the world, all exhibiting high biological productivity (Currie 1953, Shannon and Jarre-Teichmann

1999) and experiencing highly variable environmental conditions (Shannon *et al.* 1992). The degree of upwelling is dependent on the prevailing wind conditions and direction relative to the coast and the depth and width of the continental shelf (Shannon 1985). The primary production is enhanced by upwelling (Cushing 1969).

The Benguela upwelling system is bounded at both northern (tropical/equatorial Eastern Atlantic) and southern (the Indian Ocean's Agulhas Current) ends by warm water systems. Climate is the primary force driving the large marine ecosystem, with intensive fishing also important (Benguela Current Commission 2006).

The Benguela upwelling system is an important centre of marine biodiversity and is one of the most productive ocean areas in the world (Benguela Current Large Marine Ecosystem Programme (BCLME): Transboundary Diagnostic Analysis 1999). It provides favourable conditions for the production of small pelagic fish species, with sardines *Sardinops sagax*, anchovies *Engraulis encrasicolus* and round herrings *Etrumeus whiteheadi* being the most abundant (Shannon and Field 1985). The large biomass of epipelagic fish species provides the forage centre for large populations of top predators such as seabirds and seals (Shannon and Field 1985, Pillay 2001). Within the Benguela ecosystem, there are more than 20 breeding seabird islands, as well as important mainland breeding sites and artificially-constructed platforms (Figure 1).

Southern Indian Ocean

The southern Ocean is a large circumpolar body of water that extends over 36 million km^2 (Laws 1985). It is influenced by the movement of several strong currents (White and

Peterson 1996). The Antarctic Circumpolar Current (ACC) is the most important of these, and the only current that flows completely around the globe. It encircles the Antarctic continent, flowing eastward through the southern portions of the Atlantic, Indian and Pacific oceans (Pakhomov and Froneman 1999).

North of the ACC is the Subtropical Convergence or Subtropical Front (STF), usually found between 35°S and 45°S, where the average Sea Surface Temperature (SST) ranges from ca. 12°C to 7°C and salinity decreases from greater than 34.9‰ to 34.6‰ or less. Three fronts south of the STF are associated with the ACC: the subantarctic Front (SAF), the Polar Front (PF) and the southern ACC Front. The Antarctic Convergence is approximately 200 km south of the Polar Front (McQuaid and Froneman 2004, Chown and Froneman 2008).

The Prince Edward Islands are situated ca. 1600 km southeast of Cape Town within the Indian ocean sector of the Polar Front and are breeding localities for up to five million pinnipeds and seabirds (McQuaid and Froneman 2004, Chown and Froneman 2008). At these islands, 29 seabird species and three seal species have been recorded breeding. The islands support substantial proportions of the global population for several seabird species (Table 2, Cooper and Berruti 1989, Crawford and Cooper 2003). They are located in the path of the ACC with the subantarctic system to the north and the Antarctic Polar Front to the south (Figure 2) (McQuaid and Froneman 2004). The formation of these frontal zones contributes to primary and secondary production of the southern ocean. Many myctophid species are concentrated at these fronts (McQuaid and Froneman 2004, Perissinotto and McQuaid 1992).

Endemism and conservation status of seabird species

The major biological feature of the islands in the BCLME and the Prince Edward Islands is that they support large numbers of predators that breed ashore but feed at sea. There are 15 species of seabirds that breed in southern Africa (Table 1) (Cooper *et al.* 1984), and there are at least 29 seabird species that breed at the Prince Edward Islands (Crawford *et al*. 2003b). Additionally, 62 other species of seabird visit southern African waters due to the high productivity of the Benguela ecosystem and the meeting of the Indian, Atlantic and Southern oceans.

Nine of the 15 taxa of southern African seabirds are endemic to the region due to the isolation of breeding sites from suitable breeding localities farther north and south (Kirkman 2007). These are the African penguin *Spheniscus demersus*, Cape gannet *Morus capensis,* Cape cormorant *Phalacrocorax capensis*, bank cormorant *P. neglectus,* crowned cormorant *P. coronatus*, kelp gull *L. dominicanus vetula*, Hartlaub's gull *Larus hartlaubii*, swift tern *S. bergii bergii* and Damara tern *Sterna balaenarum*. Of the six non-endemic seabird taxa, two occur as small isolated populations in the BCLME (roseate tern *S. dougallii* and Leach's storm petrel *Oceanodroma leucorhoa*) and the other four species breed in fresh water as well as marine environments and extend into much of the sub–Sahara area (white-breasted cormorant *P. lucidus,* great white pelican *Pelecanus onocrotalus*, grey-headed gull *L. cirrocephalus* and Caspian tern *S. caspia*) (Kirkman 2007).

Twenty nine species of seabirds use the Prince Edward Islands for breeding and moulting. There are 16 surface nesting birds (Table 2) and 13 burrowing petrels, with the lesser sheathbill *Chionis minor* being the only other breeding bird (Crawford and Cooper 2003). All these birds are indigenous but none are endemic, as they are widely distributed at subantarctic islands (Crawford and Cooper 2003). The large distances between breeding sites and the high philopatry (natal site fidelity) of several of these species have ensured limited genetic interchange between populations and the taxonomy of some populations requires further investigation (e.g. Crawford *et al*. 2003c).

Nine of the fifteen species of seabird that breed in the BCLME are listed in South Africa's Red Data Book as threatened in one of three risk categories (Endangered, Vulnerable and Near-threatened) (Barnes 2000). The conservation status of these seabirds was assessed under IUCN categories as Endangered (Bank cormorant, Leach's storm petrel), Vulnerable (African penguin, Cape gannet, Cape cormorant, Roseate tern) and Near-threatened (Damara tern, great white pelican, Caspian tern) (Kirkman 2007).

Twelve surface-nesting seabirds at the Prince Edward Islands have an unfavourable conservation status as reflected by their IUCN classification (Table 2) (Crawford and Cooper 2003). The one surface-nesting seabird that is not regarded as threatened is the king penguin *Aptenodytes patagonicus* with numbers increasing in many parts of its range (Ellis *et al*. 1998, Woehler 2007), including at Marion Island (Crawford *et al*. 2003b). Other birds that have a wide distribution with large populations in the subantarctic regions are the subantarctic skua *Catharacta antarctica*, kelp gull and Antarctic tern *Sterna vittata* (Crawford and Cooper 2003).

Conservation threats to Southern African seabirds and seals

Several South African seabird populations are declining due to various threats (Barnes 2000). The factors that have been implicated as contributors to the declines are human induced (competition with fisheries, pollution, by-catch mortality, habitat degradation, human disturbance) (Hockey and Hallinan 1981, Crawford *et al.* 2000, Kemper *et al.* 2007, the BCLME report) and natural (mismatch between distribution of breeding sites and prey, disease, predation, displacement from breeding sites, climate effects) (Crawford *et al*. 1989, 1990, Crawford and Dyer 1995, Marks *et al*. 1997, David *et al*. 2003, Makhado *et al*. 2006). Although many of the seabird species breed at protected sites, a number of them are considered to be at serious conservation risk and they are not immune to pressures caused by humans. Many seabird species have wide distributions, often crossing international boundaries, and their conservation status may be improved through internationally-coordinated efforts. The populations of seals around the subantarctic islands and southern Africa have been increasing after termination of seal harvesting at subantarctic islands (Hofmeyr *et al*. 1997). In South Africa the provisioning of food by fishing industries (especially trawlers) has contributed to population increase (Ryan and Moloney 1988, David 1989).

Competition with fisheries for prey

Inadequate supplies of food may cause a reduction in the breeding success of seals and seabirds (Crawford and Dyer 1995). Seals and some seabirds often compete with fisheries for fish such as anchovy and sardine. Off Namibia between 1956 and 2006, the populations of African penguin and Cape gannet decreased by 90% and 95%, respectively, following a decline in the Namibian purse-seine fisheries (Crawford 2007, Crawford *et al.* 2007). In South Africa, a decrease of African penguins occurred after collapse of South Africa's sardine resource (Crawford 1998). It is important that fisheries management allows adequate food for seals and seabirds. Declines in population levels of African penguin, Cape gannet, Cape cormorant and bank cormorant could likely be reduced through the prohibition of specified types of fishing near breeding localities as well as ensuring sufficient escapement of prey (Crawford 2007, Crawford *et al*. 2008b).

At the Prince Edward Islands, most surface nesting seabird populations have decreased in the past 10 years (Crawford and Cooper 2003). For species that forage close to the island (such as the gentoo penguin *Pygoscelis papua*, rockhopper penguin *Eudyptes chrysocome filholi* and Crozet shag *Phalacrocorax melanogenis*), as well as offshore foragers (such as the macaroni penguin *E. chrysolophus*), the decrease seems likely to have resulted from an altered availability of food (Crawford and Cooper 2003). This is suggested by the changed contribution of prey in the diet of the Crozet shag (Crawford *et al*. 2003c) and a decreased mass of rockhopper penguins on their return to the island to breed (Crawford *et al*. 2008a).

Mismatch of the breeding localities and prey distributions

Between 1997 and 2005 sardine in South Africa were displaced 400 km to the south and east; the centre of distribution of commercial catches moved to an area between the locations of seabird breeding islands in the Western and Eastern Cape Provinces (Van der Lingen *et al*. 2005, Crawford *et al*. 2008b). Sardine became less available to seabirds in the Western Cape but more available to Cape gannets in the Eastern Cape (Crawford *et* *al*. 2008b). Between 2004 and 2006, the numbers of African penguins in the Western Cape decreased by 45%, in spite of a new mainland colony being established to the east of Cape Agulhas at De Hoop (Underhill *et al.* 2006). The number of Cape gannets that breed in the Western Cape decreased between 2001/02 and 2005/06 and the contribution of sardine to their diet fell (Crawford *et al.* 2008b). The proportions of the numbers of Cape cormorants and swift terns in the Western Cape that bred in the south of this province increased (Crawford *et al*. 2008b). Mismatch in the distributions of breeding localities and prey of seabirds could be partially managed through provisioning of breeding habitat where food is abundant (e.g. platforms in estuaries or fenced off headlands), and spatial management of fisheries competing for prey (Crawford *et al*. 2008b).

Pollution

Oil pollution affects seabirds, especially the African penguin. About 17000 penguins were de-oiled and released back into the wild after the *Treasure* oil spill in 2000 (Crawford *et al*. 2000, Barham *et al*. 2008). When adults are oiled and removed or die, their chicks are abandoned. Approximately 2000 orphaned chicks were hand reared and released back to Robben and Dassen islands following the *Treasure* oil spill. Their survival to breeding age was no different from that of naturally reared chicks (Barham *et al*. 2008). In the 1980s, several hundred rockhopper penguins died at Marion Island after oil was deliberately dumped (Cooper and Condy 1988, Brothers *et al*. 1999). Care should be taken when transferring fuel to the Prince Edward Islands (Prince Edward Islands Management Plan Working Group 1996, Chown and Froneman 2008).

By-catch mortality

Interactions with longline fisheries such as tuna *Thunnus* spp. and demersal Patagonian toothfish *Dissostichus eleginoides* have been identified as a primary cause of seabird decreases (Brothers *et al*. 1999, BirdLife International 2000, Gilman 2001, Nel 2002, Petersen *et al*. 2007). Longline by-catch mortality occurs because seabirds are attracted to the fishing vessels by discards and baits. They ingest baited hooks during the setting or, less commonly, during the hauling of the longline (Petersen *et al*. 2007). The hooked birds are pulled under the water and subsequently drown (Brothers *et al*. 1999, Gilman 2001). Between 2000 and 2005, an estimated 31 000 seabirds were killed by pelagic and demersal fleets operating in the Benguela ecosystem: 500 in South Africa and 30 500 in Namibia (Petersen *et al*. 2007). Many seabird species are victims of longline by-catch mortality, particularly albatrosses, petrels and shearwaters. Around 300 000 seabirds drown globally each year after diving for bait set on longlines and becoming hooked (Petersen *et al*. 2007). Seabirds die after hitting trawl warps (the rope that attaches the net to the boat) often while feeding on fish offal discharged from on-board fish processing (Brothers *et al*. 1999, Gilman *et al.* 2005, Petersen *et al*. 2007). By-catch mortality can be reduced by using bird scaring techniques such as placing tori lines above the fishing lines, reducing the amount of time the hooks are available for birds through line weighting and night setting of fishing lines (Bothers *et al*. 1999, Gilman *et al.* 2005, Petersen *et al*. 2007).

Disease

Avian cholera *Pasteurella multicida* has been recorded in South Africa, at Lambert's Bay, Dassen Island, Dyer Island and Robben Island (Williams and Ward 2002). An estimated 9500 adult Cape cormorants and 4500 chicks were killed in an outbreak at Dyer Island between 2004 and 2005 (Waller and Underhill 2007). In 2004, an outbreak of avian cholera killed several seabirds (macaroni and rockhopper penguins) at Marion Island; avian cholera has been recorded in king penguins at Marion Island (BM Dyer pers. comm.). Avian malaria *Plasmodium* spp. has been recorded in wild and captive African penguins causing mortality at a rehabilitation centre (Brossy 1992, Grim *et al.* 2003, Parsons and Underhill 2005). No haematozoa were found on blood smears of macaroni and rockhopper penguins breeding at Marion Island in 2001 (Schultz and Petersen 2003) suggesting an absence of haematozoan diseases. Disease outbreaks in susceptible colonies could lead to high mortalities of seabirds. Mortality can be decreased by removing all dead carcasses from the colonies and incinerating them (Friend 1999, Waller and Underhill 2007).

Predation

Cape fur seal *Arctocephalus pusillus pusillus* males are known to prey on African penguins, Cape gannets and cormorants (bank, Cape and crowned) around some South African islands, including Lambert's Bay, Malgas, Dassen and Dyer islands (Makhado *et al.* 2006). Throughout this thesis, the word "bull" has been used to represent both subadult and adult male fur seals. The incidence of predation by seals on seabirds in South Africa has increased in recent years. Cape fur seals kill an average of 57% of Cape gannet fledglings as they leave to sea (Makhado *et al*. 2006). At the Prince Edward Islands, there has been increased predation of seabirds by Antarctic fur seal *A. gazella* (Hofmeyr and Bester 1993).

Predators such as feral and domestic cats, domestic dogs and rodents have been introduced to several seabird breeding localities (Underhill *et al*. 2006). The impacts of such introduced predators have been reported for Dassen and Robben islands (Berruti *et al.* 1989, Crawford *et al*. 1995). Removal of predators will decrease losses of seabirds (David *et al*. 2003).

Displacement from breeding sites

Seabirds may be displaced from breeding sites by larger animals such as seals (Shaugnessy 1980, Crawford *et al*. 1989, David *et al*. 2003). This has been accentuated by the modification of islands, through removal of accumulated deposits of guano rendering seabirds more susceptible to displacement. For example, African penguins used to burrow into guano (Hockey *et al*. 2005), where they would not have been displaced by seals. Seals can block the access of seabirds to their breeding sites by lining beaches (Crawford *et al*. 1989).

Degradation of breeding habitat

Degradation of the breeding habitat of seabirds has arisen from activities such as removal of guano, causing birds to breed in depressions that are subject to flooding and predation, the removal of shade and the exclusion of birds from certain areas to facilitate collecting of eggs (Crawford *et al*. 2001, Anon. 2007). Habitat loss is also caused by industrial and port development, waste discharge, sediment removal, bait collection, the development of recreational infrastructure and the construction of roads, bridges and marinas (Simeone and Bernal 2000).

Disturbance by people

Disturbance at the breeding sites by people has been through illegal landing, guano harvesting, collection of seabird eggs and direct research activities (de Villiers *et al*. 2006). The minimization and regulation of disturbance to seals, seabirds and shorebirds is necessary and any disturbance, especially of breeding animals, is subject to the issuing of a permit from the managing conservation authority. Suitable restricted areas should be declared around island and mainland colonies, but provision should be made for tourism that has no adverse influence on seabird populations. Consideration should be given to the restriction of speeding by recreational vessels close to breeding colonies. Eco-tourism vessels or vehicles should be subject to permit conditions and a code of conduct.

Exploitation

Between the 17th and late 20th centuries, fur seal numbers were greatly depleted by indiscriminate and uncontrolled exploitation (Shaughnessy 1984). During the first half of the 20th century, commercial exploitation of eggs is thought to have drastically reduced numbers of African penguins at some breeding localities, especially at Dassen Island (Shannon and Crawford 1999). The last authorized collection of African penguin eggs were made in 1967 (Shelton *et al.* 1984, Shannon and Crawford 1999).

Climate effects

The occurrence of El Niño in 1997/98 resulted in an increase in numbers of five seabird species breeding at Marion Island that are offshore foragers, namely the northern giant petrel *Macronectes halli*, southern giant petrel *M. giganteus*, wandering albatross *Diomedea exulans*, grey-headed albatross *Thalassarche chrysostoma* and Kerguelen tern Crawford *et al.* 2003a). In contrast breeding was poor for inshore feeders such as the gentoo penguin and Crozet shag (Crawford and Cooper 2003). No impacts of global climate change on seabirds in the Benguela upwelling system have as yet been demonstrated although environmental change possibly attributable to climate change has had a major influence (Crawford *et al*. 2008b).

Interactions between top predators in the Benguela ecosystem and the Prince Edward Islands

Pinnipeds and many seabirds are highly adapted for locomotion in water but are obliged to return to land to breed and moult, where they are vulnerable to terrestrial mammalian predators (Crawford *et al.* 1989, Oosthuizen *et al*. 1997, Wiesel 2006). At sea and on land, interaction between the top predators is seen as survival of the fittest, particularly seabirds, as they are vulnerable to predation and competition for prey and breeding space (Crawford *et al.* 1989, David *et al*. 2003). Seabirds are not an important source of food for marine animals such as sea lions, fur seals, sharks and killer whales *Orcinus orca* (Williams *et al*. 1990). However, seals are known to be opportunistic predators responding to changes in the marine ecosystem or prey abundance (Beddington *et al*.

1985, Croll and Tershy 1998, Makhado 2002). In the Benguela ecosystem and at islands in the southern Indian Ocean, seals are impacting on seabird populations through predation, competition for breeding space and food resources (Shaughnessy 1984).

Quantitative accounts of seabird predation are rare (e.g. du Toit *et al.* 2004), and therefore the relative importance of predatory attacks in population declines is unknown. Predation is one of the most fundamental interactions in nature and an inherently fascinating behaviour but rarely observed in the wild. Knowledge of the nature of predator-prey relationships is fundamental for the functioning of any ecosystem and has important implications for population dynamics, conservation and management (Musick 1999). It is difficult to observe and document predation events in the marine environment. A number of predators attack, feed on or induce anti-predator behaviour in seabirds in southern Africa including the Cape fur seal (Shaughnessy 1978, Broni 1984, Marks *et al.* 1997, David *et al.* 2003), the great white shark *Carcharodon carcharias* (Randall *et al.* 1988) and the killer whale (Randall and Randall 1990).

The Cape fur seal is the most conspicuous seabird predator in the Benguela ecosystem and has been recorded hunting and feeding on gannets (du Toit 2002, David *et al.* 2003), cormorants *Phalacrocorax* spp. (Marks *et al.* 1997) and African penguins (Shaughnessy 1978, Crawford *et al.* 2001, du Toit 2002). Seals have been observed feeding on seabirds and their scats have been shown to contain seabird components (Green *et al.* 1990, Hofmeyr and Bester 1993, Makhado *et al.* 2009). Up to 7% of Cape cormorant fledglings at Dyer Island may fall victim to seals annually (Marks *et al.* 1997), while du Toit (2002) estimated that 0.2% of the African penguin population on Ichaboe Island succumbed to seal predation annually. David *et al.* (2003) calculated that 7% of fledgling Cape gannets at Malgas Island were killed by Cape fur seals between November 2000 and March 2001. These estimates are sufficiently large to warrant more attention to such attacks.

Seabird predation by seals is thought to be an extension of play behaviour (Bonner and Hunter 1982) and has been regarded as an unusual event (Cooper 1974). Some individuals prey regularly on penguins (Cobley and Bell 1998), exploiting a specialist niche food resource (Penney and Lowry 1967, Rogers and Bryden 1995, Walker *et al.* 1998). The deteriorating conservation status of some of South Africa's seabirds is cause for concern and the predation impact of seals needs quantification.

Southern Africa is one of the centres of abundance for the great white shark where it ranges from southern Mozambique to Namibia (Compagno 1991). Great white sharks were responsible for a majority of the injured and dead African penguins recovered from the shoreline of St Croix and Bird islands in Algoa Bay (Randall *et al*. 1988). However, only one African penguin has been recovered from a great white shark stomach (Bass *et al*. 1975).

The increase in the number of seals impacted on the population sizes of seabirds (Hofmeyr and Bester 1993, David *et al*. 2003, Ryan *et al.* 2003). Re-colonisation by seals of islands has displaced seabirds breeding there, for example, with an influx of seals at Mercury Island up to 15% of the global population of bank cormorants (9 000 pairs in the 1970s) as well as large numbers of African penguins and Cape cormorants were displaced from the island (Crawford *et al*. 1989). If the seal population continues to grow, further decreases in seabird populations can be expected (David 1989). On Marion Island, the increase in seal populations has not yet caused a reduction of any seabird population, although individual Antarctic fur seals have attacked and killed species of penguins breeding there (Hofmeyr and Bester 1993).

Biology of the animals

Seals

Three species of fur seal are known to occupy islands that are managed by the South African government. Two species, the subantarctic fur seal and the Antarctic fur seal breed sympatrically at the Prince Edward Islands (Condy 1978). *A. gazella* is the more polar of the two species and is generally found to the south of the APF, whereas almost all *A. tropicalis* breeding sites are to the north of the APF (Bester 1984, Hofmeyr *et al*. 1997). Only one species of seal, the endemic Cape fur seal breeds along the coasts of South Africa and Namibia (David 1989). The Cape fur seal breeds at 24 coastal colonies from Algoa Bay in South Africa to Cape Cross in Namibia (David 1987, Kirkman 2007).

From the 17th to 20th centuries, all three fur seal species were subjected to unregulated harvesting, resulting in severe reductions of their populations and local extinctions at some breeding sites (Roux 1987, Shaugnessy 1984, Shaughnessy and Fletcher 1987, David 1989). After the cessation of intensive exploitation, numbers of fur seals increased dramatically and many islands have been re-colonised (Payne 1977, Shaugnessy 1985, Bester 1987, 1990, Kerley 1987, Roux 1987, Guinet *et al*. 1994, Isaksen *et al*. 2000, Wynen *et al*. 2000). Censuses of *A. tropicalis* and *A. gazella* populations at Marion Island (46°54'S and 37°45'E) in 1994/95 yielded estimates of 50 000 and 1 200 individuals, respectively (Hofmeyr *et al*. 1997). This meant that the *A. tropicalis* population had increased at a rate of 18% per year since 1988/89 and *A. gazella* at a rate of 17% over the same period (Hofmeyr *et al*. 1997). From censuses of *A. pusillus pusillus* it was estimated that there were 1.5 to 2 million animals at the close of the 20^{th} century (Butterworth *et al.* 1995).

The increase in the Cape fur seal population in southern Africa may have been assisted by provisioning of food by the fishing industry and of breeding areas for seals through elimination of terrestrial predators from mainland sites. Seals feed behind trawlers on discarded fish (Ryan and Moloney 1988) and breed on the mainland in large numbers, especially in human exclusion zones (diamond areas).

Seabirds

Seabirds in the Benguela ecosystem have also been subjected to exploitation of their products, mainly eggs, guano and feathers, as well as being killed for food and for oil production (Best *et al.* 1997). This led to a reduction in numbers of seabirds breeding at islands (Best *et al.* 1997).

Many seabirds are long-lived with low adult mortality rates (du Toit and Bartlett 2001). They utilise the open ocean to obtain all or much of their food (Berruti *et al.* 1989) and breed on land.

The penguin species known to be preyed upon by the three species of fur seals are the king penguin, macaroni penguin and rockhopper penguin (on the Prince Edward Islands) and the African penguin (in the Benguela ecosystem). The Cape gannet, Cape cormorant, bank cormorant, crowned cormorant and white-breasted cormorant are seabirds breeding within the Benguela ecosystem that are subject to predation by the Cape fur seal. The kelp gull, Hartlaub's gull and swift tern are seabirds breeding within the Benguela ecosystem that are used as indicators of predation events.

Rationale and motivation of this study

Unlike the opportunism of the fur seals, many of the seabirds that breed in southern Africa and at the Prince Edward Islands are specialists. For several of these seabirds, especially those in southern Africa, man has adversely influenced their breeding habitat and reduced the availability of their prey (Crawford *et al*. 2001, Kemper *et al*. 2001).

The growing fur seal populations (Bester *et al*. 2003, David *et al*. 2003) are adversely impacting several seabird species that are of conservation concern (Shaughnessy 1984, David 1987, Crawford *et al.* 1989, Crawford *et al*. 1992, Harwood 1992, David *et al*. 2003). Firstly, fur seals are feeding on seabirds around breeding colonies, often inflicting levels of mortality that are thought to be unsustainable (Hofmeyr and Bester 1993, Crawford *et al*. 2001, du Toit 2002, David *et al*. 2003). Secondly, fur seals are displacing seabirds from breeding sites. For example at many islands African penguins are no longer able to burrow into guano to nest are easily displaced by the much larger fur seals (Crawford *et al*. 1989). Thirdly, fur seals congregating on landing beaches may be blocking access by penguins to breeding localities (Ryan *et al*. 2003). Fourthly, fur seals may be competing with seabirds for food (Croll and Tershy 1998). The islands off the South African coast and the Prince Edward Islands are natural reserves for birds and seals. However, there are at present some islands off South Africa where only birds breed, for example Dyer Island and Malgas Island. Fur seal numbers around those islands have increased, which has resulted in increased interactions between seals and seabirds

This thesis investigates the impact of predation by Cape fur seals on Cape gannets at Malgas Island, Western Cape, South Africa (chapter 2), and assess the impact of seal predation on Cape cormorants and African penguins at Dyer Island, Western Cape, South Africa (Chapter 3). Mortality of seabirds attributable to fur seals at some other islands off mainland South Africa and at Marion Island is reported in Chapter 4. The diet, age and sex of seals seen feeding, or thought to be feeding, on seabirds are investigated in Chapter 5. In chapter 6, the possible influence of environmental factors on the rates of predation by Cape fur seals on seabirds off South Africa's, Western Cape is examined. The hunting behaviour of seals feeding on seabirds is described in Chapter 7. In Chapter 8, the possibility of managing mortality of seabirds caused by seals through culling those animals that are responsible for the mortality is considered. Finally, Chapter 9 discusses the overall findings of this research project.

REFERENCES

Anon. (2007) Policy on the Management of Seals, Seabirds and Shorebirds. Department of Environmental Affairs and Tourism, Cape Town

Barnes KN (2000) *The Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland*. BirdLife South Africa, Johannesburg, 169pp

Barham PJ, Underhill LG, Crawford RJM, Altwegg R, Leshoro TM, Bolton DA, Dyer B M, Upfold L (2008) The efficacy of hand-rearing penguin chicks: evidence from African penguins (*Spheniscus demersus*) orphaned in the *Treasure* oil spill in 2000. *Bird Conservation International* **18**: 144–152

Bass AJ, D'Aubrey JD, Kistnasamy N (1975) Sharks off the east coast of southern Africa. IV. The families Odontaspididae, Scapanorhynchidae, Isuridae, Cetorhinidae, Alopiidae, Orectolobidae and Rhiniodontidae. *Investigational Report*. *South African Association for Marine Biological Research*, *Oceanographic Research Institute* **39**: 1–102

Beddington JR, Beverton RJH, Lavigne DM (eds) (1985) *Marine Mammals and Fisheries*. George Allen and Unwin, London

Benguela Current Commission (2006) Interim Agreement

Benguela Current Large Marine Ecosystem Programme (1999) Transboundary Diagnostic Analysis

Berruti A, Miller DG, Silbernag IP (1979) Kelp gulls catching crayfish. *Cormorant* **7**: 304

Berruti A, Adams NJ, Jackson S (1989) The Benguela ecosystem. 6. Seabirds. In: Barnes M (ed) *Oceanography and Marine Biology*. *An Annual Review* **27**: 273–335

Best PB, Crawford RJM, Van der Elst RP (1997) Top predators in southern Africa's marine ecosystems. *Transactions of the Royal Society of South Africa* **52**: 177–225

Bester MN (1984) Status of the population of the fur seals *Arctocephalus tropicalis* and *Arctocephalus gazella* north of the Antarctic Convergence. *South African Journal of Marine Science* **80**: 27–28

Bester MN (1987) Subantarctic fur seal, *Arctocephalus tropicalis,* at Gough Island (Tristan da Chunha group). In: Croxall JP, Gentry RL (eds) *Status, Biology, and Ecology of Fur Seals: Proceedings of an International Symposium and Workshop, Cambridge, England, 23–27April 1984. National Oceanic and Atmospheric AdministrationTechnical Report, National Marine Fisheries Service* **51**: 57–60

Bester MN, Bartlett PA (1990) Attendance behaviour of Antarctic and subantarctic fur seal females at Marion Island. *Antarctic Science* **2**: 309–312

Bester MN, Ryan PG, Dyer BM (2003) Population numbers of fur seals at Prince Edward Island, Southern Ocean. *African Journal of Marine Science* **25**: 549–554

BirdLife International (2000) *Threatened Birds of the World*. Lynx Edicions and BirdLife International, Barcelona and Cambridge

Bonner WN, Hunter S (1982) Predatory interactions between Antarctic fur seals, macaroni penguins and giant petrels. *British Antarctic Survey Bulletin* **56**: 75–79

Broni SC (1985) Social and spatial foraging patterns of the jackass penguin (*S. demersus*). *South African Journal of Marine Science* **20**: 241–245

Brossy JJ (1992) Malaria in wild and captive jackass penguins *Spheniscus demersus* along the southern African coast. *Ostrich* **63**: 10–12

Brothers NP, Cooper J, Løkkeborg S (1999) The incidental catch of seabirds by longline fisheries: worldwide review and technical guidelines for mitigation. *FAO Fisheries Circular* **937**: 1–100

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

Chown SL, Froneman PW (eds) (2008) *The Prince Edward Islands*: *Land-Sea Interactions in a Changing Ecosystem.* Sun Press, Stellenbosch, South Africa

Cobley ND, Bell G (1998) Weddel seal *Leptonychotes weddellii* feeding on gentoo penguins (*Pygoscelis papua). Marine Mammal Science* **14**: 881–883

Compagno LJV (1991) Government protection for the great white sharks (*Carcharodon carcharias*) in South Africa. *South African Journal of Marine Science* **87**: 284–285

Condy PR (1978) Distribution, abundance and annual cycle of fur seals (*Arctocephallus* spp) on the Prince Edward Islands. *South African Journal of Wildlife Research* **8**: 159–168

Cooper J (1974) The predators of the jackass penguin *Spheniscus demersus*. *Bulletin British Ornithological Club* **94**: 21–24

Cooper J, Berruti A (1989) The conservation status of South Africa's continental and oceanic islands. In: Huntley BJ (ed) *Biotic Diversity in Southern Africa: Concepts and Conservation.* Oxford University Press, Cape Town, pp 239–253

Cooper J, Condy PR (1988) Environmental conservation at the subantarctic Prince Edward Islands: a review and recommendations. *Environmental Conservation* **15**: 317–326

Cooper J, Williams AJ, Britton PL (1984) Distribution, population sizes and conservation of breeding seabirds in the Afrotropical region. In: Croxall JP, Evans PGH, Schreiber RW (eds) *Status and Conservation of the World's Seabirds. International Council for Bird Preservation Technical Publication* **2**: 403–419

Crawford RJM (1998) Responses of African penguins to regime changes of sardine and anchovy in the Benguela system. *South African Journal of Marine Science* **19**: 355–364

Crawford RJM (20070 Food, fishing and seabirds in the Benguela upwelling system. *Journal of Ornithology* **148** (Suppl 2): S253–S260

Crawford RJM, Duncombe Rae CM, Nel DC and Cooper J (2003a) Unusual breeding by seabirds at Marion Island during 1997/98. *African Journal of Marine Science* **25** (1): 453–462

Crawford RJM, Dyer BM (1995) Responses by four seabird species to a fluctuating availability of Cape anchovy *Engraulis capensis* off South Africa. *Ibis* **137**: 329–339

Crawford RJM, Cooper J (1996) Cape fur seal *Arctocephalus pusillus* catches Cape gannet *Morus capensis* ashore at Malgas Island. *Marine Ornithology* **24**: 53–54

Crawford RJM, Cooper J (2003) Conserving surface-nesting seabirds at the Prince Edward Islands: the roles or research, monitoring and legislation. *African Journal of Marine Science* **25**: 415–426

Crawford RJM, Boonstra HGvD, Dyer BM, Upfold L (1995) Recolonization of Robben Island by African penguins, 1983–1992. In: Dann P, Norman I, Reilly P (eds) *The Penguins: Ecology and Management*. Chipping Norton, Surrey Beatty and Sons, New South Wales, Australia pp 333–363

Crawford RJM, Cooper J, Dyer BM, Greyling MD, Klages NTW, Ryan PG, Petersen SL, Underhill LG, Upfold L, Wilkinson W, de Villiers MS, du Plessis S, du Toit M, Leshoro TM, Makhado AB, Mason MS, Merkle D, Tshingana D, Ward VL, Whittington PA (2003b) Populations of surface-nesting seabirds at Marion Island, 1994/95–2002/03. *African Journal of Marine Science* **25**: 427–440

Crawford RJM, Cooper J, Dyer BM, Wolfaardt AC, Tshingana D, Spencer K, Petersen SL, Nel JL, Keith DG, Holness CL, Hanise B, Greyling MD, du Toit M (2003c) Population, breeding, diet and conservation of the Crozet shag *Phalacrocorax melanogenis* at Marion Island, 1994/95–2002/03. *African Journal of Marine Science* **25**: 537–547

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

Crawford RJM, David JHM, Shannon LJ, Kemper J, Klages NTW, Roux J-P, Underhill LG, Ward VL, Williams AJ, Wolfaardt AC (2001) African penguins as predators and prey–coping (or not) with change. *African Journal of Marine Science* **23**: 435–447

Crawford RJM, Davis SA, Harding RT, Jackson LF, Leshoro TM, Meÿer MA, Randall RM, Underhill LG, Upfold L, van Dalsen AP, van der Merwe E, Whittington PA, Williams AJ, Wolfaardt AC (2000) Initial impact of the *Treasure* oil spill on seabirds off western South Africa. *South African Journal of Marine Science* **22**: 157–176

Crawford RJM, Dundee BL, Dyer BM, Klages NTW, Meÿer MA, Upfold (2007) Trends in numbers of Cape Gannets (*Morus capensis*), 1956/57-2005/06, with a consideration of the influence of food and other factors. *ICES Journal of Marine Science* **64**: 169–177

Crawford RJM, Makhado AB, Upfold L, Dyer BM (2008a) Mass on arrival of rockhopper penguins at Marion Island correlated with breeding success. *African Journal of Marine Science* **30**: 185–188

Crawford RJM, Siegfried WR, Shannon LV, Villacastin-Herrero CA, Underhill LG (1990) Environmental influences on marine biota off southern Africa. *South African Journal of Science* **86**: 330–339

Crawford RJM, Shannon LJ, Whittington PA (1999) Population dynamics of the African penguin *Spheniscus demersus* at Robben Island, South Africa. *Marine Ornithology* **27**: 139–147

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**(1): 189–193

Crawford RJM, Underhill LG, Raubenheimer CM, Dyer BM, Märtin J (1992) Top predators in the Benguela ecosystem – implications of their trophic position. *South African Journal of Marine Science* **12**: 675–687

Currie R (1953) Upwelling in the Benguela current. *Nature* **171**: 497–500

Cushing DH (1969) Upwelling and fish production. *FAO Fisheries Technical Paper* **84:** 40

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 off Southern Africa*. Vlaeberg Publishers, Cape Town, pp 288–302

David JHM, Cury P, Crawford RJM, Randall RM, Underhill LG, Meyer 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 MS, Wheeler M, Giese M, Fourie A (2006) Hardly hard-hearted: heart rate responses of incubating northern giant petrels (*Macronectes halli*) to human disturbance on subantarctic Marion Island. *Polar Biology* **29**: 717–720

du Toit M, Bartlett PA (2001) Soaked Cape gannets at Ichaboe Island, Namibia. *Bird Numbers* **10**(2): 8–9

du Toit M (2002) Predatory interactions between Cape fur seals and seabirds at Ichaboe Island, Namibia. MSc Thesis, University of Pretoria, Pretoria

du Toit M, Bartlett PA, Bester MN, Roux J-P (2004) Seal-seabird predation at Ichaboe Island, Namibia: prey selection by individual seals. *South African Journal of Wildlife Research* **34**: 45–54

Ellis S, Croxall JP, Cooper J (eds) (1998) *Penguin Conservation Assessment and Management Plan*. Apple Valley, USA, IUCN/SSC Conservation Breeding Specialist Group

Friend M (1999) Avian cholera. In: Friend M, Franson JC (eds) *Field Manual of Wildlife Diseases: General Field Procedures and Diseases of Birds*. US Geological Services, National Wildlife Health Center, Madison, Wisconsin, pp 75–92

Garzoli SL, Gordon AL (1996) Origins and variability of the Benguela Current. *Journal of the Geophysical Research* **101**: 897–906

Gilman EL (2001) Intergrated managemet approach to address incidental mortality of seabirds in longline fisheries. *Aquatic Conservation: Marine and Freshwater Ecosystem* **11** 391– 414

Gilman EL, Brothers N, Kobayashi D (2005) Principles and approaches to abate seabirds bycatch in longline fisheries. *Fish and Fisheries* **6**: 35–49

Goldsworthy SD (1999) Maternal attendance behaviour of sympatrically breeding Antarctic and subantarctic fur seals, *Arctocephalus* spp., at Macquarie Island. *Polar Biology* **21**: 316–325

Green K, Williams R, Handasyde K, Burton HR, Shaughnessy PD (1990) Interspecific and intraspecific differences in the diets of fur seals, A*rctocephalus* species (Pinnipedia: Otariidae), at Macquarie Island. *Australian Mammalogy* **13**: 193–200

Grim KC, van der Merwe E, Sullivan M, Parsons NJ, McCutchan TF, Cranfield MR (2003) *Plasmodium juxtanucleare* associated with mortality in black-footed penguins (*Spheniscus demersus*) admitted to a rehabilitation center. *Journal of Zoo and Wildlife Medicine* **34**: 250–255

Guinet C, Jouventin P, Georges JY (1994) Long term population changes of fur seals *Arctocephalus gazella* and *A. tropicalis* on subantarctic (Crozet) and subtropical (St. Paul and Amsterdam) islands and their possible relationship to El Niño Southern Oscillation. *Antarctic Science* **6**: 473–478

Harwood J (1992) Assessing the competitive effects of marine mammal predation on commercial fisheries. *South African Journal of Marine Science* **12**: 689–693

Hockey PAR, Dean WRJ, Ryan PG (eds) (2005) *Roberts Birds of Southern Africa*. (7th edn). John Voelcker Bird Book Fund, Cape Town

Hockey PAR, Hallinan J (1981) Effect of human disturbance on the breeding behaviour of jackass penguins *Spheniscus demersus*. *South African Journal of Wildlife Research* **1**: 59–62

Hofmeyr GJG, Bester MN (1993) Predation on king penguins by Antarctic fur seals. *South African Journal of Antarctic Research* **23**: 71–74

Hofmeyr GJG, Bester MN, Jonker FC (1997) Changes in population size and distribution of fur seals at Marion Island. *Polar Biology* **17**: 150–158

Isaksen K, Huyser O, Kirkman S, Wanless R, Wilson W (2000) Studies of seabirds and seals at Bouvetoya 1998/99. *Norsk Polarinstitutt Internrapport* **2**: 8

Kemper J, Roux J-P, Bartlett PA, Chesselet YJ, James JAC, Jones R, Wepener S, Molloy FJ (2001) Recent population trends of African penguins *Spheniscus demersus* in Namibia. *South African Journal of Marine Science* **23**: 429–434

Kemper J, Underhill LG, Crawford RJM, Roux J-P (2007) Revision of the conservation status of seabirds and seals in the Benguela ecosystem. In: Kirkman SP (ed) *Final report of BCLME (Benguela Current Large Marine Ecosystem) project on Top Predators as Biological Indicators of Ecosystem Change in the BCLME*. Avian Demography Unit, Cape Town, pp 325–342

Kerley GIH (1987) *Arctocephalus tropicalis* on the Prince Edward Islands. In: Croxall JP and Gentry RL (eds) *Status, Biology and Ecology of Fur Seals: Proceedings of an International Symposium and Workshop, Cambridge, 23–27 April 1984. National Oceanic and Atmospheric Administration Technical Report, National Marine Fisheries Service* **51**: 61–64

Kirkman SP (ed.) (2007) *Final Report of BCLME (Benguela Current Large Marine Ecosystem) Project on Top Predators as Biological Indicators of Ecosystem Change in the BCLME*. Avian Demography Unit, Cape Town

Laws RM (1985) The ecology of the Southern Ocean. *American Scientist* **73**: 26–40

Makhado AB (2002) The diet of fur seals (*Arctocephalus tropicalis* and *A. gazella*) at Marion Island. MSc thesis. University of Pretoria, Pretoria

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) Efficacy of culling seals seen preying on seabirds as a means of reducing seabird mortality. *African Journal of Ecology* **47**: 335–340

Marks MA, Brooke RK, Gildenhuys AM (1997) Cape fur seal (*Arctocephalus pusillus pusillus)* predation on Cape cormorants (*Phalacrocorax capensis)* and other birds at Dyer Island, South Africa. *Marine Ornithology* **25**: 9–12

McQuaid CD, Froneman PW (2004) The Southern Ocean Group at Rhodes University: seventeen years of biological oceanography in the Southern Ocean reviewed. *South African Journal of Marine Science* **100**: 571–577

Musick JA(ed.) (1999) *Life in the Slow Lane: Ecology and Conservation of Long-Lived Marine Animals*. American Fisheries Society Symposium 23. American Fisheries Society, Bethesda, Maryland, USA

Nel DC, Ryan PG, Watkins BP (2002) Seabirds mortality in the Patagonian toothfish longline fisheries around Prince Edward Islands, 1996–2000. *Antarctic Science* **14**: 151–161

Oosthuizen WH, Meyer 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**(1): 26–29

Pakhomov EA, Froneman PW (1999) Prince Edward Islands pelagic ecosystem, south Indian Ocean: a review of achievements, 1976–1990. *Journal of Marine Systems* **18**: 355–367

Parsons NJ, Underhill LG (2005) Oiled and injured African penguins *Spheniscus demersus* and other seabirds admitted for rehabilitation in the Western Cape, South Africa, 2001 and 2002. *African Journal of Marine Science* **27**: 289–296

Payne MR (1977) Growth of a fur seal population. *Philosophical Transaction of Royal Society of London Series B* **279**: 67–79

Penney RL, Lowry G (1967) Leopard seal predation of Adelie penguins. *Ecology* **48**: 878−882

Perissinotto R, McQuaid CD (1992) Land-based predator impact on vertically migrating zooplankton and micronekton advected to a Southern Ocean archipelago. *Marine Ecology Progress Series* **80**: 15–27

Petersen SL, Honig MB, Nel DC (2007) The impact of longline fisheries on seabirds in the Benguela Current Large Marine Ecosystem. In: Petersen S, Nel D, Omardien A (eds) *Towards an Ecosystem Approach to Longline Fisheries in the Benguela: An assessment of impacts on seabirds, sea turtles and sharks.* WWF South Africa Report Series-2007/Marine/001, pp 1–94

Petersen SL, Nel DC, Currie H (2007) Reducing vulnerable bycatch in longline fisheries operating in the Benguela Current Large Marine Ecosystem: implications for policy, management and research. In: Petersen S, Nel D, Omardien A (eds) *Towards an Ecosystem Approach to Longline Fisheries in the Benguela: An assessment of impacts on seabirds, sea turtles and sharks.* WWF South Africa Report Series-2007/Marine/001

Pillay P (2001) Competion for anchovy (*Engraulis capensis*) and sardine (*Sardinops sagax*) between the Cape gannet (*Morus capensis*), Cape fur seal (*Arctocephalus pussilus pussilus*) and the purse-seine fishery on the west coast of South Africa. MSc Thesis, University of Cape Town, Cape Town

Prince Edward Islands Management Plan Working Group (1996) *Prince Edward Islands Management Plan.* Department of Environmental Affairs and Tourism, Pretoria, South Africa

Randall RM, Randall BM (1990) Cetaceans as predators of jackass penguins *Spheniscus demersus*: deductions based on behaviour. *Marine Ornithology* **18**: 9–12

Randall BM, Randall RM, Compagno LJV (1988) Injuries to jackass penguins (*S. demersus*): evidence for shark involvement. *Journal of Zoology* **214**: 589–599

Rebelo AG (1984) Cape fur seal *Arctocephalus pusillus* kills jackass penguin *Spheniscus demersus* on land. *Cormorant* **12**: 111

Rogers T, Bryden MM (1995) Predation of Adélie penguins (*Pygoscelis adeliae*) by leopard seals (*Hydrurga leptonyx*) in Prydz Bay, Antarctica. *Canadian Journal of Zoology* **73**: 1001–1004

Roux J-P (1987) Recolonization 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. National Oceanic and Atmospheric Administration Technical Report, National Marine Fisheries Service* **51**: 189–194

Ryan PG, Moloney CL (1988) Effect of trawling on bird and seal distributions in the southern Benguela region. *Marine Ecology Progress Series* **45**: 1–11

Ryan PG, Cooper J, Dyer BM, Underhill LG, Crawford RJM, Bester MN (2003) Counts of surface-nesting seabirds breeding at subantarctic Prince Edward Island, summer 2001/02. *African Journal of Marine Science* **25**: 441–451

Schultz A, Petersen SL (2003) Absence of haematozoa in breeding macaroni *Eudyptes chrysolophus* and rockhopper *E. chrysocome* penguins at Marion Island. *African Journal of Marine Science* **25**: 499–502

Shannon LV (1985) The Benguela ecosystem, Part I. Evolution of the Benguela, physical features and processes. *Oceanography and Marine Biology: An Annual Review* **23**: 105–182

Shannon LV, Field JG (1985) Are fish stocks food-limited in the southern Benguela pelagic ecosystem? *Marine Ecology Progress Series* **22**: 7–19

Shannon LJ, Crawford RJM (1999) Management of the African penguin *Spheniscus demersus* insights from modelling. *Marine Ornithology* **27**: 119–128

Shannon LV, Jarre-Teichmann A (1999) A model of trophic flows in the northern Benguela upwelling system during the 1980s. *South African Journal of Marine Science* **21**: 349–366

Shannon LV, Crawford RJM, Pollock D, Hutchings L, Boyd AJ, Taunton-Clark J, Badenhorst A, Melville-Smith R, Augustyn CJ, Cochrane KL Hampton I, Nelson G, Japp SW, Tarr RJQ (1992) The 1980s – a decade of change in the Benguela ecosystem. *African Journal of Marine Science* **12**: 271–296

Shaughnessy PD (1978) Cape fur seals preying on seabirds. *Comorant* **5**: 31

Shaughnessy PD (1980) Influence of cape fur seals on jackass penguin numbers at Sinclair Island. *South African Journal of Wildlife Research* **10**: 18–21

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**: 61

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*. George Allen and Unwin, London, pp 119–134

Shaughnessy PD, Fletcher L (1987) Fur seals, *Arctocephalus spp.*, at Macquarie Island. *National Oceanic and Atmospheric Administration Technical Report, National Marine Fisheries Service* **51**: 177–188

Shelton PA, Crawford RJM, Cooper J, Brooke RK (1984) Distribution, population size and conservation of the jackass penguin *Spheniscus demersus*. *South African Journal of Marine Science* **2**: 217–257

Simeone A, Bernal M (2000) Effects of habitat modification on breeding seabirds: a case study in central Chile. *Waterbird* **23**: 449–456

Underhill LG, Crawford RJM, Wolfaardt AC, Whittington PA, Dyer BM, Leshoro TM, Ruthenberg M, Upfold L, Visagie J (2006) Regionally coherent trends in colonies of African penguins (*Spheniscus demersus*) in the Western Cape, South Africa, 1987–2005. *African Journal of Marine Science* **28**: 697–704

Van der Lingen CD, Coetzee JC, Demarcq H, Drapeau L, Fairweather TP, Hutchings L (2005) An eastward shift in the distribution of southern Benguela sardine. *GLOBEC International Newsletter* **11**(2): 17–22

Walker TR, Boyd IL, McCafferty DJ, Huin N, Taylor RI, Reid K (1998) Seasonal occurrence and diet of leopard seals *Hydruga leptonyx* at Bird Island, South Georgia. *Antarctic Science* **10**: 75–81

Waller LJ, Underhill LG (2007) Management of avian cholera *Pasteurella multocida* outbreaks on Dyer Island, South Africa, 2002–2005. *African Journal of Marine Science* **29**: 105–111

White WB, Peterson RG (1996) An Antarctic circumpolar wave in surface pressure, temperature and sea-ice extent. *Nature* **380**: 699–702

Wiesel I (2006) Predatory and foraging behaviour of brown hyenas (*Parahyaena brunnea* Thunberg, 1820) at Cape Fur Seal (*Arctocephalus pusillus pusillus* Schreber, 1776) colonies. PhD thesis, University of Hamburg, Hamburg, Germany

Williams AJ, Steele WK, Cooper J, Crawford RJM (1990) Distribution, population size and conservation of Hartlaub's gull *Larus hartlaubii. Ostrich* **61**: 66–75

Williams AJ, Ward VL (2002) Catastrophic cholera: coverage, causes, context, conservation and concern. *Bird Numbers* **11**: 2–6

Woehler EJ (ed.) (2007) Abstracts of oral and poster presentations. 6th International Penguin Conference, Hobart, Australia

Wynen LP, Goldsworthy SD, Guinet C, Bester MN, Boyd IL, Gjertz I, Hofmeyr GJG, White RWG, Slade R (2000) Postsealing genetic variation and population structure of two species of fur seal (*Arctocephalus gazella* and *A. tropicalis*). *Molecular Ecology* **9**: 299–314

Table 1: Estimates of the conservation status and the population sizes of seabirds that breed in southern Africa. The proportions of the southern African and global populations of each species that breed in South Africa are indicated (Anon. 2007).

