THE ZOOGEOGRAPHY OF THE CETACEANS IN ALGOA BAY

A thesis submitted in fulfilment
of the requirements for the degree of

MASTER OF SCIENCE
of
RHODES UNIVERSITY

by

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January 2011

ABSTRACT

The most recent study on cetaceans in Algoa Bay, South Africa, was conducted over 14 years ago. Consequently, knowledge of the cetacean species visiting this bay is currently based on incidental observations and stranding data. A number of developments in recent years: a deep-water port, proposed oil refinery, increased boating and fishing (commercial and recreational), a proposed Marine Protected Area, and the release of a whale-watching permit, all of which may impact these animals in some way, highlight the need for a baseline study on cetaceans. Therefore, the aim of this study was to determine the spatial and temporal distribution, and habitat preference of cetaceans in Algoa Bay. Boat-based surveys were conducted monthly between March 2009 and July 2010. At each sighting the GPS location, species, group size and composition, and behaviour were recorded. Using GIS, the sighting data was related to data layers of geographical variables such as sea surface temperature, depth and sea-floor substrate.

Approximately 365 hours of search effort were completed over 57 surveys, with a total of 346 sightings. Species observed were: southern right whales (*Eubalaena australis*), humpback whales (*Megaptera novaeangliae*), Bryde's whales (*Balaenoptera brydei*), Indian Ocean bottlenose dolphins (*Tursiops aduncus*), Indo-Pacific humpback dolphins (*Sousa chinensis*), and long-beaked common dolphins (*Delphinus capensis*). Southern right whales were observed during austral winter, utilising the shallow, protected areas of the bay as a mating and nursery ground. Humpback whales were also recorded extensively during winter, in more offshore waters, with a significant number of mother-calf pairs sighted. Bryde's whales were recorded in offshore waters during summer and autumn, where they were primarily observed travelling and foraging. Bottlenose dolphins were the most prolific species sighted. They were recorded year-round throughout the inshore waters of the bay, with large group sizes (up to 500 animals), and displayed a wide variety of behaviours. Humpback dolphins were observed in extremely shallow

and inshore waters (mean bottom depth of 6.6 m) along the south-west corner of the bay, in small groups of approximately three individuals. Common dolphins were the least observed species, and were mainly observed foraging in large groups of up to 800 individuals.

The results of this study indicate how cetaceans utilise the bay in significantly different ways. Geographical and anthropogenic factors have influenced the spatial and temporal distribution of these animals and have resulted in habitat preferences, as well as potential key habitats, in the bay Thus, this study has provided baseline information for future research and for better informed conservation and management strategies in Algoa Bay.

DECLARATION

The data obtained in this research was carried out under the auspices of a three year project on the spatial and temporal distribution of cetaceans in Algoa Bay run by Dr Stephanie Plön. The work presented in this thesis was carried out between February 2009 and January 2011, under the supervision of Ms Gillian McGregor (Geography Department, Rhodes University), in fulfilment of the academic requirements for the degree of Master of Science in Geography. This study represents original work by the author and is in accordance with the Rhodes University plagiarism policy.

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ACKNOWLEDGEMENTS

I would like to thank Marine and Coastal Management and the South African Environmental Observation Network (SAEON) for financial and logistical support. I am also grateful for the personal funding from the National Research Foundation (NRF) and the Andrew Mellon Scholarship. Thanks also to Rhodes University and the European Cetacean Society (ECS) for providing funding to present at a conference in Stralsund, Germany. I am grateful to PE Museum/ Bayworld for providing a base from which to conduct fieldwork. I would also like to thank the South African National Hydrographic Office (SANHO), the South African Weather Service (SAWS) and South African National Parks (SAN Parks) for access to data.

To Gillian McGregor, my supervisor, I am extremely grateful for your continued support, encouragement and constructive criticism throughout my masters. I really appreciate everything you have done for me, and for always believing in me. I would like to extend my gratitude to Dr Stephanie Plön for designing this project and taking me on as a student during the fieldwork phase of this research. I would like to thank Dr Angus Paterson for his input, logistical support, and guidance throughout the project. To Morven Maclean, who skippered and towed the boat when an extra hand was needed, thank you for your assistance. I am grateful to Dot Pitman for always going an extra mile to help me find valuable resources during my research. To the many, many volunteers who assisted on the cetacean surveys, thank you for all your help and your smiling faces early in the morning, and for enduring the long (and sometimes cold and wet) boat days.

I am grateful to everyone who has contributed to the final stages of this dissertation, especially Prof. Tony Booth for his help in the statistical analyses. I would also like to thank Leanne Kelly for her input and advice. To all the staff and students in the Rhodes University Geography Department, thank you for your input and assistance over these years, I really appreciate it.

To my parents and family, thank you for always supporting my many different endeavours and for encouraging me to pursue my dreams, I am deeply grateful. To my Grahamstown and PE friends - thank you for always supporting me and for constantly challenging me, I am incredibly privileged to know so many wonderful people. I would especially like to mention Shan Ambrose, Pearl Mzobe, Tarryn Govoni and Riana van der Sandt, I sincerely value your friendship and support. Finally, my greatest thanks go to my Father in Heaven for creating such an incredibly beautiful world, and for allowing me the privilege of learning more about it.

ACRONYMS

ANOVA	Analysis of Variance
CES	Coastal and Environmental Services
Coega IDZ	Coega Industrial Development Zone
Cos	Mathematical function 'cosine'
ESRI	Environmental Systems Research Institute
GAENP	Greater Addo Elephant National Park
GAMs	Generalised Additive Models
GIS	Geographical Information Systems
IUCN	International Union for the Conservation of Nature
IWC	International Whaling Commission
kn	Knots
KZN	Kwa-Zulu Natal
MPA	Marine Protected Area
n.d.	No date
nm	Nautical mile
NMBM	Nelson Mandela Bay Municipality
PE Port	Port Elizabeth Port
SAEON	South African Environmental Observation Network
SAGs	Surface active groups
SANHO	South African National Hydrographic Office
SAN Parks	South African National Parks
SAWS	South African Weather Service
Sin	Mathematical function 'sine'
SPUE	Sightings per unit (100 km) effort
STEP	Science, Technology and Environment Programme
χ^2	Chi-squared

"The scientist does not study nature because it is useful;

He studies it because he delights in it,

and he delights in it because it is beautiful"

~ Henri Poncaré ~

Humpback whale breaching in Algoa Bay. *Photo: B. Melly.*

CHAPTER 1: GENERAL INTRODUCTION

1.1. INTRODUCTION

This chapter provides an introduction to the research conducted on the cetaceans in Algoa Bay between March 2009 and July 2010. A brief overview of the study site and motivation for this research will precede the establishment of the aims and objectives. A synopsis of the methodological approach to the study will be addressed before concluding with an outline of the structure of this dissertation.

1.2. SUMMARY OF THE STUDY SITE: ALGOA BAY

Algoa Bay is a large (3 100 km^2), moderately exposed bay off the south-east coast of South Africa, with a coastline length of approximately 135 km between two headlands, Cape Recife and Cape Padrone (see Chapter Three for a detailed map). The Sundays, Swartkops and Coega Rivers are the three major rivers, all entering the western half of the bay.

Port Elizabeth city and the port are situated on the south-west corner of Algoa Bay, one of two major developed areas bordering the bay. The second developed area is the Coega Industrial Development Zone (IDZ) and newly constructed deep-water Ngqura (Coega) Port situated 20 km north of Port Elizabeth Port (PE Port). These two ports are used extensively for both recreational and commercial purposes.

Three marine conservation zones are also situated in the bay. They are comprised of the Bird Island and St Croix Island groups which are Marine Protected Areas (MPAs), and the larger proposed greater Addo Elephant National Park (GAENP) MPA situated between Coega Port and the Bird Island group. These conservation zones and the developed areas highlight some of the contrasting needs and uses of Algoa Bay, which are discussed in detail in Chapter Three.