Species	**Conservation status**	**Southern African population (breeding pairs)**	**South African population (breeding pairs)**	**Proportion of southern African population in South Africa**	**Proportion of global population in South Africa**
African penguin	Vulnerable	62 300	56 900	0.91	0.91
Leach's storm petrel	Endangered	25	25	1.00	0.00
Great white pelican	Near-threatened	7 350	3 650	0.50	0.08
Cape gannet	Vulnerable	166 200	148 000	0.89	0.89
Cape cormorant	Near-threatened	215 500	94 200	0.44	0.44
Bank cormorant	Endangered	3 132	971	0.31	0.31
Crowned cormorant	Near-threatened	2 922	1 850	0.63	0.63
White-breasted cormorant	Least concern	4 100	1 949	0.48	0.03
Kelp gull	Least concern	23 000	18 600	0.81	0.02
Hartlaub's gull	Least concern	7 325	6 561	0.90	0.90
Grey-headed gull	Least concern	3 255	2 649	0.81	0.26
Caspian tern	Least concern	500	435	0.87	0.01
Roseate tern	Vulnerable	250	250	1.00	0.01
Swift tern	Least concern	6 686	6 336	0.95	0.06
Damara tern	Near-threatened	4 620	120	0.03	0.03

Table 2: Estimates of the conservation status and the population sizes of surface-nesting seabirds at the Prince Edward Islands (South African territory). The proportions of the global populations of each species that breed at the Prince Edward Islands are indicated. Information on conservation status from Barnes (2000) and on population size and proportion from Crawford and Cooper (2003)

Species	**Conservation status**	**Annual breeding population at Prince Edward Islands (pairs)**	**Proportion of global population at the Prince Edward Islands**
King penguin	Least Concern	221 000	0.13
Gentoo penguin	Near-Threatened	1 319	<0.01
Macaroni penguin	Near-Threatened	372 000	0.04
Eastern rockhopper penguin	Near-Threatened	112 000	0.17
Wandering albatross	Vulnerable	3 719	0.44
Grey-headed albatross	Vulnerable	9 229	0.10
Indian Yellow-nosed albatross	Vulnerable	7 500	0.21
Dark-mantled sooty albatross	Near-Threatened	1 584	0.10
Light-mantled sooty albatross	Near-Threatened	329	0.02
Northern giant petrel	Near-Threatened	595	0.05
Southern giant petrel	Near-Threatened	2 830	0.09
Crozet shag	Endangered	394	0.33
Subantarctic skua	Least Concern	796	0.11
Kelp gull	Least Concern	54	<0.01
Antarctic tern	Least Concern	<15	<0.01
Kerguelen tern	Endangered	ca 60	0.03

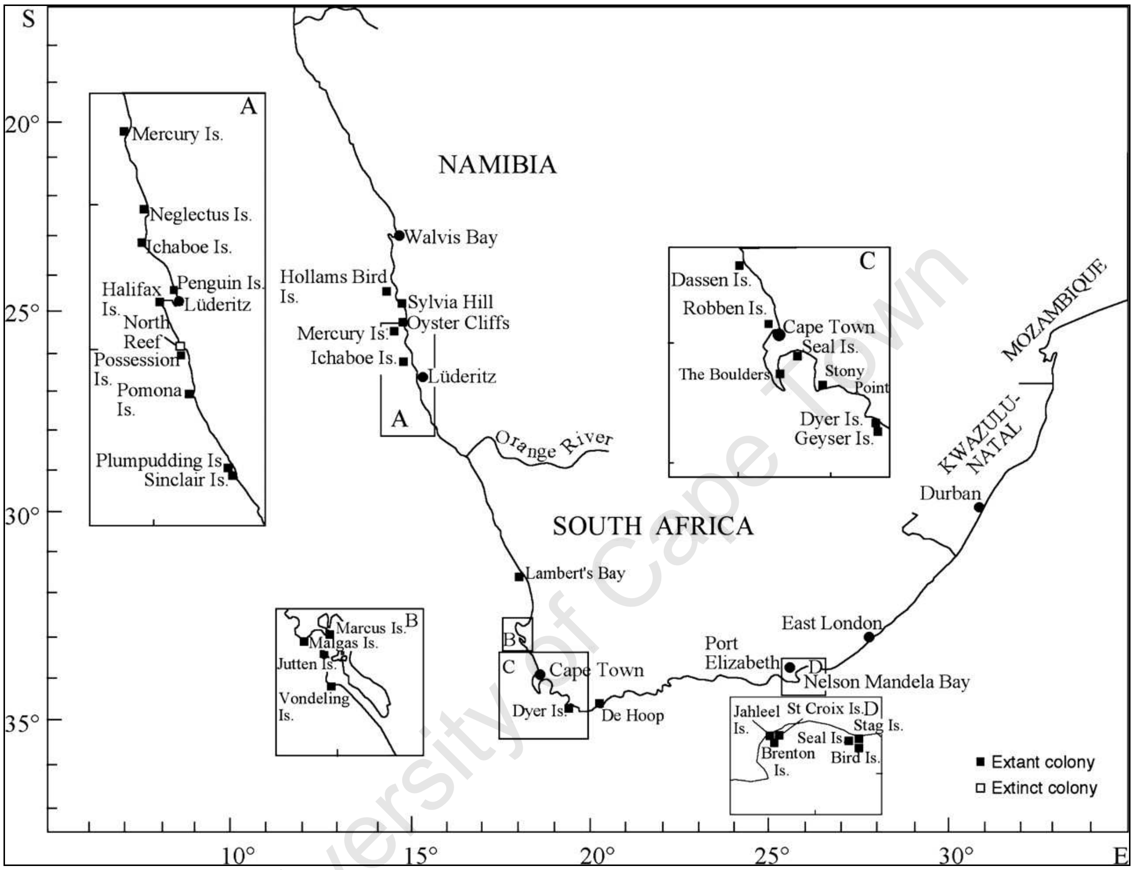

Figure 1: Locations of important seabird breeding localities in southern Africa (modified from Kirkman 2007)

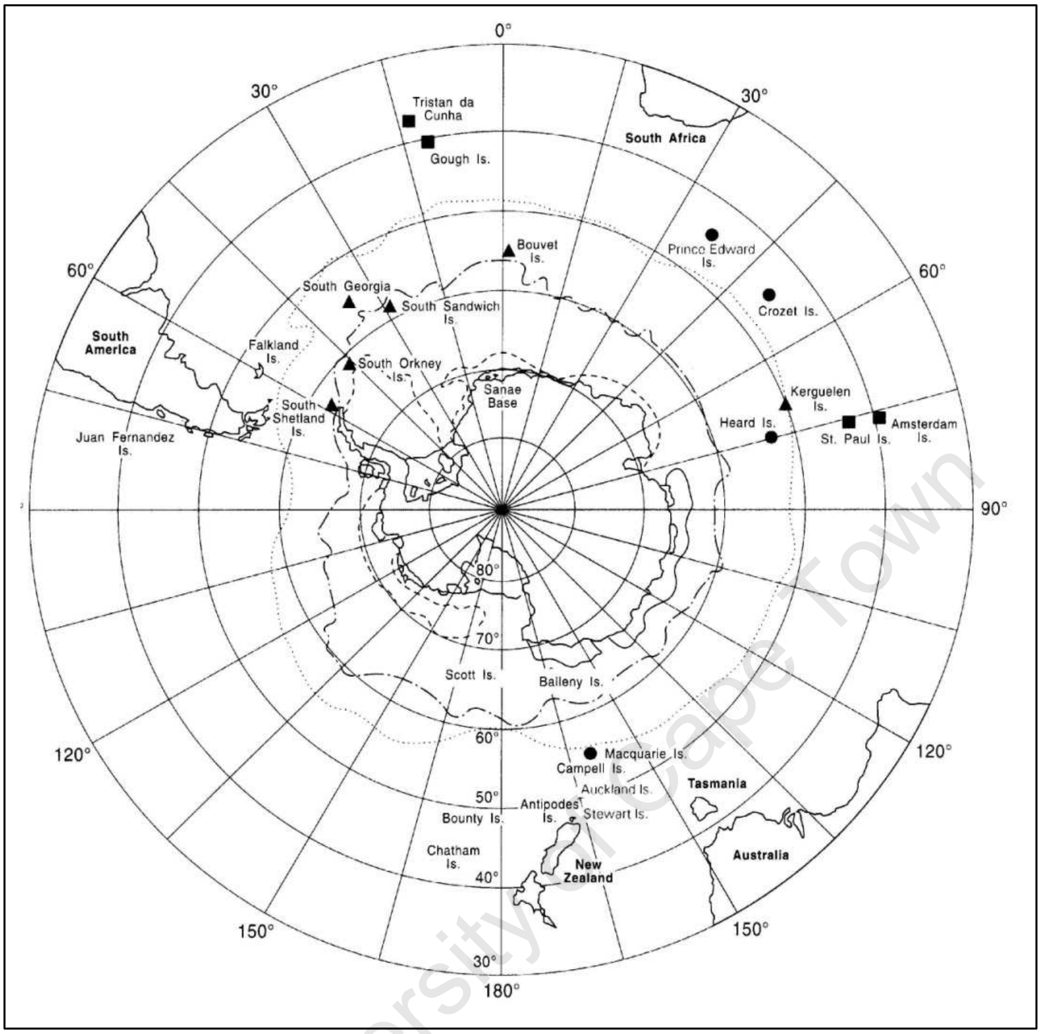

Figure 2: Map of the Southern Ocean showing the Prince Edward Islands and some other subantarctic Islands (from Hofmeyr *et al.* 1997) The mean positions of the Atarctic Polar Front (….), the winter pack ice limit (_. _. _) and the summer pack ice limit (_ _ _) are indicated.

CHAPTER 2

Impact of predation by Cape fur seals *Arctocephalus pusillus pusillus* on Cape gannets *Morus capensis* at Malgas Island, Western Cape, South Africa

Impact of predation by Cape fur seals *Arctocephalus pusillus pusillus* on Cape gannets *Morus capensis* at Malgas Island, Western Cape, South Africa

ABSTRACT

Cape fur seals *Arctocephalus pusillus pusillus* were estimated to kill some 6 000 Cape gannet *Morus capensis* fledglings around Malgas Island in the 2000/01 breeding season, 11 000 in 2003/04 and 10 000 in 2005/06. This amounted to about 29%, 83% and 57% of the overall production of fledglings at the island in these breeding seasons respectively. Preliminary modelling suggests this predation is not sustainable. There was a 25% reduction in the size of the colony, the second largest of only six extant Cape gannet colonies, between 2001/02 and 2005/06. There has been a large increase in predation by Cape fur seals on seabirds around southern African islands since the mid-1980s, coincidental with both an increase in the seal population, altered management of the islands and an altered distribution of prey for gannets and seals. At Malgas Island, most gannet fledglings were killed between 10h00 and 18h00, the period when most are in the water around the island, from mid-January to mid-March, the main fledging period. The Cape gannet is classified as Vulnerable.

INTRODUCTION

Cape fur seals *Arctocephalus pusillus pusillus* increased off southern Africa throughout the 20th century, after having been exploited to low levels of abundance at the end of the 19th century (Shaughnessy 1984, Crawford *et al*. 1989, David 1989). The population in 1993 numbered 1.5–2 million animals (Butterworth *et al*. 1995, Best *et al*. 1997). Conversely, the conservation status of several seabird species deteriorated in the 20th century (Barnes 2000, BirdLife International 2000). For example, there were about 1.45 million adult African penguins *Spheniscus demersus* at Dassen Island in 1930, whereas the global population was <0.2 million adults in 2000 (Shannon and Crawford 1999, Hockey *et al*. 2005).

The Cape gannet *Morus capensis* breeds only in southern Africa; at three colonies in Namibia and three in South Africa (Crawford *et al*. 1983). The species is regarded as Vulnerable (Barnes 2000), following a decrease in the global population of 100 000 pairs, from 250 000 pairs in the late 1960s to about 150 000 pairs at present (Crawford *et al*. 2007). At the close of the 20th century, it was observed that Cape fur seals, almost all young males, were inflicting heavy mortality on Cape gannet fledglings as they left Malgas Island (David *et al*. 2003). At that time there were about 50 000 pairs of Cape gannets on the island, one-third of the global population (Crawford *et al*. 2007). It was uncertain whether such mortality was sustainable. Hence, observations were initiated in an attempt to quantify the loss of fledglings to seals. This study examines the impact of the seals on the Cape Gannet population at Malgas Island.

MATERIAL AND METHODS

Malgas Island (33°03'S, 17°55'E) lies about 800m from the mainland on the west coast of South Africa. It is located at the northern entrance of Saldanha Bay in the Benguela upwelling system, which provides the abundant food resources on which Cape gannets feed (Berruti *et al*. 1993).

At Malgas Island, Cape gannets lay their first clutches from 15 August to 1 November, with a peak from 8 September to 12 October (Staverees *et al*. 2008). Incubation lasts 43–44 days, commencing as soon as the egg is laid (Jarvis 1970). Chicks leave their nests 90–105 days after hatching (Jarvis 1970) and can spend up to six days at the colony edge before departing to sea (Hockey *et al*. 2005). Therefore, at Malgas Island, most chicks fledge from mid-January to mid-March.

Observations on gannet mortality around Malgas Island were undertaken in a systematic manner during three gannet breeding seasons, the austral summers of 2000/01, 2003/04 and 2005/06. In 2000/01, the island was visited during 24–27 November, 13–20 December, 12–19 January and 5–13 February. In 2003/04, it was visited during 8–12 December, 9–16 January, 23–29 January, 6–12 February, 20 February–5 March and 12–25 March. In 2005/06, observations were made during 23–31 January and 15 February– 8 March. Binoculars were used to scan waters around the island for predatory activities by seals. Often, birds hovering overhead gave the first indication of an attack on a gannet by a seal (du Toit *et al.* 2004). Each mortality of a Cape gannet was recorded. The dark plumage of a fledgling Cape gannet contrasts sharpely with the white plumage of adult birds.

Malgas Island is 8.5ha in extent (Rand 1963) and it is not possible to have a view of the entire island from any particular vantage point. In 2000/01, two observers kept watch over different areas of the island during every alternate hour. Vantage points near the sea were used and it was roughly gauged that two-thirds of the area around the island was covered. On one day observations began at 07h00 and ended at 18h00 and on the following day they commenced at 08h00 and finished at 19h00. This pattern was then repeated. Hence, on each day an observer conducted observations for six hours. To estimate the number of birds killed each day, the number observed killed was doubled (to account for periods when no watches were kept. This assumes that the rate of predation did not change greatly from one hour to the next (see Figure 2). The number observed to be killed was multiplied further by 100/67 (to account for that portion of the waters around the island that was not covered). This calculation makes the assumption that the predation rate was the same for all areas around the island.

In 2003/04 and 2005/06, a single observer kept watch from a vantage point, different to those used in 2000/01, on top of a building, from which it was again gauged that only 67% of the waters around the island were covered. On each day, observations were made from 06h00 until 18h00, which approximated dawn and dusk, except for breaks totalling about one hour. Therefore, the numbers of gannet chicks observed to be killed in the 12h period were increased by factors of 12/11 and 100/67.

Based on observations made during 2000/01, it was concluded that no fledglings were killed by seals before 25 November. There were <200 gannet chicks on the island on 22 March 2005 (ABM pers. obs.), so it was also assumed that no fledglings were lost to seals after 31 March.

Total numbers of gannet fledglings killed by seals in the three breeding seasons were obtained by estimating values for days when no observations were made. Average daily predation rates were calculated for weeks when observations were made. For 2005/06, no observations were made before 23 January. Therefore, for 2005/06, the average value for 8–20 December was taken to be the average daily value observed during 13–20 December 2000 and 8–12 December 2003. For days when no observations were conducted, the average predation rates were estimated by interpolating linearly between the average values for the weeks immediately preceding and following the period with no information. For days before observations commenced, the interpolation was between zero on 24 November and the average of the first week of observations. For days after the last observations were conducted, it was between the average of the last week of observations and zero on 1 April.

To investigate the influence of time of day on predation rate, observations were made during the 2003/04 and 2005/06 breeding seasons from 05h00 to 20h00. Incidents of predation were pooled to calculate the total numbers of gannet fledglings seen to be killed by seals in intervals of one hour. Numbers of gannet fledglings at Malgas Island in the three breeding seasons were estimated as the product of the number of pairs of gannets breeding at the island and the average breeding success of each pair. Numbers of pairs breeding at the island were obtained from measurements of the area occupied by breeding birds and the density of nests. The area occupied by breeding birds was measured on aerial photographs taken in October or December of each year (Crawford *et al*. 1983, Crawford *et al*. 2007). At Malgas Island, no trend in the density of gannet nests was observed during 1994/95–2005/06, so the mean density over that period (2.84 ± 0.19 nests m–2, Crawford *et al*. 2007) was applied to all three seasons.

The breeding success of gannets was obtained by monitoring the numbers of chicks fledged by a known number of breeding pairs (0.408 chicks per pair from 49 nests in 2000/01, 0.416 chicks per pair from 317 nests in 2003/04, R Navarro in litt., and 0.020 chicks from 201 nests in 2005/06). The nests were monitored as described by Staverees *et al*. (2008). In 2005/06, the estimated production of fledglings was considerably less than the estimated loss to seals, suggesting that the production at monitored nests was not representative of the gannet colony as a whole. Therefore, the mean production of fledged chicks observed during the period 1987/88–2005/06 (the overall period of observations) was applied to that season.

The sustainability of the rate of predation of seals on gannet fledglings was investigated by estimating the level of breeding success necessary to maintain a population of Cape gannets in equilibrium. The following equation was used (Crawford *et al*. 2006):

$$B = 2(1 - S_a)(1/ S_a)^2(1/ S_i)^2$$

where B = breeding success (chicks per pair per year), S_a is the proportion of birds older than two years surviving in any year, and S_i is the proportion of post-fledging birds younger than two years surviving in any year. For Sa, the standard error of estimates ranged from 0.02 to 0.05 (Altwegg *et al.* 2008).

It was assumed that all Cape gannets breed for the first time when four years old and in every subsequent year thereafter (Crawford 1999). The equation shows the number of chicks that must successfully fledge in order to replace the number of breeding adults that die. The factor 2 is included because it is pairs of birds that produce chicks. The proportion of adults dying each year is $(1 - S_a)$. The terms $(1/S_a)^2$ and $(1/S_i)^2$ are included to account for mortality between the ages of two and four and from fledging to Age 2 respectively, both periods of two years. Values used for S_a and S_i were 0.93 and 0.71 respectively (Crawford 1999).

RESULTS

Numbers of fledglings killed

Numbers of Cape gannet fledglings estimated to be killed by seals are shown in Figure 1 for each day on which observations were made, for each of the three seasons during which information was collected. Interpolated estimates for days on which no observations were made are also shown. In 2000/01, there was an increase in numbers of fledglings killed between late November and February. In 2003/04, the highest mortality was observed from 20 February to 5 March, with the estimated numbers of fledglings killed per day decreasing on either side of that period.

In 2005/06, there was little difference in the mean numbers of fledglings killed in late January and late February/early March. It was estimated that seals killed about 5 700, 10 800 and 10 100 Cape gannet fledglings during the 2000/01, 2003/04 and 2005/06 breeding seasons respectively. In all three seasons, there was substantial variability from one day to the next in the loss of fledglings to seals (Figure 1). The maximum estimated number of fledglings killed by seals on any one day was 491 on 21 February 2004. The mean predation was ±11 chicks per day.

Diurnal trend and location of gannet fledglings killed

Few Cape gannet fledglings, 4.1% and 1.5%, were observed to be killed by seals before 10h00 or after 18h00 respectively (Figure 2). Most (94% of the total numbers observed in the 2003/04 and 2005/06 seasons) were killed between 10h00 and 18h00, with the highest rates of predation observed from 13h00 to 17h00 (3 918 or 62%). Almost all fledglings were killed in the sea after leaving the island at a distance of about 80m from the island. However, seals came ashore to kill two fledglings on land in 2004 and about 20 were taken in 2006 between 10m and 50m from the shore.

Proportions of fledglings killed

The areas occupied by breeding Cape gannets were 1.69ha in 2000/01, 1.09 in 2003/04 and 1.47 in 2005/06. The estimated numbers of gannets breeding in these three seasons were 48 000, 31 000 and 42 000 pairs respectively.

Average numbers of chicks fledged per pair of Cape gannets were 0.41 in 2000/01, 0.42 in 2003/04 and 0.02 in 2005/06. Therefore, some 19 680 chicks fledged in 2000/01, 13 020 in 2003/04 and 840 in 2005/06. The average breeding success of Cape gannets at Malgas Island during 1987/88–2005/06 was 0.42 chicks fledged per pair (RJM Crawford, unpublished data). If this average is used for 2005/06, 17 640 chicks would have fledged. The proportions of fledglings killed by seals were 29% in 2000/01, 83% in 2003/04 and 57% in 2005/06. The proportion of fledglings killed decreased as the area occupied by breeding gannets increased (Figure 3).

Sustainability of predation

The necessary average breeding success to maintain a population of Cape gannets in equilibrium, based on survival rates and age at breeding as estimated by Crawford (1999), is 0.32 chicks per pair per year. Once the estimated rates of mortality caused by seals (29%, 83%, 57%) have been incorporated, the average numbers of chicks successfully fledged by each pair $(\text{chicks/pair x } (1 - M)$, where M is the proportion of fledglings killed during fledging) is reduced to 0.07–0.30, which in each instance is less than the production required to sustain the population. In a deterministic model, a mortality of 24% of chicks fledging from the island would be sustainable, given the parameters used above ((0.42 x (1 – M)) = 0.32, where M is the proportion of fledglings killed during fledging, 0.42 is the average breeding success and 0.32 is the breeding success required to maintain a population of Cape gannets in equilibrium).

DISCUSSION

The need to impute data to estimate the overall numbers of Cape gannet fledglings killed by Cape fur seals around Malgas Island results in uncertainty in the estimates of proportions of fledglings that are killed. There were substantial gaps between periods in which observations were made, and there was also considerable day-to-day variation in numbers of fledglings observed to be killed (Figure 1). This variation could be attributable to wind conditions. On windy days, the chicks fledge by flying, and it is mainly on calm days that they swim and are killed by seals (ABM pers. obs). It was earlier estimated, using a conservative method of imputing missing values, that, in the 2000/01 season, seals killed 4 785 gannet fledglings around Malgas Island (David *et al*. 2003), a value lower than the 5 700 estimated in this study. In spite of the uncertainty, it is clear that, in each of the three breeding seasons investigated, a substantial proportion of Cape gannet fledglings (>20% and up to 83%) was killed by seals and that this mortality, particularly in 2003/04 and 2005/06, is not sustainable. This suggests the need to implement measures to reduce the mortality. From 1993–2001, 153 seals seen killing seabirds were shot around Malgas Island, leading to short-term decreases in mortality of Cape gannet fledglings (David *et al*. 2003).

That the present rate of mortality of fledglings is not sustainable is borne out by a decrease of 25% in the size of the Cape gannet colony at Malgas Island between 2001/02 and 2005/06 (Crawford *et al*. 2007), following a period of growth between the mid-1980s and the mid-1990s (Figure 4). Because Cape gannets commence breeding when aged about four years (Crawford 1999), a reduction in colony size could be expected about four years after rates of predation by seals became unsustainable. This would be subject to the provision that space was not limiting and that all mature gannets were breeding, which probably was the case, because even when the colony peaked at about 2ha in 1996/97 there were areas of the island that were not occupied by gannets or other breeding seabirds (RJMC pers. obs).

The increase of the Cape gannet colony at Malgas Island up until the mid-1990s suggests that before about 1990 any predation by seals on Cape gannet fledglings was sustainable, i.e. that seals killed less than about 24% of fledglings leaving the island. This in turn points to an increase in the rate of predation by seals on fledglings in recent years. In this regard, it is interesting to note that, in spite of intensive research on seabirds in southern Africa since the early 1950s, losses of seabirds to seals was not considered a major problem before the late 1980s.

During a parliamentary enquiry into the running of the Government Guano Islands and the sealing industry in 1906 and 1907, certain witnesses reported that seals killed penguins. The headman at Possession Island, one of the Namibian gannet colonies, had seen seals catching gannets 'but very rarely' (Shaughnessy 1978). In 1937, during the sealing season, Hewitt (1937) reported that examination of the stomach contents of seals indicated they had fed on penguins; he also observed penguins with wounds attributable to seals. Thereafter, occasional predation of seabirds around islands in southern Africa was reported in 1937 (a single event regarded as unusual; Rand 1959a), in the 1960s (Bourne and Dixon 1973), in the 1970s (Cooper 1974, Shaughnessy 1978) and in the early 1980s (Rebelo 1984). In the 1950s, a few seal stomachs examined contained seabird feathers, but Rand (1959a) considered some of these seals had scavenged on dead carcases of birds. Rand (1959b, p32) noted that 'young gannets evacuate their breeding grounds with great success. Only very few are drowned when they leave the islands for the first time.' Had seals killed large numbers of gannet fledglings at that time, it would not have been unnoticed by Rand, especially because many fledglings, after being attacked by seals, return to Malgas Island to die from their injuries (Navarro 2000). Considering the conservation status of seabirds at Bird Island, Lambert's Bay, where

Cape gannets breed, Jarvis and Cram (1971) made no mention of losses of gannets to seals. An assessment of the conservation status of Cape gannets in the early 1980s also made no mention of losses to seals (Crawford *et al*. 1983).

At Ichaboe Island, Namibia, between September 1991 and May 2000, 2 774 predation events by seals on seabirds were noted, including 932 on Cape gannets, many of which were fledglings (du Toit *et al*. 2004). In the 1994/95 and 1995/96 breeding seasons, seals killed 2 461 Cape Cormorant *Phalacrocorax capensis* fledglings around Dyer Island, Western Cape (Marks *et al.* 1997). In 1994/95, it was estimated that 7.3% of fledglings were killed at this locality (Marks *et al.* 1997). From 1987 to 2000, predation of African penguins at Lambert's Bay was deemed unsustainable (Crawford *et al*. 2001). From September 1997 to October 2002, seals killed 1 154 Cape gannets around Bird Island (Ward and Williams 2004).

In February 1987/88, seals killed at least 89 gannet fledglings as they left Malgas Island (Navarro 2000). In 1989/90, seals killed 1.2% of gannet fledglings at Malgas Island that had been banded but, because not all carcases were retrieved, a value of 2.5% was considered more likely. A minimum of 21 fledglings was killed on one day, and this rate was maintained throughout February, suggesting the loss of some 600 fledglings (Crawford and Robinson 1990). In 2000/01, some 30% of fledglings were being killed by seals, with the proportion taken increasing above 50% in 2003/04 and 2005/06.

Generally, seals have killed seabirds in the sea. The first observation in southern Africa of a seal killing a seabird ashore was of a bull catching an African penguin at Halifax Island in 1983 (Rebelo 1984). In 1995, a bull seal was observed killing an adult Cape gannet at Malgas Island (Crawford and Cooper 1996). In 2005, bull seals killed 200 adult Cape gannets at Lambert's Bay and caused abandonment of the entire colony there, some 11 000 pairs (Wolfaardt and Williams 2006).

The foregoing discussion suggests that there has been a large increase in the predation of seabirds by seals in southern Africa since the early 1980s, and especially in the last decade. Why this should be so is not entirely clear. While the islands were administered as guano islands, headmen at the islands had firearms and some shot seals that were seen preying on seabirds (RMJC pers. obs). The last collections of guano at South African islands were made at Malgas Island in 1985, Algoa Bay in 1988 and Lambert's Bay in 1991. The immediate shooting of seals seen killing seabirds would mean that the behaviour would not be learned by other animals. Some young seals were seen swimming with adults that were killing gannet fledglings (ABM pers. obs).

All 94 seals shot around Malgas Island, because they were preying on seabirds, were males aged 2–10 years (David *et al*. 2003). Predation of seabirds by Cape fur seals recorded by Shaughnessy (1978), Rebbelo (1984), Navarro (2000) and du Toit *et al*. (2004) was mainly by males. In a study off Namibia by Mecenero *et al*. (2005), very few scats of female seals contained remains of seabirds. Therefore, it appears that only a portion (young males) of the Cape fur seal population is responsible for the mortality inflicted on seabirds. For other species of seal, predation of seabirds has also been mainly by males (Bonner and Hunter 1982, Childerhouse *et al*. 2001).

It should also be noted that numbers of Cape fur seals increased throughout the 20th century, markedly so after the mid-1980s (Butterworth *et al*. 1995, Best *et al*. 1997).

South African harvests of seals decreased in the early 1980s and stopped in 1990 (Best *et al*. 1997, David *et al*. 2003). The higher numbers of seals may have led to increased interactions with seabirds.

Seals are opportunistic animals that utilise food discarded by fishing boats and take food from fishers (Wickens *et al.* 1992). Following the removal of large terrestrial predators from much of the southern African coastline, they have formed large mainland colonies (David 1989). Therefore, it is possible that their numbers are now higher than before the arrival of Europeans in southern Africa in the 1600s. By contrast, several seabirds, such as the African penguin, that are specialist feeders and compete with fisheries for food (Crawford 1998, 2004), had their breeding habitat altered through *inter alia* the removal of deposits of guano for agricultural use, and their populations decreased substantially during the 20th century (Hockey *et al*. 2005). Cape gannets construct their nests almost entirely from guano (Hockey *et al.* 2005), so the removal of guano leads to a loss of nesting material. Attempts were made to offset this by adding phosphatic sand to areas where Cape gannets breed (Ross and Randall 1990). However, in spite of this, the removal of too much guano sometimes reduced breeding success (Jarvis 1971, Randall and Ross 1979). The recent interactions between seals and seabirds off southern Africa are exacerbating the population decreases of seabirds caused by human perturbation of the marine ecosystem.

After 2000, there was a marked eastward shift in the distribution of sardine *Sardinops sagax* off South Africa (van der Lingen *et al.* 2005, Fairweather *et al*. 2006), reducing its availability to predators along South Africa's west coast. Sardine are fed upon by both Cape fur seals (Rand 1959a) and Cape gannets (Berruti *et al*. 1993). The eastward displacement of prey may have caused seals to feed more intensively on alternative prey, such as seabirds and especially fledglings which are easily caught (Navarro 2000). However, the surplus killing of seabirds by Cape fur seals observed in some studies (Navarro 2000, du Toit *et al*. 2003) indicates that killing may not be solely for food but possibly an extension of play behaviour on the part of the seals (Bonner and Hunter 1982).

Marks *et al*. (1997) recorded 12 attacks by seals on seabirds between 09h45 and 17h25. This is similar to the time of day when most gannet fledglings were killed at Malgas Island in this study (Figure 3), and corresponds to the time when most are leaving to sea (ABM pers. obs.). Most mortality on gannet fledglings at Malgas Island is inflicted from mid-January to mid-March, the main fledging period (Figure 1).

At several sub-Antarctic islands, fur seal populations have also been increasing after reductions of populations caused by harvesting (Bester *et al*. 2003). Other *Arctocephalus* species have been recorded feeding on seabirds, especially penguins (Bonner and Hunter 1982, Hofmeyr and Bester 1993). The recovery of seal populations may increase the frequency of such interactions and, as in South Africa, adversely affect the status of seabirds that are already of conservation concern (Crawford and Cooper 2003).

Acknowledgements — I thank the National Research Foundation (SANAP programme) and WWF-SA for supporting this research. We are grateful to all who assisted with observations of mortality of Cape gannet fledglings, including V Brookes, DAE Crawford, PJM Crawford, BM Dyer, JE Underhill and L Upfold. The Department of Environmental Affairs and Tourism, South African National Parks and South African

Navy provided logistical support for the surveys. We thank S Mecenero and WA Montevecchi for valuable comments on the manuscript. This paper is a contribution to the project LMR/EAF/03/02 of the Benguela Current Large Marine Ecosystem (BCLME) Programme.