1.3. MOTIVATION

On a global scale, some cetacean stocks are vastly below their original numbers due to historical whaling (Friedmann and Daly, 2004). The IUCN and the Red Data List status of South Africa notes that a number of cetacean species found off the South African coastline are currently considered as 'threatened', 'vulnerable', 'endangered' or 'data deficient' (Friedmann and Daly, 2004; Hammond *et al.*, 2008a; Hammond *et al.*, 2008b; Reeves *et al.*, 2008; Reilly *et al.*, 2008a). This includes the cetaceans found in the Algoa Bay region, illustrating the need for further research on these species.

Globally, there are a variety of threats likely to face cetacean populations in the near future, which have been described in detail by several authors (see: Richardson *et al.*, 1995; Nowacek *et al.*, 2007; Simmonds and Isaac, 2007; MacLeod, 2009). In Algoa Bay, these threats include: increased shipping traffic from the Coega development, which will be fully operational in the next five years, ship strikes (collisions with vessels), entanglement in fishing gear, the associated risks with offshore oil and gas development, coastal pollution (industrial and urban sources), a rise in recreational boating (particularly powerboats and jet skis), the destruction or alteration of coastal habitats, overfishing and climate change (Klinowska, 1991; Best *et al.*, 2001a; Friedmann and Daly, 2004).

Recently there has been increased interest in boat-based whale watching in Algoa Bay, with a permit set to be released in 2010/ 2011 (Government Gazette, 2009a; Government Gazette, 2009b). Worldwide, whale-watching is on the increase, however, little is presently known about the short- or long-term effects of this activity on cetaceans (Wilson *et al.*, 1997; Constantine *et al.*, 2004; Hoyt, 2005; Bejder *et al.*, 2006). A long-term study by Bejder *et al*. (2006), illustrated that the primary contributor to the decline in dolphin abundance in Shark Bay, Australia, was associated with harassment by vessels, and that future management decisions need to take into account these well-documented long-term studies in order to maintain healthy cetacean populations.

The proposed MPA, which would form part of the GAENP owned by SAN Parks (Coastal and Environmental Services, n.d.), requires baseline information on which cetaceans visit MPAs, and their distribution patterns and habitat preference, as it affects how the MPAs will be controlled and managed in the future (Hooker *et al.*, 1999; Cañadas *et al.*, 2005). Determining which species utilise the MPA may assist in elucidating potential threats to the biodiversity. These need to be determined as cetaceans are considered to be an important indicator of ecosystem health, which is required to be at a high level in and around the MPAs (Bowen, 1997; Hooker and Gerber, 2004; Cañadas *et al.*, 2005).

The most recent study on cetaceans in Algoa Bay was conducted over 14 years ago by Karczmarski (1996) on humpback and bottlenose dolphins. Thus, most current knowledge of the cetacean species visiting the bay is based on incidental observations and stranding data (discussed further in Chapter Two). This deficiency in research has resulted in a lack of data pertaining to the distributional patterns of cetaceans in the region. Many anthropogenic and biological factors impact the abiotic and biotic components of this marine ecosystem, and these impacts are expected to increase in the near future, stressing the importance of conducting a baseline survey of these keystone species.

1.4. AIM

The aim of this research is to determine the spatial and temporal distribution and habitat preference, of the cetaceans in Algoa Bay. This includes areas within and outside the proposed MPA. In addition, this study aims to relate this distribution to geographical parameters.

1.5. RESEARCH OBJECTIVES AND QUESTIONS

In order to achieve the aim of this thesis, five objectives were defined with their associated research questions (R.Q.), which are described below. The methods associated with these objectives are discussed in detail in Chapter Four.

Objective 1: To collect primary data on cetacean location, behaviour and other related geographical variables via different survey and opportunistic techniques.

> *R.Q. Which cetaceans are found in Algoa Bay?*

Objective 2: To acquire secondary spatial and non-spatial data on geographical and anthropogenic variables.

> *R.Q. Can various geographical and anthropogenic variables be used to explain cetacean distribution (in objective four)?*

Objective 3: To determine the spatial and temporal distribution and behaviour of the different cetacean species in Algoa Bay.

R.Q. Where (spatial) and when (temporal) are cetaceans located in Algoa Bay?
R.Q. Where are key behaviours observed, and do the behaviours of the animals help explain cetacean distribution?

Objective 4: To relate the spatial and temporal distribution and behaviour of cetaceans to the geographical and anthropogenic variables determined in objective two.

R.Q. Are there associations between cetacean distribution and the surrounding geographical and anthropogenic variables, identified in objective two?
R.Q. Are there potential key habitats for each of the cetacean species in Algoa Bay?

Objective 5: To produce a set of recommendations and guidelines, using the maps and information produced, for improved management, conservation and research.

R.Q. How can the outcomes of this research be used to form a baseline for future research, conservation and development strategies?

1.6. RESEARCH DESIGN AND METHODS

The processes that were employed in this dissertation are summarised in Figure 1.1. A variety of methods were used to meet the different objectives of this study. A literature review formed the foundation of this research in order to determine appropriate aims and objectives, as well as the choice of methods used to collect the data produced (Figure 1.1). Data was obtained quantitatively through dedicated boat-based surveys and opportunistic sightings, with additional environmental data collected from secondary sources. Various spatial and statistical analyses were performed on the data, after which the results were discussed and compared to other relevant studies, using the literature acquired in the review.

The marked growth in information technology over the last two decades has resulted in the development of new graphical and statistical techniques. More recently, the integration of GIS tools and environmental models has improved the analysis of species distributions in relation to the environment, and thus made a significant contribution to the field of applied ecology and biogeography. An understanding of the effectiveness of these tools and the need for baseline data on cetaceans in the Algoa Bay region, has led to the formation of the aim and objectives for this study. A detailed explanation of these methods used in this research is described in Chapter Four.

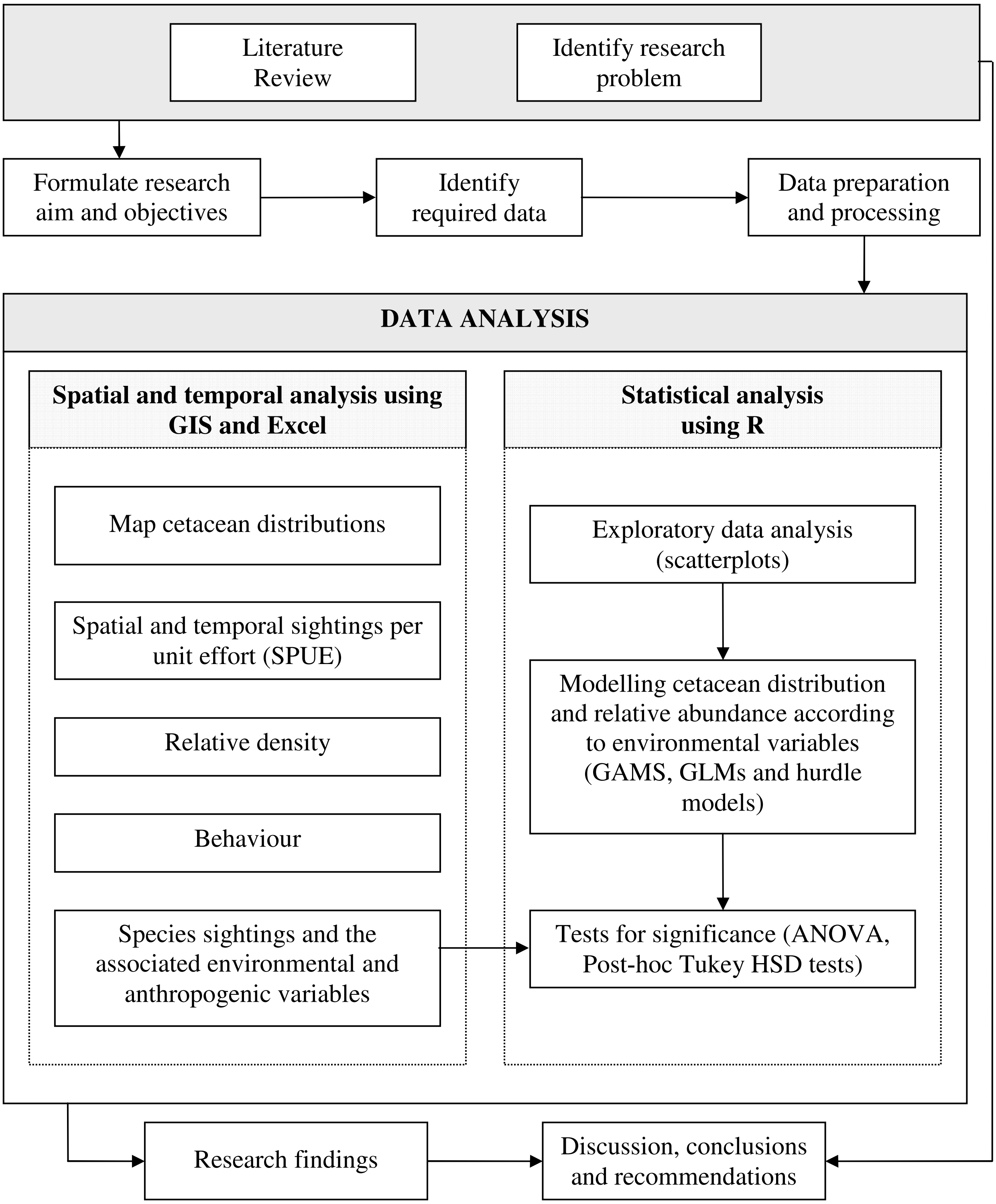

Figure 1.1. Research design.

1.7. THESIS OUTLINE

Chapter One provides an introduction to the study by establishing the context and rationale of this research. It ends with the aims, objectives, and the research questions, which form the base of the research matrix from which this study is designed.

Chapter Two provides a review of literature pertaining to the theoretical framework of this thesis. Included in this chapter is an examination of studies that have contributed to the methodological approach of this dissertation. An overview of some of the cetacean species previously recorded in the Algoa Bay region is also provided.

An overview of the geographical, hydrological and biological features of the study area, are outlined in Chapter Three. In order to establish the context of this study, the overall weather patterns and several development and conservation strategies in Algoa Bay are also discussed.

Chapter Four presents a detailed examination of the methods used to achieve the aforementioned objectives. It expounds on the methodology behind the chosen procedures for data acquisition, and describes how this data was processed and analysed using the relevant tools for spatial and statistical data analysis.

Chapter Five delineates the results of the analyses performed on the data obtained from this research. These results are presented in various formats, including tables, graphs and maps, thereby fully describing the spatial and temporal distribution and habitat preference of the cetaceans in Algoa Bay.

Chapter Six discusses the results of the spatial and temporal distribution of the cetaceans in Algoa Bay. These results were integrated with the theory detailed in Chapter Two, and the knowledge of the study area described in Chapter Three. This chapter concludes with an overview of the critical habitats for the cetaceans, and the implications for conservation and management.

Chapter Seven concludes this dissertation by providing a synthesis of the outcomes of this research, based on the aim and objectives established in Chapter One. Furthermore, it outlines the limitations of this study and provides recommendations for future research, conservation and management.

CHAPTER 2: LITERATURE REVIEW

2.1. INTRODUCTION

This chapter reviews the literature pertaining to the theoretical framework of this thesis. It begins by defining the concept of zoogeography and how it forms the basis of this study. The review then examines the role of cetaceans in their aquatic environment and the importance of defining this role through determining areas of high use (critical habitats) for each cetacean species. This research is also based on case studies of previous habitat studies and marine mammal surveys, outlined in this chapter. This review will outline how GIS has played a crucial role in increasing the understanding of the complex spatial and temporal relationships that cetaceans have with their marine environment. Current knowledge of the cetacean species studied in this research is also discussed towards the end of this chapter.

2.2. ZOOGEOGRAPHY

Explaining, quantifying and monitoring patterns in population distribution is a fundamental aspect of understanding a species' ecology in a particular environment (Evans and Hammond, 2004). Identifying and monitoring these changes is the essence of conservation research (Evans and Hammond, 2004). Patterns in the spatial and temporal distribution of animals enables scientists to determine whether there are areas of animal concentration in relation to various anthropogenic activities, that can form key focus areas for conservation efforts (Evans and Hammond, 2004). This forms the foundation for the field of zoogeography.

Zoogeography is a branch of the science of biogeography that is concerned with the geographic distribution of animal species (Brown and Lomolino, 1998). It studies the past, present and future patterns of animal distribution (and their attributes) in the natural environment and the processes that affect these distributions (Brown and Lomolino, 1998). Most geographical locations have information on the presence or absence of cetacean species, but a large gap still remains with regards to their basic biology, life history and distribution along much of the world's coastlines (Mignucci-Giannoni, 1998; Parra *et al.*, 2006). Algoa Bay in the Eastern Cape Province in South Africa is no exception, with four fundamental questions that need to be answered for this area:

Which cetacean species are found in the bay?
What is their spatial distribution?
What is their temporal distribution?
What environmental parameters determine their distribution?

This study will attempt to answer the first three questions, forming a basis from which the fourth question can be answered through defining critical habitats/ areas. These questions will be further examined in Chapters Four to Seven.

2.3. ROLE OF CETACEANS IN AQUATIC ECOSYSTEMS

Marine mammals are large and abundant in the oceans, living and feeding in almost every part of the aquatic environment from rivers, estuaries and continental shelves, to tropical and polar waters (Katona and Whitehead, 1988; Bowen, 1997). They interact with a wide variety of organisms in these different systems, playing an important role in the structure and function of various communities in the aquatic environment (Katona and Whitehead, 1988; Bowen, 1997).

Cetaceans are major consumers on most trophic levels (Bowen, 1997; Hoyt, 2005). Being long-lived, they can be used as indicators of ecosystem health and productivity, reflecting the effects of human and natural factors on lower trophic levels in the marine environment (Hooker and Gerber, 2004; Wells *et al.*, 2004). Cetaceans are also used as indicators due to the many feeding associations that exist between cetaceans and various bird and fish species (Katona and Whitehead, 1988). Their diverse role in the marine environment provides a context within which the impacts of environmental change (both anthropogenic and natural) can be understood at both large and small scales (Bowen, 1997; Hoyt, 2005).

These long-lived consumers can also influence prey dynamics through their responses to changes in prey density by fasting, migrating or changing their diet (Katona and Whitehead, 1988; Bowen, 1997). Where a substantial overlap occurs, this has resulted in competition between commercial fisheries and small cetaceans, with most studies indicating that the impact is felt more by cetaceans than fisheries (Sekiguchi *et al.*, 1992; Young, 2000; Kaschner *et al.*, 2006a). An example of this is the dramatic decrease in numbers of the formerly abundant common dolphin (*Delphinus delphis*) in the Mediterranean Sea as a result of the depletion of small pelagic fish stocks (Bearzi *et al.*, 2006).

The ecological role of cetaceans in aquatic ecosystems is still poorly understood despite the value of cetaceans to humans and the environment (Bowen, 1997). While some cetacean populations are recovering at rapid rates, others are becoming endangered or extinct (Van Blaricom, 2000). Thus, long-term, interdisciplinary research is required to cover a wide range of spatial and temporal scales, in order to fully understand their role in marine ecosystems (Wilson *et al.*, 1997; Bearzi *et al.*, 2009).

2.4. THE CONCEPT AND IMPORTANCE OF CRITICAL HABITATS

A home-range is the area used by an individual or population to perform various activities such as foraging, mating, breeding and calving (Shane *et al.*, 1986; Ingram and Rogan, 2002). There are vast differences in cetacean distribution patterns, with some populations resident within confined areas, and others, nomadic or migratory (Wilson *et al.*, 1997; Rowntree *et al.*, 2001; Campbell *et al.*, 2002). These differences are influenced by factors such as the biological requirements of a species and habitat heterogeneity, both of which determine patterns of distribution and use of critical habitats within the home range of a species (Ballance, 1992).

Interactions between cetaceans and their habitat are complex, and occur at various spatial and temporal scales, resulting in high spatial heterogeneity within their home-range (Kenney and Winn, 1986; Reilly, 1990; Allen *et al.*, 2001). This is influenced by geographic conditions such as SST, bottom depth, distance to land, tidal flow, currents, fronts, upwellings, salinity, chlorophyll, bottom substrate, and bottom topography; as well as anthropogenic disturbances including noise, pollution and shipping traffic (Smith *et al.*, 1986; Selzer and Payne, 1988; Richardson *et al.*, 1995; Mignucci-Giannoni, 1998; Davis *et al.*, 2002; Bräger *et al.*, 2003; Picanço *et al.*, 2009; Weir *et al.*, 2009). These geographical (physiographic and hydrographic) and anthropological features result in distinct core areas within their home-range (Davis *et al.*, 1998).