REFERENCES

Barnes KN (2000) *The Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland*. BirdLife South Africa, Johannesburg, 169pp

Berruti A, Underhill LG, Shelton PA, Moloney C, Crawford RJM (1993) Seasonal and interannual variation in the diet of two colonies of the Cape gannet *Morus capensis* between 1977–78 and 1989. *Colonial Waterbirds* **16**: 158–175

Best PB, Crawford RJM, van der Elst RP (1997) Top predators in the southern Africa's marine ecosystem. *Transactions of the Royal Society of South Africa* **52**: 177–225

Bester MN, Ryan PG, Dyer BM (2003) Population numbers of fur seals at Prince Edward Island, Southern Ocean. *African Journal of Marine Science* **25**: 549–554

BirdLife International (2000) *Threatened Birds of the World*. Lynx Edicions and BirdLife International, Barcelona and Cambridge, 852pp

Bonner WN, Hunter S (1982) Predatory interactions between Antarctic fur seals, macaroni penguins and giant petrels. *British Antarctic Survey Bulletin* **56**: 75–79

Bourne WRP, Dixon TJ (1973) Observations of seabirds, 1967–1969. *Sea Swallow* **22**: 29–60

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

Childerhouse S, Dix B, Gales N (2001) Diet of New Zealand sea lions (*Phocarctos hookeri*) at the Auckland Islands. *Wildlife Research* **28**: 291–298

Cooper J (1974) The predators of the jackass penguin (*Spheniscus demersus*). *Bulletin British Ornithological Club* **94**: 21–24

Crawford RJM (1998) Responses of African penguins to regime changes of sardine and anchovy in the Benguela system. In: Pillar SC, Moloney CL, Payne AIL, Shillington FA (eds) *Benguela Dynamics: Impacts of Variability on Shelf-Sea Environments and their Living Resources. South African Journal of Marine Science* **19**: 355–364

Crawford RJM (1999) Seabird responses to long-term changes of prey resources off southern Africa. In: Adams NJ, Slotow RH (eds) *Proceedings of the 22nd International Ornithological Congress, Durban*. BirdLife South Africa, Johannesburg, pp 688–705

Crawford RJM (2004) Accounting for food requirements of seabirds in fisheries management — the case of the South African purse seine fishery. In: Shannon LJ, Cochrane KL, Pillar SC (eds) *Ecosystem Approaches to Fisheries in the Southern Benguela*. *African Journal of Marine Science* **26**: 197–203

Crawford RJM, Barham PJ, Underhill LG, Shannon LJ, Coetzee JC, Dyer BM, Leshoro TM, Upfold L (2006) The influence of food availability on breeding success of African penguins *Spheniscus demersus* at Robben Island, South Africa. *Biological Conservation* **132**: 119–125

Crawford RJM, Cooper J (1996) Cape fur seal *Arctocephalus pusillus* catches Cape gannet *Morus capensis* ashore at Malgas Island. *Marine Ornithology* **24**: 53–54

Crawford RJM, Cooper J (2003) Conserving surface-nesting seabirds at the Prince Edward Islands: the roles of research, monitoring and legislation. *African Journal of Marine Science* **25**: 415–426

Crawford RJM, David JHM, Shannon LJ, Kemper J, Klages NTW, Roux J-P, Underhill LG, Ward VL, Williams AJ, Wolfaardt AC (2001) African penguins as predators and prey — coping (or not) with change. In: Payne AIL, Pillar SC, Crawford RJM (eds) *A Decade of Namibian Fisheries Science. South African Journal of Marine Science* **23**: 435–447

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

Crawford RJM, Dundee BL, Dyer BM, Klages NTW, Meÿer MA, Upfold L (2007) Trends in numbers of Cape Gannets (*Morus capensis*), 1956/57–2005/06, with a consideration of the influence of food and other factors. *ICES Journal of Marine Science* **64**: 169–177

Crawford RJM, Robinson GA (1990) Impacts of seals on seabirds. Report of the Subcommittee of the Sea Fisheries Advisory Committee appointed at the request of the Minister of Environment Affairs and of Water Affairs, to advise the Minister on scientific aspects of sealing. Sea Fisheries Research Institute, Cape Town, pp 84–87

Crawford RJM, Shelton PA, Cooper J, Brooke RK (1983) Distribution, population size and conservation of the Cape gannet *Morus capensis*. *South African Journal of Marine Science* **1**: 153–174

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

David JHM, Cury P, Crawford RJM, Randall RM, Underhill LG, Meyer MA (2003) Assessing conservation priorities in the Benguela ecosystem, South Africa:

analysing predation by seals on threatened seabirds. *Biological Conservation* **114**: 289–292

du Toit M, Bartlett PA, Bester MN, Roux J-P (2004) Seal-seabird predation at Ichaboe Island, Namibia: prey selection by individual seals. *South African Journal of Wildlife Research* **34**: 45–54

du Toit M, Boere GC, Cooper J, de Villiers MS, Kemper J, Lenten B, Petersen SL, Simmons RE, Underhill LG, Whittington PA, Byers OP (2003) Conservation Assessment and Management Plan for Southern African Coastal Seabirds. Avian Demography Unit, Cape Town, and Conservation Breeding Specialist Group, Apple Valley, Minnesota, p 28

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

Hewitt JHC (1937) The Government Guano Islands. *Farming in South Africa* **12**: 591–592

Hockey PAR, Dean WRJ, Ryan PG (2005) *Roberts Birds of Southern Africa* (7th edn). John Voelcker Bird Book Fund, Cape Town, 1296pp

Hofmeyr GJG, Bester MN (1993) Predation on king penguins by Antarctic fur seals. *South African Journal of Antarctic Research* **23**: 71–74

Jarvis MJF (1970) Interactions between man and the South African gannet *Sula capensis*. *Ostrich Supplement* **8**: 497–513

Jarvis MJF (1971) Ethology and ecology of the South African gannet, *Sula capensis*. PhD Thesis, University of Cape Town, South Africa, 253pp

Jarvis MJF, Cram DL (1971) Bird Island, Lamberts Bay, South Africa: an attempt at conservation. *Biological Conservation* **3**: 269–273

Marks MA, Brooke RK, Gildenhuys AM (1997) Cape fur seal *Arctocephalus pusillus* predation on Cape cormorants *Phalacrocorax capensis* and other birds at Dyer Island, South Africa. *Marine Ornithology* **25**: 9–12

McMahon CR, Holley D, Robinson S (1999) The diet of itinerant male Hooker's sea lions, *Phocarctos hookeri*, at sub-Antarctic Macquarie Island. *Wildlife Research* **26**: 839–846

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

Navarro RA (2000) Cape fur seal predation on Cape gannet fledglings. *Bird Numbers* **9**(2): 15–16

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

Rand RW (1959b) The biology of guano-producing seabirds. The distribution, abundance and feeding habits of the Cape gannet, *Morus capensis*, off the south-western coast of the Cape Province. *Investigational Report, Division of Sea Fisheries, South Africa* **39**: 1–36

Rand RW (1963) The biology of guano-producing seabirds. 4. Composition of colonies on the Cape islands. *Investigational Report, Division of Sea Fisheries, South Africa* **46**: 1–32

Randall R, Ross GJB (1979) Increasing population of Cape gannets on Bird Island, Algoa Bay, and observations on breeding success. *Ostrich* **50**: 168–175

Rebelo AG (1984) Cape fur seal *Arctocephalus pusillus* kills jackass penguin *Spheniscus demersus* on land. *Cormorant* **12**: 111

Ross GJB, Randall RM (1990) Phosphatic sand removal from Dassen Island: effect on penguin breeding and guano harvests. *South African Journal of Science* **86**: 172–174

Shannon LJ, Crawford RJM (1999) Management of the African penguin *Spheniscus demersus* — insight from modelling. *Marine Ornithology* **27**: 119–128

Shaughnessy PD (1978) Cape fur seals preying on seabirds. *Comorant* **5**: 31

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

Staverees L, Crawford RJM, Underhill LG (2008) Factors influencing the breeding success of Cape gannets *Morus capensis* at Malgas Island, 2002/03. *Ostrich* **79**: 67–73

van der Lingen CD, Coetzee JC, Demarcq H, Drapeau L, Fairweather TP, Hutchings L (2005) An eastward shift in the distribution of southern Benguela sardine. *GLOBEC International Newsletter* **11**(2): 17–22

Ward VL, Williams AJ (2004) Coastal killers: causes of seabird mortality. *Bird Numbers* **13**(1): 14–17

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

Wolfaardt A, Williams AJ (2006) Sealed off: predation threatens seabirds and tourism. *Africa — Birds & Birding* **11**(2): 61–67

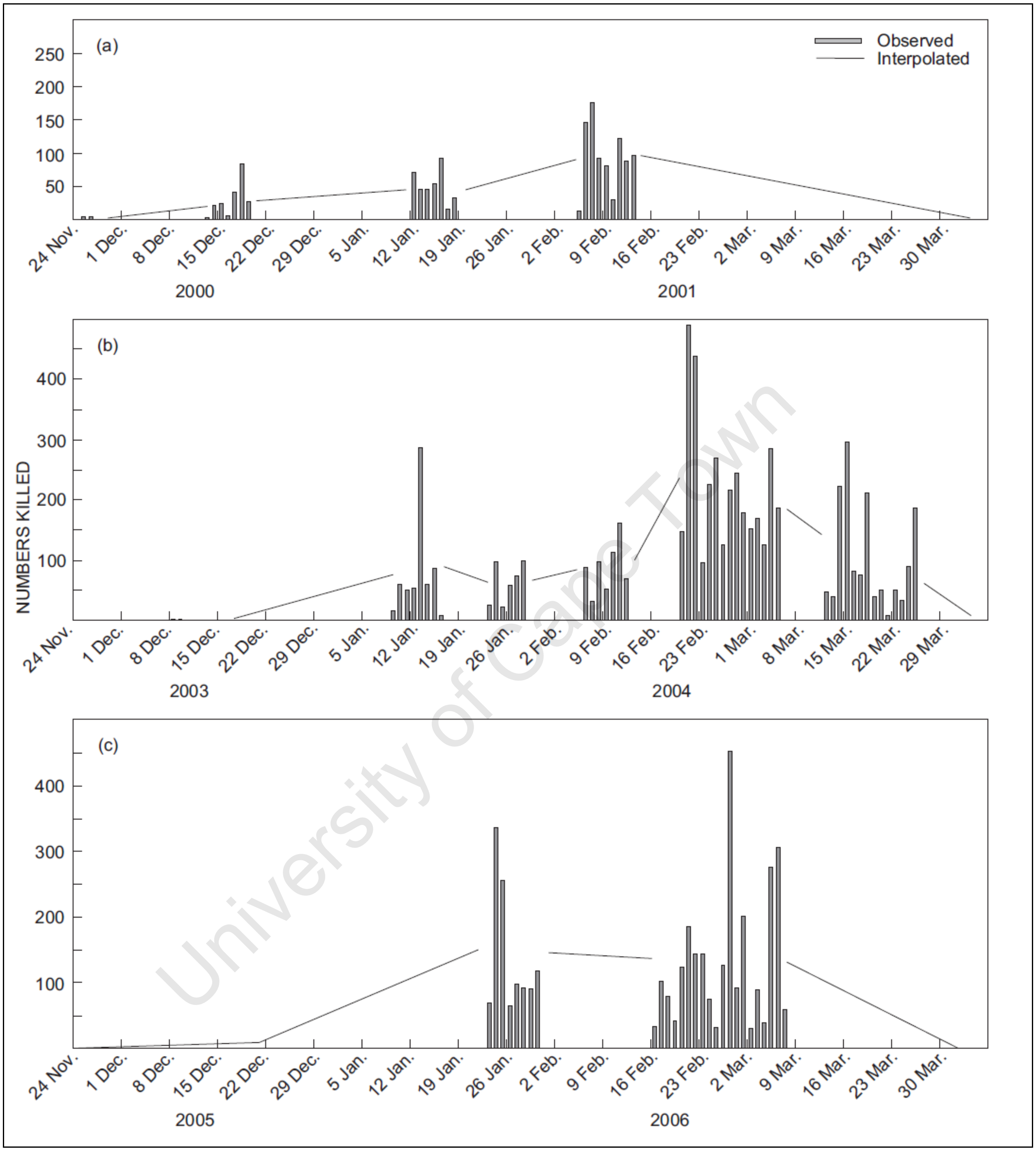

Figure 1: Estimates of numbers of Cape gannet fledglings killed at Malgas Island during (a) 2000/01, (b) 2003/04 and (c) 2005/06

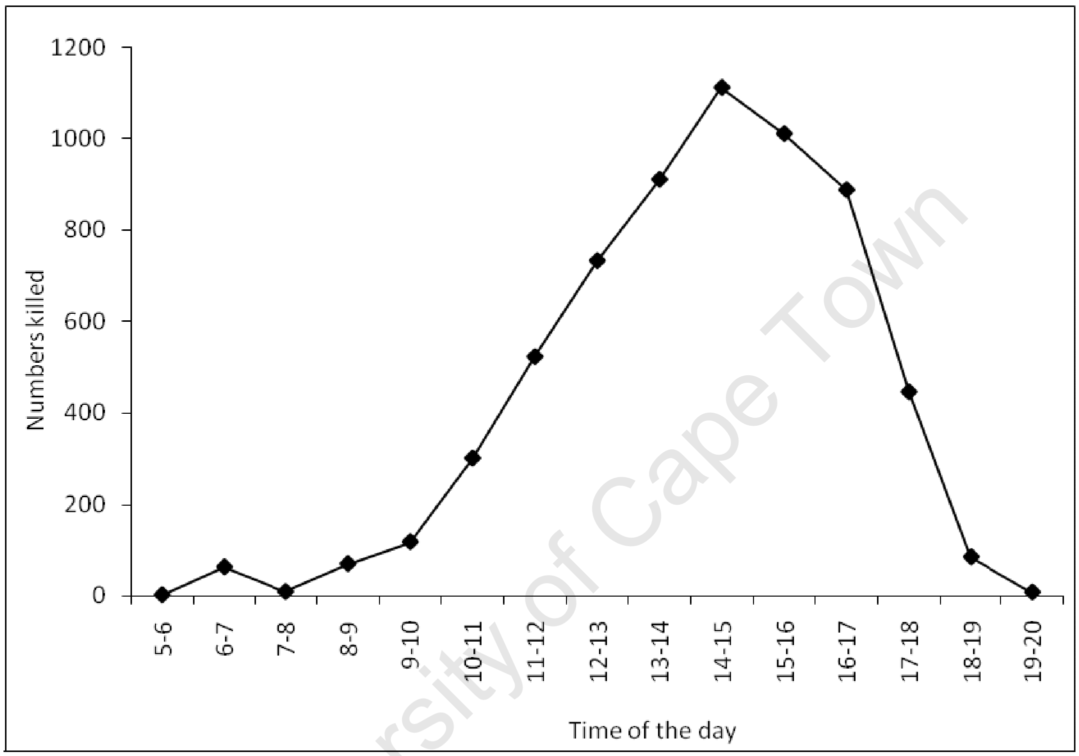

Figure 2: : Overall number of Cape gannet fledglings observed to be killed at Malgas Island in relation to time of day, 2003/04 and 2005/06

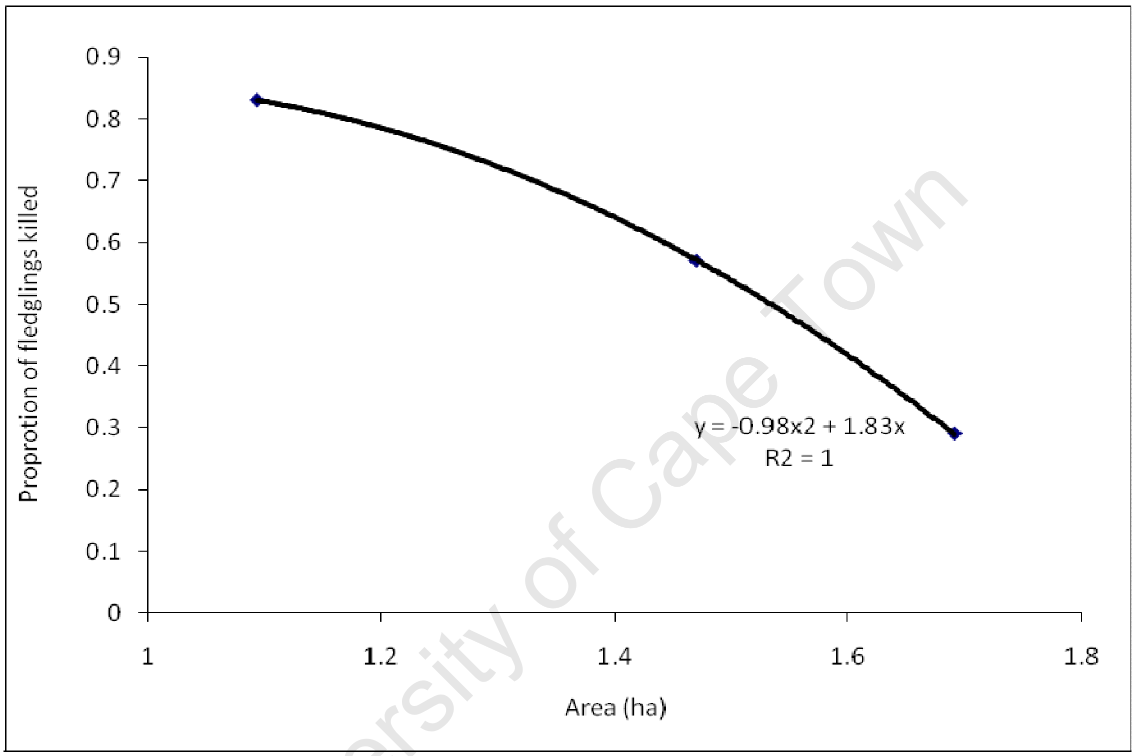

Figure 3: Relationship between the proportion of Cape gannet fledglings killed by seals and the area occupied by Cape gannets during breeding at Malgas Island

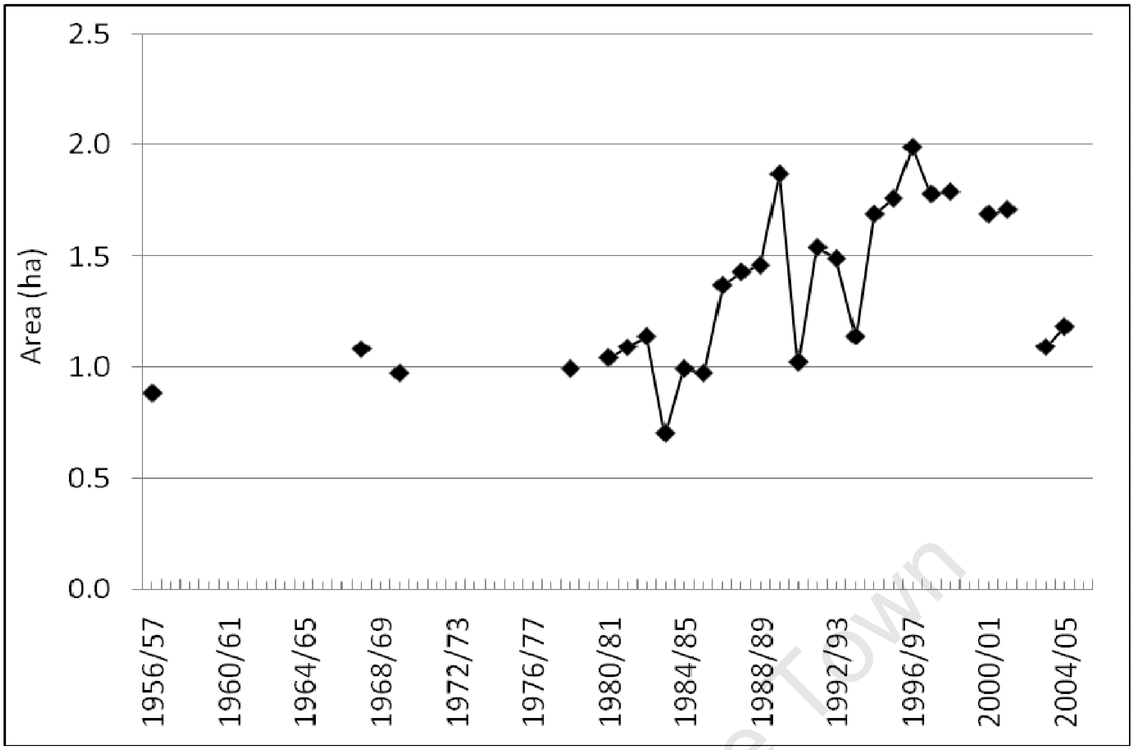

Figure 4: Trends in the area occupied by breeding Cape gannets at Malgas Island, 1956/57–2005/06 (from Crawford *et al*. 2007)

CHAPTER 3

An assessment of the impact of predation by Cape fur seals *Arctocephalus pusillus pusillus* on seabirds at Dyer Island, South Africa

An assessment of the impact of predation by Cape fur seals *Arctocephalus pusillus pusillus* on seabirds at Dyer Island, South Africa

ABSTRACT

At Dyer Island, South Africa, observations of predation of seabirds by Cape fur seals *Arctocephalus pusillus pusillus* were made during 2004 and 2006/07. It was estimated that seals killed up to 7% of African penguin *Spheniscus demersus* adults possibly more because observations were not conducted in the early part of the breeding season. This may have contributed to the penguin colony not increasing in spite of food becoming more available in its vicinity during an eastward shift of epipelagic fish resources off South Africa at the start of the 21st century. Seals also killed substantial numbers (4–8%) of Cape cormorant *Phalacrocorax capensis* fledglings as they left the island. Although this mortality may be sustainable, Cape cormorants have also been affected by disease. Penguin adults were most susceptible to mortality in the breeding season as they returned to feed chicks in the evening, Cape cormorant fledglings as they left to sea in the mornings when wind slacks and departure from the island may be difficult. Mortality inflicted by seals on adult cormorants was low.

INTRODUCTION

Several studies have reported feeding of fur seals on seabirds (e.g. Navarro 2000, Cooper 1974, Shaughnessy 1978, Bonner and Hunter 1982, du Toit *et al*. 2004, Goldsworthy *et al.* 1997). Between 1990 and 2006, this behaviour increased at sub-Antarctic islands in the southern Indian Ocean (Hofmeyr and Bester 1993) and around southern Africa (Makhado *et al.* 2006), where several of the target seabirds are of conservation concern (David *et al.* 2003). At Malgas Island, South Africa, predation by Cape fur seals *Arctocephalus pusillus pusillus* on Cape gannets *Morus capensis* between 2000 and 2006 was thought to be unsustainable and the gannet colony decreased from 58 000 pairs in the 1990s to 50 000 pairs in 2005 (Crawford *et al.* 2007a). At Dyer Island, South Africa, Cape fur seals killed about 842 adult African penguins *Spheniscus demersus* and 2461 Cape cormorants *Phalacrocorax capensis* between 1994 and 1996 (Marks *et al.* 1997) and 214 African penguins and 553 Cape cormorants between 1999 and 2001 (Johnson *et al.* 2006).

African penguins, Cape cormorants, Cape gannets are endemic to southern Africa, feed mainly on anchovy *Engraulis encrasicolus* and sardine *Sardinops sagax*, and are all listed as Vulnerable in terms of criteria of the World Conservation Union (IUCN), as a result of substantial recent decreases in their populations (Kemper *et al.* 2007).

The Dyer Island group ($34^0$41'S, $19^0$25'E) is an Important Bird Area (Barnes 1998) that is a provincial nature reserve managed by CapeNature. It consists of two islands: Dyer Island, approximately 20 ha in size, and the smaller Geyser Rock, which lies 230 m southwest of Dyer Island (Figure 1) and where some 7000–10000 Cape fur seal pups were born annually from 1971 to 2003 (Kirkman *et al.* 2007). Dyer Island is the southernmost of South Africa's main seabird breeding localities, and easternmost of those in the Western Cape Province. Situated some 55 km west of Cape Agulhas, the southern tip of Africa, it is an important link between seabird breeding localities farther north in the Western Cape and those in the Eastern Cape, which are some 600 km to the east (Underhill *et al.* 2006). There are no large islands or seabird colonies between Dyer Island and the islands in the Eastern Cape (Barnes 1998).

Recent eastward displacements of anchovy (Roy *et al.* 2007) and sardine (Fairweather *et al.* 2006) have reduced the availability of prey to some seabirds in the Western Cape, leading to decreased reproductive success, survival rates and sizes of breeding colonies (Crawford *et al.* 2007c). There have been associated shifts to the south and east in the distributions of several seabirds (Crawford *et al.* in 2007b), so that Dyer Island now supports one of the few stable colonies of African penguins in the Western Cape (Underhill *et al.* 2006), as well as substantial proportions of the populations of Cape cormorants and swift terns *Sterna bergii* in that province (Crawford *et al.* 2007b, Crawford *et al.* 2007c). It is therefore important to reassess the impact of predation by Cape fur seals on seabirds at Dyer Island. This paper reports recent observations at the island of mortality rates of seabirds attributable to seals and their seasonal patterns. It considers the likely impact of the predation on populations of seabirds at the island.

METHODS

Fourteen species of seabird have bred at Dyer Island, but great white pelicans *Pelecanus onocrotalus* and Cape gannets no longer do so (Hockey *et al*. 2005). Only small numbers of Caspian terns *Sterna caspia* (BM Dyer, Marine and Coastal Management, unpublished) and grey-headed gulls *L. cirrocephalus* (McInnes 2006) breed at the island, and then erratically. For African penguin, Leach's storm petrel *Oceanodroma leucorhoa*, Cape cormorant, bank cormorant *P. neglectus*, crowned cormorant *P. coronatus*, white-breasted cormorant *P. lucidus*, kelp gull *Larus dominicanus*, Hartlaub's gull *L. hartlaubii*, swift tern *Sterna bergii* and roseate tern *S. dougallii* numbers breeding at the island during 2004−2006 were collated from the literature.

Leach's storm petrels feed offshore at night, the gulls mainly in the intertidal zone or by dipping on the sea surface and the terns by dipping on the surface (Hockey *et al.* 2005). Seals have not been recorded killing these seabird species at Dyer Island (Marks *et al.* 1997). Hence, observations on mortality inflicted by Cape fur seals concentrated on the African penguin and the four species of cormorant. In the Western Cape, the main breeding season for African penguin is February–September, of Cape cormorant September–February, of bank cormorant May–October, of crowned cormorant December–March and of white-breasted cormorant April–December (Hockey *et al.* 2005). Fledging of chicks occurs towards the end of these periods. Therefore, predation of seabirds by Cape fur seals at Dyer Island was investigated at intervals during June–December 2004 to assess its impact on African penguins and the four cormorant species.

Further observations were conducted during 11–18 December 2006 and 10–16 January 2007 to obtain additional information on three of the cormorants.

A single observer kept watch daily from either 05h00 until 18h00 or from 06h00 until 19h00 except for breaks totalling about one hour. Mortality of seabirds was gauged by moving regularly between a single vantage point on top of a building at the northern side of the island, from which most of the sea around the island could be viewed, and the boat house, where the remainder of the sea was visible. All predation events and the time of day at which they occurred were recorded. The area where the predation occurred was noted, as well as the sex and approximate age of the seal inflicting the mortality. The island complex was subdivided into eight zones (Zone 1 to Zone 8) (Figure 1), two of which (4 and 5) are at Geyser Rock. The sex was determined from the profile of the head and neck, using features described by Apps (2000). The nose of a male is more pointed than that of a female, with a thicker neck and broader flippers. The age was gauged from size (Miller *et al.* 1996). It was estimated that during the period of observations two-thirds of the waters around the island were observed. Numbers of birds killed per day were computed by multiplying the recorded number by 100/67 (to account for that 1/3 of the mortality gauged to have been missed) and by 12/11 (to account for periods when no watches were kept).

Estimates of total numbers of seabirds killed by seals during the periods investigated were obtained by imputing values for days when no observations were made. This was done by calculating average daily predation rates for weeks when observations were made and linearly interpolating between these averages for days without observations.

For African penguin adults in 2004, it was assumed that mortality commenced on 1 June and ended on 31 October. For the purpose of interpolation, mortality was taken to be zero on these two dates. Similarly, for Cape cormorant fledglings, mortality was taken to be zero on 31 December 2004, 30 November 2006 and 31 January 2007. In reality, the respective breeding seasons extend beyond these dates (Hockey *et al*. 2005), so that mortality is likely to have been underestimated.

RESULTS

The mean numbers (pairs) of seabirds estimated to breed at Dyer Island during 2004–2006 are shown in Table 1. No Leach's storm petrels were recorded breeding in 2005 and 2006; only one pair was thought to breed in 2004 (Crawford *et al.* 2007e).

Numbers of seabirds observed killed for each day by Cape fur seals at Dyer Island, adjusted to account for mortality that would have been missed, and interpolated values for days when no observations were made, are shown in Figure 2. The estimated overall numbers of seabirds killed from June–December 2004 and from December 2006–January 2007 are shown in Table 2. In both periods, the highest mortality was inflicted on Cape cormorant fledglings, of which more than 6600 were estimated to be killed. This accounted for some 95% of the overall mortality of seabirds. Small numbers (< 12) of adult Cape, crowned and white-breasted cormorants were killed. More than 300 African penguins were estimated to be killed, mostly during June–December 2004.

No mortality of Leach's storm petrel, bank cormorant, gulls or terns attributable to Cape fur seals was recorded. If it is assumed that the number of adult birds at Dyer Island is double the number of pairs that breed, the estimated annual mortality rate of adults attributable to seals was 1–7% for African penguins, 0–0.02% for Cape cormorants, 0–0.4% for crowned cormorants and 0–1% for white-breasted cormorants. These are likely to be underestimates because observations of losses were not made over full years. On the other hand, not all adults may have bred (e.g. breeding participation of African penguins varies from 0.7–1.0, Hockey *et al.* 2005) so that the number of adults may be underestimated and the mortality rate may be overestimated. The mean clutch of Cape cormorants is about 2.3 eggs and in food rich years 87% of eggs hatch and 91%of chicks fledge (Hockey *et al.* 2005), which gives a breeding success of 1.8 chicks per pair. If it is assumed that pairs fledge two chicks each, the estimated annual mortality rate of fledglings attributable to seals was 4–8%.

Most Cape cormorants were killed between 07h00 and 11h00, with little mortality after 17h00 (Figure 3). Most African penguins were killed in the afternoon or evening, after 15h00 (Figure 3). Most of the predation on seabirds was conducted by sub-adult seals aged about 4–8 years. Predation events were witnessed around the entire island but mostly off Zones 6, 7 and 8 (Figure 4). Most of the attacks happened close to the island, in shallow water.

For African penguins, most of the observed mortality occurred between June and October, whereas Cape cormorants were killed from October to January (Figure 5). No observations were conducted from February to May.

DISCUSSION

Imputing data to estimate the overall numbers of seabirds killed by Cape fur seals results in uncertainty in the estimates (Makhado *et al.* 2006). In this study, there were substantial gaps between periods in which observations were made and there was also considerable day-to-day variation in numbers of fledglings observed to be killed (Figure 2). Furthermore, observations were not conducted year-round. However, it appears that Cape fur seals inflicted only low mortality on adult cormorants, gulls and terns.

However, the annual mortality rate of adult African penguins of up to 7% is of concern. This value is similar to the 9% estimated during 1994–1996 (Marks *et al.* 1997) and larger than the 2.0–2.5% by Johnson *et al.* (2006) for 1999−2001. If it is assumed that normal adult survival is 0.91, the maximum reported value (Crawford *et al.* 2006), that immature survival is 0.51 (Shannon and Crawford 1999) and that all African penguin aged four years or older breed every year (Randall 1983, Crawford *et al.* 1999, Whittington *et al.* 2005), it is necessary for each pair to fledge 0.47 chicks annually to maintain a population in equilibrium (Crawford *et al.* 2006). An additional loss of 7% of adult penguins would reduce survival of adult birds to 0.84 per annuam, requiring that pairs >0.96 chicks each year to maintain equilibrium (Crawford *et al.* 2006). This is mere than any measure of breeding success up until 2005 (Hockey *et al.* 2005), and hence considered unsustainable. At Lambert's Bay, mortality of penguins attributable to seals was also deemed to be unsustainable (Crawford *et al.* 2001) and the penguin colony there has since become extinct (Crawford *et al.* 2007c). The Dyer Island penguin colony might have been expected to benefit from an eastward displacement of prey in the Western Cape in the late 1990s and early 2000s (Fairweather *et al.* 2006, Roy *et al.* 2007).

However, it remained relatively stable in this period (Underhill *et al.* 2006) so that recent decreases of penguins in the north of this province have not been offset by increases at Dyer Island (Crawford *et al.* 2007c).

The annual mortality rate of Cape cormorant fledglings attributable to Cape fur seals (4–8%) is similar to the estimate of 7.3% during 1994–1996 (Marks *et al.* 1997). For an equilibrium population of Cape cormorants, it has been estimated that survival of birds in their first year should be 0.55 (Crawford *et al.* 1992). Therefore the predation of Cape cormorant fledglings by seals at Dyer Island is not necessarily unsustainable and the number of birds breeding at the island has recently increased (Crawford *et al.* 2007b). However, large numbers of Cape cormorants at the island have died in recent years as a result of outbreaks of avian cholera *Pasteurella multocida* (Waller and Underhill 2007), so again it is desirable to minimize mortality, especially given large decreases of Cape cormorants in Namibia and in the north of the Western Cape (Crawford *et al.* 2007b).

Predation of seabirds by seals is not common to all seals. It seems to be learned behaviour, especially undertaken by sub-adult males (David *et al.* 2003). The removal of these "problem" seals may bring about a long-term reduction in losses of seabirds to seals in South Africa (Makhado *et al.* in press), unlike for New Zealand sea lions *Phocarctos hookeri*, where both male and females are involved in predation of yellow-eyed penguins *Megadyptes antipodes*. However, in the predation of yellow-eyed penguins, one seal was possibly responsible for most kills (Lalas *et al.* 2007).

The seasonal patterns observed for predation of African penguins and Cape cormorants by seals at Dyer Island accord with the breeding seasons of these seabirds (but no observations were made from February to May). At Dyer Island, African penguins moult ashore in the austral summer, especially October–December, when they do not feed at sea (Crawford *et al.* 2006a). Losses to seals occur mainly during the breeding period, which commences early in the year (Hockey *et al.* 2005). It is likely that mortality was underestimated through not conducting observations from February–May. In the Western Cape, breeding by Cape cormorants is mainly from September–February (Crawford *et al.* 1999). At Dyer Island in 2006, Cape cormorants began to breed late in November and chicks began to fledge in December. Some mortality of fledglings at the end of the breeding period may have been missed.

The African penguin and Cape cormorant are vulnerable to attacks by seals in different ways. Adult African penguins are vulnerable because they must swim to and from breeding colonies to feed chicks. Adult Cape cormorants fly to their nests and so are relatively safe from seals. However, cormorant fledglings are inexperienced flyers and become vulnerable when they leave the colony and swim for the first time. A similar situation exists with Cape gannets *Morus capensis* (Makhado *et al.* 2006).

At Ichaboe Island, Namibia, between September 1991 and May 2000, predation of 2774 seabirds by seals was noted, the majority being fledglings of Cape gannets and Cape cormorants (du Toit *et al.* 2004). Some young African penguins are killed around breeding colonies, but many do not loiter at colonies once they have left to sea and they frequently move in excess of 1000 km from their natal island (Randall 1989). Adult penguins seemed particularly vulnerable to seals in the afternoon, perhaps because of a heavier mass when returning food to chicks than when leaving the island to feed. By contrast, Cape cormorant fledglings were most at risk early in the day, when winds are calmer and hence flight away from the island may be more difficult. At Dyer Island, most attacks on seabirds by seals were recorded along the sheltered (during southerly winds) northern side of the island.

Acknowledgements – I thank the National Research Foundation (SEACHANGE programme) and WWF-SA for supporting this research. The Department of Environmental Affairs and Tourism (South Africa) and CapeNature provided logistical support.

REFERENCES

Apps P (2000) Smither's Mammals of Southern Africa, field guide. Struik, Cape Town

Barnes KN (ed.) (1998) The Important Bird Areas of Southern Africa. BirdLife South Africa, Johannesburg 169pp

Bonner WN, Hunter S (1982) Predatory interactions between Antarctic fur seals, macaroni penguins and giant petrels. *British Antarctic Survey Bulletin* **56**: 75–79

Cooper J (1974) The predators of the jackass penguin (*Spheniscus demersus*). *Bulletin of the British Ornithological Club* **94**: 21–24

Crawford RJM (2007) Trends in numbers of three cormorants *Phalacrocorax* spp. breeding in South Africa's Western Cape Province. 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*. Avian Demography Unit, Cape Town, pp 173–178

Crawford RJM, David JHM, Shannon LJ, Kemper J, Klages NTW, Roux J-P, Underhill LG, Ward VL, Williams AJ, Wolfaardt AC (2001) African penguins as predators and prey–coping (or not) with change. *South African Journal of Marine Science* **23:** 435–447

Crawford RJM, Dundee BL, Dyer BM, Klages NT, Meÿer MA, Upfold L (2007a) Trends in numbers of Cape gannets (*Morus capensis*), 1956/57–2005/06, with a consideration of the influence of food and other factors. *ICES Journal of Marine Science* **64**: 169–177

Crawford RJM, Dyer BM, Kemper J, Simmons RE, Upfold L (2007b) Trends in numbers of Cape cormorants (*Phalacrocorax capensis*) over a 50-year period, 1956–57 to 2006–07. *Emu* **107**: 1–9

Crawford RJM, Dyer BM, Upfold L (1999) Seasonal pattern of breeding by Cape and crowned cormorants off western South Africa. *Ostrich* **70**: 193–195

Crawford RJM, Hemming M, Kemper J, Klages NTW, Randall RM, Underhill LG, Venter AD, Ward VL, Wolfaardt AC (2006a) Molt of the African penguin, *Spheniscus demersus*, in relation to its breeding season and food availability. *Acta Zoologica Sinica* **52**: 444–447

Crawford RJM, Fairweather T, Underhill LG, Wolfaardt AC (2007c) Implications for seabirds of an unfavourable, long-term change in the distribution of prey: a South African experience. 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*. Avian Demography Unit, Cape Town, pp 243–249

Crawford RJM, Underhill LG, Altwegg R, Dyer BM, Upfold L (2007d) The influence of culling, predation and food on kelp gulls *Larus dominicanus* off western South Africa. 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*. Avian Demography Unit, Cape Town, pp 181–188

Crawford RJM, Underhill LG, Raubenheimer CM, Dyer BM, Martin J (1992) Top predators in the Benguela ecosystem–implications of their trophic position. *South African Journal of Marine Science* **12**: 675–687

Crawford RJM, Whittington PA, Dyer BM, Upfold L (2007e) Trends in numbers of Leach's storm petrel, Hartlaub's gull and swift and roseate terns breeding in South Africa. 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*. Avian Demography Unit, Cape Town, pp 211–213

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

du Toit M, Bartlett PA, Bester MN, Roux J-P (2004) Seabird predation by individual seals at Ichaboe Island, Namibia. *South 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

Goldsworthy SD, Hindell MA, Crowley HM (1997) Diet and diving behaviour of sympatric fur seals *Arctocephalus gazella* and *Arctocephalus tropicalis* at Macquarie Island. In: Hindell MA, Kemper C (eds) *Marine mammal research in the southern hemisphere: Status, ecology and medicine.* Surrey Beatty, Sydney, pp 151–163

Hockey PAR, Dean WRJ, Ryan PG (eds) (2005) *Roberts Birds of Southern Africa* (VIIth edn). John Voelcker Bird Book Fund, Cape Town, 1296pp

Hofmeyr GJG, Bester MN (1993) Predation on king penguins by Antarctic fur seals. *South African Journal of Antarctic Research* **23**: 71–74

Johnson RL, Venter A, Bester MN, Oosthuizen WH (2006) Seabird predation by white shark and Cape fur seal at Dyer Island. *African Journal of Marine Science* **29**: 105–111

Kemper J, Underhill LG, Crawford RJM, Kirkman SP (2007) Revision of the conservation status of seabirds and seals breeding in the Benguela ecosystem. 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*. Avian Demography Unit, Cape Town, pp 697–704

Kirkman SP, Oosthuizen WH, Meÿer MA, Kotze PGH, Roux J–P, Underhill LG (2007) Making sense of censuses 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

Lalas C, Ratz H, McEwan K, McConkey SD (2007) Predation by New Zealand sea lions (*Phocarctos hookeri*) as a threat to the viability of yellow-eyed penguins (*Megadyptes antipodes*) at Otago Peninsula, New Zealand. *Biological Conservation* **135**: 235–246

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, Underhil LG, Wilke C (in press). Efficacy of culling seals seen preying on seabirds as a means of reducing seabird mortality. *African Journal of Ecology*

Marks MA, Brooke RK, Gildenhys AM (1997) Cape fur seal (*Arctocephalus pusillus pusillus)* predation on Cape cormorants (*Phalacrocorax capensis)* and other birds at Dyer Island, South Africa. *Marine Ornithology* **25**: 9–12

McInnes AM (2006) Biology of grey-headed gull *Larus cirrocephalus* in South Africa. MSc thesis, University of KwaZulu-Natal, South Africa

Miller CM, Oosthuizen WH, Wickens PA (1996) Cape fur seals trapped in trawling gear: age structure, sex ratio, seasonality and distribution. *South African Journal of Marine Science* **17**: 105–111

Navarro RA (2000) Cape fur seal predation on Cape gannet fledglings. *Bird Numbers* **9**(2): 15–16

Randall RM (1989) Jackass penguins. In: Payne AIL, Crawford RJM (eds) *Oceans of Life off Southern Africa*. Vlaeberg, Cape Town, pp 244–256

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

Shannon LJ, Crawford RJM (1999) Management of the African penguin *Spheniscus demersus* insights from modelling. *Marine Ornithology* **27**: 119–128

Shaughnessy PD (1978) Cape fur seals preying on seabirds. *Cormorant* **5**: 31

Underhill LG, Crawford RJM, Wolfaardt AC, Whittington PA, Dyer BM, Leshoro TM, Ruthenberg M, Upfold L, Visagie J (2006) Regionally coherent trends in colonies of African penguins *Spheniscus demersus* in the Western Cape, South Africa, 1987–2005. *African Journal of Marine Science* **28**: 697–704

Waller LJ, Underhill LG (2007) Management of avian cholera *Pasteurella multocida* outbreaks on Dyer Island, South Africa, 2002–2005. *African Journal of Marine Science*, **29**: 105–111

Whittington PA, Klages NTW, Crawford RJM, Wolfaardt AC, Kemper J (2005) Age at first breeding of the African Penguin. *Ostrich* **76**: 14–20

Table 1: Numbers of breeders pairs of some seabirds breeding at Dyer Island in 2004 and 2005

Species	**Breeding pairs**		**Source**
	2004	**2005**	
African penguin	2216	2053	Underhill *et al.* 2006
Leach's Storm petrel	1	0	Crawford *et al.* 2007e
Cape cormorant	33024	22766	Crawford *et al.* 2007b
Bank cormorant	35	28	Crawford *et al.* 2007b
Crowned cormorant	150	250	Crawford 2007
White-breasted cormorant	78	110	Crawford 2007
Kelp gull	320	465	Crawford *et al.* 2007d
Hartlaub's gull	36	277	Unpublished
Swift tern	1206	798	Crawford *et al.* 2007e
Roseate tern	3	16	Crawford *et al.* 2007e

Table 2: Observed plus imputed numbers of different species and age categories of seabirds killed by Cape fur seals at Dyer Island from June–December 2004 and December 2006–January 2007 (see Figure 2). The percentage contribution of different categories to the overall number estimated to have been killed in the two periods is shown

Species	**2004**	**2006/07**	**Overall**	**% of total**
African penguin	299	36	335	4.8
Cape cormorant (fledglings)	2265	4350	6615	94.7
Cape cormorant (adults)	11	0	11	0.2
Crowned cormorant	0	2	2	0.0
White-breasted cormorant	0	2	2	0.0
Unidentified seabirds	12	6	18	0.3
Total	2587	4396	6983	100

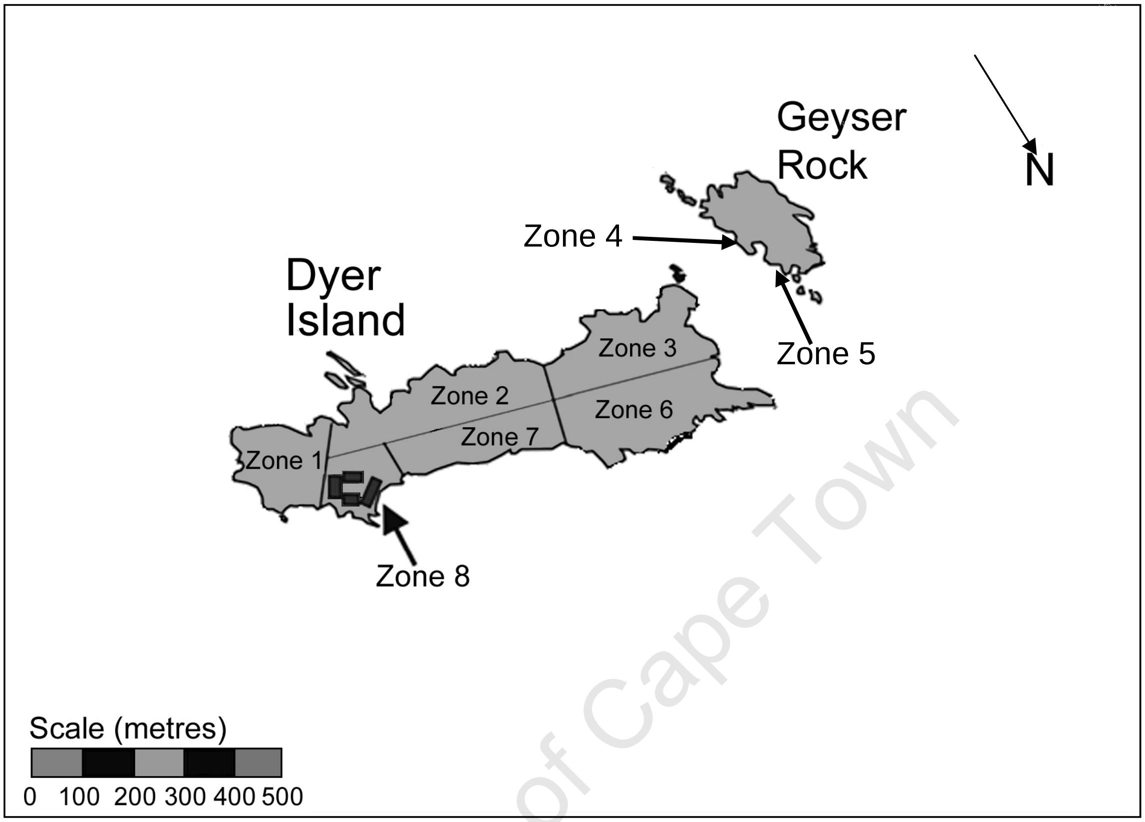

Figure 1: Map of Dyer Island and Geyser Rock illustrating different zones where predation events were recorded (from Johnson *et al*. 2006)

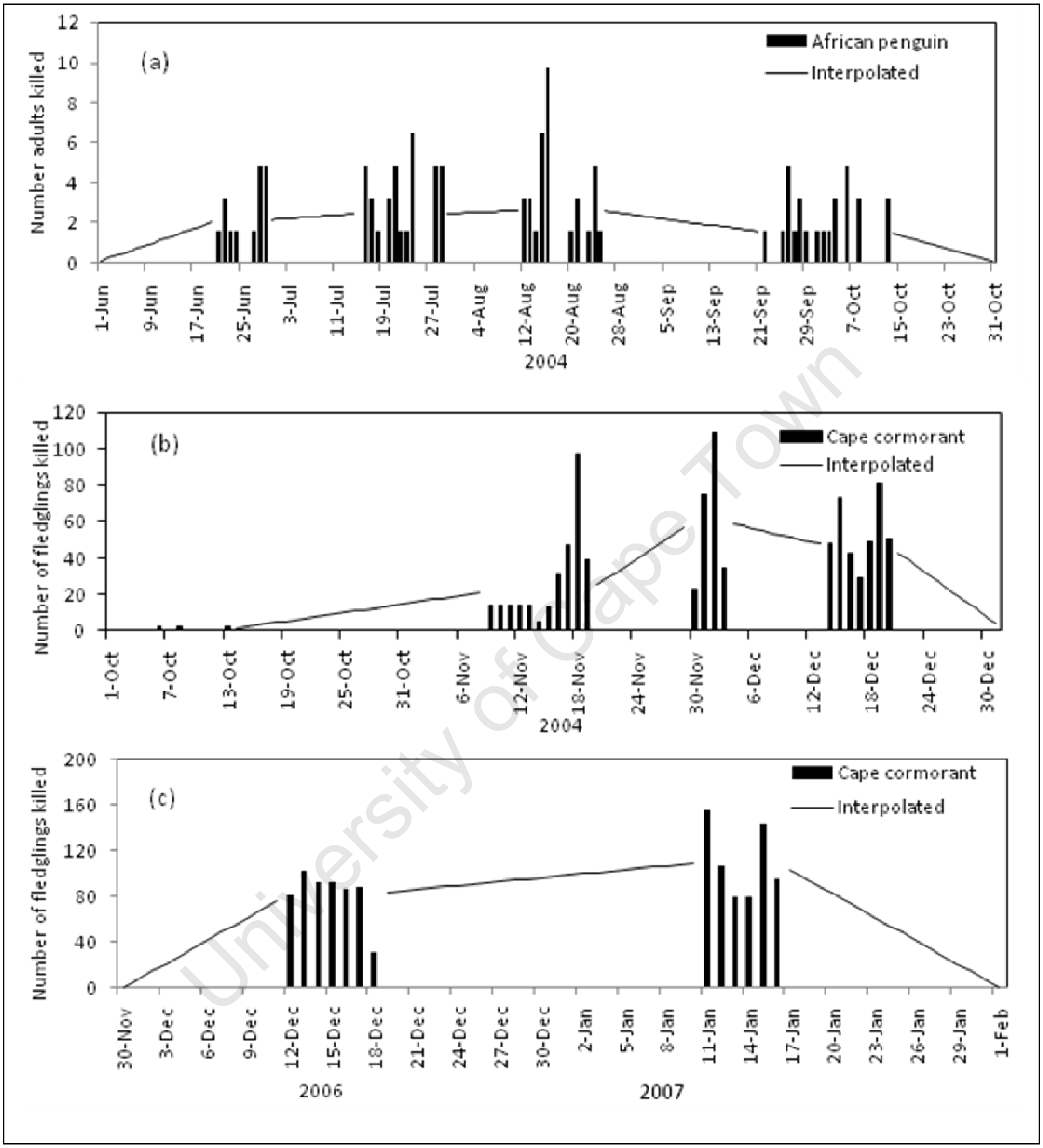

Figure 2: Numbers of seabirds killed per day at Dyer Island with interpolated lines showing imputed numbers: (a) African penguin adults in 2004; (b) Cape cormorant fledglings in 2004; (c) Cape cormorant fledglings in 2006/07

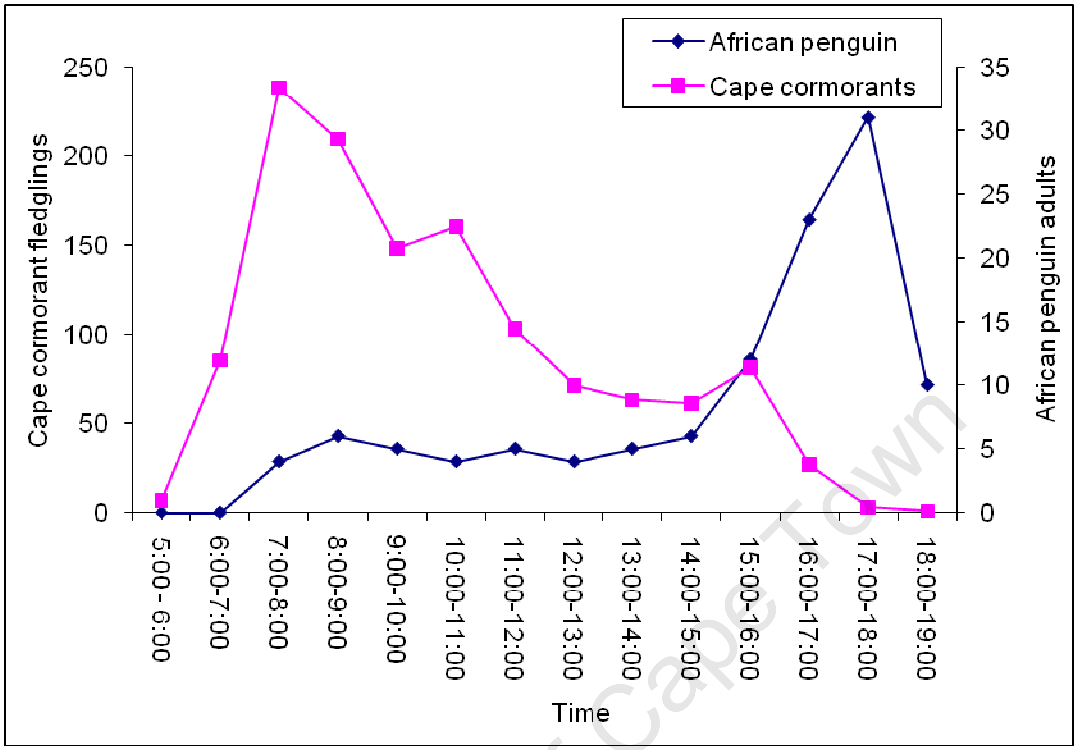

Figure 3: Overall number of African penguin adults and Cape cormorant fledglings observed to be killed at Dyer Island in relation to time of the day. Information for 2004 and 2006/07 has been combined. Observations for African penguins were from June–October and for Cape cormorants from October–January. On 1 June, civil daylight was from 7h43 to 17h45, on 1 October from 6h23 to 18h50, and on 1 January from 5h38 to 20h01.