These core areas are known as critical habitats, which are defined as areas of high use or parts of an animal's range that are vital for survival and maintenance of a healthy population (Harwood, 2001; Ingram and Rogan, 2002; Hoyt, 2005). For cetaceans, examples of critical habitats are areas of high concentrations of prey for foraging, or where they avoid predation (Hanson and Defran, 1993; Keiper *et al.*, 2005; Sironi *et al.*, 2008). Areas where high concentrations of prey are located include regions where there are significant structural features such as steep gradients or complex topographies (shelf edges and continental slopes), which may increase the efficiency of prey detection through prey aggregation (Selzer and Payne, 1988; Baumgartner, 1997; Robinson *et al.*, 2009).

Areas where cetaceans perform important activities such as mating, calving, raising offspring, and resting, are also considered to be critical habitats (Elwen and Best, 2004; Lusseau and Higham, 2004; Stensland *et al.*, 2006). Migratory whale species use suitable habitats such as shallow protected bays and soft substrate, found in areas on the continental shelf along the South African coastline, for rearing their young (Best *et al.*, 2001a; Elwen and Best, 2004). Bays provide shelter from strong currents and greater protection from predators, enabling calves to utilise the energy obtained from suckling for growing, rather than moving, so that migration to the feeding grounds in the Antarctic region can happen as soon as possible (Thomas and Taber, 1984; Best and Rüther, 1992; Elwen and Best, 2004).

The identification and definition of a critical habitat is necessary for the establishment of spatially appropriate conservation plans which can be used to delineate marine protected areas (MPAs) (Hastie *et al.*, 2003; Cañadas *et al.*, 2005). As marine mammals have complex interactions within their environment, information needs to be collected continuously on cetacean distribution, at various scales, in order to design and manage effective MPAs (Hastie *et al.*, 2003). However, MPAs should protect an ecosystem rather than an individual species, and in theory, should take into account that boundaries in the marine environment are fluid and dynamic (Harwood, 2001; Hooker and Gerber, 2004).

Management strategies are dependent on both intensity of habitat use and location (Kenney and Winn, 1986; Ingram and Rogan, 2002). As each individual cetacean population uses various habitats within their range at different intensities, site-specific studies are necessary to determine habitat use before recommendations are made regarding coastal conservation and management (Kenney and Winn, 1986; Guinet *et al.*, 2001; Ingram and Rogan, 2002). Most marine management decisions are based on physiographic features as they are more stable over time. However, predator-prey interactions and other influences that key indicator species (such as cetaceans) have on their environment must also be taken into account, despite their temporal and spatial variability (Cañadas *et al.*, 2005; Robinson *et al.*, 2009).

Resources in the marine environment are patchy and largely hidden from view. Consequently, a population cannot necessarily move to a new area if an important habitat is being negatively impacted on by humans activities (Arthur *et al.*, 1996; Wilson *et al.*, 1997). For this reason, to understand the social structure and zoogeography of these fauna, and define critical habitats for conservation strategies and effective marine management (for example, the establishment of MPAs), these areas need to be identified, well defined and understood (Wilson *et al.*, 1997; Hastie *et al.*, 2003; Hoyt, 2005; Cañadas and Hammond, 2008).

2.5. REVIEW OF CETACEAN HABITAT STUDIES

Cetacean studies have used a variety of geographical and biological parameters to help define the habitat preferences of a species (Davis *et al.*, 1998; Baumgartner *et al.*, 2001). This includes the use of variables such as bottom depth, SST and prey distribution, to delineate distribution patterns and therefore the habitat preferences within a study area (Allen *et al.*, 2001; Cañadas *et al.*, 2002). Three examples of studies that have used geographical features to define cetacean distribution and habitats are outlined below.

A large-scale study conducted by Cañadas *et al*. (2002), illustrated the use of two variables, depth and slope, to describe cetacean distribution in the Mediterranean waters off southern Spain. The distribution of all the species studied varied significantly, and could be classified into two groups: deep water and shallow water species, with the dividing depth line at 600 m. This classification was used to determine which habitats were important for the common prey species consumed by each species in a group, and therefore, where the key feeding areas were located. This study formed a baseline from which other studies in the region could analyse cetacean distribution incorporating other variables, in order to create MPAs and protect vulnerable species in the area.

Elwen and Best (2004) hypothesised that several variables would be associated with the discontinuous distribution of southern right whale (*Eubalaena australis*) mother-calf pairs compared to unaccompanied whales off the south coast of South Africa. The variables tested included: water calmness, sea-floor sediment, water depth, distance to land and slope of the sea-floor. It was found that unaccompanied whales were found in significantly deeper waters and further offshore than mother-calf pairs, and that mother-calf pairs were generally found off sandy beaches in more protected areas (calm waters). Through clarifying what the key habitats of the mother-calf pairs consisted of, Elwen and Best (2004) were able to hypothesise the potential long-term benefits of these animals using such habitats, leading to more defined and directed future studies.

Weir *et al*. (2009) focused on three habitat parameters to determine the fine-scale habitat selection of white-beaked dolphins (*Lagenorhynchus albirostris*) and short-beaked common dolphins (*Delphinus delphis*) in the Minch, Scotland. Water depth, SST and distance to land, were used to determine whether habitat partitioning occurs between these two species in the study area. This study revealed that both species illustrated a degree of spatial overlap, however, common dolphins appeared to be more widely distributed, in more shallow waters and closer to land than the white-beaked dolphins.

Basing conservation measures, such as the establishment of MPAs, on geographical variables is more manageable and more easily defined compared to using biological variables (for example, prey distribution), as these geographical variables tend to fluctuate less over space and time (Cañadas *et al.*, 2002; Viddi *et al.*, 2010). These studies illustrate the applicability of using habitat parameters to define both fine- and broad-scale cetacean distribution patterns.

2.6. MARINE MAMMAL SURVEYS

Conducting surveys in the marine environment poses unique problems in both data capture and data analysis. In order to use the most appropriate survey technique, several factors need to be considered such as the project objectives and outcomes, the size of the study area, the location and conditions of the study area, and the amount of logistical and financial support available (Aragones *et al.*, 1997; Evans and Hammond, 2004; Dawson *et al.*, 2008).

There are three primary methods for conducting surveys on marine mammals: land-based surveys, aerial surveys and ship/ boat-based surveys (Aragones *et al.*, 1997). Land-based surveys use observation points on land to provide basic information on the biology and ecology of marine mammals visiting the coastal areas of a study site (Bristow *et al.*, 2001; Evans and Hammond, 2004). This method has proven successful in areas such as New Quay Bay, Wales, where shore-based monitoring methods were used to observe group size, group structure and site fidelity of bottlenose dolphins (*Tursiops truncatus*) (Bristow *et al.*, 2001). Conversely, this method is not applicable in study areas where large stretches of coastline are isolated, as is the case in Algoa Bay.

Aerial surveys use low-flying aircrafts to carry out rapid line-transects over large areas (Aragones *et al.*, 1997; Best, 2000). In South Africa, coastal aerial surveys were conducted 300 – 600 m offshore between Muizenberg and Woody Cape (on the south coast) to determine the coastal distribution, movements and site fidelity of southern right whales (Best, 2000). These aerial surveys yielded accurate information on population trends in the region (Best, 2000). However, this method is costly and requires strong logistical support (Aragones *et al.*, 1997).