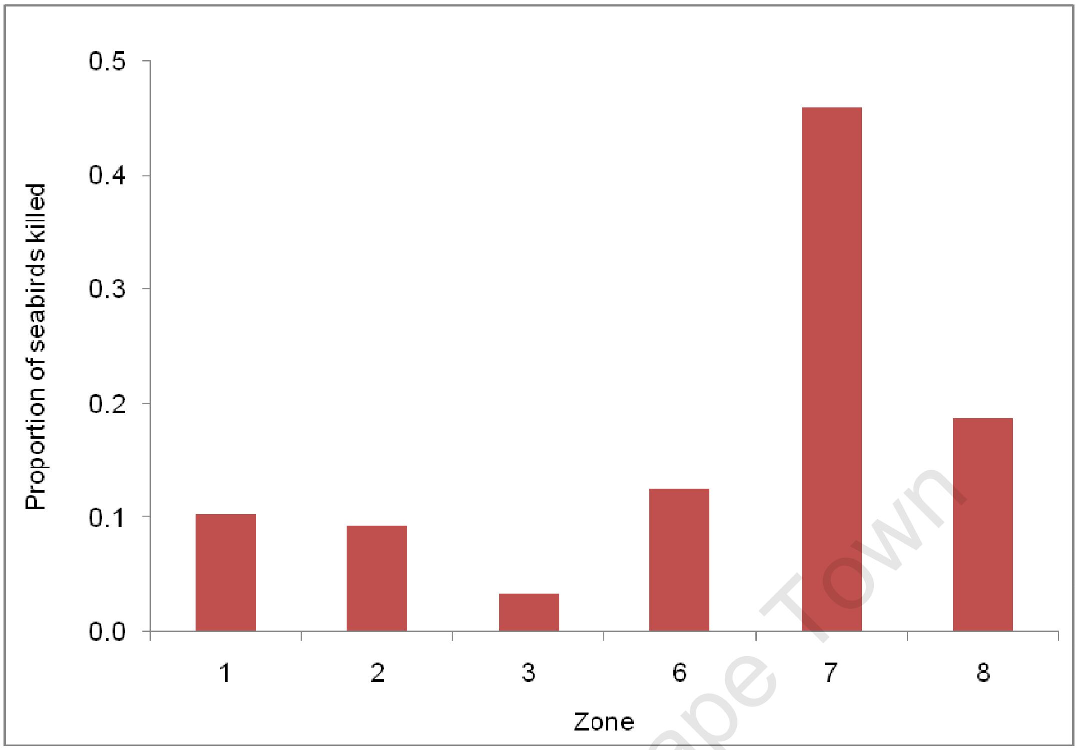

Figure 4: Proportions of seabirds killed in various zones around Dyer Island. The information for all species has been lumped

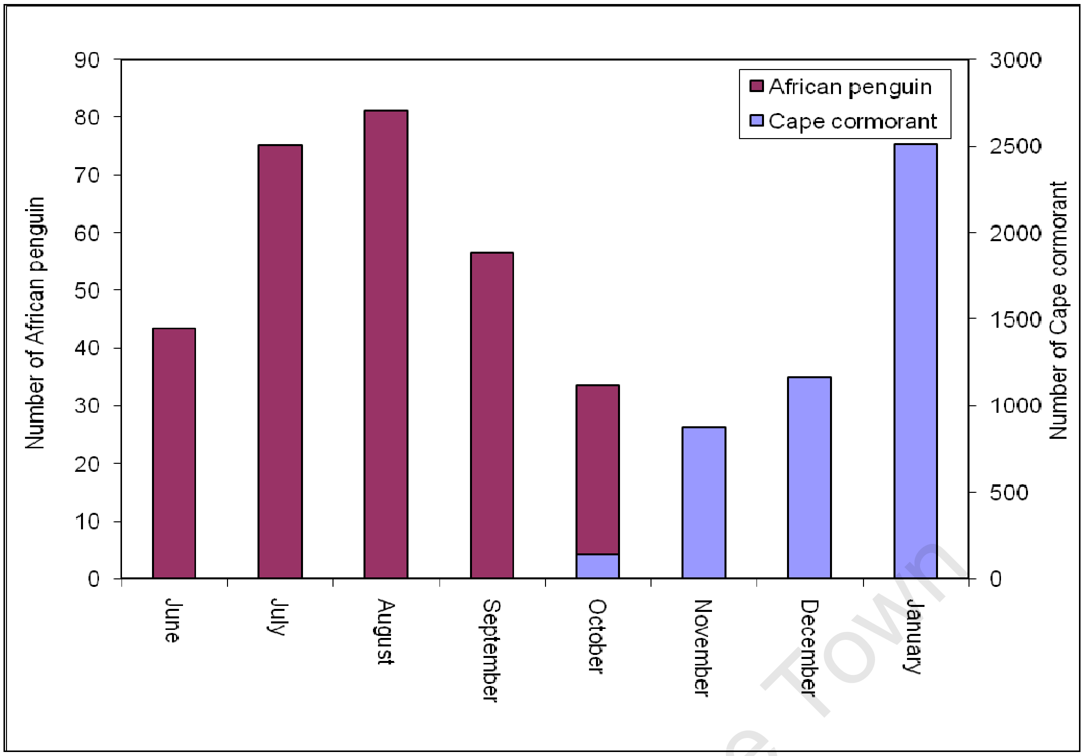

Figure 5: Numbers of African penguin adults and Cape cormorant fledglings killed per month (June–January) at Dyer Island. Information from different years has been lumped. No mortality of African penguin adults was recorded from November to January. No observations were made from February to May

CHAPTER 4

On the predation of seabirds by fur seals *Arctocephalus* spp. at other localities in South Africa and at Marion Island

On the predation of seabirds by fur seals *Arctocephalus* spp. at other localities in South Africa and at Marion Island

ABSTRACT

Predation on seabirds by Cape fur seals *Arctocephalus pusillus pusillus* occurs at many localities in southern Africa. Although the effect of such predation on seabird populations has only been quantified at a few localities, it may be having a severe impact at other localities also. Several hundred Cape gannet *Morus capensis* fledglings are killed annually at Bird Island (Lambert's Bay) and threatened penguins and cormorants are attacked at other localities. At subantarctic Marion Island, Antarctic fur seals *A. gazella* feed on king *Aptenodytes patagonicus* and macaroni *Eudyptes chrysolophus* penguins. However, predation there on seabirds by subantarctic fur seals *A. tropicalis* has not yet been observed. King penguins are mostly killed in winter and macaroni penguins, which are absent from the island in winter, in summer. Predation of seabirds by seals has recently increased in southern Africa and may be doing so at Marion Island. In both regions fur seal populations are expanding.

INTRODUCTION

Although many populations of fur seals were heavily exploited for skins and oil in the 19th and early 20th centuries, there was a dramatic decrease in the demand for seal products in the 1980s (Harwood 1992). As a consequence of this, of changes in human distribution (Harwood 1992), and of the implementation of sustainable management practices (Best *et al*. 1997), a number of seal populations increased in size in the 20th century. These included the Cape fur seal *Arctocephalus pusillus pusillus,* some two million of which are now distributed around the west and south coasts of southern Africa (Butterworth *et al*. 1995, Best *et al*. 1997). At South Africa's Prince Edward Islands, there has been recent growth in numbers of subantarctic *A. tropicalis* and Antarctic *A. gazella* fur seals, which now number approximately 150 000 and 5 800 individuals at these islands, respectively (Hofmeyr *et al*. 2006).

All three of these fur seals were subjected to intense, uncontrolled harvesting from the 17th to 20th centuries (Shaughnessy and Butterworth 1981), which resulted in severe reductions in their population sizes and local extinctions at some breeding sites (Shaughnessy and Fletcher 1987). For example Cape fur seals stopped breeding at 23 localities (Best and Shaughnessy 1979, Shaughnessy 1982) and the overall population size was reduced below 100 000 individuals (Shaughnessy and Butterworth 1981, Butterworth *et al*. 1995). After the cessation of intensive exploitation, numbers often increased dramatically, and many islands were re-colonized (Payne 1977, Bester 1987, Kerley 1987, Roux 1987, Guinet *et al*. 1994, Isaksen *et al*. 2000).

In certain instances, the increases in seal numbers had unfavourable conservation consequences for seabirds. For example, seabirds were displaced from their nesting sites (Crawford *et al.* 1989) or subjected to predation by seals (David *et al*. 2003, Makhado *et al*. 2006). Predation can have a major effect on the population dynamics of top predators (Krebs *et al.* 1995, 2001, Oro *et al.* 1999, Woodworth 1999), reducing breeding success and survival (Whittam and Leonard 1999, Makhado *et al*. 2006). Recent years have seen an increase in predation of seabirds by seals at several localities administered by South Africa (Chapter 2 and 3), which has been ascribed to the increased population sizes of fur seals (David *et al*. 2003, Hofmeyr *et al.* 2006).

Earlier chapters aimed to assess the extent of predation by Cape fur seals on seabirds at Malgas and Dyer islands, off mainland South Africa. Some additional observations were conducted on Cape fur seals preying on seabirds at Bird (Lambert's Bay), Dassen and Robben islands off South Africa and at Marion Island, one of the two islands in the subantarctic Prince Edward Islands group. This chapter reports and discusses these additional observations.

METHODS

At Bird Island (Lambert's Bay, 3 ha) observations were made of predation of Cape gannet *Morus capensis* fledglings by Cape fur seals during the 2006/07 and 2007/08 gannet breeding seasons by Y. Chesselet of CapeNature, who recorded the number of predation events but not the amount of time spent searching. At Dassen Island (36 days during September 2003 and 2005 and October 2005) and Robben Island (5 days during 2005), I made observations of predation of all seabirds by Cape fur seals. Dassen Island is 223 ha in extent and Robben Island 507 ha, so that only a small portion of their coastlines was observed at any one time. Observations were conducted throughout the day as described in chapter 2.

At Marion Island (292 km^2), I made observations of predation by fur seals on penguins (Spheniscidae) at Kildalkey Beach for at least two hours on 10 days in each month from May 1999 to April 2000, and occasionally at Goodhope Bay. A record was kept of the period of observations, which were conducted as described in Chapter 2. Additionally, opportunistic observations were conducted by other field assistants in 1995/6, 1997/8 and 2006/07.

The species of seal and penguin involved in predation interactions were recorded. Four species of penguin breed at Marion Island (Cooper 2003): king penguin *Aptenodytes patagonicus*, gentoo penguin *Pygoscelis papua*, macaroni penguin *Eudyptes chrysolophus* and rockhopper penguin *E. chrysocome*. The sex and maturity stage (adult or subadult) of the seals were recorded. They were distinguished as described by Condy (1978). The colour of the chest and face of *A. tropicalis* bulls is white to orange, the belly is brown to ginger and the rest of the body is dark grey to dark brown (Bester 1977) while the cows have a white to orange chest and face and their dorsal surface is grey to brown with a light brown to ginger belly. Further, *A. tropicalis* have short broad flippers compared to the long, slender appendages of *A. gazella*. *Arctocephalus gazella* bulls have a silvery grey chest and neck with a slightly dark face and grey to dark brown body (Condy 1978) while cows have a white to grey neck and chest, grey to brown dorsal surface and white to grey belly (Condy 1978) and are smaller in size. The number of seals involved in each attack was noted. All observations conducted in the four seasons were grouped to examine the seasonal patterns of attacks on different species of penguins.

It was noted whether the interaction occurred on land or in the sea. Predation events on land were recognised by seals chasing penguins and at sea by seals thrashing their prey on the surface. For events at sea, the approximate distance from the coastline of the attack was gauged. The outcome of each predation interaction was recorded as: penguin escaped apparently unharmed; penguin returned to the island injured; penguin returned to and died at the island; penguin killed outright. For a subsample of penguins killed, the length of time that seals fed on carcases was recorded. Observations were made of other species of seabirds present at the attacks and of the response of seals to the presence of killer whales *Orcinus orca*.

RESULTS

South African islands

At Lambert's Bay, 310 and 372 Cape gannet fledglings were killed by Cape fur seals during the 2006/07 and 2007/08 gannet breeding seasons.

At Dassen Island, 45 adult African penguins *Spheniscus demersus* were observed to be killed by Cape fur seals. Most predation was recorded in the late afternoon as the penguins returned from foraging, but some mortality occurred in the morning (Figure 1).
At Robben Island, Cape fur seals were observed to kill two bank cormorants *Phalacrocorax neglectus* and five African penguins. An additional three African

penguins were found wounded on the beach, and the wounds appeared to have been inflicted by seals.

Marion Island

At Marion Island, 236 attacks by fur seals on penguins were recorded: 159 on king penguins, 76 on macaroni penguins and one on a rockhopper penguin. No predation on gentoo penguins was observed. Only *A. gazella* was seen to attack penguins. This behaviour was not displayed by *A. tropicalis*. All seals involved in the predation events were bulls, 94% adults and 6% subadults. For king penguins 86 (61%) of the attacks proved fatal, for macaroni penguins 56 (39%), and the solitary rockhopper penguin died.

On 25 occasions, *A. gazella* was seen chasing and killing penguins on land. On 20 of these occasions, the seals followed the penguins from the sea to the land. The remainder (211) of the attacks took place at sea. The average number of seals attacking a penguin during a predation event was 2.75 for all seasons combined. However, each attack on land involved only one seal.

The number of penguins observed to be attacked at Marion Island in each split year is indicated in Figure 2. Few observations were made in 1995/96 and 2006/07. More attacks were recorded in 1997/98 and 1999/00. In the first two seasons of observations, most birds attacked were king penguins; in the latter two seasons, most were macaroni penguins. No observation of an attack on a macaroni penguin was recorded in 1997/98. The only observation of an attack on a rockhopper penguin was in March 2000. Most king penguins were attacked in winter, from June–August (Figure 3). Most macaroni penguins were attacked from October–March, especially in December and January.

For both king and macaroni penguins, most attacks were made within about 5 m of the coastline (Figure 4). No attacks were recorded at distances farther than 50 m offshore. In 1997/98 and 1999/00, backwash (retreat of a wave) was observed to influence the capture of penguins. On 26 occasions, penguins using a large wave to attempt a landing on the shoreline were pulled back to sea and caught by seals.

Approximately 65% of penguins attacked by seals were killed outright, 3% died on land, 29% escaped, and the remainder were injured (Figure 5). On average seals spent about 11 minutes feeding on penguins they had killed (n = 42).

On 39 occasions when penguins were killed, giant petrels *Macronectes* spp. fed on small pieces of flesh torn from the penguin or on the carcass. On 19 occasions, killer whales were observed. Whenever they were present, predation on seabirds by *A. gazella* stopped, with the seals sometimes moving away.

DISCUSSION

Numbers of Cape fur seals increased markedly during the 20th century (Butterworth *et al*. 1995, Best *et al*. 1997). Whereas predation by these seals on seabirds was seldom reported in the early 20th century, such events are now common (Makhado *et al*. 2006). In the late 1990s and early 2000s, Cape fur seals inflicted substantial mortality on Cape gannets and Cape cormorants at Bird (Lambert's Bay) Island (Ward and Williams 2004), on Cape gannets at Malgas Island (Makhado *et al*. 2006) and on African penguins and Cape cormorants at Dyer Island (Marks *et al*. 1997, Johnson *et al*. 2006, Chapter 3).

The predation of gannet fledglings by seals at Lambert's Bay is persisting and, similarly to the situation at Malgas Island, the mortality inflicted may not be sustainable if management control is not implemented. Although unsustainable mortality has not been demonstrated at Lambert's Bay, the gannet colony there has recently decreased. In 2005/06, Cape fur seals killed about 200 adult gannets on land at Lambert's Bay and caused abandonment of breeding by the entire colony (Wolfaardt and Williams 2006). Such disturbance may also have caused partial abandonment in the previous season (2004/05), when the colony decreased in size by about 50% (Crawford *et al*. 2007). In 2005/06, seals killed about 20 gannets ashore at Malgas Island (L. Pichegru, pers. comm.). Prior to these observations, there had only been one record of a seal killing a Cape gannet on land (Crawford and Cooper 1996), although seals regularly kill fledglings around islands (David *et al*. 2003). Clearly, attacks by seals on birds ashore may have a major impact on colonies of Cape gannets, unless controlled.

Limited observations of attacks by seals on seabirds at Dassen and Robben islands confirm the widespread nature of this behaviour. To date, attacks have been recorded at the following localities around the southern African coastline from north to south and east: Ichaboe Island (du Toit *et al.* 2004), Halifax Island (Rebelo 1984), Possession Island (Shaughnessy 1978), Bird Island at Lambert's Bay (Crawford *et al*. 2001, Ward and Williams 2004, Wolfaardt and Williams 2006), Malgas Island (Crawford and Robinson 1990, Crawford and Cooper 1996, Navarro 2000, Makhado *et al*. 2006), Jutten Island (MCM unpublished data), Vondeling Island (BM Dyer pers. comm. MCM), Dassen

Island (Cooper 1974), Robben Island (Marine and Coastal Management unpublished data), Cape Point, Boulders Beach (MA Meÿer pers. comm. MCM) and Dyer Island (Marks *et al*. 1997, Johnson *et al*. 2006).

Not only Cape fur seals prey on seabirds, but also Antarctic fur seals at Marion Island (Hofmeyr and Bester 1993), although interestingly this behaviour has not yet been recorded for subantarctic fur seals at Marion Island. However, at Amsterdam Island, subantarctic fur seals killed rockhopper penguins (Paulian 1964). New Zealand fur seals *A. fosteri* kill rockhopper penguins at Campbell Island, New Zealand (Bailey and Sorensen 1962) and penguins at Macquarie Island, Australia (Green *et al*. 1990).

Up until 1993, predation on seabirds by *A. gazella* had only been observed for king penguins at Marion Island (Hofmeyr and Bester 1993). This study indicates that substantial numbers of macaroni penguins also may be taken, as well as the occasional rockhopper penguin. Whether this is a new situation or predation on such species was overlooked previously is uncertain. Macaroni and rockhopper penguins are absent from Marion Island for six months each year, returning in spring to breed (Cooper 2003). At Marion Island, macaroni penguins are attacked by Antarctic fur seals in the summer months, whereas most king penguins are killed in winter. Many seals are attracted to the areas and seasons of high penguin traffic (Ainley *et al.* 2005). Penguins travel in groups, especially when returning from foraging and densities are highest near the shoreline, where most attacks were noted. The paucity of observations of predation by seals on rockhopper and gentoo penguins at Marion Island may result from the much lower numbers of these species (67 000 pairs and 800 pairs, respectively) at the island than for king (215 000 pairs) and macaroni (356 000 pairs) penguins (Crawford *et al*. 2003).

There are large colonies of king and macaroni penguins at both Kildalkey Bay and Goodhope Bay (Cooper 2003). Other seals have been observed feeding on rockhopper and gentoo penguins, Weddell seals *Leptonychotes weddellii* on gentoo penguins (Cobley and Bell 1998). Macaroni penguins are fed upon by subadult Antarctic fur seals at Bird Island, South Georgia (Bonner and Hunter 1982).

As in South Africa, the predation of seabirds by Antarctic fur seals may have intensified at Marion Island. Over a period of eight years, from 1986 to 1993, only 15 king penguins were observed to be killed by these seals (Hofmeyr and Bester 1993), whereas in the four split years covered by this study 159 king penguins were attacked. The difference could be at least partly attributable to increased observation effort from 1995/96 to 2006/07 as well as an increase in fur seal population size. The populations of fur seals are expanding at Marion Island (Hofmeyr *et al*. 2006), as they also have in southern Africa.

Acknowledgements – I am grateful to the National Research Foundation through its SANAP (South African National Antarctic Programme) and SEACHANGE programmes for supporting this research. I thank the CapeNature for conducting observations at Bird island Lambert's bay and making these available and all field workers who helped with the data collection at the islands, including many of my colleagues at Mammal Research Institute, University of Pretoria and Marine and Coastal Management, Department of Environmental Affairs and Tourism.

REFERENCES

Ainley DG, Ballard G, Karl BJ, Dugger KM (2005) Leopard seal predation rates at penguin colonies of different size. *Antarctic Science* **17**: 335–340

Bailey AM, Sorensen JH (1962) Subantarctic Campbell Island. *Proceedings of Denver Museum of Natural History* **10**: 305

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

Best PB, Crawford RJM, van der Elst RP (1997) Top predators in southern Africa's marine ecosystems. *Transactions of the Royal Society of South Africa* **52**: 177–225

Bester MN (1977) Habitat selection, seasonal population changes, and behaviour of the Amsterdam Island fur seal *Arctocephalus tropicalis* on Gough Island. D.Sc. Thesis, University of Pretoria, Pretoria

Bester MN (1987) Subantarctic fur seal *Arctocephalus tropicalis* at Gough Island (Tristan da Cunha Group). In: Croxall JP, Gentry RL (eds) *Status, Biology and Ecology of Fur Seals*. *National Oceanic and Atmospheric Administration Technical Report, National Marine Fisheries Service* **51**: 57–60

Bonner WN, Hunter S (1982) Predatory interactions between Antarctic fur seals, macaroni penguins and giant petrels. *British Antarctic Survey Bulletin* **56**: 75–79

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

Cobley ND, Bell G (1998) Weddel seal *Leptonychotes weddellii* feeding on gentoo penguins (*Pygoscelis papua). Marine Mammal Science* **14**: 881–883

Condy PR (1978) Distribution, abundance and annual cycle of fur seals (*Arctocephalus* spp.) on the Prince Edward Islands. *South African Journal of Wildlife Research* **8**: 159–168

Cooper J (1974) The predators of the jackass penguin *Spheniscus demersus*. *Bulletin British Ornithological Club* **94**: 21–24

Cooper J (ed.) (2003) Seabirds and seals at the Prince Edward Islands. *African Journal of Marine Science* **25**: 415–564

Crawford RJM, Cooper J (1996) Cape fur seal *Arctocephalus pusillus* catches Cape gannet *Morus capensis* ashore at Malgas Island. *Marine Ornithology* **24**: 53–54

Crawford RJM, Cooper J, Dyer BM, Greyling MD, Klages NTW, Ryan PG, Petersen SL, Underhill LG, Upfold L, Wilkinson W, de Villiers MS, du Plessis S, du Toit M, Leshoro TM, Makhado AB, Mason M, Merkle D, Tshingana D, Ward VL, Whittington PA (2003) Populations of surface-nesting seabirds at Marion Island, 1994/95–2002/03. *African Journal of Marine Science* **25**: 427–440

Crawford RJM, David JHM, Shannon LJ, Kemper J, Klages NTW, Roux J-P, Underhill LG, Ward VL, Williams AJ, Wolfaardt AC (2001) African penguins as predators and prey — coping (or not) with change. In: Payne AIL, Pillar SC, Crawford RJM (eds) *A Decade of Namibian Fisheries Science. South African Journal of Marine Science* **23**: 435–447

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

Crawford RJM, Dundee BL, Dyer BM, Klages NT, Meyër MA, Upfold L (2007) Trends in numbers of Cape gannets (*Morus capensis*), 1956/57–2005/06, with a consideration of the influence of food and other factors. *ICES Journal of Marine Science* **64**: 169–177

Crawford RJM, Robinson GA (1990) Impacts of seals on seabirds. In: *Report of the Subcommittee of the Sea Fisheries Advisory Committee appointed at the request of the Minister of Environment Affairs and of Water Affairs, to advise the Minister on Scientific Aspects of Sealing.* Sea Fisheries Research Institute. Cape Town, pp 84–87

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

du Toit M, Bartlett PA, Bester MN, Roux J-P (2004) Seal-seabird predation at Ichaboe Island, Namibia: prey selection by individual seals. *South African Journal of Wildlife Research* **34**: 45–54

Green K, Williams R, Handasyde K, Burton HR, Shaughnessy PD (1990) Interspecific and intraspecific differences in the diets of fur seals, *Arctocephalus* species (Pinnipedia: Otariidae), at Macquarie island. *Australian Mammalogy* **13**: 193–200

Guinet C, Jouventin P, Georges JY (1994) Long term population changes of fur seals *Arctocephalus gazella* and *A. tropicalis* on subantarctic (Crozet) and subtropical

(St. Paul and Amsterdam) islands and their possible relationship to El Niño Southern Oscillation. *Antarctic Science* **6**: 473–478.

Harwood J (1992) Assessing the competitive effects of marine mammal predation on commercial fisheries. *South African Journal of Marine Science* **12**: 689–693

Hofmeyr GJG, Bester MN (1993) Predation on king penguins by Antarctic fur seals. *South African Journal of Antarctic Research* **23**: 71–74

Hofmeyr GJG, Bester MN, Makhado AB, Pistorius PA (2006) Population change of subantarctic and Antarctic fur seals at Marion Island. *South African Journal of Wildlife Research* **36**: 55–68

Isaksen K, Huyser O, Kirkman S, Wanless R, Wilson W (2000) Studies of seabirds and seals at Bouvetoya 1998/99. *Norsk Polarinstitutt Internrapport* **2**: 8

Johnson RL, Venter A, Bester MN, Oosthuizen WH (2006) Seabird predation by white shark and Cape fur seal at Dyer Island. *African Journal of Marine Science* **29**: 105–111

Kerley GIH (1987) *Arctocephalus tropicalis* on the Prince Edward Islands. In: Croxall JP, Gentry RL (eds) *Status, Biology and Ecology of Fur Seals: Proceedings of an International Symposium and Workshop, Cambridge, 23–27 April 1984. National Oceanic and Atmospheric Administration Technical Report, National Marine Fisheries Service* **51**: 61–64

Krebs CJ, Boonstra R, Boutin S, Sinclair ARE (2001) What drives the 10-year cycle of snowshoe hares? *Bioscience* **51**: 25–35

Krebs CJ, Boutin S, Boonstra R, Sinclair ARE, Smith JNM, Dale MRT, Turkington KMR (1995) Impact of food and predation on the snowshoe hare cycle. *Science* **269**: 1112–1115

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

Marks MA, Brooke RK, Gildenhys AM (1997) Cape fur seal (*Arctocephalus pusillus pusillus*) predation on Cape cormorants (*Phalacrocorax capensis)* and other birds at Dyer Island, South Africa. *Marine Ornithology* **25**: 9–12

Navarro RA (2000) Cape fur seal predation on Cape gannet fledglings. *Bird Numbers* **9**(2): 15–16

Oro D, Pradel R, Lebreton J-D (1999) The effects of nest predation and food availability on life history traits in Audouin's gull. *Oecologia* **118**: 438–445

Paulian P **(***1964)* Contribution à l'étude de l'otarie de l'île d'Amsterdam. Mammalia *28*: 1–146

Payne MR (1977) Growth of a fur seal population. *Philosophical Transactions of the Royal Society of London Series B* **279**: 67–79

Rebelo AG (1984) Cape fur seal *Arctocephalus pusillus* kills jackass penguin *Spheniscus demersus* on land. *Cormorant* **12**: 111

Roux J-P (1987) Recolonization processes in the subantarctic fur seal, *Arctocephalus tropicalis*, on Amsterdam Island. In: JP Croxall, RL Gentry (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**: 189–194

Shaughnessy PD (1978) Cape fur seals preying on seabirds. *Comorant* **5**: 31

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

Shaughnessy PD, Fletcher L (1987) Fur seals, *Arctocephalus* spp., at Macquarie Island. *NOAA Techinical Report NMFS* **51**: 177–188

Ward VL, Williams AJ (2004) Coastal killers: causes of seabird mortality. *Bird Numbers* **13**(1): 14–17

Whittam RM, Leonard ML (*1999*) *Predation and breeding success in roseate terns* (Sterna dougallii). Canadian Journal of Zoology *77: 851–856*

Wolfaardt A, Williams AJ (2006) Sealed off: predation threatens seabirds and tourism. *Africa – Birds and Birding* **11**: 61–67

Woodworth BL (1999) Modeling population dynamics of a songbird exposed to parasitism and predation and evaluating management options. *Conservation Biology* **13**: 67–76

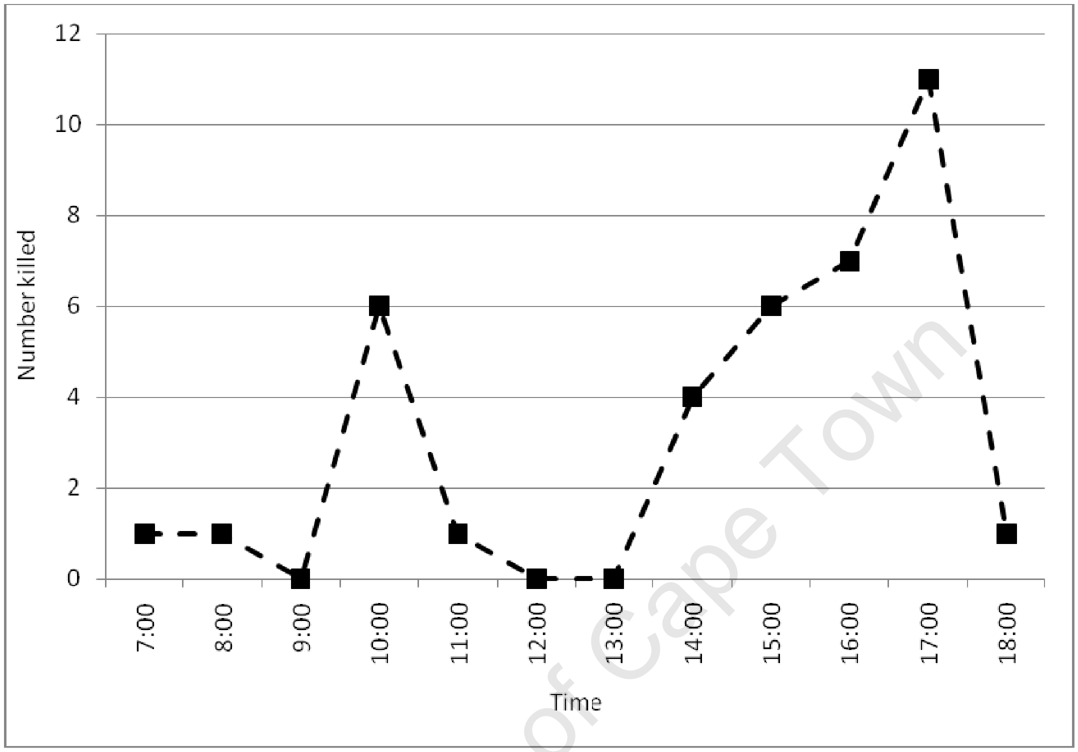

Figure 1: Number of African penguins killed at Dassen Island at different times of the day, September 2003, October 2004 and September 2005. On account of small sample sizes, observations for all years has been lumped

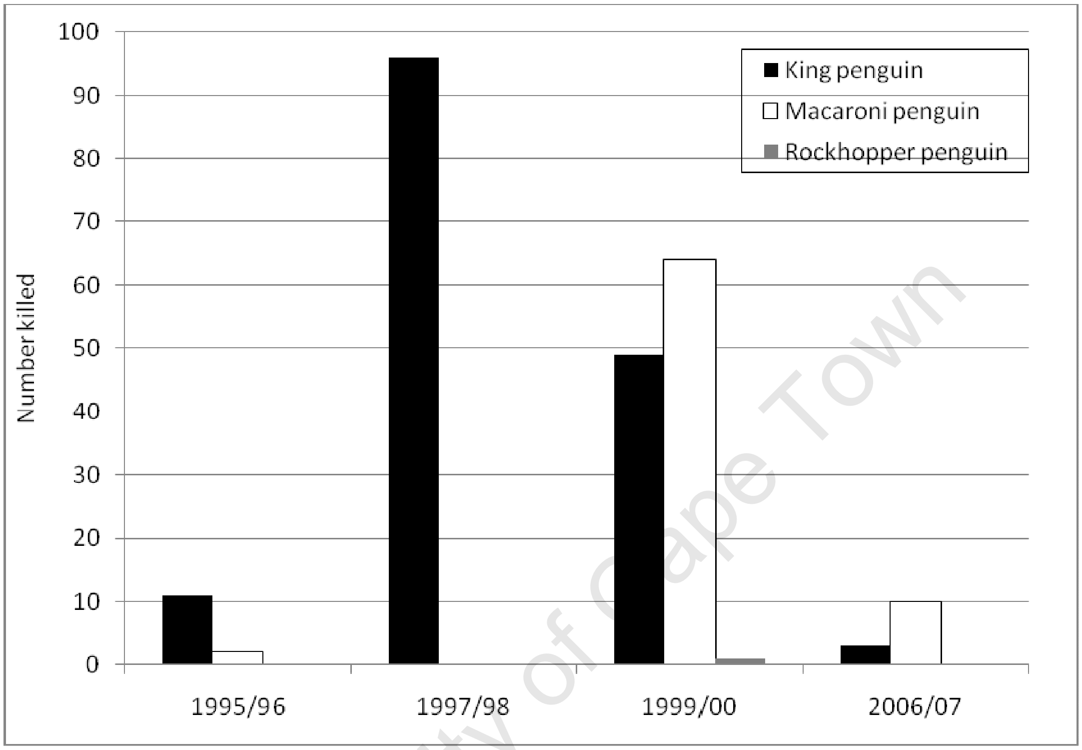

Figure 2: Number of three species of penguin observed to be killed by the Antarctic fur seals at Marion Island in four split years

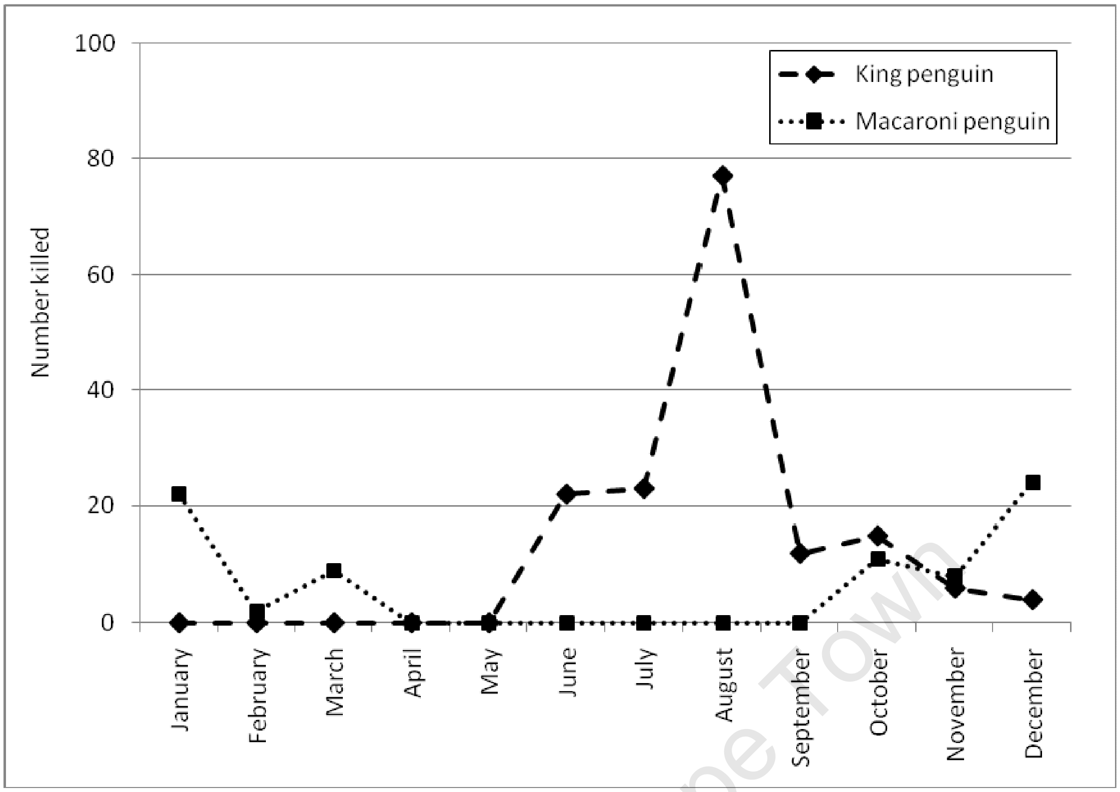

Figure 3: Numbers of king and macaroni penguins observed to be killed by Antarctic fur seals at Marion Island in each month of the year. On account of small sample sizes, information for the four split years has been lumped

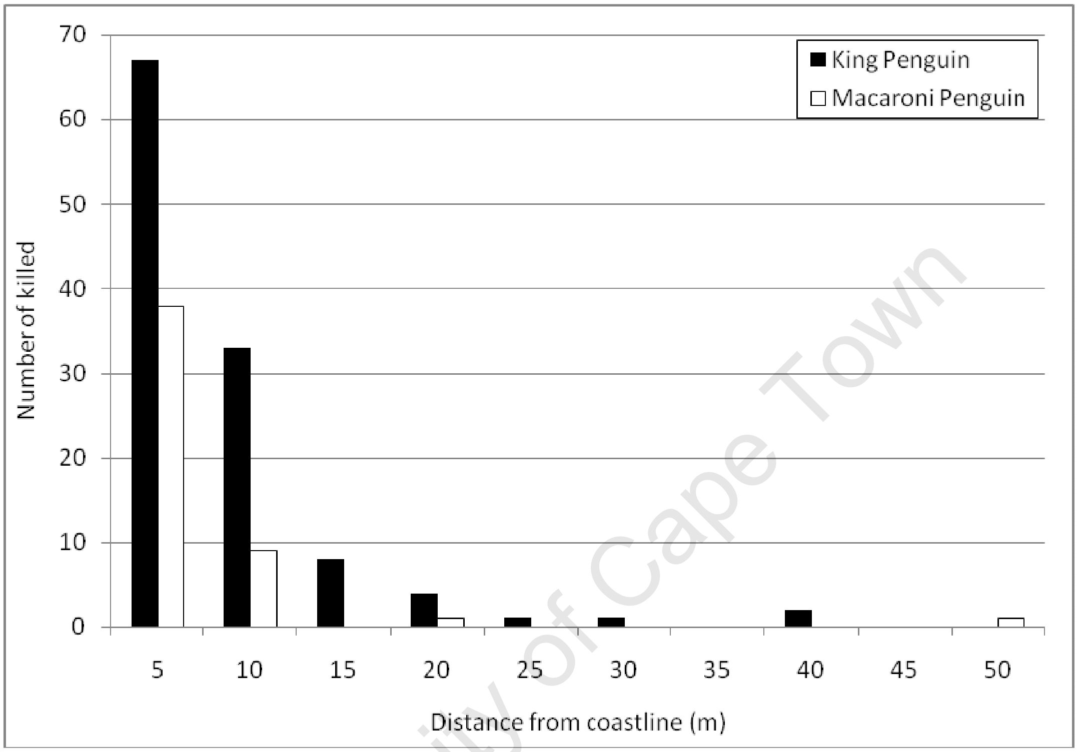

Figure 4: Numbers of king and macaroni penguins observed to be killed by Antarctic fur seals at different distances from the coastline at Marion Island.