Boat-based surveys allow for the investigation of spatial and temporal trends of a species, habitat use, the estimation of the relative abundance of a species (for long-term monitoring of population trends), and can also provide a platform for photo-identification studies (Aragones *et al.*, 1997). Many cetacean studies have successfully adopted this method for a wide-range of study areas which survey cetaceans (for example: Holt *et al.*, 1987; Barlow, 1995; Weir *et al.*, 2009; de Boer, 2010). However, there are several assumptions which are made when conducting these surveys, and they are also assumed in this study. These assumptions, described in detail by Aragones *et al.* (1997), Evans and Hammond (2004), Dawson *et al.* (2008) and Hammond (2009), are as follows:

1. All individuals/ groups are observed and accurately identified along a trackline
2. All individuals/ groups are observed only once within a survey and the animal does not move in response to the vessel before detection
3. Group size (and other variables) is measured or estimated accurately

There are large financial and logistical costs of performing equal-coverage sighting surveys (Dawson *et al.*, 2008). This, combined with the reality of conducting surveys where a good survey design was intended but not achieved, has lead to the development of spatial data analysis methods (see section 2.7) to overcome these problems (Dawson *et al.*, 2008; Hammond, 2009). Study areas which survey cetaceans using platforms of opportunity (Mignucci-Giannoni, 1998; Evans and Hammond, 2004), as well as areas where line transects were not possible but detailed environmental data were collected, have also applied similar methods of spatial analysis (for example: Cañadas *et al.*, 2005; Cañadas and Hammond, 2008; Dawson *et al.*, 2008). These methods include the development of spatial and statistical modelling, which have illustrated how the distribution and relative abundance of an individual is a function of the surrounding environmental conditions such as SST, bottom depth, sea-floor substrate, latitude and longitude (Evans and Hammond, 2004).

This research aims to use methods adapted from Cañadas *et al.* (2005), and Cañadas and Hammond (2008), where both used a non-systematic line-transect sampling method to conduct boat-based surveys. These studies collected sighting data and additional data on the physical and environmental features, such as depth and slope of the sea-floor. The study area was divided into grid cells, with a cell resolution of two minutes, and was used to correct sighting data with the amount of search effort carried out within each cell. These two papers demonstrate how GIS and spatial analysis techniques can be used to compensate for these aforementioned problems of using unequal coverage survey designs. Data generated in this manner may be used to implement appropriate conservation and management strategies.

2.7. APPLYING GIS IN MAPPING DISTRIBUTION PATTERNS

Spatial data analysis refers to the analytical methods applied to raw geographical data (such as sighting locations) in order to produce useful spatial information (Booth, 2004; Longley *et al.*, 2005). A key tool used to perform spatial data analysis is a geographic information system (GIS). GIS is a system of hardware, software and liveware that assembles, stores, manipulates and displays geographically referenced data (Longley *et al.*, 2005; Maguire *et al.*, 2005). GIS in the context of this research, was used to observe and examine the relationship between marine mammals and their environment by comparing animal locations and densities to both environmental variables (such as bottom depth and SST) and anthropogenic activities (Stensland *et al.*, 2006; Norman, 2008; Vigness-Raposa *et al.*, 2009). This helps to define distribution patterns and critical habitats, which ultimately leads to a better understanding of a species biogeography, in order to produce applicable and spatially appropriate marine management strategies and conservation measures (Stensland *et al.*, 2006; Norman, 2008). GIS is consequently useful in analysing and interpreting data from marine mammal surveys through elucidating information on the abundance, behaviour and distribution of a particular species (Nelson *et al.*, 2008; Nelson *et al.*, 2009). Examples of studies that have used GIS to examine the relationship between the spatial distribution of marine mammal species and the surrounding environment are outlined below.

de Stephanis *et al*. (2008) examined the spatial association between various cetacean species based on their distribution over several seasons and their link to a certain habitat type (bottom depth and slope). This research took place in the Straight of Gibraltar and used the distribution of sightings and the associated cetacean behaviour to define their habitats. Although this study defines the habitats well, it does not extend to a discussion of the significance of having well-defined habitats for management and conservation purposes.

Kaschner *et al*. (2006b) took a similar approach to de Stephanis *et al*. (2008) in determining the spatial association of cetacean species, to certain habitat types. However, this idea was developed further by qualitatively and quantitatively defining the habitats used by marine mammals based on several environmental parameters, to determine their distribution at a regional scale. This distribution was then further modelled using statistics, to review the species distribution at a global scale. This was done through creating habitat suitability models (using spatial modelling and GIS) that quantitatively determined the maximum range of a species, and predicted the distributions of various cetacean species. The application of this was to assist in re-evaluating existing assumptions and knowledge on a species distribution, which is needed for direction in future research and management decisions.

Parra *et al*. (2006) used GIS and several statistical tests to construct a spatial database for three bays off the northern section of the Great Barrier Reef in Australia. Three geographical layers were used and combined with the geo-referenced sighting data: the coastline, river mouths and bottom depth. The correlation between these three environmental features and the two cetacean species, the snubfin (*Orcaella heinsohni*) and Indo-Pacific humpback dolphins (*Sousa chinensis*) were analysed, thereby outlining suitable and important areas for these two populations. Distinct and workable critical areas for coastal and marine managers were defined to establish whether the existing protected areas in the region were sufficiently protecting the critical habitats of these two dolphin species.

A GIS study by Robinson *et al*. (2009), in the outer southern Moray Firth, north-east Scotland, revealed a strong spatial preference of minke whales (*Balaenoptera acutorostrata*) for various geographical parameters. Bottom depths between 20 and 50 m, steep slopes with a north-facing aspect, and sandy-gravel sediment were preferred by this species, illustrating a highly specific and non-uniform use of their habitat that varied significantly both spatially and temporally. These parameters therefore provided a reference for deriving suitable conservation measures.

GIS can also be used to manage the impacts of dolphin-based tourism through defining critical habitats as demonstrated in a study by Lusseau and Higham (2004). These critical habitats were areas mostly used for resting or socialising by bottlenose dolphins. They were used to design a multi-level marine mammal sanctuary in Doubtful Sound, New Zealand, that took into account the economic sustainability of tourism operations while still maximising the protection of the dolphins throughout the different seasons.

Despite the application of GIS and statistics in spatial data analysis, studies on marine mammals have only used these tools to a limited extent (Nelson et al., 2009; Booth, A.J., 2010: Pers. Comm.). Nonetheless, GIS and statistics can be useful in determining the relationship between cetaceans and their environment, where these variables tend to occur at different spatial and temporal scales, and can be both static and dynamic (Booth, 2004; Robinson *et al.*, 2009). The studies mentioned in this review have used GIS as a tool to indicate the strength of the relationship between the ecology of cetaceans (i.e. their distribution, abundance and behaviour), and the surrounding habitat. Thus, GIS provides a cost-effective approach to improved monitoring and conservation of the marine environment, through collecting and storing a wide range of environmental and species data (Hooker *et al.*, 1999; Parra *et al.*, 2006; Robinson *et al.*, 2009).

GIS is therefore ideally suited to integrating data on biotic and abiotic variables, and presenting the data in a format suitable for further analysis of these relationships. Thus, the present project will draw on the methods and viewpoints from the studies reviewed to examine the spatial and temporal distribution of the cetaceans in Algoa Bay. These research findings will establish whether there is a link between the species distribution patterns and various geographical parameters. This will be used to assist in defining key habitats.

2.8. OUTLINE OF CETACEA

2.8.1. Introduction

There are approximately 83 species of cetaceans worldwide, with 51 species found in the coastal waters off southern Africa (Rice, 1998; Best, 2007). This high diversity off southern Africa can be attributed to the unique oceanographic conditions, which gives rise to a wide variety of oceanic conditions in a relatively small region (Ross and Best, 1989; Reilly *et al.*, 1997; Best, 2007).

Several key authors have contributed to the understanding of the cetacean species which visit the Eastern Cape coastline of South Africa. This knowledge, combined with stranding data and anecdotal evidence collected from biologists, whaling statistics and incidental sightings, have contributed to the acknowledgment of six species which potentially utilise the inshore areas of Algoa Bay.