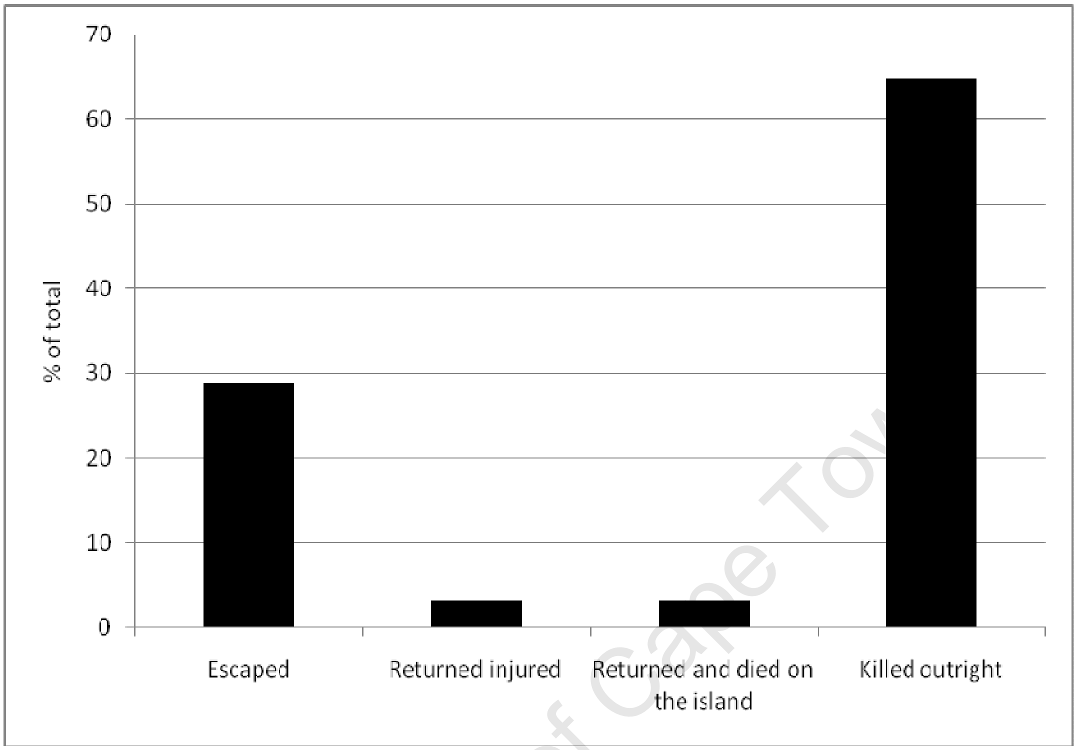

Figure 5: The fate of penguins that were attacked by Antarctic fur seals at Marion Island during May 1999 and April 2000

CHAPTER 5

Prey, sex and age of Cape fur seals *Arctocephalus pusillus pusillus* collected at Malgas Island, South Africa, during the fledging of Cape gannets *Morus capensis*, 1999–2008

Prey, sex and age of Cape fur seals *Arctocephalus pusillus pusillus* collected at Malgas Island, South Africa, during the fledging of Cape gannets *Morus capensis*, 1999–2008

ABSTRACT

In six years between 1999 and 2008, 141 Cape fur seals *Arctocephalus pusillus pusillus* that were feeding on, or about to attack, Cape gannet *Morus capensis* fledglings as they left Malgas Island, South Africa, were shot and collected. All the collected seals were bulls. Examination of the stomachs of 93 of these seals showed that Cape gannets contributed an average of 70% by mass of the diet, and known prey items of Cape gannets, which may have been obtained from the alimentary tract of fledglings, a further 5%. Hence, when the seals were culled they were subsisting mainly on the fledglings. Other prey items of the seals included rock lobster *Jasus lalandii* and common octopus *Octopus vulgaris*. The ages of the seals were estimated from measures of their total length and previously published information on ages at length. All were 10 years old or less and the mean age was 4.5 years. There was a decrease over time in both the maximum and mean age of bulls culled.

INTRODUCTION

The Cape fur seal *Arctocephalus pusillus pusillus* is endemic to southern Africa and is the only pinniped species that breeds in the region (Skinner and Chimimba 2005). Its population increased markedly in the 20th century and was estimated in 1995 to be about two million individuals (Butterworth *et al*. 1995), most of which occurred in the

Benguela upwelling system (David 1989). They consume more than one million tonnes of food per year (Crawford *et al*. 1992). Since 1937, seals have increasingly been observed feeding on seabirds (Rand 1959, Cooper 1974, Shaughnessy 1978, Rebelo 1984, Crawford and Cooper 1996, Marks *et al.* 1997, Navarro 2000, Crawford *et al.* 2001, David *et al.* 2003, du Toit *et al.* 2004, Makhado *et al.* 2006), several of which are classified as Threatened (David *et al*. 2003). However, seabirds are less abundant than several other prey organisms (Crawford *et al.* 1992) and generally from only a minor component of the diet of Cape fur seals (Rand 1959, David 1987, Mecenero *et al.* 2005) Cape gannets *Morus capensis* breed at six colonies, three in Namibia and three in South Africa (Crawford *et al*. 2007). Their numbers at Namibian colonies decreased by more than 90% after 1956 (Crawford *et al*. 2007). Numbers at the two colonies off South Africa's west coast, including Malgas Island (33°03'S, 17°55'E), have also recently decreased (Crawford *et al*. 2008). At Malgas Island, predation on Cape gannet fledglings by Cape fur seals is thought to be unsustainable (Makhado *et al*. 2006) and, to reduce this impact, culling of seals seen feeding, or thought to be feeding, on seabirds has been undertaken around the island in five years since 1999 (Chapter 8). This chapter reports on the food, sex and age of the culled seals.

METHOD AND MATERIALS

In 1999, 2000, 2001, 2003, 2007 and 2008, attempts were made to cull Cape fur seals feeding on, or thought about to attack, seabirds around Malgas Island during the main fledging period of Cape gannets, in January, February and March. Culling was conducted under permit issued by South Africa's Department of Environmental Affairs and Tourism. As many as possible of the seals that were culled were collected; some sank before they could be retrieved. The method to cull the seals and collect their carcasses is described in Makhado *et al*. (2009).

Except in 2007, the stomach contents of culled seals were collected. From 1999–2003, for each stomach, the mass of each different prey species was recorded, as well as the mass of unidentifiable prey items, by weighing on a scale. In 2008, for each stomach, individual prey species were grouped and their proportional contribution to the total amount of food in the stomach gauged by visual inspection. This less rigorous process was followed on account of a reduced personel capacity. As availability of prey species may vary between years, the per cent contribution by mass of different prey items to the diet was calculated for each year. Prey items were identified using identification reference manuals and experience. The following were used as idefication materials for each species: for birds, only feathers and fresh flesh; fish, only fresh fish, and cephalopods (lower beaks) and crustacean carapace were used for cephalopod. For the whole period (1999–2008), the proportional contribution (by mass) of different prey items to the diet was calculated by giving equal weighting to each year. Most predation by Cape fur seals on Cape gannets occurs after 11h00 (Makhado *et al*. 2006). Therefore the percentage contribution of gannet fledglings to the diet was also estimated for the overall period for seals culled before and after 11h00. The Chi-squared statistic was computed to examine the influence of year and time of collection on the contribution of Cape gannet fledglings to the diet of seals.

For all collected seals, the sex was determined by examination of genital organs. The total length (dorsally from tip of snout to base of tail) of all culled seals was measured, and their age was estimated by field workers, based on previous field experience. It is these estimated ages that have previously been reported for a sub-sample of the collections of culled individuals (David *et al*. 2003, Makhado *et al*. 2009). Oosthuizen and Miller (2000) reported the lengths and ages of bull Cape fur seals, where ages were determined from longitudinal sections of upper canine teeth, and they developed the regression equation relating age A (years) to length L (cm):

$L = 107.12 + 6.680A$,

with $r^2 = 0.96$. This relationship was used to estimate the ages ($A = (L - 107.12)/6.68$) of the culled seals from their lengths and the results were compared to the ages estimated by field workers.

It was investigated whether the age structure of seals that killed seabirds reflected the age structure of male seals in the population as a whole. Information was available on the proportional contribution of different age classes to the harvest of bull seals at Kleinzee (29° 40′S, 17° 5′E), north-western South Africa, from 1981–1989 (Anon. 1990). Numbers alive at age in an un-harvested population were estimated, assuming that there were 1000 bulls in their first year (age 0) and that subsequent annual survival was 0.92 for bulls less than 12 years old and 0.70 for bulls aged 12 years or more (Butterworth *et al*. 1995). The proportional contributions of age classes of bull seals harvested at Kleinzee, culled at Malgas Island and expected in an un-harvested population were compared.

RESULTS

Diet

A total of 141 seals was culled and collected at sea during 1999–2001, 2003, 2007 and 2008. Of these, 93 were dissected and their stomach contents removed and examined. No dissections were undertaken in 2007. Four of the stomachs were empty. Cape gannet fledglings were present in 73 of the 89 stomachs that contained prey items and dominated the diet, contributing annual averages of 56–80% (mean 70%) of the mass of food in the stomachs (Figure 1). The 16 stomachs which did not contain gannet fledglings were probably from seals for which the attack on a gannet was the first of the day, and they were unable to feed on the fledgling before they were shot. No other species of seabird was found in the stomachs. Prey of Cape gannets, such as anchovy *Engraulis encrasicolus*, which may have been obtained through seals feeding on the fledglings, was also prominent (Crawford and Dyer 1995). Sometimes Cape fur seals feed only on the viscera of gannet fledglings (Makhado *et al*. 2009). Common octopus *Octopus vulgaris* contributed 11% by mass of the prey of the culled Cape fur seals and rock lobster *Jasus lalandii* 9%. These would have been primary prey since Cape gannet do not feed on these two prey species and they are known to occur in the diet Cape fur seals. Several other organisms were eaten (Table 1). For 13 seals that were culled earlier than 11h00, 10 contained Cape gannet fledglings, but these contributed an average of 6% by mass of stomach contents. For 76 seals which were culled later than 11h00, only 27 seals contained other prey species. The contribution of Cape gannet fledglings to the diet of seals culled around Malgas Island was not significantly different between years (χ^2 = 2.71, df = 4, P =0.61).

Sex and age

All 141 of the seals collected were bulls. There was a close relationship between the mean length at age of seals, whose age was determined from sections through upper canine teeth (Oosthuizen *et al*. 2000), and the mean length at age of seals culled at Malgas Island, as estimated by field workers (Figure 2). However, the mean length at estimated age of culled seals was less than that of seals that were accurately aged, suggesting that the age of the culled seals was overestimated. In order to compare the age structure of male seals killing seabirds with the age structure of male seals in a natural population, it was necessary to correct the bias. The mean lengths at age of bull seals that were aged by Oosthuizen and Miller (2000) are shown in Figure 3. The significant linear relationship between length and age of bull seals was used to reassign ages to the seals culled at Malgas Island, which ranged from 0.9–10 years, with a mean of 4.5 years. Most (93%) of the seals culled at Malgas Island were between one and seven years old (Figure 4). By contrast, most of the bull seals culled at Kleinzee (81%) were aged seven years or older, with a peak at 8–10 years (Anon. 1990, Figure 4). In an unharvested population, the number of bulls decreases with age but a substantial proportion are aged 12 years or older (Figure 4).

The null hypothesis of equal median ages in each of the six years in which culling took place was rejected (χ^2 =11.93, df=5, P=0.036). Further analyses showed that the significance could be attributed to a decrease in the median age of bull seals culled at Malgas Island between 1999 and 2000, from 5.7 years (n=21) to 3.6 years (n=40), and that the median ages in the five subsequent years in which culling took place between

2000 and 2008 were not significantly different (χ^2=5.49, df=4, P=0.24) (Figure 5). It is noteworthy that the lower quartile in 1999, 4.5 years, was larger than the median age in the following year, 3.6 years.

DISCUSSION

The diet of seals is an important factor in determining management policies for seal populations (Castley *et al.* 1991). Estimating the diet of any free-ranging animal is a difficult undertaking and prone to inaccuracies. Stomach content analysis gives an indication of food eaten but involves the sacrifice of animals, and it may not be clear which species are secondary prey items (obtained from the alimentary tracts of primary prey). Further, some prey species may be digested more rapidly than others (Pierce and Boyle 1991, Pierce *et al*. 1991, Klages and Bester 1998). Stomach lavage and enema procedures are not widely used to investigate seal diets because sample sizes are often small and animals may require chemical immobilization, thereby increasing the risk of injury or fatality (Antonelis *et al.* 1987, Harvey and Antonelis 1994). They have been analyzed for several species of pinnipeds (Gales *et al.* 1993, Harvey and Antonelis 1994, Kiyota *et al.* 1999, Lowry and Carretta 1999, Kirkman *et al.* 2000). Regurgitates contain prey remains such as fish bones, otoliths and cephalopod beaks. Often the prey remains are too large to pass through the pyloric sphincter and are, therefore, regurgitated from the stomach (Bigg and Fawcett 1985, Jobling and Breiby 1986). Although regurgitates may be found in areas where pinnipeds come ashore, they are often less abundant than scats (Jobling and Breiby 1986, Gales *et al.* 1993) and have largely been excluded from pinniped diet studies.

Identification of prey remains in scats may be used, but only hard remains (e.g. otoliths, bones, scales and eye lenses of fish, beaks and lenses of cephalopod, carapaces of crustaceans, bones and feather of seabirds) are likely to be identifiable (e.g. Cherel *et al.* 1997). Some hard parts are entirely digested or are reduced in size during passage through the digestive tract (Pierce and Boyle 1991, Pierce *et al*. 1991, Klages and Bester 1998). Many studies have demonstrated the potential biases associated with the scat sampling method (Jobling and Breiby 1986, Pierce and Boyle 1991, Bowen 2000, Makhado *et al.* 2008), including the accumulation of cephalopod beaks in the stomach (Bigg and Fawcett 1985, Gales *et al.* 1993, Harvey and Antonelis 1994) and underestimation of size and frequency of occurrence of some prey species (Bigg and Fawcett 1985, Harvey 1989, Tollit *et al.* 1997). Captive feeding studies on several pinniped species have shown that factors such as species, sex, individual activity level, stomach size, gut length, prey digestibility, feeding regime and meal size affect the degree of erosion and recovery of prey remains in scats (Harvey and Antonelis 1994, Tollit *et al.* 1997, Marcus *et al*. 1998, Bowen 2000, Orr and Harvey 2001). Although studies to account for these biases have been conducted (Sinclair *et al.* 1994, Antonelis *et al*. 1987, Tollit *et al*. 1997), the different retention and digestive rates of prey remains in the stomach continue to be a leading drawback for diet studies in which scat samples alone are used. However, despite these and other biases inherent to the method (Dellinger and Trillmich 1988, Klages and Bester 1998), scat analysis provides the least intrusive method of investigating the diets of the fur seals (Pierce *et al*. 1991).

Historically, the diet of Cape fur seals was established through the shooting of animals at sea (Rand 1959, David 1987), but more recently the collection and analysis of scats has been employed (Mecenero *et al*. 2006). Similarly, to earlier studies, this investigation was based on stomach content analysis. However, in comparing results repeated by various authors, it is important to be aware of the biases of different methods used as discussed above. The bulk of the diet of Cape fur seals is comprised of abundant fish and squid species, with minor quantities of crustaceans (David 1987), which is similar to this study. Off South Africa, the most important species in the diet were the commercially important sardine *Sardinops sagax*, anchovy *Engraulis encrasicolus*, horse mackerel *Trachurus trachurus* and two species of hake *Merluccius capensis* and *M. paradoxus* (Rand 1959, David 1987). From 1974–1985, for Cape fur seals collected at sea, about 75% of the diet was teleost fish, followed by cephalopods and crustaceans that contributed 17% and 5%, respectively (David 1989). In Namibia, the non-commercial pelagic goby *Sufflogobius bibarbatus* was the dominant prey item (David 1987). Other prey species important were horse mackerel, hake, lantern fish and pelagic fish. Hake was an important prey at all three seal colonies (Van Reenen Bay and Atlas and Wolf bays), where the occurrence of pelagic fish in seal scats was low. Hard part remains of cephalopods (beaks) and crustaceans were negligible. Horse mackerel and hake are commercially important in Namibia (Mecenero *et al*. 2006).

Seabirds are generally uncommon in the diet of Cape fur seals. For seals collected at sea, two stomachs of 1647 examined contained bird remains (David *et al.* 2003). Mecenero *et al*. (2005) reported that the frequency of occurrence of seabirds in the diet was negligible at 0.1%, contrastingly seabirds were the most common prey species in this study. However, Cape fur seals feed on seabirds around seabird breeding localities (Cooper 1974, Shaughnessy 1978, Rebelo 1984, Crawford and Cooper 1996, Marks *et al.* 1997, Navarro 2000, Crawford *et al.* 2001, David *et al.* 2003, du Toit *et al.* 2004, Makhado *et al.* 2006). In this study, Cape gannet fledglings dominated the diet of Cape fur seals hunting around Malgas Island, emphasizing the diversity of the Cape fur seal diet and the ability of certain individuals to specialize on certain prey items.

Predation of seabirds, mainly penguins (Spheniscidae), has been documented for other otariids (Hofmeyr and Bester 1993, McMahon *et al*. 1999, Childerhouse *et al*. 2001) and less commonly for phocids (Rogers and Bryden 1995, Cobley and Bell 1998). Individual seals may supplement their diet with seabirds, rather than specialize on seabirds (Cobley and Bell 1998). For otariids, it is believed that only a few individuals within a population, usually males, are responsible for most predation on seabirds (Bonner and Hunter 1982, McMahon *et al*. 1999, Childerhouse *et al*. 2001, du Toit *et al*. 2004, Chapters 2 and 3). If this is the case, it suggests the possibility of controlling the loss of seabirds to seals (Makhado *et al.* 2009), which is especially important in the case of threatened seabird species (David *et al*. 2003).

It is noteworthy that at Malgas Island all the predation on Cape gannet fledglings was by bull seals of age 10 years or less, that were generally younger than bulls harvested at the Kleinzee Cape fur seal breeding colony. It is during this time that the females are nurturing their pups. It should be borne in mind that the cull at Kleinzee in the 1980s was restricted to bulls and that harvesters may have avoided some young seals because they were uncertain of their sex (WH Oosthuizen, Department of Environmental Affairs and Tourism unpublished records). On the other hand, the harvest of bull seals over several consecutive seasons would have reduced the number of older animals in the take. It is likely that the young bulls that feed on seabirds at Malgas Island are too small to hold territories and to control harems at seal breeding colonies. Butterworth *et al.* (1995) considered territorial bulls to be 10 years or older. Gilbert and Erickson (1977) suggested that dispersal of non-breeding seals may occur due to intraspecific competition for food and also competition for space..

The bulls harvested in the colony at Kleinzee were older than those engaged in killing birds Malgas Island (Chapter 2), suggesting that once bulls start trying to enter the colonies with a view to becoming beach masters, they tend to stop predation on seabirds (Figure 4). The mean age of bull seals feeding on Cape gannet fledglings and the recent decrease in the maximum age of such seals indicate that culling of seals feeding on gannets may gradually be eliminating those animals that have learnt to feed on seabirds. In 2001 and 2008, the minimum age of seals feeding on gannets increased, perhaps indicative that successive culls also discourage the learning of this feeding behavior by young bulls. Consistent culling may eliminate this behavior to a substantial extent (Makhado *et al*. 2009), but a few more years of culling seals feeding on seabirds will be needed to establish whether this will be the case.

Acknowledgements – I thank the National Research Foundation and WWF-SA for supporting this research. The Department of Environmental Affairs and Tourism (South Africa) and CapeNature provided logistical support.

REFERENCES

Anon. (1990) *Report of the Subcommittee of the Sea Fisheries Advisory Committee appointed at the request of the Minister of Environment Affairs and of Water Affairs, to advise the Minister on the Scientific Aspects of Sealing.* Sea Fisheries Research Institute, Cape Town

Antonelis GA, Lowry MS, DeMaster DP, Fiscus CH (1987) Assessing northern elephant seal feeding habits by stomach lavage. *Marine Mammal Science* **3**: 308–322

Bigg MA, Fawcett I (1985) Two biases in diet determination of northern fur seals *Callorhinus ursinus*. In: Beddington JRH, Beverton RJH, Lavigne DM (eds) *Marine Mammals and Fisheries.* George Allen and Unwin Ltd, London, pp 284–299

Bonner WN, Hunter S (1982) Predatory interactions between Antarctic fur seals, macaroni penguins and giant petrels. *British Antarctic Survey Bulletin* **56**: 75–79

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

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

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 Marine Science* **11**: 573–577

Cherel Y, Guinet C, Tremblay Y (1997) Fish prey of Antarctic fur seals *Arctocephalus gazella* at lle de Croy, Kerguelen. *Polar Biology* **17**: 87–90

Childerhouse S, Dix B, Gales N (2001) Diet of New Zealand sea lions *Phocarctos hookeri* at the Auckland Islands. *Wildlife Research* **28**: 291–298

Cobley ND, Bell G (1998) Weddel seal *Leptonychotes weddellii* feeding on gentoo penguins (*Pygoscelis papua*). *Marine Mammal Science* **14**: 881– 883

Cooper J (1974) The predators of the jackass penguin *Spheniscus demersus*. *Bulletin British Ornithological Club* **94**: 21–24

Crawford RJM, Cooper J (1996) Cape Fur Seal *Arctocephalus pusillus* catches Cape Gannet *Morus capensis* ashore at Malgas Island. *Marine Ornithology* **24**: 53–54

Crawford RJM, David JHM, Shannon LJ, Kemper J, Klages NTW, Roux J-P, Underhill LG, Ward VL, Williams AJ, Wolfaardt AC (2001) African penguins as predators and prey – coping (or not) with change. *South African Journal of Marine Science* **23**: 435–447

Crawford RJM, Dundee BL, Dyer BM, Klages NTW, Meÿer MA, Upfold L (2007) Trends in numbers of Cape gannets (*Morus capensis*), 1956/57–2005/06, with a consideration of the influence of food and other factors. *ICES Journal of Marine Science* **64**: 169–177

Crawford RJM, Dyer BM (1995) Responses by four seabirds to a fluctuating availability of Cape anchovy *Engraulis capensis* off South Africa. *Ibis* **137**: 329–339

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

Crawford RJM, Underhill LG, Raubenheimer CM, Dyer BM, Martin J (1992) Top predators in the Benguela ecosystem – implications of their trophic position. *South African Journal of Marine Science* **12**: 675–687

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 (1987) South African fur seals *Arctocephalus pusillus pusillus.* In: Croxall JP, Gentry RL (eds) *Status, Biology and Ecology of Fur Seals. NOAA Technical Report*, *National Marine Fisheries Service* **51**: 65–71

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

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

Dellinger T, Trillmich F (1988) Estimating diet composition from scat analysis in otariid seals (Otariidae): is it reliable? *Canadian Journal Zoology* **66**: 1865–1870

du Toit M, Bartlett PA, Bester MN, Roux J-P (2004) Seal-seabird predation at Ichaboe Island, Namibia: prey selection by individual seals. *South African Journal of Wildlife Research* **34**: 45–54

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

Gilbert JR, Erickson AW (1977) Distribution and abundance of seals in the pack ice of the Pacific sector of the Southern Ocean. In: Llano GA (ed) *Adaptation within Antarctic Ecosystem.* Smithsonian Institution, Washington, D.C, pp 703–740

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

Harvey JT, Antonelis GA (1994) Biases associated with non-lethal methods of determining the diet of northern elephant seals. *Marine Mammal Science* **10**: 178–187

Hofmeyr GJG, Bester MN (1993) Predation on king penguins by Antarctic fur seals. *South African Journal of Antarctic Research* **23**: 71–74

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

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

Kiyota M, Kawai C, Baba N (1999) Estimation of diet of male northern fur seals *Callorhinus ursinus* based on analysis of fecal and regurgitated materials. *Bulletin National Research Institute Far Seas Fisheries* **36**: 1–7

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

Lowry MS, Carretta JV (1999) Market squid *Loligo opalescens* in the diet of California sea lions *Zalophus californianus* in southern California (1981–1995). *CalCOFI Report* **40**: 196–207

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, Crawford RJM, Underhill LG (2006) Impact of predation by Cape fur seals *Arctocephalus 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, Wilkie 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

Marcus J, Bowen WD, Eddington JD (1998) Effects of meal size on otolith recovery from fecal samples of gray and harbor seal pups. *Marine Mammal Science* **14**: 789–802

Marks MA, Brooke RK, Gildenhuys AM (1997) Cape fur seal *Arctocephalus pusillus* predation on Cape cormorants *Phalacrocorax capensis* and other birds at Dyer Island, South Africa. *Marine Ornithology* **25**: 9–12

McMahon CR, Holley D, Robinson S (1999) The diet of itinerant male Hooker's sea lions, *Phocarctos hookeri*, at sub-Antarctic Macquarie Island. *Wildlife Research* **26**: 839–846

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, Bester MN (2006) Diet of Cape fur seals *Arctocephalus pusillus pusillus* at three mainland breeding colonies in Namibia. 1. Spatial variation. *African Journal of Marine Science* **28**: 57–71

Navarro RA (2000) Cape fur seal predation on Cape gannet fledglings. *Bird Numbers* **9**(2): 15–16

Oosthuizen WH, Miller EH (2000) Bacular and testicular growth and allometry in the Cape fur seal *Arctocephalus pusillus pusillus* (Otariidae). *Marine Mammal Science* **16**: 124–140

Orr AJ, Harvey JT (2001) Quantifying errors associated with using fecal samples to determine the diet of the California sea lion *Zalophus californianus*. *Canadian Journal of Zoology* **79**: 1080–1087

Pierce GJ, Boyle PR (1991) A review of methods for diet analysis in piscivorous marine mammals. *Oceanography and Marine Biology Annual Review* **29**: 409–486

Pierce GJ, Boyle PR, Diack JSW (1991) Identification of fish otoliths and bones in faeces and digestive tracts of seals. *Journal of Zoology* **224**: 320–328

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

Rebelo AG (1984) Cape fur seal *Arctocephalus pusillus* kills jackass penguin *Spheniscus demersus* on land. *Cormorant* **12**: 111

Rogers T, Bryden MM (1995) Predation of Adélie penguins (*Pygoscelis adeliae*) by leopard seals (*Hydrurga leptonyx*) in Prydz Bay, Antarctica. *Canadian Journal of Zoology* **73**: 1001–1004

Rogers TL, Bryden MM (1997) Density and haul-out behaviour of leopard seals *Hydrurga leptonyx* in Prydz Bay, Antarctica. *Marine Mammal Science* **13**: 293–302

Shaughnessy PD (1978) Cape fur seals preying on seabirds. *Cormorant* **5**: 31

Sinclair EH, Loughlin TR, Pearcy WG (1994) Prey selection by northern fur seals *Callorhinus ursinus* in the eastern Bering Sea. *Fishery Bulletin* **92**: 144–156

Skinner JD, Chimimba CT (2005) *The Mammals of the Southern African Subregion* (3rd edn). Cambridge University Press, Cape Town

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

Walker TR, Boyd IL, McCafferty DJ, Huin N, Taylor RI, Reid K (1998) Seasonal occurrence and diet of leopard seals *Hydruga leptonyx* at Bird Island, South Georgia. *Antarctic Science* **10**: 75–81

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

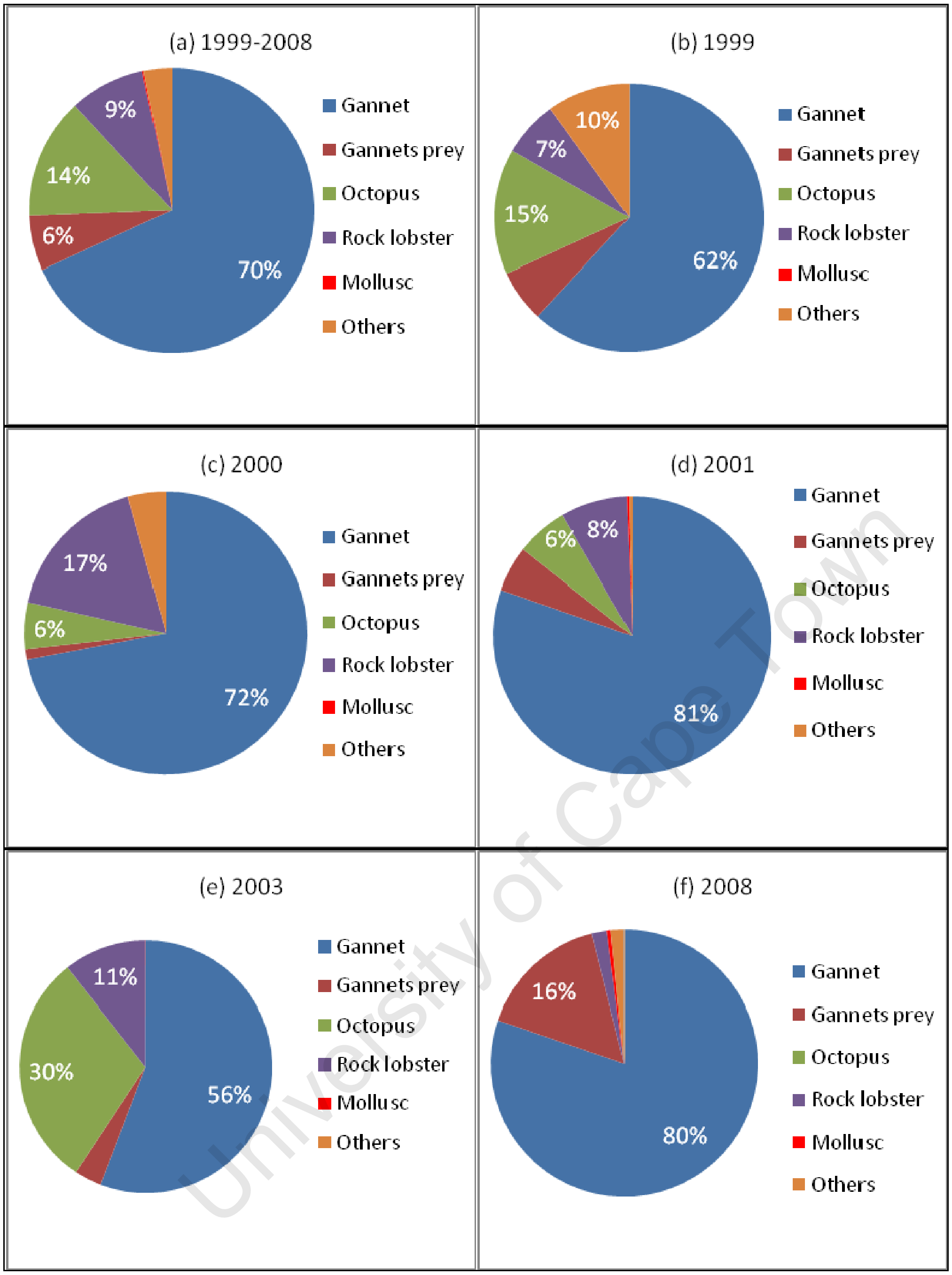

Figure 2: The contribution by mass of Cape gannets and other items to the contents of stomachs of Cape fur seals that were culled at Malgas Island because they were feeding, or suspected to be feeding, on Cape gannets. Items that may have come from the stomachs of Cape fur seals that were culled at Malgas Island because they were feeding, or suspected to be feeding, on Cape gannets. Items that may have come from the stomachs of Cape gannets have been grouped as “Gannet prey”. Contributions are shown for individual years, as well as for all sampled seasons combined

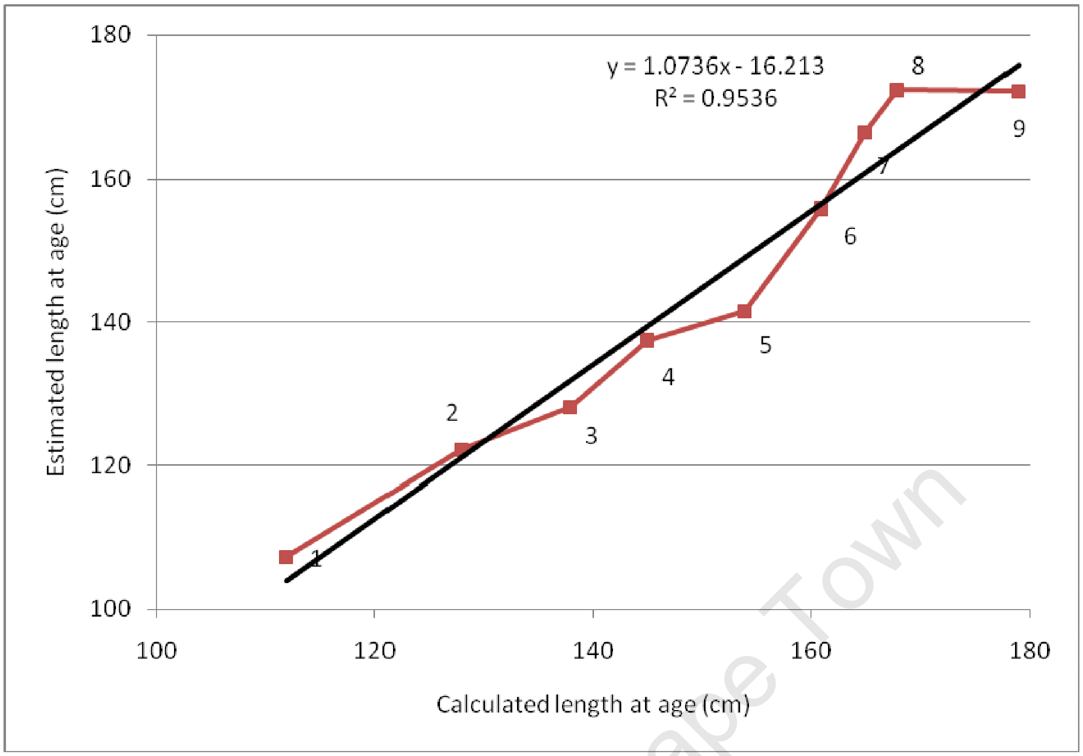

Figure 2: Comparison of the age at length of bull Cape fur seals calculated from Oosthuizen and Miller (2000) and the mean length at age of bull seals culled at Malgas Island, whose age was estimated by field workers at Malgas Island. Although a close relationship is apparent, mean size of estimated ages is generally smaller than the calculated size at age, suggesting that the estimated age was too high (1–9 on the figure represent ages of seals)

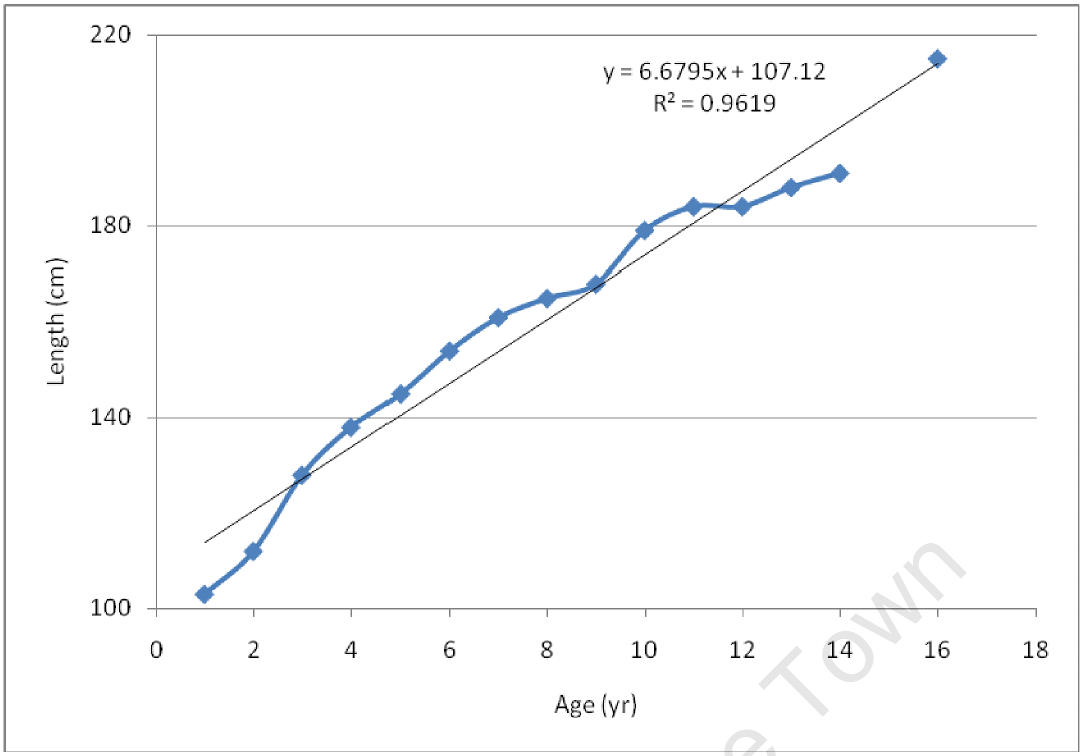

Figure 3: Scatter plot of length against age for bull Cape fur seals from data in Oosthuizen and Miller (2000). The best fitting linear regression curve is shown and was subsequently used to calculate the ages of bull seals at Malgas Island that were feeding, or attempting to feed on Cape gannets. The bulls from Malgas Island were culled and their lengths were measured

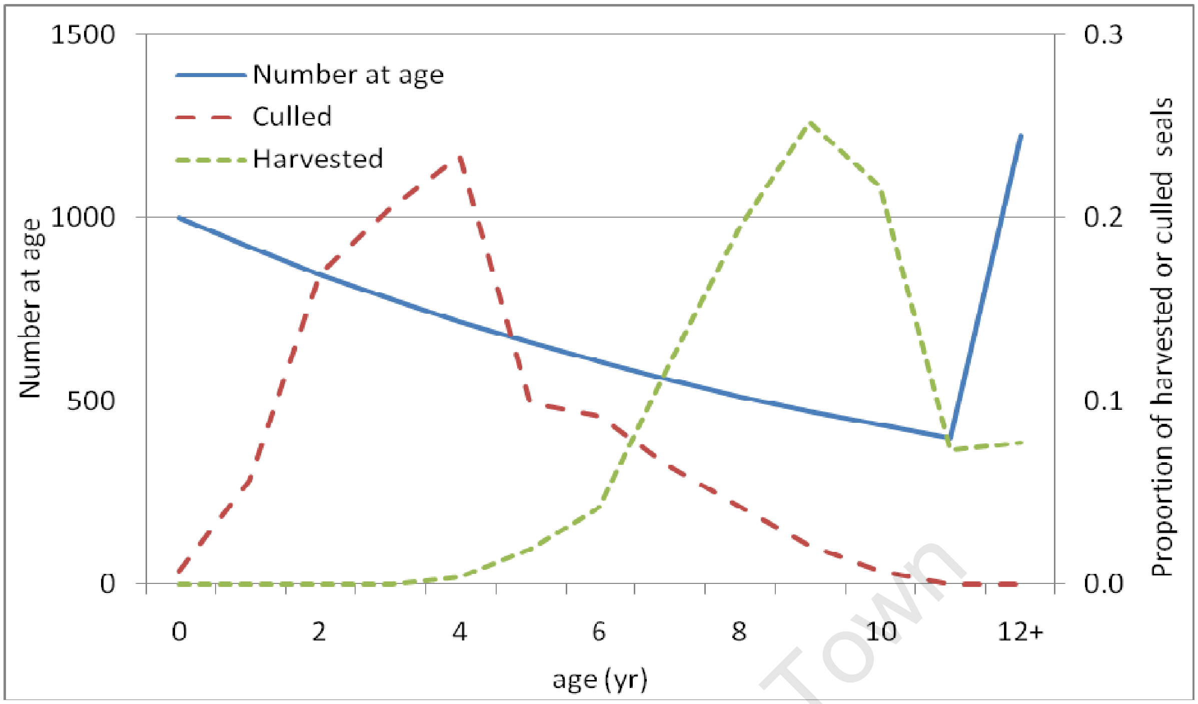

Figure 4: Comparison of the numbers at age of bulls in an unharvested population of Cape fur seals with the proportional contribution of different ages to the harvest of bulls at Kleinzee during 1981–1989 (Anon. 1990) and to bulls culled at Malgas Island during 1999–2008. [1]

---

[1] Numbers and proportions are given for individual ages up to 11 years of age, and then for all bulls aged 12 years or more. Butterworth *et al*. (1995) considered 12 years to be the age at which bulls held territories. In the estimation of numbers alive at age, it was assumed that there were 1000 bulls in their first year (age 0) and that subsequent annual survival was 0.92 for bulls less than 12 years old and 0.70 for bulls aged 12 years or more (Butterworth *et al*. 1995). All bulls culled at Malgas Island were 10 years or younger. The harvests at Kleinzee were of animals that could be identified by sealers as bulls. Hence younger males present at the Kleinzee colony during the harvests may have been under represented. Older males were probably selectively harvested, so that their proportional contribution to overall numbers at the colony could be expected to be lower than in an unharvested situation

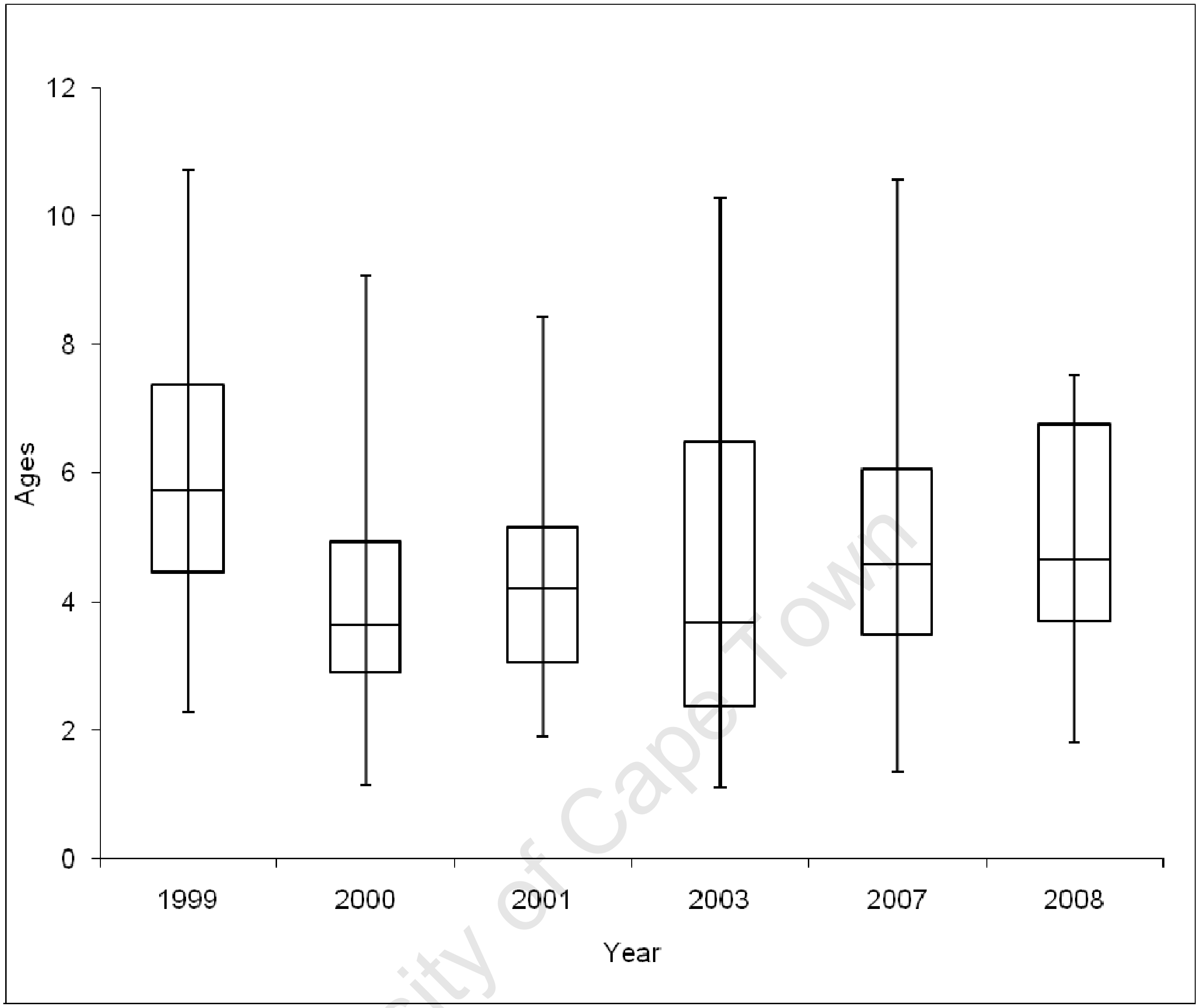

Figure 5: The box and whisker charts showing the estimated maximum, median and minimum ages of bull Cape fur seals culled at Malgas Island during 1999, 2000, 2001, 2003, 2007 and 2008

Table 1: Per cent contribution by mass of prey species to the diet of Cape fur seals culled around Malgas Island because they were feeding, or suspected to be feeding, on seabirds. The assumed nature of the prey (primary or secondary) is indicated

Prey species	**Primary/Secondary**	**% contribution by mass**
Cape gannet *Morus capensis*	Primary	70.08
Anchovy *Engraulis encrasicolus*	Secondary	1.36
Pelagic fish spp	Secondary	3.02
Unidentified fish spp	Secondary	0.26
Sole *Austroglossus microlepis*	Primary	0.72
Hottentot *Pachymetopon aeneum*	Primary	0.68
Steentjie *Spondyliosoma emarginatum*	Primary	0.23
Snoek *Thyrsites atun*	Secondary	0.06
Dog shark *Squalus megalops*	Primary	0.02
Hagfish *Myxine* sp.	Primary	0.02
Rock sucker *Chorisochismus dentex*	Primary	1.01
Sandcord *Parapercis punctulata*	Primary	0.01
Octopus *Octopus vulgaris*	Primary	11.30
Rock lobster *Jasus lalandii*	Primary	8.80
Crabs	Primary	0.00
Mantis shrimp *Pterygosquilla armata*	Primary	1.62
Squid beaks *Mastigoteuthis* spp	Primary	0.32
Sea urchins *Sterechinus neumayeri*	Primary	0.33
Molluscs	Primary	0.04
Gastropods *Cypraea chinensis*	Primary	0.10
Bivalve *Cerastoderma edule*	Primary	0.01
Barnacles *Chthamalus stellatus*	Primary	0.01

CHAPTER 6

Influence of temporal and environmental factors on the predation rate of Cape fur seals on seabirds along the South African coast

Influence of temporal and environmental factors on the predation rate of Cape fur seals on seabirds along the South African coast

ABSTRACT

Of environmental factors considered, time of the day had the most important influence on predation by Cape fur seals *Arctocephalus pusillus pusillus* on fledglings of Cape gannets *Morus capensis* and Cape cormorants *Phalacrocorax capensis* and adult African penguins *Spheniscus demersus*. Fledglings of gannets and cormorants were mainly killed between mid morning and late afternoon, coinciding with the time they left the islands and were in the water. Most adult African penguins were killed as they returned in the evening from foraging at sea. Wind speed and direction, sea state and tide had a variable and lesser influence on predation rates. Although these variables might be used to interpolate predation rates through periods when observations are not conducted, their contribution will be limited and there will remain considerable uncertainty in actual numbers of fledglings killed. Uncertainty will best be decreased by extending the period of observations so as to reduce the amount of days for which predation rates are interpolated.