Aerial surveys in the 1980s and 1990s observed the status, trends and site fidelity of southern right whales off the southern Cape coastline (Best, 1990; Best, 2000). Inshore and offshore forms of Bryde's whales were also observed during this period (Best, 1977; Best *et al.*, 1984; Best, 2001). Dwarf minke whales have been observed in the inshore areas off the west and east coast of South Africa, with no direct observations off the south coast (Best, 1985; Best, 2007). However, this could be due to this species being easily confused with Bryde's whales which are similar in appearance (Best, 2007). Humpback whales are known to occur world-wide, with the winter breeding grounds occurring in lower latitudes such as Angola and Mozambique (Findlay *et al.*, 1994; Findlay and Best, 1995). This species has also been recorded in other areas of the sub-region, including South Africa, utilising the coastal waters as a migratory corridor from the Antarctic feeding grounds to their tropical breeding grounds (Findlay *et al.*, 1994; Best and Sekiguchi, 1996; Best, 2007).

More extensive research/ reviews have been done on the smaller cetaceans off the south-east coast of South Africa (Saayman *et al.*, 1972; Ross, 1984; Findlay *et al.*, 1992). Observations of bottlenose dolphins, humpback dolphins and common dolphins were recorded in Algoa Bay in a study by Saayman *et al*. (1972). The presence and knowledge of these species have since been updated by numerous reviewers since (see: Ross, 1984; Cockcroft and Ross, 1989; Ross *et al.*, 1989; Cockcroft and Peddemors, 1990; Findlay *et al.*, 1992; Best, 2007; Reisinger and Karczmarski, 2009).

There are many debates on the taxonomy of several cetacean species/ sub-species, including those that have been addressed in this study. This research relies on species descriptions by Ross (1984), Karczmarski (1996), and Best (2007). The following species descriptions summarise the present knowledge of the cetaceans located within the inshore areas of Algoa Bay. The identifiable features, habitat, ecology, range and population status are outlined for each of these species.

2.8.2. Mysticetes

Baleen whales are distinctive with their large mouths and body size (Würsig, 1989). They have long keratinous plates that extend from the upper jaw to filter out invertebrates from the water in order to feed (Würsig, 1989). Their diet mainly consists of euphausiid crustaceans (krill) and copepods, and they usually feed independently, with little or no group cooperation involved in prey capture (Würsig, 1989; Best, 2007). A thick blubber layer acts as a fat reserve, allowing these animals to undergo vast migrations from summer feeding grounds in the high latitudes to winter breeding grounds in the lower latitudes (Würsig, 1989).

With the exception of the southern right whale, the whale species observed in the coastal areas of the Eastern Cape are rorquals (Würsig, 1989; Best, 2007). Unlike the right whales, rorquals lunge for their prey (either below or at the water surface), ingesting krill and various small fish species (Würsig, 1989; Best, 2007). Presently, little is known about the behaviour and movements of this order, as most activity takes place at a range of depths (Würsig, 1989).

2.8.2.1. Southern right whale (*Eubalaena australis*)

Characteristic features

Southern right whales have an average length of 13.9 m (International Whaling Commission, 1986; Ross and Best, 1989; Best, 2007). Sexual maturity is reached between seven and nine years of age with a calving interval of three to four years (Payne *et al.*, 1990). These animals are distinguishable from other cetaceans by the lack of dorsal fin and the large wart-like callosities on their heads, forming a pattern unique to every individual (Plate 1) (Payne, 1986; Best, 2007).

Range

Southern right whales are found in circumpolar and temperate waters, extending towards the tropics with the warm ocean currents during austral summer (Figure 2.1) (Cummings, 1985a; Best, 2007; Belgrano *et al.*, 2008). These wintering grounds are used from June to December, with a peak in activity occurring during September/ October (Burnell and Bryden, 1997; Elwen and Best, 2004). In southern Africa, these whales have been observed from Baia dos Tigres in Angola to Maputo Bay in Mozambique, with the highest concentration on the southern coastline of South Africa, between Cape Town and Port Elizabeth (Best, 1990; Best *et al.*, 2003; Mate *et al.*, 2010). However, after the drastic population decline during the extensive whaling period, their range was more limited along the coastline, with southern right whales predominantly observed along the south coast of South Africa (Best, 2007; Belgrano *et al.*, 2008). With the significant population growth over the last three decades, this species has once again been expanding their range to their previously known limits (Best, 2007; Belgrano *et al.*, 2008).

Plate 2.1. The head of a southern right whale. *Photo: B.Melly.*

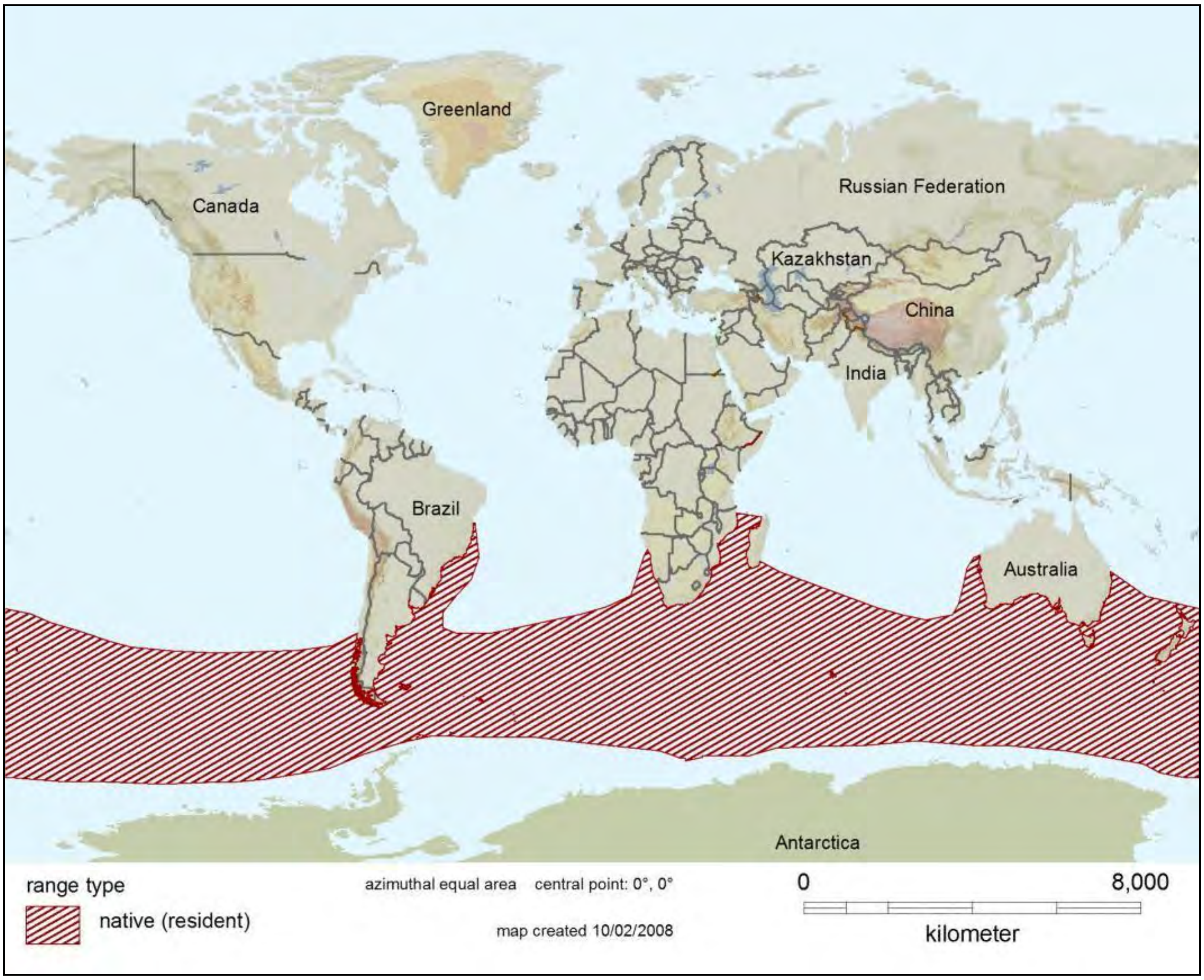

Figure 2.1. Worldwide distribution of the southern right whale (Reilly *et al.*, 2008b).

Habitat and ecology

The coastal regions of the southern continents, including South Africa, are used as breeding and calving grounds during austral winter (Cummings, 1985a; Burnell and Bryden, 1997). Off the coast of South Africa, southern right whales are found in groups of one to ten animals, with the nursery groups mostly comprised of mother-calf pairs (Best *et al.*, 2003; Patenaude, 2003; Costa *et al.*, 2005). These animals utilise shallow waters which are less than two kilometres from land, but occasionally have been observed further offshore (Payne, 1986; Best *et al.*, 2001b).