INTRODUCTION

The role predation plays in the dynamics of prey populations is controversial. Other factors, besides predation, may regulate or limit prey populations, and various aspects influence the degree to which predation affects prey populations (Gese and Knowlton 2001). The understanding of predator-prey relationships is hampered by a multitude of factors that operate in the environment in which the interaction is happening, and by a general lack of knowledge of most ecological systems (Gese and Knowlton 2001). Factors such as the densities of the prey and predators, environmental conditions, mechanisms of prey defence and strategies of attack of the predator can influence the predation process (Holling 1959).

In the Benguela ecosystem off southern Africa, predation on seabirds by Cape fur seals *Arctocephalus pusillus pusillus* has become a concern because of recent declines in, and a poor conservation status of, several of the seabird species (David *et al*. 2003). Preliminary analyses indicate that for some seabirds the predation by seals is too large to be sustainable (Makhado *et al*. 2006, Chapter 2). However, this was based on assumptions that mortality of seabirds could be interpolated between different periods of observations.

Predation is known to be affected by the environment in which it occurs (Hammerschlag *et al.* 2006). Predators and their prey often have different sensory capabilities with discrete strengths and weaknesses that are called into play during a predatory event (Ellis 1986), so that the ability to detect and attack prey is likely to be affected by the environmental conditions pertaining to the predatory event. Activity peaks of predators should be correlated with periods when environmental and biological factors are optimal for exploitation of a selected prey (Rogers *et al*. 1984, Sundström *et al.* 2001, Heithaus 2004). If environmental factors are strongly related to the frequency of predation, it may be possible more accurately to interpolate the frequency of attacks by seals on seabirds. This chapter examines the influence of various environmental variables, such as time of day, tide, sea state and wind strength and direction, on the rate of predation of Cape fur seals on seabirds at Malgas and Dyer islands off western South Africa, so as to provide a basis for refining estimates of mortality of seabirds attributable to seals at these islands. Such refinement may assist with the identification of mitigation measures.

METHODS

Observations on the mortality of Cape gannet *Morus capensis* fledglings around Malgas Island were undertaken during three gannet breeding seasons, the austral summers of 2000/01, 2003/04 and 2005/06 (Makhado *et al*. 2006). At Dyer Island, observations on predation of Cape cormorant *Phalacrocorax capensis* fledglings and African penguin *Spheniscus demersus* adults were conducted at intervals during June–December 2004 and December 2006–January 2007 (chapter 3).

A single observer kept watch daily from either 05h00 or 06h00 until 18h00 or 19h00, except for breaks totalling about one hour. At the commencement of each hour the following environmental conditions were recorded: time, precipitation, cloud cover, wind direction, wind strength, sea state, swell height, cloud cover and tide level. This was so that their influence on predation rates could be considered.

Binoculars and a telescope were used to scan waters around the island for predatory activities of Cape fur seals. Often birds hovering overhead gave the first indication of an attack by a seal on a seabird (du Toit *et al.* 2004). Incidents of predation were pooled to calculate the total numbers of gannet fledglings seen to be killed by seals in intervals of one hour.

For Cape gannets at Malgas Island generalized linear models were fitted to the data, using a binomial distribution and the logistic link function. The number of gannet chicks attacked in each hour of the day was modelled, using the number of gannet chicks at sea on the day as the total in the binomial distribution. The models were fitted using Genstat 8 (Genstat Committee 2005). Details of explanatory variables considered are given below.

For seabirds at Dyer Island the relationship between environmental variables and the occurrence of seal predation on seabirds was explored using a generalized linear model (McCullagh and Nelder 1989). A logistic regression model was used (binomial distribution with the number of trials fixed at one) and the logit transformation as link function. Modelling was undertaken using Genstat 8 (Genstat Committee 2005). The environmental variables were introduced as explanatory variables into the model, either as continuous variables or as "factors", as appropriate. The Akaike Information Criterion (AIC) was used to guide model selection. Juvenile Cape cormorants were mostly preyed upon in November and December, and the model for this species was restricted to observations made over this period. During the analysis for African penguin, data for the period between 05h00 and 13h00 were lumped. This was done on account of the few predations that were recorded from 05h00 to 13h00, and during analysis there was no significant difference shown..

Explanatory variables were hour of day (for Cape gannets and African penguins 12 levels from 06h00–07h00 to 17h00–18h00; for Cape cormorants 14 levels from 05h00–06h00, to 18h00–19h00), wind strength (four levels: light, moderate, strong and very strong for Cape gannets corresponding approximately to Beufort scale 4–5, 6, 7+ and for African penguins(≤3, 4–5), 6 and ≥7 repeatedly; three levels: light (≤3), windy = moderate + strong (4–6), and very strong (≥7) for African penguins; two levels: light = light + moderate (≤ 4) and windy = strong + very strong (≥5) for Cape cormorants), tide (two levels: low, high), wind direction (four levels: 1 NW, 2 NE, 3 SE, 4 SW) and swell (three levels: low, moderate, high). There were anticipated to be associations between some of the pairs of explanatory variables, for example wind strength (wind strength was recorded from the strength of the wind during the days of observations and were compared with the data collected from South African Weather Bureau) and swell, so that individual regression coefficients need to be interpreted with caution. Although some of the environmental factors considered in the analysis may have similar effects on predation, all of the factors were first introduced as additive effects to assess their relative contribution to predation probabilities.

RESULTS

At Malgas Island, 4724 predations of Cape gannet fledglings by Cape fur seals were observed during three periods of observations undertaken in 2000/01, 2003/04 and 2005/06. The maximum estimated number of Cape gannet fledglings killed by seals on any one day was 491 on 21 February 2004. At Dyer Island, totals of 115 predations on African penguin adults and 1257 on Cape cormorant fledglings were recorded during two periods of observation (2004 and 2006/07).

For the observation on Cape gannet fledglings, the best-fitting generalized linear model accounted for 39% of the deviance (Table 1). The most important explanatory variable was hour of the day. When only this variable was fitted, 31% of the deviance was accounted for. According to the fitted model, attacks peaked at 14h00–15h00 (Table 1). This is accord with a univariate model relating attacks to time of day (Figure 1).

Holding time at 14h00, tide as high and swell as low, probabilities of predation were calculated for different strengths and directions of wind. More attacks were predicted to occur when the wind was blowing from NE and fewest when it was from the SE. Attacks were predicted to be most frequent when winds were very strong (Figure 2a). This was also the case when tide and swell were both low (Figure 2b). When both tide and swell were high, most attacks were predicted to occur in SE winds. Considerably fewer attacks were predicted for other wind directions. Again very strong winds favoured attacks (Figure 2a). This was also true for low tide and high swell (Figure 2b). Overall, the generalized linear model predicted that predation of Cape gannet fledglings would increase as wind strength increased and, except at very strong winds, as swell decreased, with SW winds most favoured for attacks (Table 2).

For Cape cormorant fledglings at Dyer Island, the model with the smallest value for the AIC explained 26% of the total deviance. The explanatory variables in this model were hour of day, wind direction and wind strength (calm or windy). Hour of the day alone explained 18.4% of the deviance. The inclusion of interaction terms between these variables did not lead to a reduction in the AIC. This model suggested that the largest probability of predation was during the hour 09h00–10h00, that probabilities of predation were largest when the wind was NW and least when the wind was SW, with intermediate values for winds from NE and SE. Probabilities for NW and SW winds are shown in Figure 3. The probability of predation was higher in calm than in windy conditions (Figure 3).

For African penguin adults at Dyer Island, the model with the smallest value for the AIC explained 17.8% of the total deviance. Time of the day alone explained 15.1% of the deviance. Attacks occurred during all daylight hours but the probability of attack was largest in the late afternoon between 16h00 and 18h00, when tides were high and winds were very strong (Figure 4).

DISCUSSION

Prey may have a distribution and vulnerability that varies according to the time of the day, so that the probability of a predator encountering and capturing prey may be increased by foraging at the optimal time (Fallows *et al.* 2006). Time of the day was the most important factor influencing the rates of predation by Cape fur seals on the fledglings of Cape gannets and Cape cormorants and on adult African penguins. Upon fledging, Cape gannets and Cape cormorants leave their breeding colonies mainly between mid morning and late afternoon by flying or by walking into the sea, which is when most were killed (Makhado *et al.* 2006, chapter 3). This was also case for Cape gannet fledglings at Ichaboe Island, Namibia (du Toit *et al.* 2004). African penguin adults frequently return from foraging trips to islands in the evening (Underhill 2004), and at Dyer Island most were killed between 16h00 and 18h00 (Chapter 3). At Ichaboe Island, predation on African penguins was also mainly in the evening, commencing about 15h00 (du Toit 2002). Therefore in estimating total mortality of fledglings of Cape gannets and Cape cormorant attributable to seals, it is important that observations are conducted between mid-morning (09h00) and late afternoon (17h00) and of adult African penguins in the late afternoon and evening. Further information on times of predation is required for African penguins because at some localities such as Robben Island adults frequently return from foraging after night fall (Underhill 2004). No diurnal pattern was evident in predation by leopard seals *Hydrurga leptonyx* on Adélie penguins (Penney and Lowry 1967).

For Cape gannet fledglings and African penguin adults, but not Cape cormorant fledglings, wind strength increased the rate of predation by seals (Figures 2 and 4). Wind may facilitate departure of gannet fledglings from islands by flying, thereby increasing the concentration of fledglings in the near-shore waters. Newly-fledged gannets are aided by wind in taking off from the water (Navarro 2000), thereby decreasing their chances of escape from seals.

Strong winds have a tendency to pick up sea swells. Some seabirds breeding in the Benguela ecosystem may be particularly vulnerable to Cape fur seals when landing in heavy seas because the shoreline is then encumbered by intense surf (du Toit 2002). For example, Cape gannet fledglings and African penguin adults are often drawn back into the sea in such conditions when attempting land at islands (pers. obs.). However, model output suggested that low swells or calm seas sometimes increased predation on gannet and cormorant fledglings. Heavy seas increased predation by leopard seals on Adélie penguins (Penney and Lowry 1967).

Model output indicated that wind direction had a variable influence on losses of Cape gannet fledglings to predation, depending on factors such as swells and tide. For Cape cormorant fledglings, loses were highest during NW winds. For African penguin adults, which do not fly, wind appeared to have little influence on predation rates. The influence of tides on predation rates of seabirds was equivocal.

Overall, the physical explanatory variables considered in this chapter had a less important influence on predation rates than time of day. For example, in the case of Cape gannet fledglings the multivariate model accounted for 39% of the deviance, compared with 31% when only time of the day was fitted. Hence, although wind strength, wind direction, tide and sea swell may have some influence on the predation rate, their inclusion did not lead to large increases in the deviance that was accounted for. In all instances, there remained a considerable proportion (61−83%) of the deviance that was not explained by the models, indicative of high variability in the predation rates (Makhado *et al.* 2006). Therefore, although information on the physical environmental variables might be used to interpolate predation rates through periods when observations are not conducted, their contribution will be limited and there will remain considerable uncertainty in actual numbers of fledglings killed. Uncertainty will best be decreased by extending the period of observations so as to reduce the amount of days for which predation rates are interpolated.

Acknowledgements — I thank the National Research Foundation (SANAP and SEACHANGE programme) and WWF-SA for supporting this research. CapeNature, the Department of Environmental Affairs and Tourism, South African National Parks and South African Navy provided logistical support for the surveys. This paper is a contribution to the project LMR/EAF/03/02 of the Benguela Current Large Marine Ecosystem (BCLME) Programme.

REFERENCES

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

du Toit M (2002) Predatory interactions between Cape fur seals and seabirds at Ichaboe Island, Namibia. MSc thesis, University of Pretoria, Pretoria

du Toit M, Bartlett PA, Bester MN, Roux J-P (2004) Seal-seabird predation at Ichaboe Island, Namibia: prey selection by individual seals. *South African Journal of Wildlife Research* **34**: 45–54

Ellis DV (1986) *Animal Behaviour and its Applications*. Lewis Publishers, Chelsea, 329 pp

Fallows C, Martin RA, Hammerschlag N (2006) Predator-prey interactions between white sharks (*Carcharodon carcharias*) and Cape fur seals (*Arctocephalus pusillus pusillus*) at Seal Island, South Africa and comparisons with patterns observed at other sites. *Apex Images Scientific Report*, pp 1–18

GenStat Committee (2005) *GenStat for Windows*. (8th edn). VSN International, Oxford, UK

Gese EM, Knowlton FF (2001) The role of predation in wildlife population dynamics. In: Ginnetr TF, Henke SE (eds) *The Role of Predator Control as a Tool in Game Management.* Agricultural Research and Extension Center, San Angelo, Texas, pp 7–25

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

Heithaus MR (2004) Predator–prey interactions. In: Carrier JC, Musick JA, Heithaus MR (eds) *Biology of Sharks and their Relatives*, CRC Press, Boca Raton, pp 488–512

Holling CS (1959) The components of predation as revealed by a study of small mammal predation of the European pine sawfly. *Canadian Entomologist* **91**: 293–320

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

McCullagh P, *Nelder* JA (eds) (*1989) Generalized Linear Models* (2nd edn). Chapman and Hall, New York, USA

Navarro RA (2000) Cape fur seal predation on Cape gannet fledglings. *Bird Numbers* **9**(2): 15–16

Penney RL, Lowry G (1967) leopard seal predation of Adélie penguins. *Ecology* **48**: 878–882

Rogers SC, Church DW, Weatherly AH, Pincock DG (1984) An automated ultrasonic telemetry system for the assessment of locomotor activity in free-ranging trout, *Salmo gairdneri*, Richardson. *Journal of Fish Biology* **25**: 697–710

Sundström LF, Gruber SH, Clermont SM, Correia JPS, de Marignac JRC, Morrissey JF, Lowrance CR, Thomassen L, Oliveira MT (2001) Review of elasmobranch behavioral studies using ultrasonic telemetry with special reference to the lemon shark, *Negaprion brevirostris*, around Bimini Islands, Bahamas. *Environmental Biology of Fish* **60**: 225–250

Underhill JG (2004) Patterns of arrival and departure of African penguins *Spheniscus demersus* on Robben Island, and an assessment of disturbance caused by vehicular traffic. BSc (Hons) project. Department of Zoology, University of Cape Town, Cape Town

Table 1: Results of the generalized linear model for the number of Cape gannet chicks attacked by Cape fur seals at Malgas Island in relation to environmental explanatory variables. The model fitted had a binomial distribution and logistic link function, and accounted for 39% of the deviance. The reference level for time was 12h00–13h00, for wind strength it was light, for tide it was high, for wind direction it was 4 and for swell it was high. S.E. = standard error. The value of t and its probability are shown

Parameter	**Estimate**	**S.E.**	**t**	**Probability**
Constant	-4.9471	0.0542	-91.33	<.001
Time 6	-2.312	0.124	-18.66	<.001
Time 7	-4.414	0.353	-12.49	<.001
Time 8	-2.233	0.125	-17.92	<.001
Time 9	-1.6679	0.0973	-17.14	<.001
Time 10	-0.5973	0.0645	-9.26	<.001
Time 11	-0.3020	0.0582	-5.19	<.001
Time 13	0.1221	0.0501	2.44	0.015
Time 14	0.2833	0.0486	5.83	<.001
Time 15	0.1599	0.0499	3.21	0.001
Time 16	-0.0481	0.0524	-0.92	0.359
Time 17	-0.5502	0.0591	-9.31	<.001
Wind StrMod	0.2957	0.0401	7.38	<.001
Wind StrStrong	0.7212	0.0392	18.40	<.001
Wind StrVStrong	1.2369	0.0420	29.43	<.001
Tide2 2	-0.2758	0.0313	-8.81	<.001
WindDir4 1	0.1055	0.0314	3.36	<.001
WindDir4 2	0.2207	0.0412	5.36	<.001
WindDir4 3	0.1683	0.0365	4.61	<.001
Swell Low	0.7296	0.0351	20.77	<.001
Swell Mod	0.5643	0.0404	13.95	<.001

Table 2: Number of Cape gannet fledglings predicted by the generalized linear model to be attacked by Cape fur seals at Malgas Island (2003/04 and 2005/06) for different combinations of environmental explanatory variables (for wind direction 1=NW, 2= NE, 3= SE and 4= SW)

Wind Strength	**Wind direction**	**High swell**	**Low swell**	**Both high and low swells**
Light	1	8	97	105
	2	20	58	78
	3	16	48	64
	4	9	119	128
	All four directions	53	322	375
Moderate	1	20	51	71
	2	1	30	31
	3	26	25	51
	4	18	75	93
	All four directions	65	181	246
Strong	1	22	20	42
	2	21	9	30
	3	22	58	80
	4	34	50	84
	All four directions	99	137	236
V. Strong	1	0	13	13
	2	21	16	37
	3	31	7	38
	4	59	4	63
	All four directions	111	40	151
All four wind strengths	1	50	181	231
	2	63	113	176
	3	95	138	233
	4	120	248	368
	All four directions	328	680	1008

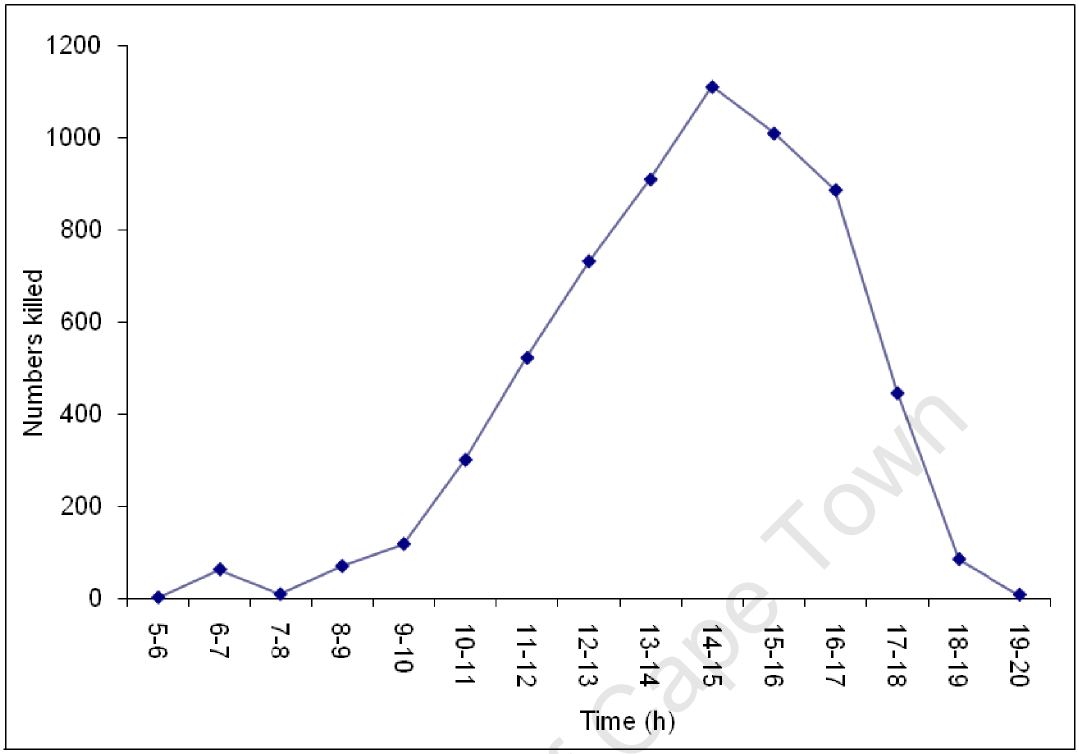

Figure 1: Overall numbers of Cape gannet fledglings observed to be killed at Malgas Island in relation to time of day, 2003/04 and 2005/06 (Makhado *et al*. 2006)

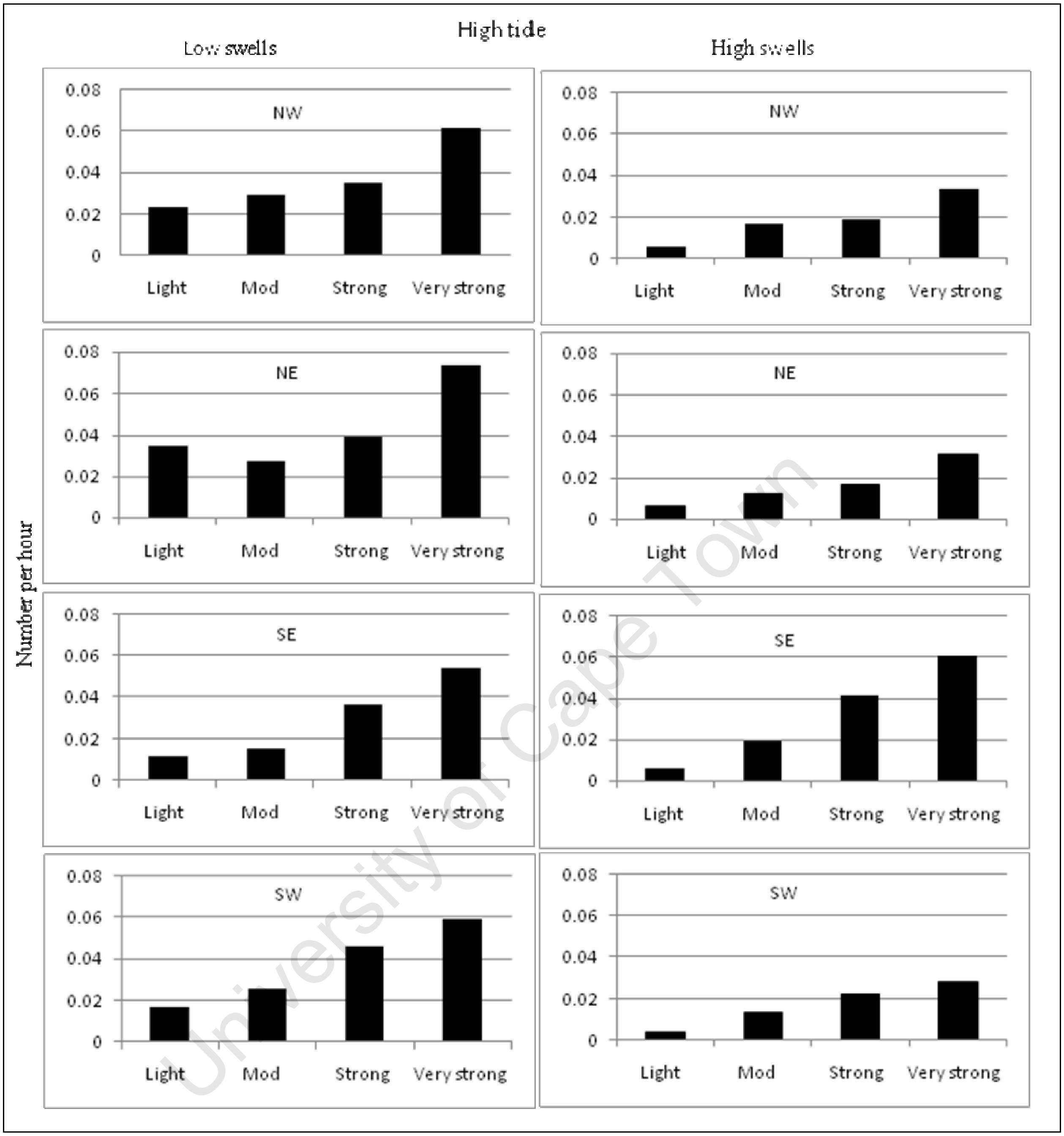

Figure 2(a): Predicted number of attacks by seals on Cape gannet fledglings at Malgas Island for different strengths and directions of wind at high tide, 2003/04 and 2005/06

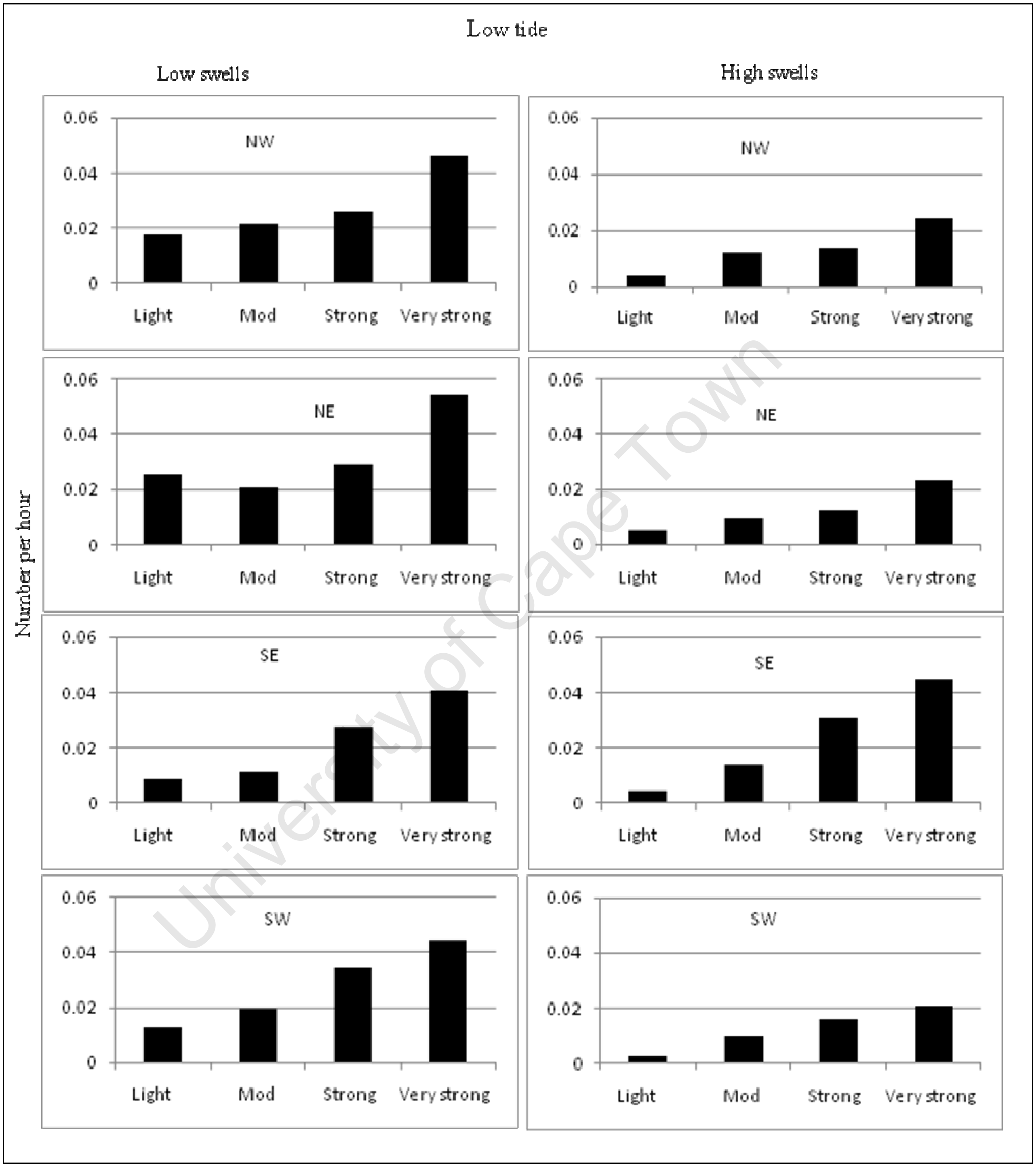

Figure 2(b): Predicted number of attacks by seals on Cape gannet fledglings at Malgas Island for different strengths and directions of wind at low tide, 2003/04 and 2005/06

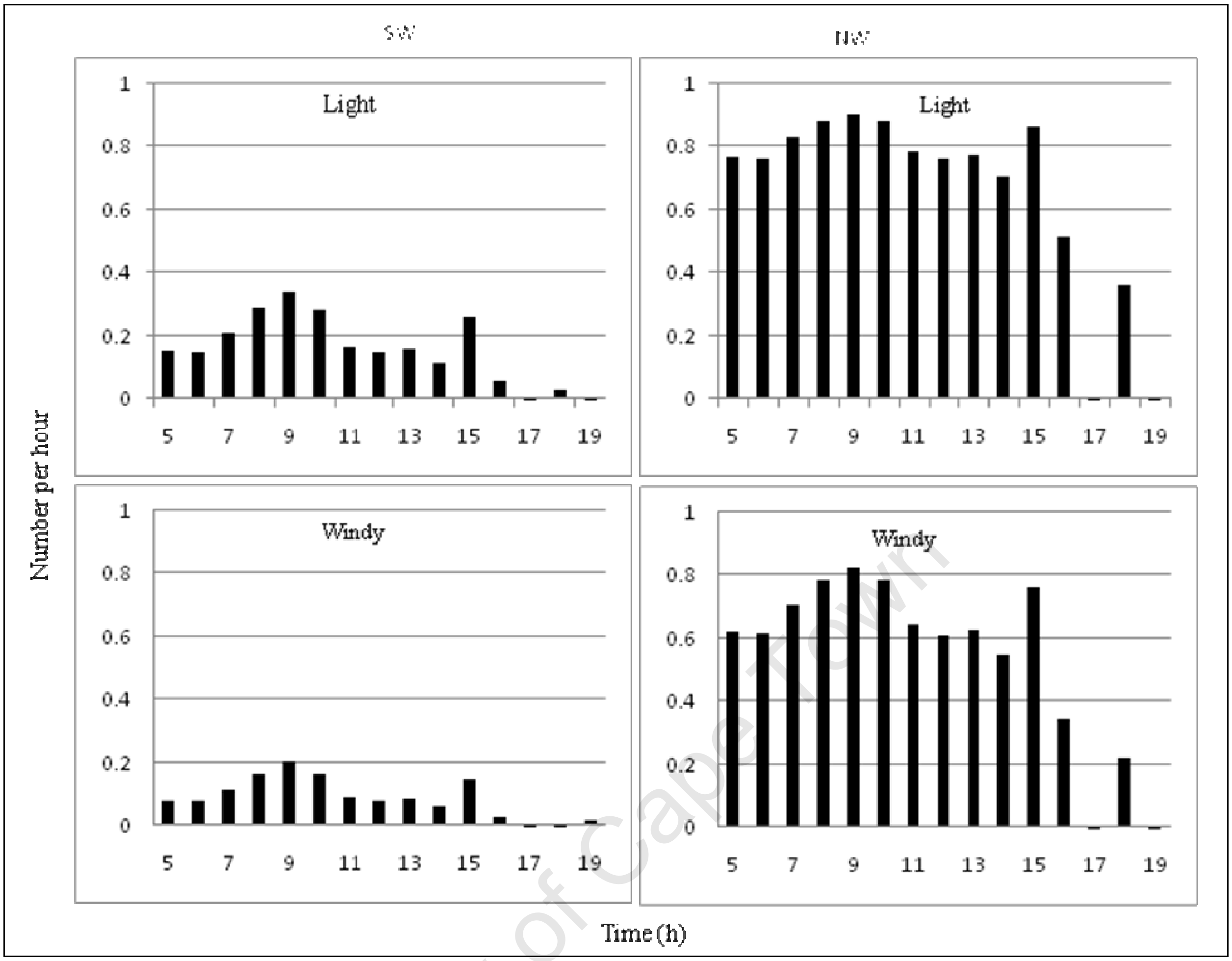

Figure 3: Predicted number of attacks by seals on Cape cormorant fledglings at Dyer Island for different strengths of wind and hour of day, June–December 2004 and December 2006–January 2007. The left-hand panel is wind from the SW and the right-hand panel for wind from the NW

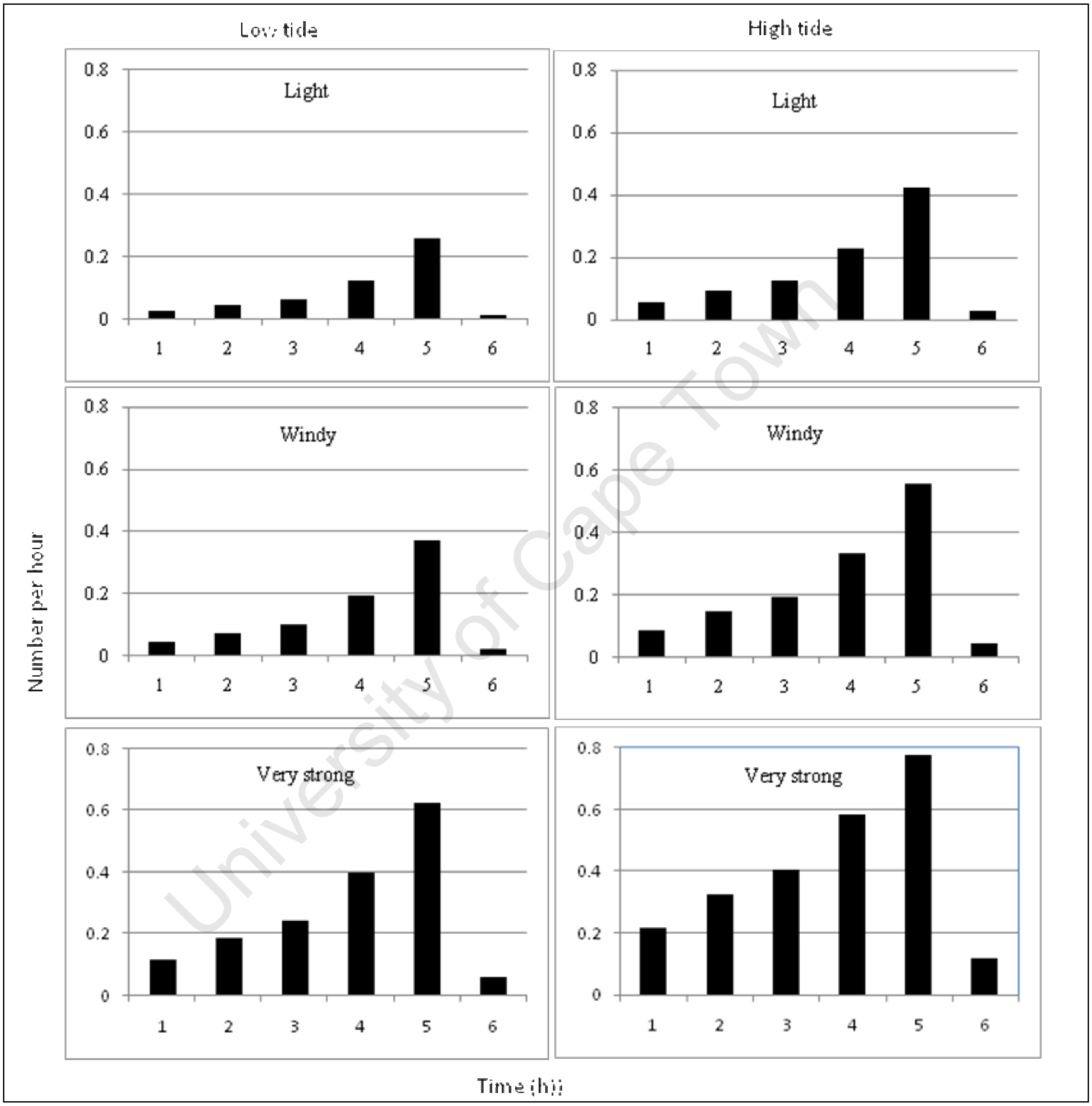

Figure 4: Predicted number of attacks by seals on adult African penguins at Dyer Island for different strengths of wind and hour of day, June–December 2004 and December 2006–January 2007. The left-hand panel is for low tide and the right-hand panel for high tide. Hour of day has six categories: 1 represents 05h00−13h00; 2 14h00−15h00, 3 15h00−16h00, 4 16h00−17h00, 5 17h00−18h00, 6 18h00−19h00

CHAPTER 7

The hunting behaviour of Cape fur seals *Arctocephalus pusillus pusillus* preying on seabirds

The hunting behaviour of Cape fur seals *Arctocephalus pusillus pusillus* preying on seabirds

ABSTRACT

The hunting behaviour of Cape fur seals *Arctocephalus pusillus pusillus* feeding on seabirds was investigated at Malgas and Dyer islands, South Africa, in 2003/04 and 2005/06 and 2004 and 2006/07 respectively. At these islands, Cape fur seals killed mainly fledgling Cape gannets *Morus capensis* and Cape cormorants *Phalacrocorax capensis* and adult African penguins *Spheniscus demersus*. Attacks on seabirds were identified mainly through the presence of other birds overhead and sometimes by the thrashing of a victim in, or throwing of it from, the water. Most attacks occurred beyond the surf zone at distances of 20–100 m from the island. Predation on seabirds involved an average of 2.1 seals, but solitary attacks were observed. Sometimes seals shared carcasses. On average attacks lasted 11 min for both Cape gannets and Cape cormorants and 16 min for African penguins. Most attacks were from under or behind birds. Birds were usually attacked repeatedly and thrown several times from the water. Very few birds escaped, the majority being killed outright. Usually most, or a substantial proportion, of the carcass was utilized but some surplus killing was observed.

INTRODUCTION

Predator-prey interactions are of central importance in ecology, with implications for population dynamics, management and conservation (Musick 1999, Walters 1997). Predation is believed to have shaped several aspects of the life histories and behaviours of birds (Côté and Sutherland 1997). Mortality due to predation can be high, particularly in the avian early stages (Côté and Sutherland 1997). Large endothermic predators, by virtue of their size, mobility and nutritional requirements, have the potential to place extraordinary pressures on their prey populations (Terborgh 1990, Seidensticker and McDougal 1993), which in turn may lead to marked effects on the structure and function of ecosystems (Berger *et al.* 2001, Soule *et al.* 2003, Williams *et al.* 2004). Foraging by large predators comprises complex, potentially energetically demanding behaviours, depending on the type of prey involved (Stephens and Krebs 1986). Activities such as locating, pursuing and capturing prey, as well as processing and assimilating food, as occurs in active hunting mammalian predators, can each represent a significant energetic cost to the animal (Williams *et al*. 2004).

How marine predators select a specific prey animal from a group of apparently similar prospects is not fully known. Understanding the prey selection processes of predators includes consideration the antipredatory tactics of their prey (Fallows *et al.* 2006). This aspect of predator interaction with mobile prey remains poorly understood (Fallows *et al.* 2006). Seabird predation by seals has been hypothesised to be an extension of play behaviour (Bonner and Hunter 1982) and was reported as an unusual event (Cooper

1974). However, some individuals are regarded as regular penguin predators (Cobley and Bell 1998), exploiting a temporary food resource (Penney and Lowry 1967, Rogers and Bryden 1995) or a specialist niche (Walker *et al.* 1998).

Most studies of pinniped foraging behaviour are limited because the foraging activity occurs at depth and is unobservable by researchers. However, in those situations where seals take advantage of high prey concentrations in a limited area, direct observation can provide insight into consumption rates and foraging behaviour (London 2006).

Cape fur seals are carnivorous top predators in the Benguela upwelling system (Mecenero *et al.* 2006). They have been observed hunting seabirds off Malgas (Crawford and Robinson 1990, Crawford and Cooper 1996, Navarro 2000), Dyer (Marks *et al.* 1997) and Bird (Lambert's Bay) (Crawford *et al*. 2001, Ward and Williams 2004) islands, South Africa and Ichaboe Island, Namibia (du Toit *et al*. 2004).

During their breeding season many Cape fur seals are at their breeding colonies. However, non-breeding animals often occur at seabird breeding localities (David *et al.* 2003, this study chapter 8), where they may kill large numbers of seabirds (e.g. Makhado *et al*. 2006). Seals also hunt around seabird colonies outside their breeding season (chapter 8). At Malgas and Dyer islands, observations were made of the behavior of seals that hunted Cape gannets *Morus capensis*, African penguins *Spheniscus demersus* and Cape cormorants *Phalacrocorax capensis* in surface waters adjacent to the islands. The high frequencies of attacks by Cape fur seals on these seabirds (e.g. Makhado *et al.* 2006) provided an exceptional opportunity to examine the hunting behavior of the seals. This chapter documents and discusses aspects of their hunting behaviour. Records were also kept, and are reported, of the maturity stages of seabirds attacked and how a predation event was first noticed.

STUDY AREA AND METHODS

Observations were undertaken at Malgas and Dyer islands on attacks of Cape fur seals on seabirds. An attack was defined as being an attempt by seals to capture a bird. Both islands are in South Africa's Western Cape Province. Observations at Malgas Island were undertaken in 2003/04 and 2005/06 and at Dyer Island in 2004 and 2006/07. The species and maturity stage (fledgling, juvenile, adult) of the bird being attacked was recorded, using information in Hockey *et al*. (2000). The majority of attacks at Malgas Island were on Cape gannet fledglings (Makhado *et al.* 2006) and at Dyer Island on Cape cormorant fledglings and African penguin adults (chapter 4). Only attacks on these three categories of seabird prey are reported below.

Searches were made for attacks on seabirds using both aerial and sea surface cues. Often birds, especially gulls *Larus* spp., congregate over a seal attack, and searching the sea beneath such birds then reveals the predation event (du Toit *et al*. 2004). Attacks were also identified through seals thrashing prey on the surface, or tossing it into the air; the attack was therefore located prior to the arrival of other species of seabirds attracted to the incident. When seabirds congregated over an attack, the species present were identified and their numbers recorded. Twice Cape fur seals were recorded catching seabirds on land at Malgas Island. In one instance, the incident was captured on video camera by Dr L. Pichegru (Percy FitzPatrick Institute of African Ornithology, University of Cape Town), who kindly made the footage available for analysis.

For selected predatory events (sometimes several such events were taking place concurrently), it was recorded whether the attack was first observed in blue or white water, or on the island. White water was defined as the surf zone where waves were breaking near to the island or there was strong backwash, and blue water as the region farther offshore, although in windy conditions white water is also present offshore. The approximate distance from the island at which attacks on seabirds were first noted was also recorded. This was estimated by pacing out a distance of 10 m on the island and using that distance to gauge the distances from the island at which birds were being attacked.

The number of seals participating in a predatory event were counted and seals were categorized according to their sex and age (adult, subadult, brown neck, pup, undetermined) classes using the descriptions of Rand (1956). The head and neck of a seal were often visible during a predation event, and seals frequently held one flipper vertically above the surface of the water for a while, especially after preying on a bird. The size class of seals was estimated by judging the size of the seal's neck and flippers against the size of the bird carcass. Sex was determined by the shape of the head in conjunction with body size. Male seals have a thicker neck and a more pronounced forehead than the females, and their flippers are larger and broader in relation to the body (Rand 1956). In older males, the head and neck are also paler (Bonner 1981, King 1983).

The duration of a predatory event was recorded to the nearest minute. The time of commencement of the predatory event was taken to be when it was first noticed. The time of the end of the event was taken to be when the seal was last seen attacking or feeding on the birds. The direction from which the bird was attacked was noted (from above, behind, in front, the side, underneath or whether a wing or flipper was grasped). The number of discrete attacks on a bird was recorded: if a seal left off holding a bird, that attack was deemed to have ended. The number of times a bird was thrown clear of the water was also recorded. Notes were kept on the behavior of seals that were hunting, e.g. shaking their victim to subdue it and access its flesh or sharing of the prey with other seals. The ultimate fate of a bird that was attacked was recorded as killed outright, left to die at sea, escaped or returned in an injured state to the island. The extent of utilization of birds caught was noted through observing the predation event through binoculars. Additionally, daily searches for injured birds and washed-up seabird carcasses were conducted around the islands before starting observations of predation events. Injuries attributable to sharks were identified using information in Randall *et al* (1988). Such carcass were not further considered. For birds that were fed upon at sea and their carcasses retrieved at islands, it was ascertained whether the abdomen, breast, neck and thighs had been eaten, and whether the bird had been de-gloved, i.e. had its skin cast over its head (Marks *et al*. 1997).

RESULTS

Stages of maturity of seabirds and signs of attacks

At Malgas Island, 6437 Cape gannets were killed by seals; only 72 (1.11%) were adults; the remainder (6365) were recently fledged juveniles. Of 1268 Cape cormorants killed at Dyer Island, 11 (0.88%) were adults and the remainder were fledglings. In contrast, of

113 African penguins killed at Dyer Island, 101 (89.4%) were in adult plumage and the remaining 12 were juveniles.

For Cape gannets (n = 1805) and African penguins (n = 109) most attacks by seals were first noticed through the presence of birds congregating above the predation event, with 18 attacks on Cape gannets noticed through activities at the water surface. For Cape cormorants (n = 485), 99% of attacks were similarly first noticed from birds overhead, with attention drawn to just 1% from activity at the water surface.

Kelp gulls *Larus dominicanus* were the dominant seabird to congregate over attacks on gannets at Malgas Island (n = 1823 incidents) and were recorded at every incident. On average, there were about 14 kelp gulls at each predation event (range 1–50). Hartlaub gulls *L. hartlaubii* were also recorded at kills (average of one bird, range 0–49; present at 30.0% of the incidents). Both gulls scavenged on scraps loosened from victims. At times, Kelp gulls also ate abandoned carcasses. Swift terns *Sterna bergii* (mean 0.002 birds) and other species of tern (mean 0.2 birds) were rarely present in low numbers. During 13% of attacks, adult Cape gannets hovered over kills of gannet fledglings (mean seven birds, range 0–183), but did not feed at them.

At Dyer Island, Kelp gulls were again the dominant seabird attending kills (mean 10 birds, range 1–32, n =603). An average of 0.06 Hartlaub's gulls hovered above kills (range 1–5). Up to 27 swift terns were recorded over attacks at Dyer Island, but the average value was 0.1 terns. On 10 occasions, giant petrels *Macronectes* spp. were observed feeding on carcasses or scraps made available during an attack. No Cape cormorants or African penguins attended attacks on either of these species at Dyer Island.

Areas of hunting

For all three seabirds, most attacks by Cape fur seals took place in blue water, i.e. beyond the surf zone. A few attacks occurred in white water around the island edges (Figure 1). Twice, Cape gannets were attacked ashore at Malgas Island. A bull seal came ashore on 7 January 2005 and killed about 22 breeding adults in the gannet colony and one fledgling on the island's shoreline (L. Pichegru pers. comm.). The birds were caught behind the neck and shaken to death. The seal returned to sea with one adult in its mouth and started feeding on the bird. In the second instance of predation on land, the seal caught a Cape gannet fledgling on the shoreline and returned to the sea to feed on it. No African penguins or Cape cormorants were observed to be killed on land during the study. The proportion of attacks in white water was largest for African penguins (14%), followed by Cape cormorants (11%) and Cape gannets (5%).

At Malgas Island, attacks on gannets occurred at distances of 0–430 m from the island, mostly from 10–100 m (Figure 2). Similarly, at Dyer Island, Cape cormorants were mostly killed at distances of 10–100 m from the island, whereas most African penguins were attacked 30–100 m offshore (Figure 2). At Dyer Island, two attacks on Cape cormorant fledglings were recorded in shallow water but the seals moved to deeper water to feed on birds.

Number, sex and maturity of seals involved in attacks

The average numbers of seals that attended predation events were 2.9 for Cape gannets at Malgas Island (range 1–16, n = 1742; 26.5% of attacks were by a single seal), 1.5 for Cape cormorants at Dyer Island (range 1–8, n = 494; 72% of attacks were by a single seal) and again 1.5 for African penguins at Dyer Island (range 1–9, n = 167; 70% of attacks were by a single seal). For all predation events, the average number of seals involved was 2.1, 38% of attacks were by single seals and thus 62% by groups of two or more seals. Of seals seen preying on seabirds, 98% were males (58% bulls (without brown neck), 40% subadult and 2% of unidentified sex. Only 13 (0.23%) attacks were carried out by big brown bulls.

Duration of a predation event

The duration of predation events by Cape fur seals on Cape gannet fledglings at Malgas Island ranged from 1–55 min (n = 1693), with most events lasting 5–20 min (Figure 3). The average duration of these events was 11 min. At Dyer Island, predation events on adult African penguins lasted 1–34 min (mean 16 min, n = 96) and on Cape cormorant fledglings 1–39 min (mean 11 min, n = 492). For both species, most predation events lasted 5–20 min (Figure 3).

Direction of attack

For all three species of seabird, more than 80% of attacks by Cape fur seals took place from behind or underneath the birds (Figure 4). Few birds were first attacked from the front, side or above, or caught by their wings or flippers. Sample sizes were 1823 for Cape gannet fledglings, 494 for Cape cormorant fledglings and 109 for African penguin adults. Occasionally seals were seen porpoising and chasing after birds as they tried to swim away or take off.

Number of times birds were attacked

The numbers of times individual fledglings of Cape gannets and Cape cormorants and adults African penguins were attacked by Cape fur seals are shown in Figure 5. Cape gannet and Cape cormorant fledglings were mostly attacked between 4 to 7 times (53% and 65% respectively), with 18% and 6% of individuals being attacked more than ten times. For African penguins, 25% of birds were attacked more than 10 times. Only 33% were attacked between 4 to 7 times (Figure 5). The median number of attacks was six for Cape gannet fledglings (n = 1802), six for Cape cormorant fledglings (n = 492) and eight for African penguin adults (n = 106). The medians were significantly different between species (Kruskal-Wallis test: H (2, n = 2374) = 32.46, p = 0.0001).

The numbers of times birds were thrown from the water are shown in Figure 6. For all seabirds, 50 % or more birds were thrown from the water more than 10 times. The medians were > 10 (n =1802) for Cape gannet fledglings, > 10 (range 1 – > 10) for Cape cormorant fledgling and 10 (range 4 – > 10) for African penguin adults. The means were significantly different between species (Kruskal-Wallis test: H (2, n = 2279) = 15.70109, p = 0.0004).

Seals were also observed to attempt to shake the bird's body sideways. On four occasions, when the sea was calm and the wind still, seals were recorded killing and feeding on Cape gannet fledglings and Cape cormorant fledglings without shaking or tossing the birds and hence little splashing. They tore flesh off their victims. On about 15 occasions, seals caught birds and then dived away with them and disappeared. They were also recorded killing birds, leaving them and later returning to feed on them. When many Cape gannet and Cape cormorant fledglings were in the sea, seals killed nine birds (eight Cape gannet fledglings and one Cape cormorant) and went on to kill other birds without feeding much on those that were first killed. Occasionally, 3 birds were attacked by two seals at the same time. On 14 occasions at Malgas Island, seals were seen sharing the carcass of a Cape gannet fledgling. They were young bulls.

In many predation events, seals de-gloved the birds through forcing the skin over the head. About 20% of Cape gannets that washed ashore were de-gloved. Other techniques used to feed on seabirds included biting the abdomen, breast muscles and/or cloaca or ripping skin off the neck.

Fate and utilization of birds attacked

For all three seabirds, almost all individuals (about 99%) were killed outright. Few were left to die at sea or managed to escape (Figure 7). In several instances, for all three seabirds, seals fed only on the abdomen (12%) and/or breast muscles (1%), although many carcasses were fully utilized (Figure 8). For carcasses found washed ashore at islands, in the majority (60%) of instances only the abdomen and breast had been utilized, and sometimes only the abdomen (15%) (Figure 9). It was less likely (4%) for African penguin adults that only the abdomen had been utilized than was the case for fledglings of Cape gannets and Cape cormorants.

DISCUSSION

Attacks by Cape fur seals on Cape gannets and Cape cormorants were mostly on fledglings, which leave to sea by swimming or short flight before dropping into the water. Conversely, for African penguins, which swim and have a more protracted breeding and fledging season than Cape gannets and Cape cormorants (Hockey *et al*. 2005), mostly adults were preyed upon. Naïve fledglings may require less effort to kill than adult birds (Penney and Lowry 1967) and may also congregate in large numbers to provide a ready source of food (e.g. Makhado *et al*. 2006). As at Ichaboe Island in Namibia (du Toit *et al*. 2004), most predation events were identified through the presence of other birds overhead, some of which feed on scraps or carcasses of victims.

Cape fur seals feed mainly over the continental shelf (David 1987), but foraging may take place as far as 220 km offshore (Shaughnessy 1985), especially by older animals (Oosthuizen 1991). They are able to dive to depths of 200 m, although 66% of dives are to a depth less than 50 m (Mecenero *et al.* 2005) and dives to depths greater than 150 m are rare (Kooyman and Gentry 1986). Half of the dives occur at night; they become shallower as the night progresses, possibly in response to prey migrating to the surface during the night (David 1989). Day dives are mostly shallow to pursue shoaling fish (David 1989). In this study, most feeding by Cape fur seals was in shallow water within 100 m of islands. This spatial pattern may simply reflect a reduced availability of seabirds farther away from their breeding islands.

Cape fur seals have previously been recorded taking seabirds from seabird nesting areas. At Halifax Island, Namibia, an adult bull caught an African penguin on land about 20 m from the water. It killed the penguin by beating it against the ground (Rebelo 1984). Between 1981 and 1986, an adult bull caught African penguins on the beach at Ichaboe Island, Namibia (Crawford and Cooper 1996). At Malgas Island, staff of the West Coast National Park twice saw seals chase Cape gannets ashore (Crawford and Cooper 1996). At Lamberts Bay during 2005/06 breeding season, the entire colony of Cape gannets abandoned breeding after seals entered the colony and attacked nesting birds, killing more than 200 (Wolfaardt and Williams 2006).

At Malgas and Dyer islands, seals hunted both solitarily and in groups. Marks *et al.* (1997) related an anecdotal account of a seal which they thought to be a female apparently trying to teach two juveniles to feed on Cape cormorant fledglings at Dyer Island. Similarly, at Malgas Island one seal apparently attempted to teach two younger ones to kill cormorant fledglings (R.A. Navarro, Animal Demography Unit, University of Cape Town, pers. comm.). Young seals sometimes accompany individuals that feed regularly on birds and may learn this behaviour and even continue feeding on the carcass once the main predator has left (du Toit *et al.* 2004). Hiruki *et al.* (1999) noted incidents of leopard seals *Hydrurga leptonyx* interacting while hunting, with one seal capturing and releasing Antarctic fur seal *A. gazella* pups to another, although they referred to it as leopard seals tolerating one another while hunting.

King (1983) described young male seals as active, noisy and engaging in play. At Ichaboe Island, fur seals often play in the surf zone adjacent to the island (du Toit *et al.*

2004). Predation of seabirds by Cape fur seals may start when curious seals capture birds at play (du Toit *et al*. 2004). Some may be killed and found to be tasty (Navarro 2000).

Similarly to earlier reports (Shaughnessy 1978, Williams 1988, Rebelo 1984, Hofmeyr and Bester 1993, David *et al*. 2003, du Toit *et al.* 2004), only male Cape fur seals were observed feeding on seabirds. In pinnipeds predation on birds may be restricted to male pinnipeds (Riedman 1990). In some ottarid species also, males are the predominant hunters of seabirds (Gentry and Johnson 1981, Bonner and Hunter 1982, Pitcher and Fay 1982, Harcourt 1993, Byrnes and Hood 1994). This contrasts a study on leopard seals where both sexes attacked and fed on seabirds (Rogers and Bryden 1995). Harcourt (1993) suggests that adult male South American sea lions *Otaria flavescens* are able to exploit a food source (South American fur seals *Arctocephalus australis)* that the smaller females are unable to utilize. Female Cape fur seals engage in reproduction at a younger age than males (Shaughnessy 1982) and are at seal breeding colonies when young males are feeding on fledglings of Cape gannets and Cape cormorants. By contrast, the seal breeding colony at Geyser Rock is close to Dyer Island and adult penguins are taken later in the seal breeding season.

Penney and Lowry (1966) found the duration of feeding by leopard seals on Adelie penguins *Pygoscelis adeliae* to range from 5–23 min, similar to the mean times of 11–16 min recorded for Cape fur seals feeding on three seabird species in this study. As recorded in previous studies (Marks *et al.* 1997, du Toit *et al.* 2004), typically Cape fur seals approached birds from below or behind, grabbing them by the chest, neck or head. The birds were then thrashed on the surface, resulting in the skin being torn loose and flung over the head or legs to expose the viscera and breast muscles. Feeding by Cape fur seals generally involved several attacks on individual birds. Similar behavior was recorded on a study by Marks *et al.* (1997).

Cape fur seals are capable of maintaining rapid porpoising for > 20 min (Martin *et al*. 2005) and they exhibit remarkable agility, focus and control, consistently employing zig-zag evasive manoeuvers when escaping predators (Martin *et al*. 2005). It is likely that these abilities make them efficient predators in the sea.

The techniques used by Cape fur seals for stripping seabirds were similar to those reported by Lucas and McLaren (1988) for the grey seal *Halichoerus grypus* (Phocidae) at Sable Island off Nova Scotia, Canada. Leopard seals also repeatedly smack penguins on the water surface in an attempt to dismember them and they toss penguins several meters into the air (Todd 1988).

Marks *et al.* (1997) reported that they rarely found de-gloved carcasses of Cape cormorants on Dyer Island. However, in this study for all three seabirds 10–20 % of attacks ended in victims being de-gloved. They may be because of greater search effort in this study.

Cape fur seals often eat only the viscera and stomach contents of seabirds they have attacked (Cooper 1974, Crawford and Robinson 1990). These parts are accessed via the abdomen (Cooper 1974). Many abandoned carcasses wash ashore at Malgas Island (pers. obs.) and other localities (Cooper 1974). That most of those encountered in this study showed substantial utilization suggests that Cape fur seals were not only killing seabirds but indeed feeding on them.

Surplus killing has been defined as predators killing prey in numbers exceeding that which can be consumed at one time (Wobeser 2000). It is characterized by an absence of, or a low level of, utilization of the carcass by the predator (Short *et al.* 2002). On occasion, Cape fur seals appeared to kill seabirds in excess of their requirements. This behavior has been described in red foxes *Vulpes vulpes* (Short *et al.* 2002), spotted hyenas *Crocuta crocuta* (Kruuk 1972), mink *Mustela vison* (Wobeser 2000) and other mammalian predators (Short *et al.* 2002) and has been previously been proposed for killer whales *Orcinus orca* (Stacey *et al.* 1990, Jefferson *et al.* 1991). Alternate explanations are that such predation could represent a form of play behavior or result from adults training younger animals to hunt (Bonner and Hunter 1982, Gaydos *et al*. 2005).

Acknowledgements — I thank the National Research Foundation (SANAP programme) and WWF-SA for supporting this research. The Department of Environmental Affairs and Tourism, South African National Parks and South African Navy provided logistical support for the surveys. This paper is a contribution to the project LMR/EAF/03/02 of the Benguela Current Large Marine Ecosystem (BCLME) Programme.

REFERENCES

Berger J, Stacey PB, Bellis L, Johnson MP (2001) A mammalian predator-prey imbalance: grizzly bear and wolf extinction affect avian neotropical migrants. *Ecological Applications* **11**: 967–980

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 *Arctocephalus* (Geoffrey Saint-Hilaire and Cuvier, 1826). In: Ridgway SH, Harrison RJ (eds) *Handbook of Marine Mamma*ls: *The Walrus, Sea Lions, Fur Seals And Sea Otter*. Academic Press, New York

Bonner WN, Hunter S (1982) Predatory interactions between Antarctic fur seals, macaroni penguins and giant petrels. *British Antarctic Survey Bulletin* **56**: 75–79

Byrnes PA, Hood WR (1994) First account of Steller sea lion (*Eumetopias jubatus*) predation on a California sea lion *Zalophus californianus*. *Marine Mammal Science* **10**: 381–383

Cobley ND, Bell G (1998) Weddel seal *Leptonychotes weddellii* feeding on gentoo penguins (*Pygoscelis papua). Marine Mammal Science* **14**: 881–883

Cooper J (1974) The predators of the jackass penguin *Spheniscus demersus*. *Bulletin British Ornithological Club* **94**: 21–24

Côté IM, Sutherland WJ (1997) The effectiveness of removing bird predators to protect bird populations. *Conservation Biology* **11**: 395–405

Crawford RJM, Cooper J (1996) Cape fur seal *Arctocephalus pusillus* catches Cape gannet *Morus capensis* ashore at Malgas Island. *Marine Ornithology* **24**: 53–54

Crawford RJM, David JHM, Shannon LJ, Kemper J, Klages NTW, Roux J-P, Underhill LG, Ward VL, Williams AJ, Wolfaardt AC (2001) African penguins as predators and prey-coping (or not) with change. *South African Journal of Marine Science* **23**: 435–447

Crawford RJM, Robinson GA (1990) Impacts of seals on seabird. In: Report of the Subcommittee of the Sea Fisheries Advisory Committee appointed at the request of the Minister of Environment Affairs and of Water Affairs, to advise the Minister on Scientific Aspects of Sealing. Sea Fisheries Research Institute. Cape Town, pp 84–87

David JHM (1987) South African fur seals *Arctocephalus pusillus pusillus.* In: Croxall JP, Gentry RL (eds) *Status, Biology and Ecology of Fur Seals. NOAA Technical Report*, *National Marine Fisheries Service* **51**: 65–71

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

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

du Toit M, Bartlett PA, Bester MN, Roux J-P (2004) Seal-seabird predation at Ichaboe Island, Namibia: prey selection by individual seals. *South African Journal of Wildlife Research* **34**: 45–54

Fallows C, Martin RA, Hammerschlag N (2006) Predator-prey interactions between white sharks (*Carcharodon carcharias*) and Cape fur seals (*Arctocephalus pusillus pusillus*) at Seal Island, South Africa, and comparisons with patterns observed at other sites. *Apex Images Scientific Report*, pp 1–18

Gaydos JK, Raverty S, Baird RW, Osborne RW (2005) Suspected surplus killing of harbor seal pups (*Phoca vitulina*) by killer whales (*Orcinus orca*). *Northwestern Naturalist* **86**: 150–154

Gentry RL, Johnson H (1981) Predation by sea lions on northern fur seal neonates. *Mammalia* **45**: 423–430

Harcourt R (1993) Individual variation in predation on fur seals by southern sea lions (Otaria *byronia*) in Peru. *Canadian Journal of Zoology* **71**: 1908–1911

Heithaus MR (2004) Predator-prey interactions. In: Carrier JC, Musick JA, Heithaus MR (eds) *Biology of Sharks and Their Relatives*. CRC Press, Boca Raton, pp 488–512

Hiruki LM, Schwartz MK, Boveng PL (1999) Hunting and social behaviour of leopard seals *Hydrurga leptonyx* at Seal Island, South Shetland Islands, Antarctica. *Journal of Zoology, London* **249**: 97–109

Hockey PAR, Dean WRJ, Ryan PG (eds) (2005) *Roberts Birds of Southern Africa* (VIIth edn). John Voelcker Bird Book Fund, Cape Town

Hofmeyr GJG, Bester MN (1993) Predation on king penguins by Antarctic fur seals. *South African Journal of Antarctic Research* **23**: 71–74

Jefferson TA, Stacey PJ, Baird RW (1991) A review of killer whale interactions with other marine mammals: predation to co-existence. *Mammal Review* **21**:151–180

King JE (1983) *Seals of the World*. British Museum (Natural History), London, and Cornell University Press, Ithaca, NY

Klimley AP, Anderson SD, Pyle P, Henderson RP (1992) Spatiotemporal patterns of white shark *Carcharodon carcharias* predation at the South Farallon Islands, California. *Copeia* **3**: 680–690

Kooyman GL, Gentry RL (1986) Diving behaviour of south African fur seals. In: Gentry RL, Kooyman GL (eds) *Fur Seals: Maternal Strategies on Land and at Sea.* University Press, Princeton, New Jersey, pp 142–152

Kruuk H (1972) Surplus killing by carnivores. *Journal of Zoology* **166**: 233–244

London JM (2006) Harbor Seals in Hood Canal: predators and prey. PhD thesis, University of Washington

Lucas Z, Mclaren IA (1988) Apparent predation by Grey seals, *Halichoerus grypus*, on seabird around Sable Island, Nova Scotia. *Canadian Field-Naturalist* **102**: 675–678

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

Marks MA, Brooke RK, Gildenhys AM (1997) Cape fur seal (*Arctocephalus pusillus pusillus)* predation on Cape cormorants (*Phalacrocorax capensis)* and other birds at Dyer Island, South Africa. *Marine Ornithology* **25**: 9–12

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

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, Bester MN (2006) Diet of Cape fur seals *Arctocephalus pusillus pusillus* at three mainland breeding colonies in Namibia. 1. Spatial variation *African Journal of Marine Science* **28**: 57–71

Musick JA (1999) Ecology and conservation of long-lived marine animals. *American Fisheries Society Symposium* **23**: 1–10

Navarro RA (2000) Cape fur seal predation on Cape gannet fledglings. *Bird Numbers* **9**(2): 15–16

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 Marine Science* **11**: 21–29

Penney RL, Lowry G (1967) Leopard seal predation of Adélie penguins. *Ecology* **48**: 878−882

Pitcher KW, Fay FH (1982) Feeding by Steller sea lions on harbor seals. *Murrelet* **63:** 70–71

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

Rebelo AG (1984) Cape fur seal *Arctocephalus pusillus* kills jackass penguin *Spheniscus demersus* on land. *Cormorant* **12**: 111

Riedman ML (1990) *The Pinnipeds: Seals, Sea Lions and Walruses*. University of California Press, Berkeley

Rogers T, Bryden MM (1995) Predation of Adélie penguins (*Pygoscelis adeliae*) by leopard seals (*Hydrurga leptonyx*) in Prydz Bay, Antarctica. *Canadian Journal of Zoology* **73**: 1001–1004

Seidensticker J, McDougal C (1993) Tiger predatory behaviour, ecology and conservation. *Symposia of the Zoological Society of London* **65**: 105–125

Shaughnessy PD (1978) Cape fur seals preying on seabird. *Comorant* **5**: 31

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 (1985) Interactions between fisheries and Cape fur seals in southern Africa. In: Beddington JR, Beverton RJH, Lavigne DM (eds) *Marine Mammals and Fisheries*. George Allen and Unwin, London, pp 119–134

Short J, Kinnear JE, Robley A (2002) Surplus killing by introduced predators in Australia—evidence for ineffective anti-predator adaptations in native prey species? *Biological Conservation* **103**: 283–301

Stacey PJ, Baird RW, Hubbard-Morton AB (1990) Transient killer whale (*Orcinus orca*) harassment, predation, and ''surplus killing'' of marine birds in British Columbia. *Pacific Seabird Group Bulletin* **17**: 38

Stephens DW, Krebs JR (1986) *Foraging Theory*. Princeton University Press, Princeton, New Jersey

Soule ME, Estes JA, Berger J, Martinez del Rio C (2003) Ecological effectiveness: conservation goals for interactive species. *Conservation Biology* **17**: 1238–1250

Terborgh J (1990) The role of felid predators in neotropical forests. *Vida Silvestre Neotropical* **2**: 3–5

Todd FS (1988) Weddell seal preys on chinstrap penguin. *Condor* **90**: 249–250

Walker TR, Boyd IL, McCafferty DJ, Huin N, Taylor RI, Reid K (1998) Seasonal occurrence and diet of leopard seals *Hydruga leptonyx* at Bird Island, South Georgia. *Antarctic Science* **10**: 75–81

Walters C (1997) Challenges in adaptive management of riparian and coastal ecosystems. *Conservation Ecology* **1**: 1

Ward VL, Williams AJ (2004) Coastal killers: causes of seabird mortality. *Bird Numbers* **13**(1): 14–17

Williams AJ (1988) Guano birds heading for extinction? *African Wildlife* **42**: 77–81

Williams TM, Estes JA, Doak DF, Springer AM (2004) Killer appetites: assessing the role of predators in ecological communities. *Ecology* **85**: 3373–3384

Williams TM, Fuiman LA, Horning M, Davis RW (2004) The cost of foraging by a marine predator, the Weddell seal *Leptonychotes weddellii*: pricing by the stroke. *Journal of Experimental Biology* **207**: 973–982

Wobeser G (2000) Suspected surplus killing of grebes by mink. *Blue Jay* **58**: 137–139

Wolfaardt A, Williams AJ (2006) Sealed off: predation threatens seabirds and tourism. *Africa – Birds & Birding* **11**(2): 61–67

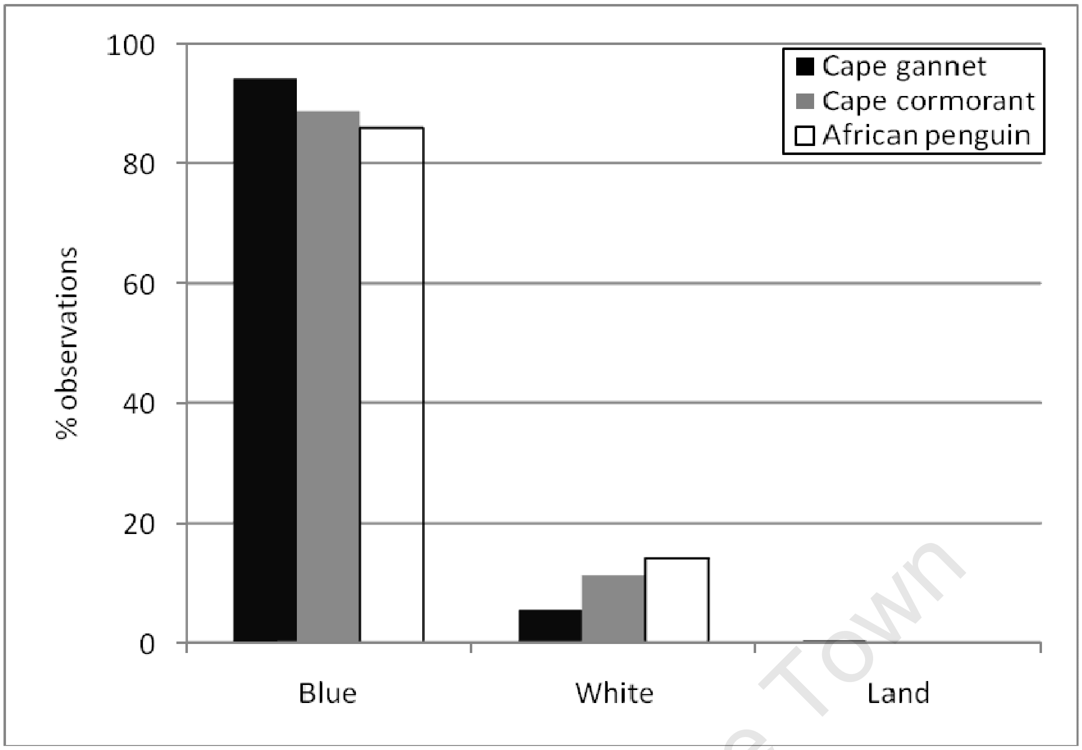

Figure 1: Habitat of attacks by the Cape fur seals on Cape gannets (Malgas Island), and Cape cormorants and African penguins (Dyer Island) – Blue = blue water, white = surf zone, land = on land

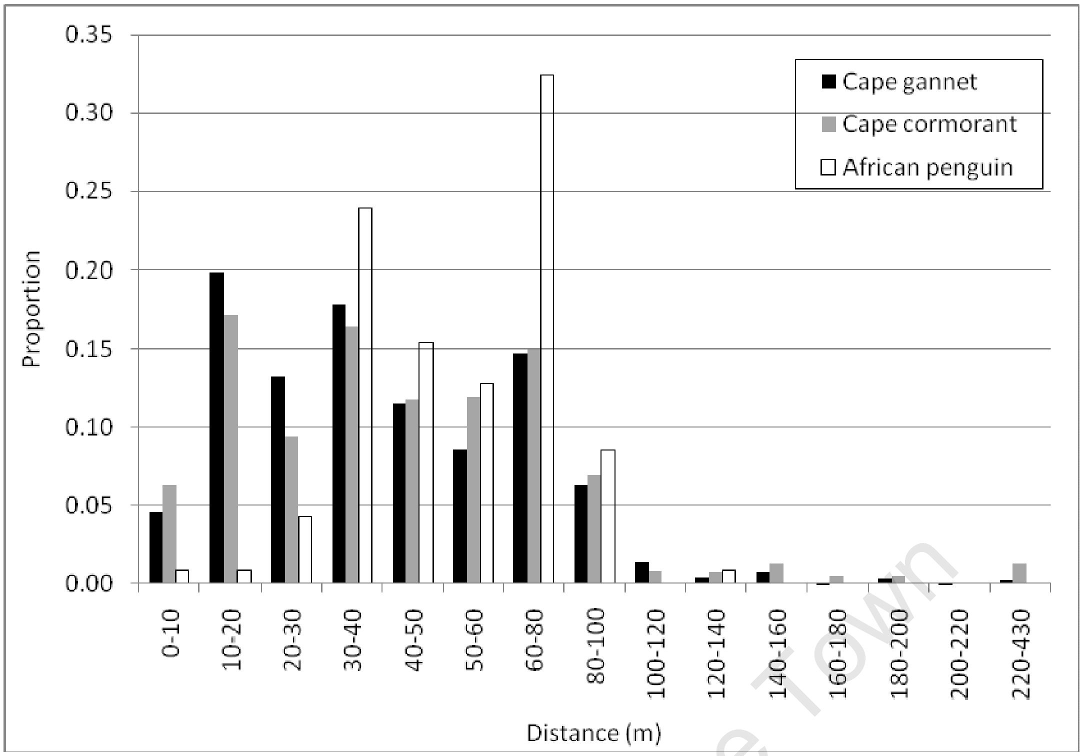

Figure 2: Distances (m) from the islands at which attacks by Cape fur seals on Cape gannets (Malgas Island) and Cape cormorants and African penguins (Dyer Island) were recorded

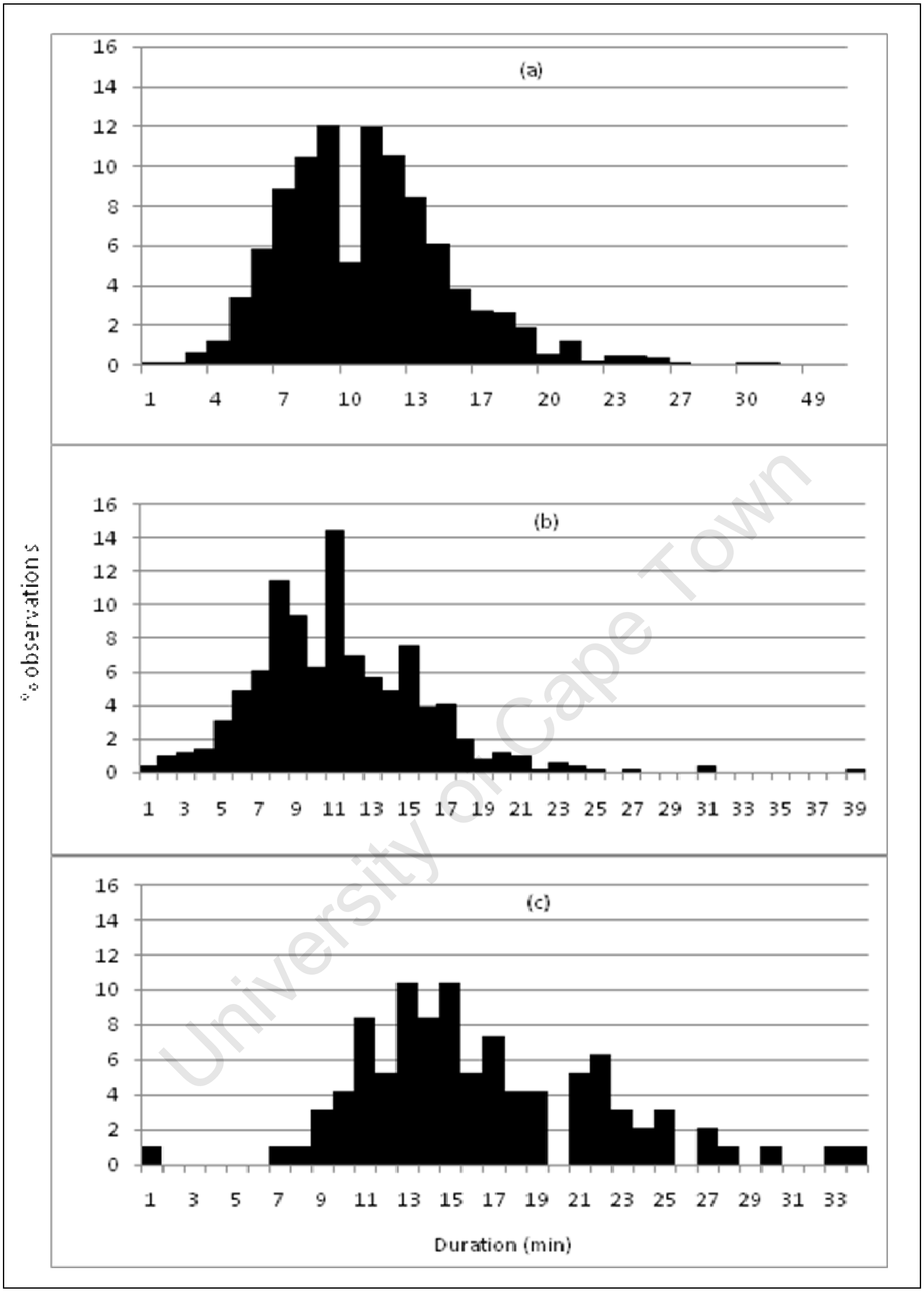

Figure 3: Time spent by Cape fur seals feeding on individual (a) Cape gannets, (b) Cape cormorants and (c) African penguins

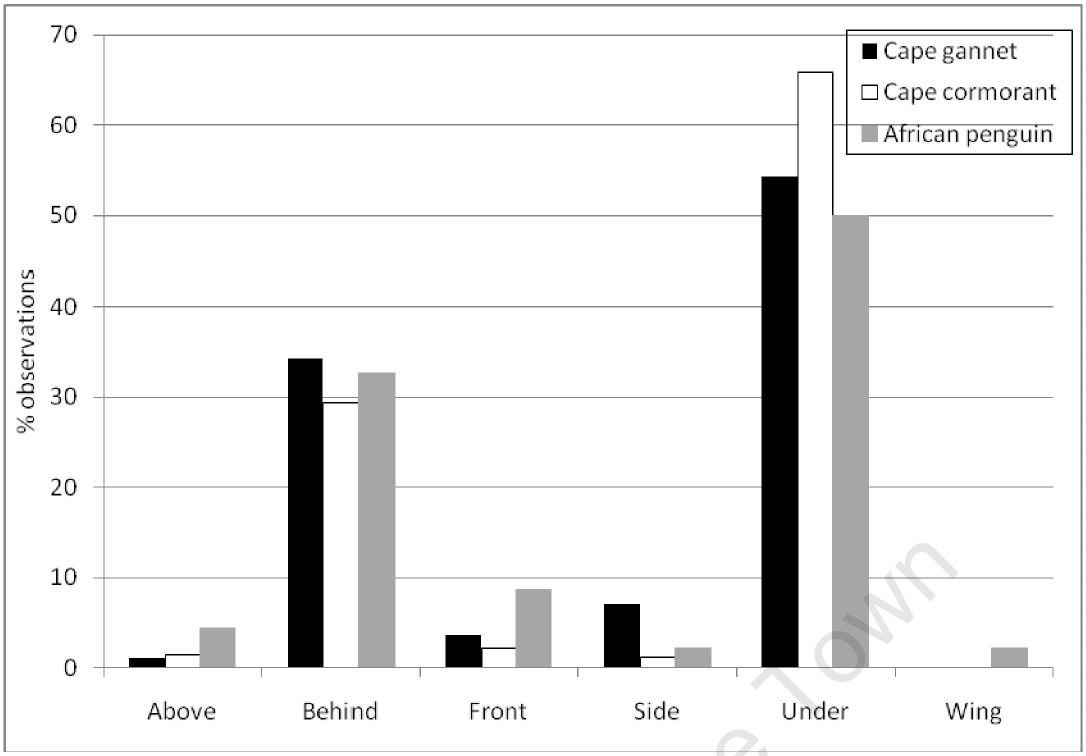

Figure 4: Observations on the direction from which seabirds were first attacked by Cape fur seals during predation – Under = underneath, wing = wing or flipper

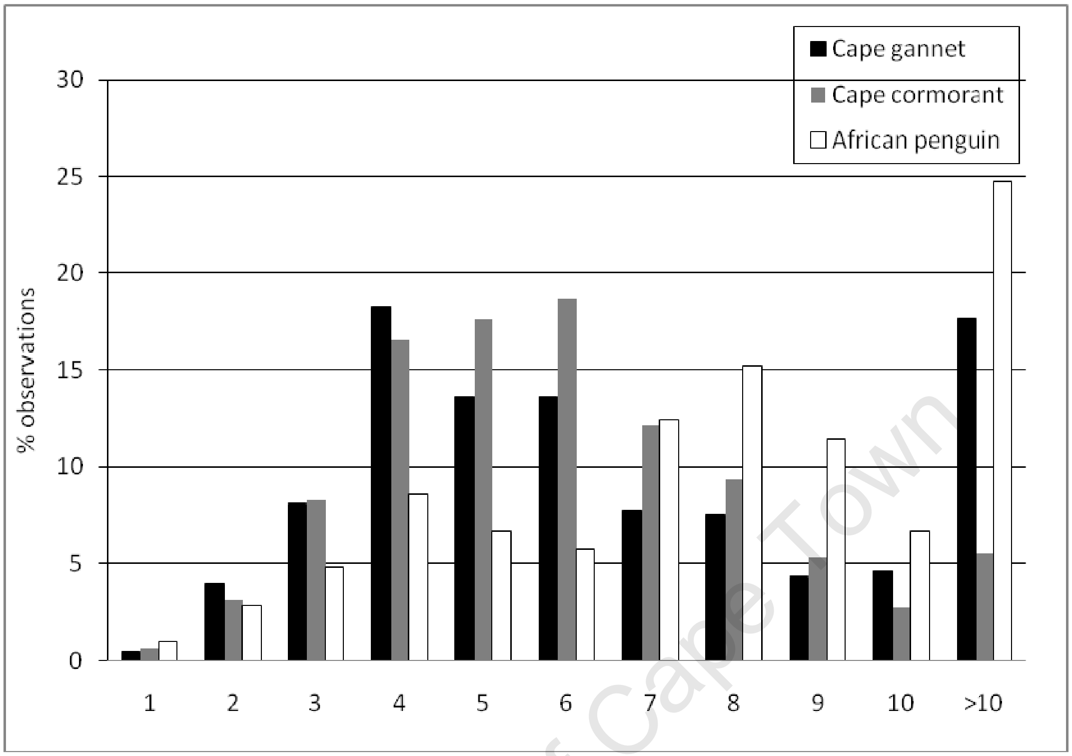

Figure 5: The number of times individual seabirds were attacked by the Cape fur seals

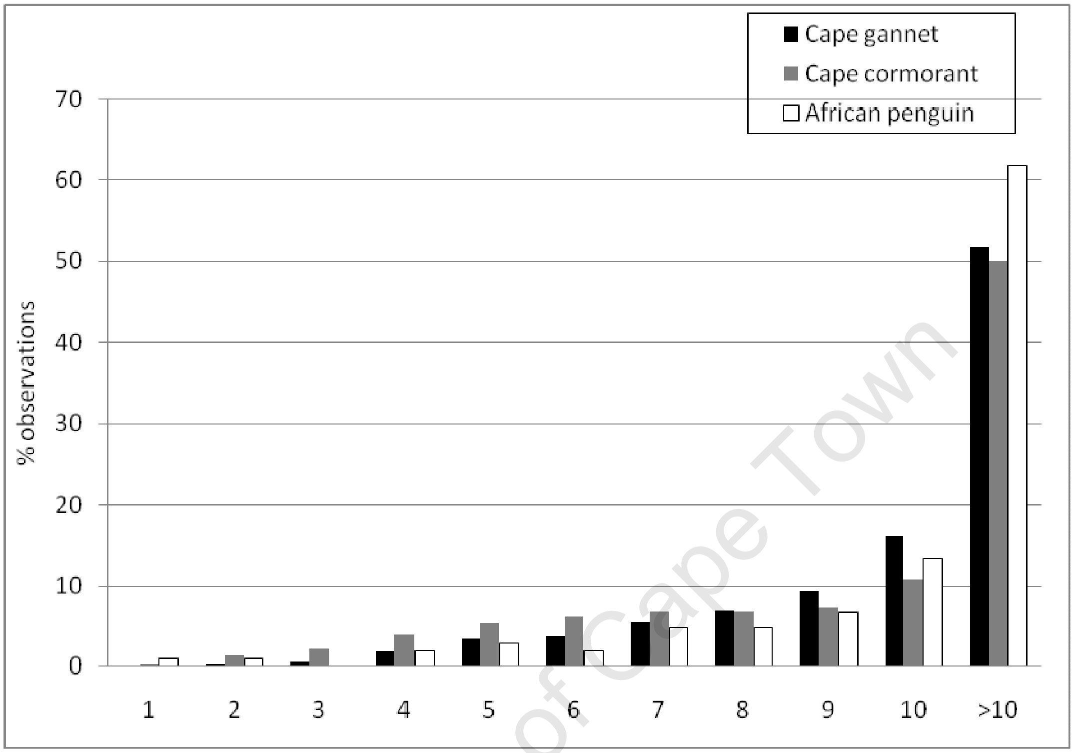

Figure 6: The number of times individual seabirds were thrown out of the water during attacks by Cape fur seals

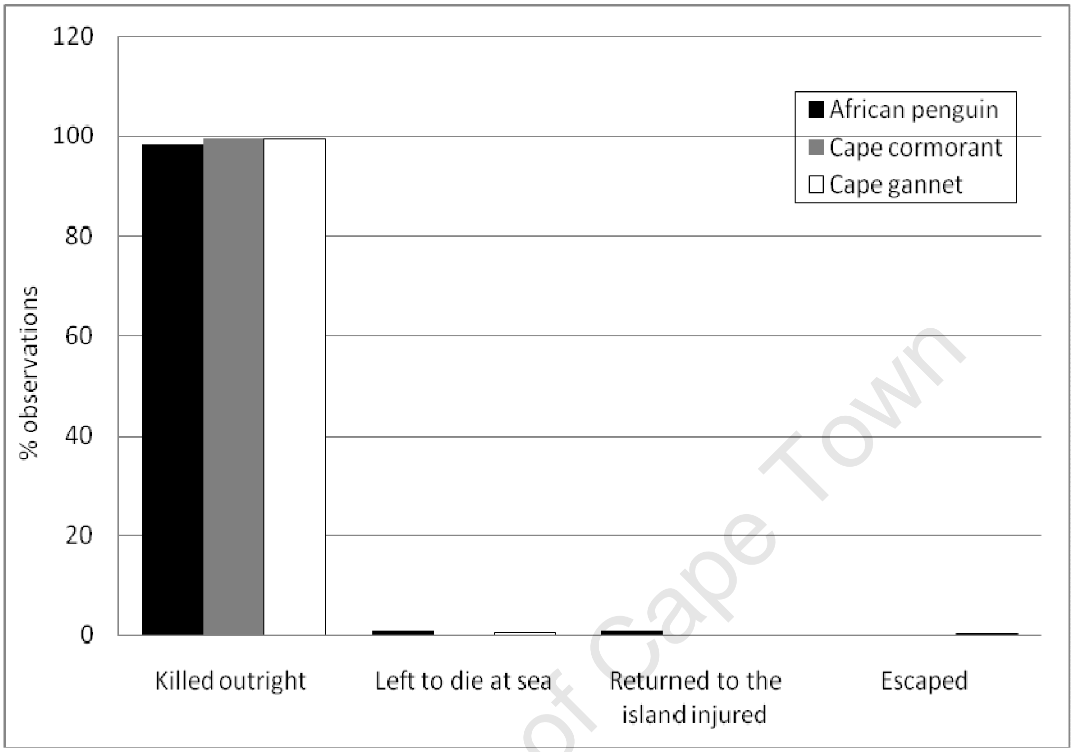

Figure 7: The fate of seabirds that were attacked by Cape fur seals

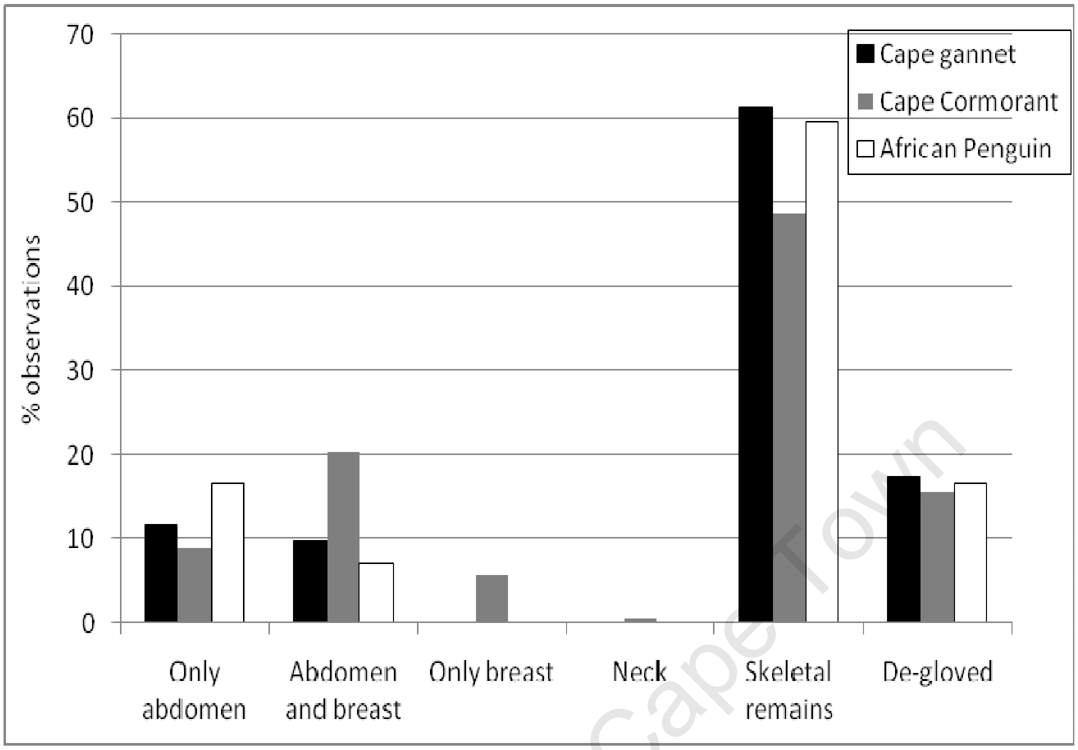

Figure 8: The extent of utilization of seabirds fed upon by Cape fur seals. Skeletal remains signifies use of most tissue other than bones

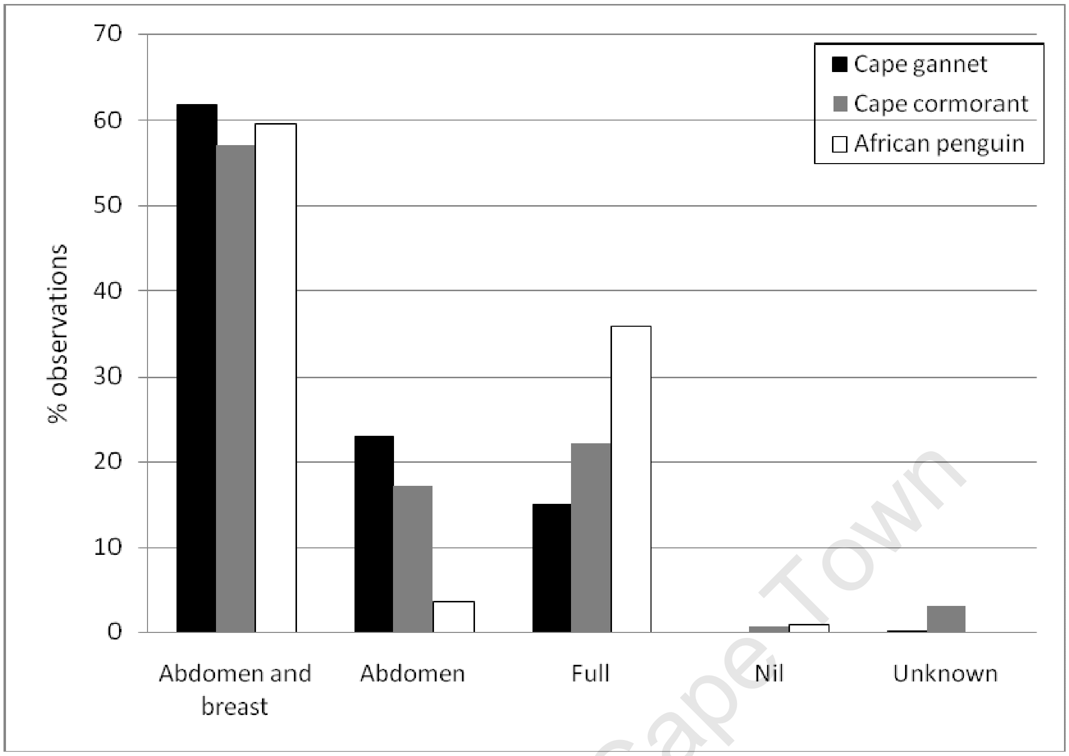

Figure 9: The extent of utilization of seabird carcasses washed ashore

CHAPTER 8

The efficacy of culling seals seen preying on seabirds as a means of reducing seabird mortality

The efficacy of culling seals seen preying on seabirds as a means of reducing seabird mortality

ABSTRACT

In the 2006/2007 breeding season of Cape gannets *Morus capensis* at Malgas Island, the removal of 61 Cape fur seals *Arctocephalus pusillus pusillus* that preyed on gannet fledglings when they left to sea significantly reduced the mortality rate of these fledglings. However, because seals learned to avoid the boat used for their removal, it was not possible to remove all the seals that killed gannet fledglings and some mortality continued. The seals inflicting the mortality were all sub-adult males, with an average age of <5 years. Sustained removal of these animals may reduce this feeding behaviour, which is at present having an adverse impact on several threatened seabirds in the Benguela ecosystem.