These coastal habitats are comprised of shallow, gently sloping bays sheltered from wind and swell, where females give birth and nurse their young (Thomas and Taber, 1984; Elwen and Best, 2004; Sironi *et al.*, 2008). Mating activities are generally observed in separate areas to these calving grounds (Payne, 1986; Patenaude, 2003; Elwen and Best, 2004). These mating activities are often classed as 'surface active groups' (SAGs), which consist of two to ten animals (with one focus animal that is generally a female) that perform various behaviours such as mating, exposing their bellies and flippers at the surface of the water, rolling, spyhopping and splashing (Best *et al.*, 2003; Patenaude, 2003; Best, 2007). Other behaviours associated with southern right whales in the coastal areas include breaching, and sailing (Cummings, 1985a).

Population status

The southern right whale population is estimated to be approximately 3100, with a population growth rate of 7% per year since 1971, they therefore have a national Red List status of 'least concern' (Friedmann and Daly, 2004; Reilly *et al.*, 2008b). Nevertheless, this population is only 10 to 20% of the estimated original population size off southern Africa (Best *et al.*, 2001a).

2.8.2.2. Humpback whale (*Megaptera novaeangliae*)

Characteristic features

Humpback whales grow to a maximum length of 15.2 m in females and 14.3 m in males, with their head comprising up to 30% of the length of the body (Best, 2007). These whales mature sexually between four and five years of age with a calving interval of approximately two years (Findlay *et al.*, 1994; Best *et al.*, 1999). Humpback whales have a characteristic dorsal fin situated two-thirds of the way down the back, towards the fluke, with the back arching in this area before a dive (Best, 2007). They have large, 'wing-like' flippers with white markings that are occasionally seen during surface activity. The trailing edge of the fluke is serrated with white and black markings on the ventral side that is often displayed before a dive (Winn and Reichley, 1985; Best, 2007). The head is rounded, with the surface of the rostrum encompassing a pattern of knob-like protuberances, apparent at a close range (Würsig, 1989; Findlay and Best, 1995).

Range

Humpback whales are a cosmopolitan species, migrating from the summer feeding grounds in the polar regions (up to 64^{o} S), to lower latitude breeding grounds in winter (Figure 2.2) (Jefferson and Schiro, 1997; Rice, 1998). Off southern Africa, the main breeding grounds are from Angola to Gabon on the west coast, to Mozambique and Tanzania on the east coast, as well as along the various islands that are located in this region (Findlay *et al.*, 1994; Rice, 1998; Best *et al.*, 1999; Barendse *et al.*, 2010).

Habitat and ecology

Humpback whales utilise both coastal and offshore areas (along the continental shelf) in their wintering grounds (Best *et al.*, 1998; Keiper *et al.*, 2005; Clapham, 2009). Contrastingly, mother-calf pairs are generally found in more sheltered and shallow areas along the coastline (Picanço *et al.*, 2009). Although mother-calf pairs are recorded along the South African coastline, this region is predominantly used as a migratory corridor, with most calving and mating occurring in the more tropical regions (Angola and Mozambique) (Dawbin, 1966; Best, 1994; Best, 2007). Births occur between July and October, and peak in August (Klinowska, 1991). Group sizes consist of an average of two individuals, but range from one to five animals (Best and Sekiguchi, 1996; Best, 2007). Social interactions and mother-calf pairs are found in approximately 25% of these groups (Best and Sekiguchi, 1996; Best, 2007).

This species uses either lunge-feeding or 'bubble-netting' to feed on euphausiids, amphipods, stomatopods, and krill in the sub-Antarctic (Winn and Reichley, 1985; Findlay and Best, 1995). Opportunistic feeding has also occasionally been observed along the west coast of South Africa (Findlay and Best, 1995; Best, 2007; Barendse *et al.*, 2010). Other behaviours in their wintering grounds include: spy hopping, breaching, fluking, tailslapping, flippering and lobtailing (Würsig, 1989; Clark and Clapham, 2004; Smith *et al.*, 2008).

Plate 2.2. Humpback whale breaching (Cape Padrone in background). *Photo: B. Melly.*

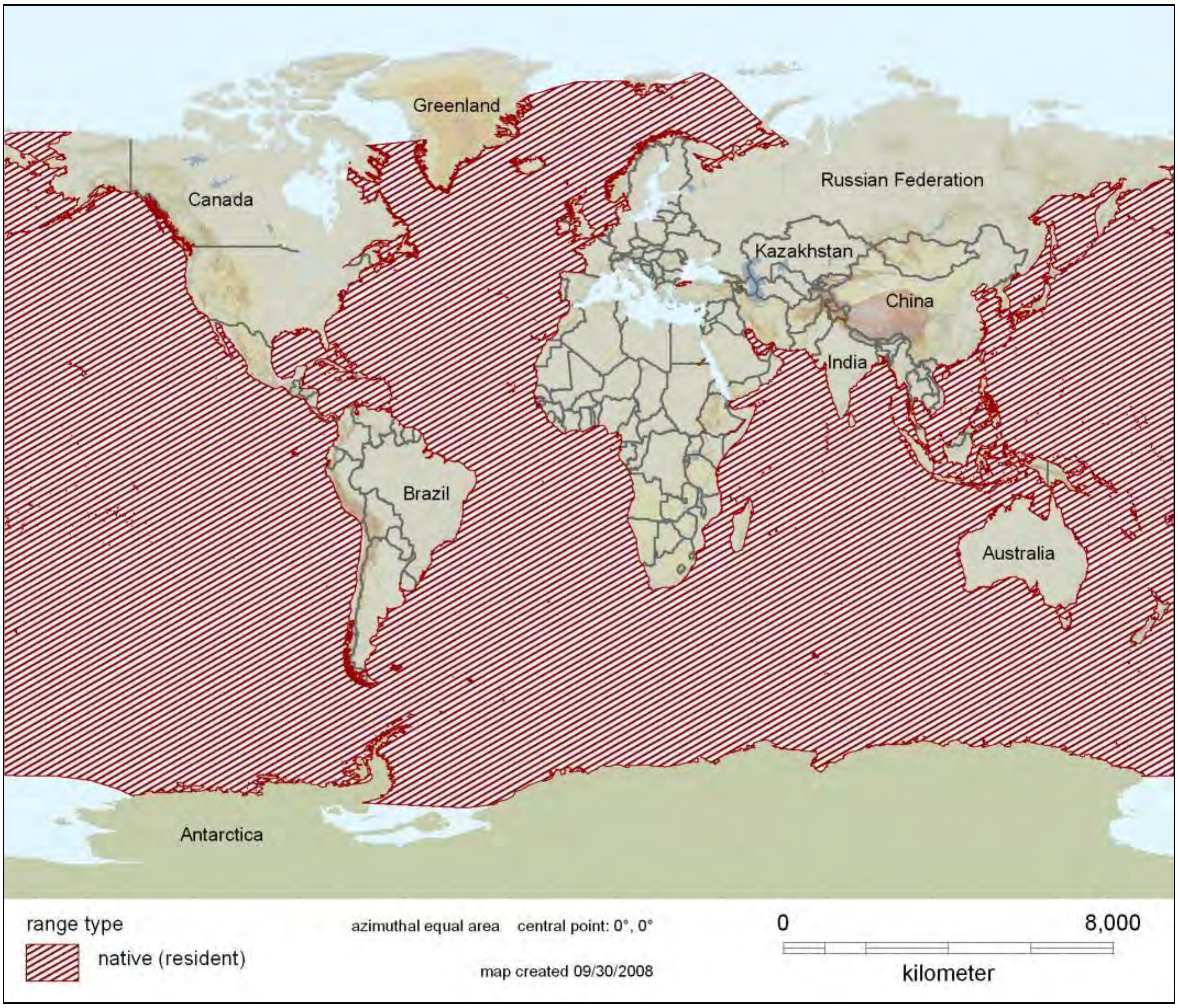

Figure 2.2. Worldwide distribution of the humpback whale (Reilly *et al.*, 2008c).