INTRODUCTION

Over the past decades, many native vertebrate species have increased in abundance (Garrott *et al*. 1993), whereas others have declined because of anthropogenic habitat changes (Reid and Miller 1989, World Conservation Monitoring Centre 1992). Overabundant species (Wagner and Seal 1992, Garrott *et al*. 1993) have contributed to the decline of rare vertebrates through predation, competition, habitat change, disease transmission and hybridization (Caughley 1981, Jenks and Wayne 1992, Wagner and

Seal 1992, Garrott *et al*. 1993). The control of populations of these abundant species and their harmful effects on other species has received close attention (Jewell *et al.* 1981, McCullough and Barrett 1992, Garrott *et al*. 1993, Harris and Saunders 1993). It is a common concern in efforts to recover endangered species (Goodrich and Buskirk 1995, Yodzis 2001).

Off western South Africa, culling of Cape fur seals *Arctocephalus pusillus pusillus* seen preying on seabirds has been undertaken in an effort to limit the mortality of seabirds, several of which have an unfavourable conservation status (David *et al*. 2003). Cape fur seals are opportunistic animals that have benefited from several human activities. For example, they utilize fish discarded by fishing boats and take fish from fishers (e.g. Wickens *et al*. 1992). Subsequent
to the elimination of some large mammalian predators from much of the southern African coastline, and to the exclusion of humans from diamond areas along the coast, large breeding colonies of Cape fur seals have formed at several sites on the mainland (e.g. Kirkman *et al*. 2007).

The population of Cape fur seals increased markedly during the 20th century (Butterworth *et al*. 1995). By contrast, several seabirds, such as the African penguin *Spheniscus demersus,* are specialist feeders that compete with fisheries for food, had their breeding habitat altered *inter alia* through the removal of deposits of guano for agricultural use, and decreased substantially during the 20th century (Hockey *et al.* 2005 and references therein). Recent interactions between seals and seabirds off southern Africa are exacerbating the population decreases in seabirds caused by human perturbation of the marine ecosystem (e.g. Crawford *et al*. 1989, David *et al*. 2003). For example, at Malgas Island, in three seasons between 2000/2001 and 2005/2006, Cape fur seals killed 28–83% (average 56%) of Cape gannets *Morus capensis* fledged at the island, a mortality rate that is considered unsustainable (Makhado *et al*. 2006).

In the southern African situation, much of the predation of seabirds by seals was thought to be attributable to a few rogue seals; mostly males aged 2–10 years (David *et al*. 2003). It was hoped that the removal of these individual seals would substantially lessen their impact on seabirds but, in the longer-term, this proved not to be the case. Mortality increased to unsustainable levels in seasons following removal of the rogue seals (Makhado *et al*. 2006). This necessitated further investigations on the long-term effect of removal of rogue seals on seabird mortality. Therefore, at the conclusion of the 2006/2007 breeding season for Cape gannets, more observations were conducted at Malgas Island (33°03'S, 17°55'E) off western South Africa and are reported in this paper. The paper also presents additional information on the sex and age of seals inflicting the mortality, investigates how the proportion of fledglings killed is related to the number of seals that hunt them and explores the dependency of seals on seabirds as a food source by examining the extent of carcase utilization by the seals.

METHODS

From 5–12 February and 15–18 February 2007, estimates were made at Malgas Island of the number of Cape gannet fledglings entering the sea and of the number of fledglings killed by Cape fur seals. In the first of these periods, a team based at the island shot, under permit, the seals that were searching for or killing Cape gannet fledglings. No culling was undertaken in the second period.

The number of gannet fledglings entering the water and the number killed by seals were recorded by two observers, who kept watch from vantage points over different areas around the island during the same alternate hours, commencing at 08h00 hours and concluding at 18h00 hours. The vantage points allowed all fledglings entering the sea and all predation events during the periods of observation to be recorded.

On the first visit, the inflatable boat was guided by observers using two way radio to the site of predation event, where an experienced marksman attempted to shoot the seal that had killed a gannet fledgling. An attempt was made to retrieve the carcases of all culled seals and killed gannets using gaffs. For each day, the total numbers of shots fired and seals killed, including those that were not retrieved, were recorded.

The sex of all seals that were shot was determined from the profile of their heads and necks, using features described by Apps (2000). The nose of males is more pointed, their neck thicker and their flipper is broader (M.A Meÿer, Department of Environmental Affairs and Tourism, ABM pers. obs.). The standard lengths (American Society of Mammalogists 1967) and axillary girths of all seals collected were measured. The ages of culled seals were estimated from size, based on previous experience with known age individuals (Miller *et al.* 1996).

None of the collected seals was weighed, but mass (M, kg) was estimated from measurements of length (L, cm) and axillary girth (G, cm) using the relationship developed by Castellini and Kooyman (1990) and Castellini and Calkins (1993):

$M = 4.57 \times 10^{-5}[LG^2]$.

The mass and condition of carcases of gannet fledglings, which were recovered, was recorded. The average mass of Cape gannet chicks at fledging is 2.9 ± 0.3 kg (Jarvis 1974, Batchelor and Ross 1984, Navarro 1991). In most instances, seals were still by sea feeding on the carcases at the time of their collection. As seals would probably have fed further, the extent of carcase utilizations will be underestimated. A Chi-squared test was used to compare the proportions of Cape gannet fledglings that were killed by seals in the periods 5–12 February and 15–18 February. The Chi squared statistic was calculated as:

$$\chi^2_{calc} = \sum_{i=1}^{k} \frac{\left(x_i - n_i \overline{p}\right)^2}{n_i \overline{p}\overline{q}}, \qquad (1)$$

where x_i is the number of chicks killed in period i

n_i is the total number of chicks going to sea in period i

$\overline{p}$ is the proportion of all chicks killed $\left\{\overline{p} = \frac{\sum x_i}{\sum n_i}\right\}$

$\overline{q}$ is the proportion of all chicks not killed $\{\overline{q} = 1 - \overline{p}\}$, and

k = 2.

We used a generalized linear model with a binomial distribution and the logit transformation to explore the relationship between the proportions of gannets in the water that were killed by seals and two explanatory variables: the number of shots fired on the previous day (shots fired were taken to be a measure of hunting effort; it was considered that prior effort may deter seals from preying on seabirds) and the estimated daily number of seals engaging in killing gannets. The latter values were estimated by backcasting from the number of predatory seals that remained alive at the end of the cull and adding to this the numbers killed each preceding day.

RESULTS

The number of Cape gannet fledglings observed entering the sea showed substantial variation about a mean value of 161 per day (SD = 73) (Table 1). The number of gannet fledglings observed killed by seals decreased from 61 on 8 February to zero on 11 February but increased again to 32 on 18 February (Table 1). The percentage of fledglings entering the sea that was killed by seals decreased from 16% during 5–11 February to 7% during 15–18 February.

Both the number (r = –0.29, P = 0.41, n = 10) and proportion (r = –0.43, P = 0.21, n = 10) of fledglings killed were negatively related to time. A significantly lower proportion of fledglings was killed in the post culling period of observations than during the period of culling (χ^2 = 31.15, *P* < 0.001, df =1).

The number of seals culled fell during the period of the cull, from a peak of 25 individuals on day 2 to zero on the final day (Table 1). In total, 61 seals were shot and killed. It was estimated that further four seals were still killing gannet fledglings when the shooting ceased, but the boat was not able to approach them sufficiently close enough to shoot them. The backcasting approach to estimating daily numbers of predatory seals suggested that on 5 February, the first day of the cull, there were 65 seals engaged in killing gannets (Table 1). The generalized linear model accounted for 51.6% of the deviance: both the estimated number of predatory seals (positive effect) and the number of shots fired the previous day (negative effect) had a significant impact on the proportion of gannet fledglings killed (both P < 0.001) (Table 2):

$$\text{logit } P = -2.40 + 0.034 \times \text{seals alive on the day} - 0.034 \times \text{shots fired previous day},$$

where P = is the proportion of gannet fledglings killed.

For the 61 seals shot, the estimated average age was 4.8 years (SD = 1.4); it ranged between 2 and 8 years. For the 33 that were retrieved, the estimated average age was 4.7 years (SD = 1.5). All animals retrieved were males. Their average length was 141.2 cm (SD = 17.6) and their average axillary girth was 86.4 cm (SD = 12.6). Using the allometric equation to estimate mass, their average mass was found to be 50.8 kg (SD = 22.4, range 19.5–123.7 kg).

In total, 61 carcases of gannet fledglings that had been killed by seals were retrieved. The average mass of these was 2.2 kg (SD = 0.4). About 50% of the retrieved carcasses were without breast muscles and viscera. For about 20% of the carcases, only the viscera had been eaten. About 7.5% of the carcasses had been fully utilized.

DISCUSSION

Protecting threatened species from extinction requires management interventions, which may involve the removal of problem predators (David *et al*. 2003). Where individual rogue animals are causing the problem, their specific removal should eliminate the problem, as long as measures are put into place to discourage other animals from becoming problems in the future (National Marine Fisheries Service 1996). For example, the removal of three troublesome California sea lions *Zalophus californianus* at Ballard Locks, Seattle, to a captive facility (National Oceanic and Atmospheric Administration 1996) and the use of acoustic alarms (Marine Mammal Commission 2000) reduced depredations by sea lions on steelhead trout *Oncorhynchus mykiss* passing through the locks on their way to spawning grounds up river (National Oceanic and Atmospheric Administration 1999). Culls of seals eating gannet fledglings around Malgas Island rapidly reduced the mortality rate in 1999 and 2000 (David *et al*. 2003) and similarly around Ichaboe Island in Namibia (du Toit *et al*. 2004). In this study, the removal of 61 seals inflicting mortality on Cape gannet fledglings resulted in an immediate reduction in the mortality rate confirming that culling rogue animals is an effective way to reduce seabird mortality in the short term. However, predation of gannet fledglings recommenced within a week of cessation of culling rogue seals (Table 1), in accordance with previous observations that the intervention might not have a beneficial effect in the long term. It is difficult to remove all the seals that are killing the birds because, after a period of culling, seals become wary of approach by a boat (M.A Meÿer, pers. Obs.).

Hence, some seals that have developed a technique to hunt seabirds remain, with the potential to pass the technique on to younger animals. It is possible that persistent culling of seals that eat seabirds may decrease this feeding behaviour of seals. Given that the average age of seals feeding on gannet fledglings at Malgas Island is estimated to be < 5 years, it might be hoped that persistent removal of these individuals over a period of 5 years would largely eliminate the behaviour. In 1999/2000, 55% of seals killing seabirds were 6 years and older compared to 24% in this study (Marine and Coastal Management, unpublished data). This reduced age of animals killing seabirds probably resulted from the removal of seals around Malgas Island during 1999/2000.

Seabirds are not an important component of the diet of Cape fur seals (David *et al*. 2003, Mecenero *et al.* 2005). Even for those individuals that have learnt to catch seabirds, the often poor utilization of carcasses (David *et al*. 2003) suggests that seabirds are not essential in the diet and hence that the behaviour might be stopped by the removal of all animals that are practising it.

Culling, defined as the directed reduction in the size of a population to achieve some specified objective (Jewell *et al*. 1981) may involve lethal or nonlethal methods of removal. Culling using nonlethal methods involves the capture of individual animals and their relocation elsewhere in the wild or their confinement in captivity (e.g. Fraker and Mate, 1999). In the context of seals preying on seabirds off southern Africa, this is not regarded as a control option because no means of safely capturing wild Cape fur seals at sea have yet been developed. Previous efforts to condition Cape fur seals against certain behaviours also proved unsuccessful (Shaughnessy *et al.* 1981). Lethal culling may involve the targeted removal of offending individuals or the indiscriminant killing of large numbers of animals (essentially, culling at the population level) with a view to reducing the number or severity of interactions between the population being culled and other populations. As in this study, David *et al*. (2003) reported that all seals causing mortality of seabirds were sub-adult males.

Hence, it is only a segment of the seal population that is having an adverse impact on southern Africa's seabird populations (see also Shaughnessy 1978, Rebelo 1984, Navarro

2000, du Toit *et al*. 2004, Mecenero *et al*. 2005), so that nonselective culling should be avoided. Culling at the population level will not necessarily remove the individuals that are implicated in the presumed interaction (Lavigne 2003). To have a maximum beneficial effect, the seals killing birds should be removed before they have inflicted substantial mortality, for example when the fledging of Cape gannet chicks is commencing rather than late in the fledging period. In other species, for example during predation on penguins (Marks *et al.* 1997), the fledging period may not be as distinct.

Acknowledgements – I thank the National Research Foundation (SANAP programme) and WWF-SA for supporting this research. We are grateful to all who assisted with observations of mortality of Cape gannet fledglings and culling of seals, including L. Upfold, D Kotze and T. Nethononda. L. Antony assisted with the statistical analysis. The Department of Environmental Affairs and Tourism, South African National Parks and South African Navy provided logistical support for the surveys. This paper is a contribution to the project LMR ⁄ EAF ⁄ 03 ⁄ 02 of the Benguela Current Large Marine Ecosystem (BCLME) Programme.

REFERENCES

American Society of Mammalogists (1967) Standard measurements of seals. *Journal of Mammalogy* **48:** 459–462

Apps P (2000) *Smither's Mammals of Southern Africa: field guide. Struik,* Cape Town

Batchelor AL, Ross GJB (1984) The diet and implications of dietary change of Cape gannets on Bird Island, Algoa Bay. *Ostrich* **55**: 45–63

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. Modeling the dynamics of the Cape fur seal *Arctocephalus pusillus pusillus*. *South African Journal of Marine Science* **16**: 161–183

Castellini MA, Calkins DG (1993) Mass estimates using body morphology in Steller sea lions. *Marine Mammal Science* **9**: 48–54

Castellini MA, Kooyman GL (1990) Length, girth and mass relationships in Weddel seals (*Leptonychotes weddellii*). *Marine Mammal Science* **6**: 75–77

Caughley G (1981) Overpopulation. In: Jewell PA, Holt S, Hart D (eds) *Problems in management of locally abundant wild mammals*. Academic Press, New York, pp 7–19

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

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

du Toit M, Bartlett PA, Bester MN, Roux J-P (2004) Seal-seabird predation at Ichaboe Island, Namibia: prey selection by individual seals. *South African Journal of Wildlife Research* **34**: 45–54

Fraker MA, Mate BR (1999) Seals, sea lions, and salmon in the Pacific Northwest. In: Twiss Jr JR, Reeves RR (eds) *Conservation and Management of Marine Mammals*. Smithsonian Institution Press, Washington, DC

Garrott RA, White PJ, White CAV (1993) Overabundance: an issue for conservation biologists? *Conservation Biology* **7**: 946–949

Goodrich JM, Buskirk SW (1995) Control of abundant native vertebrates for conservation of endangered species. *Conservation Biology* **9**: 1357–1364

Harris S, Saunders G (1993) The control of canid populations. In 65th Symposium, Zoological Society of London, London **65**: 441–464

Hockey PAR, Dean WRJ, Ryan PG (2005) *Roberts Birds of Southern Africa* (7th edn). John Voelcker Bird Book Fund, Cape Town, 1296 pp

Jarvis MJF (1974) The ecological significance of clutch size in the South African Gannet (*Sula capensis* (Lichtenstein)). *Journal of Animal Ecology* **43**: 1–17

Jenks SM, Wayne RK (1992) Problems and policy for species threatened by hybridization: the red wolf as a case study. In: McCullough DR, Barrett RH (eds) *Wildlife 2001: populations*. Elsevier Applied Science, New York, pp 237–251

Jewell PA, Holt S, Hart D (eds) (1981) *Problems in management of locally abundant wild mammals*. Academic Press, New York pp 21–55

Kirkman SP, Oosthuizen WH, Meÿer MA, Kotze PGH, Roux J-P, Underhill LG (2007) Making sense of censuses − 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

Lavigne DM (2003) Marine mammals and fisheries: the role of science in the culling debate. In: Gales N, Hindell M, Kirkwood R (eds) *Marine Mammals: Fisheries, Tourism and Management Issues*, CSIRO Publishing, Collingwood, Australia, pp 31–47

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

Marine Mammal Commission (2000) *Annual Report to Congress 1999*. Marine Mammal Commission, Maryland

Marks MA, Brooke RK, Gildenhuys AM (1997) Cape fur seal *Arctocephalus pusillus* predation on Cape cormorants *Phalacrocorax capensis* and other birds at Dyer Island, South Africa. *Marine Ornithology* **25**: 9–12

McCullough DR, Barrett RH (1992) Wildlife 2001: populations. Elsevier Applied Science, New York

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

Miller CM, Oosthuizen WH, Wickens PA (1996) Cape fur seals trapped in trawling gear: age structure, sex ratio, seasonality and distribution. *South African Journal of Marine Science* **17**: 105–111

National Marine Fisheries Service (1996) Environmental assessment on conditions for lethal removal of California sea lions at the Ballard Locks to protect winter steelhead. *NMFS Environmental Assessment Report*, pp 1–81

National Oceanic and Atmospheric Administration (1996) *National Marine Fisheries Service OK's Permanent Home for Seattle's sea lions at Sea World in Florida.* NOAA, Available at: http://www.publicaffairs.noaa.gov/pr96/apr96/noaa 96–130.html

National Oceanic and Atmospheric Administration (1999) *Steelhead-eating sea lions all but gone from Seattle's Ballard Locks*. NOAA, Available at: http://www.publicaffairs.noaa.gov/releases99/may99/noaa99–128.html

Navarro RA (1991) Food addition and twinning experiments in the Cape gannet: effects on breeding success and chick growth and behavior. *Colonial Waterbirds* **14**: 92–102

Navarro RA (2000) Cape fur seal predation on Cape gannet fledglings. *Bird Numbers* **9**(2): 15–16

Rebelo AG (1984) Cape fur seal *Arctocephalus pusillus* kills jackass penguin *Spheniscus demersus* on land. *Cormorant* **12**: 111

Reid WV, Miller KR (1989) *Keeping options alive: the scientific basis for conserving biodiversity*. World Research Institute, Washington, D.C

Shaughnessy PD (1978) Cape fur seals preying on seabirds. *Comorant* **5**: 31

Shaughnessy P, Semmelink A, Cooper J, Frost P (1981) Attempts to develop acoustic methods of keeping Cape fur seals, *Arctocephalus pusillus*, from fishing nets. *Biological Conservation* **21**: 141–158

Wagner FH, Seal US (1992) Values, problems, and methodologies in managing overabundant wildlife populations: an overview. In: McCullough DR, Barrett RH (eds) *Wildlife 2001: populations*. Elsevier Scientific Publications, London

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

World Conservation Monitoring Centre (1992) *Global Biodiversity: Status of the Earth's Living Resources*. Chapman and Hall, London

Yodzis P (2001) Must top predators be culled for the sake of fisheries? *Trends in Ecology and Evolution* **16**: 78–84

Table 1: Numbers of Cape gannet fledglings entering the sea and killed by seals, numbers of seals alive and shot, percentages of Cape gannet fledglings in the water that were killed by seals and number of seals killed, for each day of observation

Date	**No. gannet fledglings entering water**	**No. gannet fledglings killed by seals**	**No. seals shot during day**	**No. seals alive at start of day**	**% of birds killed**	**No. shots fired the previous day**
05 Feb 2007	0	5	5	65	0	8
06 Feb 2007	157	43	25	60	27.38	8
07 Feb 2007	225	11	4	35	4.88	45
08 Feb 2007	234	61	18	31	26.07	11
09 Feb 2007	97	2	4	13	2.06	36
10 Feb 2007	76	17	5	9	22.37	6
11 Feb 2007	61	0	0	4	0	16
15 Feb 2007	167	2	0	4	1.19	0
16 Feb 2007	112	2	0	4	1.79	0
17 Feb 2007	203	19	0	4	9.36	0
18 Feb 2007	275	32	0	4	11.64	0

Table 2: Results of the generalized linear model relating the proportion of fledgling Cape gannets killed around Malgas Island during 10 days in February 2007 with two explanatory variables

Explanatory variable	**Regression estimate**	**SD**	**t**	**P**
Constant	–2.403	0.123	–19.5	<0.001
Estimated no. predatory seals alive the same day	0.03393	0.00379	8.94	<0.001
Number of shots fired the previous day	–0.03361	0.00668	–5.03	<0.001

CHAPTER 9

Discussion and Conclusions

Discussion and Conclusions

There are opportunistic and specialised predators in the Benguela upwelling marine ecosystem. In general, the opportunistic predators have benefited from human activities, whereas specialists have been disadvantaged by them. For example, the opportunistic Cape fur seal *Arctocephalus pusillus pusillus* utilizes fish discarded by fishing boats and also takes fish from fishing nets. By contrast, several seabirds, such as the African penguin *Spheniscus demersus*, are specialist feeders that compete with fisheries for food and have had their breeding habitat altered *inter alia* through the removal of guano deposits for agricultural use.

There were large changes in the structure and functioning of the Benguela ecosystem during the 20th century. Cape fur seals, which had been exploited to low levels of abundance by the end of the 19th century, increased rapidly in numbers (Butterworth *et al.* 1995). Commercial fisheries were initiated (Crawford *et al.* 1987). Between them, Cape fur seals and the fisheries removed two million tonnes more fish and cephalopods from the Benguela ecosystem in the 1980s than they did in the 1930s (Crawford *et al.* 1992). In this period, the consumption of fish and cephalopods by seals rose from 0.1 to 1.0 million tonnes, and the harvest by man from some 0.01 to 1.3 million tonnes (Crawford *et al.* 1992). The diet of Cape fur seals and the catch by fisheries overlap considerably with the diet of seabirds breeding off the coast of South Africa, including

African penguins and Cape gannets *Morus capensis* (Crawford *et al.* 1987, David 1989, Hockey *et al*. 2005).

Following the removal of large terrestrial predators, such as the brown hyaena *Parahyaena brunnea*, from much of the southern African coastline, the Cape fur seal formed large mainland colonies in the latter part of the 20th century (Kirkman *et al.* 2007). It is possible that its numbers are now higher than before the arrival of Europeans in southern Africa in the 1600s. During the 20th century, populations of Subantarctic fur seals *A. tropicalis* and Antarctic fur seals *A. gazella* increased at South Africa's Subantarctic Prince Edward Islands following decades of earlier exploitation of these species (Bester *et al*. 2003, David *et al*. 2003). The increase in the fur seal populations was in part a recovery from earlier exploitation to low levels of abundance. Off South Africa, it may also result from man's provision of new food and breeding resources for seals. Cape fur seals feed behind fishing trawlers on discarded fish and breed on the mainland in large numbers, especially in human exclusion zones (diamond areas) where mainland predators have also been eliminated. Fisheries have recently commenced around the Prince Edward Islands (Hofmeyr and Bester 2002) but the extent to which these fisheries contribute to the food of fur seals there is unknown.

Populations of several southern African seabirds decreased substantially during the 20th century (Best *et al*. 1997). The populations of some seabird species at the Prince Edward Islands have also recently decreased, leading to concern about their conservation status (Barnes 2000, BirdLife International 2000, Crawford and Cooper 2003). Recent interactions between seals and seabirds off southern Africa and at the Prince Edward Islands are exacerbating some of the decreases and worsening the conservation status of some seabirds (Crawford *et al.* 1989, David *et al*. 2003). Fur seals are feeding on seabirds around breeding colonies, often inflicting heavy mortality that in cases is thought to be unsustainable (Hofmeyr and Bester 1993, Crawford *et al*. 2001, du Toit *et al.* 2004, David *et al*. 2003). Fur seals are also displacing seabirds from breeding sites; for example African penguins that are no longer able to burrow into guano are easily displaced from surface nests by the much larger fur seals (Crawford *et al*. 1989). Fur seals congregating on landing beaches may be blocking access by penguins to breeding localities (Ryan *et al*. 2003). Fur seals may also be competing with seabirds for food (Crawford *et al*. 1992, Croll and Tershy 1998).

South Africa has a constitution which provides within its Bill of Rights (s 24(b)) that everyone has the right to have the environment protected for the benefit of present and future generations, through reasonable legislative and other measures that *inter alia* promote conservation and secure ecologically sustainable development and use of natural resources. This accords with the Rio Declaration of 1992 which states that in order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation. Similarly, the World Summit on Sustainable Development in 2002 encouraged the application by 2010 of the ecosystem approach, noting the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem and a decision of the Conference of Parties to the Convention on Biological Diversity. It also encouraged states to maintain or restore populations of marine species at levels that can produce the maximum sustainable yield, taking into consideration relationships among species, and to promote sustainable use and conservation of marine living resources while addressing critical uncertainties for the management of the marine environment and climate change.

Given human perturbation of southern Africa's marine ecosystems and the poor conservation status of several of the region's seabirds, it is necessary to manage adverse interactions between seals and seabirds. In order to do so, good information is required. This thesis has attempted to provide such information.

Chapter 2 estimated the mortality of Cape gannet fledglings attributable to Cape fur seals for three breeding seasons at Malgas Island. Similarly, Chapter 3 examined the extent of predation by Cape fur seals on African penguin adults and Cape cormorant *Phalacrocorax capensis* fledglings at Dyer Island. For Cape gannets and African penguins, the mortality inflicted by the seals appeared unsustainable, whereas for Cape cormorants, although large numbers of fledglings were killed, the mortality seemed to be sustainable. This was borne out by the fact that the numbers of Cape gannets at Malgas Island and African penguins at Dyer Island have decreased, whereas numbers of Cape cormorants at Dyer Island have been stable. At Bird Island, Lambert's Bay, seals kill substantial numbers of Cape gannets (Ward and Williams 2004). At this locality, it was predicted that if the predation rate on African penguins continued at its observed rate, although actual numbers involved were small, the colony would be extinct by 2011 (Crawford *et al.* 2001) and extinction in fact occurred in 2006 (Crawford *et al.* 2008a). Seals prey on seabirds at several other southern African localities (Chapter 4). At some of these, information is still insufficient to assess the impact of the mortality on the seabird populations. At Marion Island, Antarctic fur seals have killed substantial numbers of king penguins *Aptenodytes patagonicus* and macaroni penguins *Eudyptes chrysolophus* (Chapter 4).

There are uncertainties in gauging the mortality of seabirds that is attributable to seals, including estimating mortality in periods when no observations were conducted. As a first approximation, it was assumed that mortality rates could be interpolated between periods when observations were made. In order to examine this hypothesis, environmental conditions were recorded during periods when observations of mortality were made at Malgas and Dyer islands. The influence of environmental factors on predation rates was examined in Chapter 6. It was found that the time of day explained most of the variability in predation rates. Other variables such as wind strength, wind direction, tides and swells had less influence on predation rates. There is considerable variation in predation rates that cannot be accounted for by environmental variables. Therefore, it is likely that uncertainty concerning predation rates can best be reduced by decreasing the periods for which interpolation of information is required.

The diet of Cape fur seals consists mainly of teleost fish, with cephalopods, crustaceans and rock lobster also eaten (David 1987). Cape fur seals have been observed to prey on seabirds (Rand 1959, Cooper 1974, Shaughnessy 1978, Rebelo 1984, Crawford and Cooper 1996, Marks *et al.* 1997, Navarro 2000, Crawford *et al.* 2001, David *et al.* 2003, du Toit *et al.* 2004, Makhado *et al.* 2006). Being generalist feeders in a highly variable ecosystem, Cape fur seals can be expected to feed on locally abundant prey species, such as seabirds. In Chapter 5, the diet, age and sex of seals seen feeding, or thought to be feeding, on seabirds were investigated. It was found that that Cape gannets dominated the diet of these fur seals by a high margin. Known prey items of Cape gannets, which may have been obtained from the alimentary tract of fledgling gannets, were also identified but in smaller percentages. Hence, when the seals were culled they were subsisting mainly on the fledglings. Other prey items of these seals included the rock lobster *Jasus lalandii* and the common octopus *Octopus vulgaris*.

It is only a small proportion of the Cape fur seal population that is feeding extensively on seabirds, almost exclusively males and mostly subadult bulls (Chapter 5). This means that it may be possible to manage the mortality of seabirds caused by seals through culling those animals that are responsible for the mortality (Chapter 8). It is possible that older bulls may be teaching younger males to hunt seabirds, and hoped that the removal of such specialist feeders may greatly reduce the habit. The fact that only a limited portion of the Cape fur seal population is feeding on seabirds means that indiscriminate culling of seals is unlikely to have immediate benefit for seabirds and highlights the need to understand the nature of the interaction. The hunting behaviour of seals feeding on seabirds is described in Chapter 7. Most of the mortality on seabirds is inflicted in close proximity to islands, further increasing the probability of this form of control reducing seabird mortality. However, feeding by seals on seabirds is a behaviour that is likely to be relearnt and may need ongoing control.

Environmental change has recently caused a substantial eastward displacement off South Africa of two of the prey species of Cape fur seals: sardine *Sardinops sagax* and anchovy *Engraulis encrasicolus* (Fairweather *et al*. 2006, Roy *et al*. 2007, Coetzee *et al*. 2008). The subsequent reduction in prey off South Africa's west coast may have been partially responsible for the recent increase in numbers of seabirds being killed by seals in this region, and in the particular the sudden increase in attacks ashore. That food recently became scarce in the north and central portions of the Western Cape, is suggested by several observations for seabirds that feed preferentially on sardine and anchovy. In 2005, Cape gannets in the Western Cape, which then fed primarily on low-energy fishery discards, had a higher foraging effort and exploited a greater area than those in the Eastern Cape, which fed mainly on sardine and anchovy (Pichegru *et al.* 2007). At Malgas Island, measured breeding success for Cape gannets was very low (0.02 chicks per pair) in the 2005/06 breeding season (Grémillet *et al.* 2008). In the same season, all gannets at the Lambert's Bay colony abandoned breeding at an early stage (Crawford *et al*. 2007a). At Robben Island, survival of adult African penguins decreased after 2004 (Crawford *et al.* 2008a).

In South Africa, the displacement of seabirds by seals from breeding sites has hitherto been controlled by non-lethal interventions such as the construction of walls (Shaughnessy 1980) and seal-disturbance programmes that have caused seals to relocate to other localities (Crawford *et al.* 1999, Crawford *et al.* 2001). Another possible intervention is the creation of a temporary electrical barrier between seals and seabirds, which may also prevent seals chasing seabirds on land, a relatively new behaviour for Cape fur seals (Wolfaardt and Williams 2006). Should it be wished to control growth of the Cape fur seal population, the use of contraceptives, rather than lethal methods, may be considered. Such techniques have been successfully applied on lions *Panthera leo* in Etosha National Park, Namibia (Seal 1989).

In order better to manage adverse interactions between seals and seabirds in southern Africa, more information is required on predation of seabirds by seals. For example, at Dyer Island observations were not conducted throughout a year so that mortality of

African penguins attributable to seals may be underestimated (Chapter 3). At several other localities only sketcky information has been gathered (Chapter 4). More information is also needed on seabird demography, e.g. breeding success of Cape cormorants (Chapter 3), in order to model sustainability of predation rates. Further, although observations on a decrease in the average age of seals killing seabirds at Malgas Island has led to formulation of the hypothesis that this behaviour is taught by older males to younger seals, this needs to be tested by continuing observations on numbers and ages of seals killing seabirds around Malgas Island.

Although Cape fur seals are at present abundant in the Benguela ecosystem, it should be borne in mind that this was not the case a century ago, and natural decreases in seals may occur. There have been several suggestions that the structure of the Benguela ecoststem has changed (e.g. Lynam *et al*. 2006, Crawford *et al*. 2007b) and climate change may further alter its functioning (Crawford *et al*. 2008b).

REFERENCES

Barnes KN (2000) *The Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland*. BirdLife South Africa, Johannesburg

Best PB, Crawford RJM, Van der Elst RP (1997) Top predators in southern Africa's marine ecosystems. *Transactions of the Royal Society of South Africa* **52**: 177–225

Bester MN, Ryan PG, Dyer BM (2003) Population numbers of fur seals at Prince Edward Island, Southern Ocean. *African Journal of Marine Science* **25**: 549–554

BirdLife International (2000) *Threatened Birds of the World*. Lynx Edicions and BirdLife International. Barcelona and Cambridge, U.K

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

Coetzee JC**,** van der Lingen CD, Hutchings 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

Cooper J (1974) The predators of the jackass penguin *Spheniscus demersus*. *Bulletin British Ornithological Club* **94**: 21–24

Crawford RJM, Cooper J (1996) Cape fur seal *Arctocephalus pusillus* catches Cape gannet *Morus capensis* ashore at Malgas Island. *Marine Ornithology* **24**: 53–54

Crawford RJM, Cooper J (2003) Conserving surface-nesting seabirds at the Prince Edward Islands: the roles of research, monitoring and legislation*. African Journal of Marine Science* **25**: 415–426

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

Crawford RJM, David JHM, Shannon LJ, Kemper J, Klages NTW, Roux J-P, Underhill LG, Ward VL, Williams AJ, Wolfaardt AC (2001) African penguins as predators and prey – coping (or not) with change. *South African Journal of Marine Science* **23**: 435–447

Crawford RJM, Dundee BL, Dyer BM, Klages NTW, Meÿer MA, Upfold L (2007a) Trends in numbers of Cape gannets (*Morus capensis*), 1956/57–2005/06, with a consideration of the influence of food and other factors. *ICES Journal of Marine Science* **64**: 169–177

Crawford RJM, Dyer BM, Cordes I, Williams AJ (1999) Seasonal pattern of breeding, population trend and conservation status of Bank Cormorants *Phalacrocorax neglectus* off southwestern Africa. *Biological Conservation* **87**(1): 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**: 171–184

Crawford RJM, Shannon LV, Pollock DE (1987) The Benguela ecosystem. Part IV. The major fish and invertebrate resources. *Oceanography and Marine Biology Annual Review* **25**: 353–505

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**(1): 189–193

Crawford RJM, Underhill LG, Raubenheimer CM, Dyer BM, Martin J (1992) Top predators in the Benguela ecosystem – implications of their trophic position. *South African Journal of Marine Science* **12**: 675–687

Crawford RJM, Underhill LG, Upfold L, Dyer BM 2007. An altered carrying capacity of the Benguela upwelling system for African Penguins (*Spheniscus demersus*). In: Kirkman SP (ed) *Final report of BCLME (Benguela Current Large Marine Ecosystem) project on Top Predators as Biological Indicators of Ecosystem Change in the BCLME*. Avian Demography Unit, Cape Town, pp 251-257

Croll DA, Tershy BR (1998) Penguins, fur seals, and fishing: prey requirements and potential competition in the South Shetland Islands, Antarctica. *Polar Biology* **19**: 365–374

David JHM (1987) South African fur seals *Arctocephalus pusillus pusillus.* In: Croxall JP, Gentry RL (eds) *Status, Biology and Ecology of Fur Seals. NOAA Technical Report, National Marine Fisheries Service* **51**: 65–71

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

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

du Toit M, Bartlett PA, Bester MN, Roux J-P (2004) Seal-seabird predation at Ichaboe Island, Namibia: prey selection by individual seals. *South 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

Grémillet D, Pichegru L, Kuntz G, Woakes AG, Wilkinson S, Crawford RJM, Ryan PG (2008) A junk-food hypothesis for gannets feeding on fishery waste. *Proceedings of the Royal Society, London Biological Series* **18**: 1–8

Hockey PAR, Dean WRJ, Ryan PG (2005) *Roberts Birds of Southern Africa* (7th edn). John Voelcker Bird Book Fund, Cape Town, 1296pp

Hofmeyr GJG, Bester MN (1993) Predation on king penguins by Antarctic fur seals. *South African Journal of Antarctic Research* **23**: 71–74

Hofmeyr GJG, Bester MN (2002) Entanglement of pinnipeds at Marion Island. *South African Journal of Marine Science* **24**: 383–386

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

Lynam CP, Gibbons MJ, Axelsen BE, Sparks CA, Coetzee J, Heywood BG, Brierley AS. (2006) Jellyfish overtake fish in a heavily fished ecosystem. *Current Biology* **16**: 492-493

Marks MA, Brooke RK, Gildenhuys AM (1997) Cape fur seal *Arctocephalus pusillus* predation on Cape cormorants *Phalacrocorax capensis* and other birds at Dyer Island, South Africa. *Marine Ornithology* **25**: 9–12

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

Navarro RA (2000) Cape fur seal predation on Cape gannet fledglings. *Bird Numbers* **9**(2): 15–16

Pichegru L, Ryan PG, van der Lingen CD, Coetzee J, Ropert-Coudert Y, Grémillet D (2007) Foraging behaviour and energetics of Cape gannets *Morus capensis* feeding on live prey and fishery discards in the Benguela upwelling system. *Marine Ecology Progress Series* **350**: 127–126

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

Rebelo AG (1984) Cape fur seal *Arctocephalus pusillus* kills jackass penguin *Spheniscus demersus* on land. *Cormorant* **12**: 111

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

Ryan PG, Cooper J, Dyer BM, Underhill LG, Crawford RJM, Bester MN (2003) Counts of surface-nesting seabirds breeding at Subantarctic Prince Edward Island, summer 2001/02. *African Journal of Marine Science* **25**: 441–451

Seal US (1989) Fertility control as a tool for regulation of wildlife populations. *Eastern Wildlife Damage Control Conferences. Fourth Eastern Wildlife Damage Control Conference*. University of Nebraska, Lincoln

Shaughnessy PD (1978) Cape fur seals preying on seabirds. *Cormorant* **5**: 31

Shaughnessy PD (1980) Influence of Cape fur seals on jackass penguin numbers at Sinclair Island. *South African Journal of Wildlife Research* **10**: 18–21

Ward VL, Williams AJ (2004) Coastal killers: causes of seabird mortality. *Bird Numbers* **13**(1): 14–17

Wolfaardt A, Williams AJ (2006) Sealed off: predation threatens seabirds and tourism. *Africa – Birds & Birding* **11**(2): 61–67