Population status

A survey off Mozambique in 2003 estimated a humpback whale population of over 5800 individuals along the east coast of South Africa, with a population increase of eight percent since 1990 (Best and Sekiguchi, 1996; Friedmann and Daly, 2004). Data along the west coast is insufficient for determining the population size or the species Red List status, but humpback whales are considered to be 'near threatened' in this region (Klinowska, 1991; Friedmann and Daly, 2004). However, they are listed as 'least concern' by the IUCN due to steadily increasing population numbers over the last few decades (Klinowska, 1991; Friedmann and Daly, 2004).

2.8.2.3. Bryde's whale (*Balaenoptera brydei*)

Characteristic features

Bryde's whales are similar in size and shape to sei whales and minke whales (Best, 2007; Kato and Perrin, 2009). The size of the inshore form of *B. brydei*, ranges from 13 to 15 m in length (Best *et al.*, 1984; Cummings, 1985b). The dorsal fin is falcate and situated two thirds along the back, but unlike the minke whale, this species has dark flippers and three parallel ridges running along the rostrum (Best, 1977; Best, 2007). Bryde's whales are counter-shaded with a grey-black dorsal and white ventral surface, with irregular white patterns on the dorsal surface of their body (Best, 1977; Best, 2007). Sexual maturity appears to occur at body lengths between 12 and 13 m (Best, 2007). However, knowledge of the breeding and calving cycles and locations for this species is limited (Best, 2007; Wiseman, 2008; Penry, 2010). These animals do not appear to show a marked seasonality in breeding, with conception occurring throughout the year (Omura, 1959; Best, 2007; Penry, 2010).

Range

Bryde's whales are a non-migratory, tropical and subtropical species, found worldwide (Figure 2.3) (Tershy *et al.*, 1990; Mullin *et al.*, 1994; Barlow, 2006). In southern Africa, three subpopulations exist, one of which is an inshore, resident population south of 30 ^{o}S occurring within 37 km of the coast (Best *et al.*, 1984; Best, 2001; Penry, 2010). Two offshore, migratory populations are found along the west coast of southern Africa and the south of Madagascar, possibly extending towards the Seychelles (Best, 2001; Friedmann and Daly, 2004).

Plate 2.3. Bryde's whale. *Photo: B. Melly.*

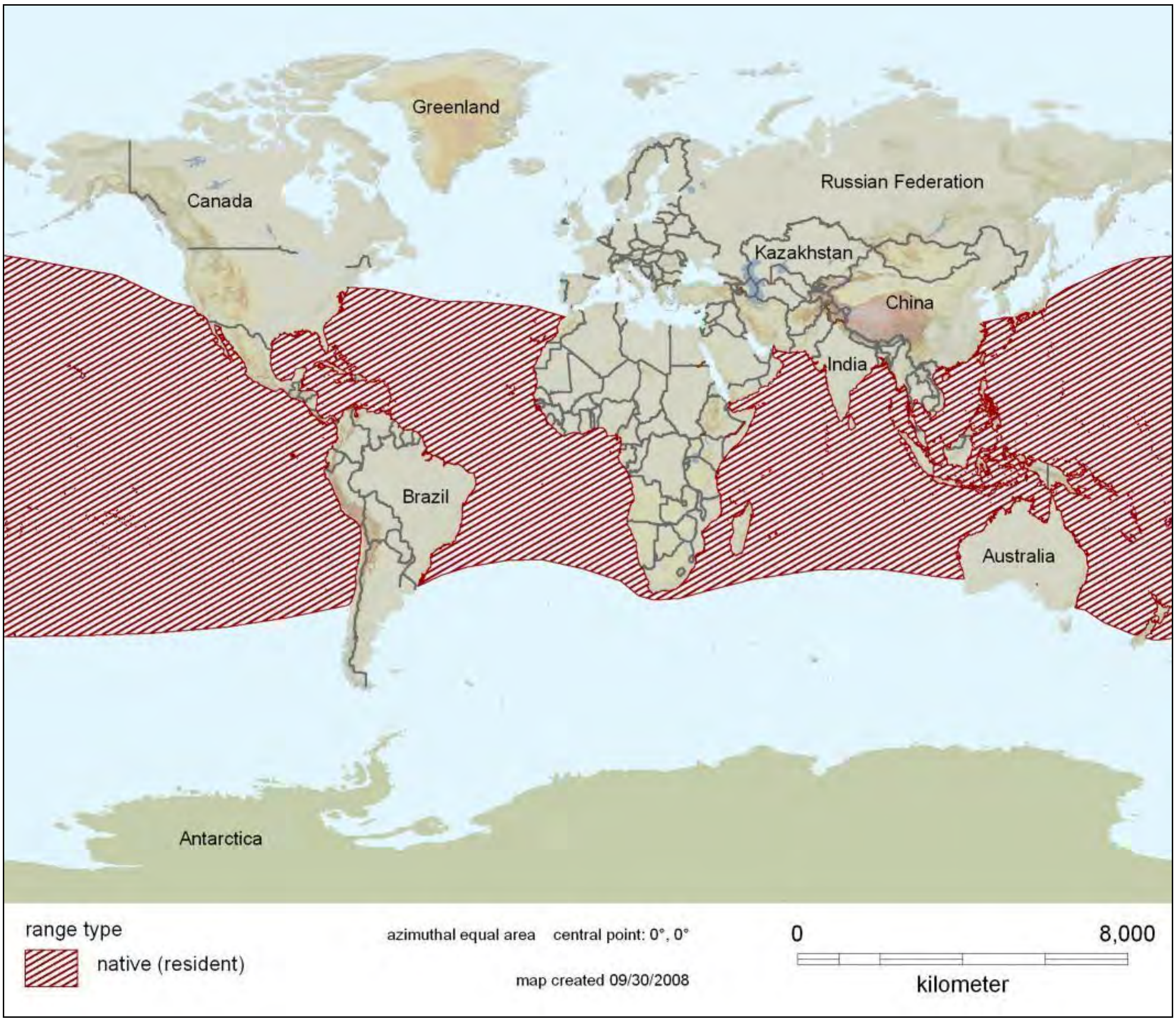

Figure 2.3. Worldwide range of Bryde's whales (Reilly *et al.*, 2008a).

Habitat and ecology

Little is known about the habitat preferences for this species (Best, 2007; Wiseman, 2008; Penry, 2010). Group sizes of Bryde's whales range from one to eight animals (O'Callaghan and Baker, 2002; Wiseman, 2008), but they have also been observed in groups as large as 100 individuals, usually in response to high prey densities (Best, 2001). Bryde's whales feed on pelagic fish, using vertical or lunge feeding, and often undergo small seasonal migrations to follow the movement of their prey (Cummings, 1985b; O'Callaghan and Baker, 2002). These animals also have a number of feeding associations with other marine animals such as gannets, dolphins, seals, penguins and gulls (Zerbini *et al.*, 1997; O'Callaghan and Baker, 2002; O'Donoghue *et al.*, 2010b).

Population status

Friedmann and Daly (2004) estimate an inshore Bryde's whale population of 519 off South Africa, which is similar to the estimate given by Best *et al.* (1984) of approximately 580 animals. Both approximations were thought to be underestimated due to many secondary sightings being omitted (Best, 2007). However, a recent study conducted on these animals suggests that the population size of these animals may be as small as 130 to 250 individuals (Penry, 2010).

The three Bryde's whale subpopulations appear to have little gene flow between them, and are therefore generally considered separately for management strategies (Best, 2007). The inshore stock are listed as 'vulnerable' based on the population being less then 1000 individuals, with the two offshore stocks being listed as 'data deficient' (Friedmann and Daly, 2004; Reilly *et al.*, 2008a). The population trend for all of the subpopulations is currently unknown (Friedmann and Daly, 2004).

2.8.3. Odontocetes

Odontocetes differ from mysticetes as they have a smaller body size and bear teeth (Best, 2007). Their diet consists of a much wider variety of prey, predominantly squid and different fish species (Saayman *et al.*, 1972; Klinowska, 1991; Best, 2007). Compared to mysticetes, odontocetes are limited more to coastal waters, with restricted habitats, and have much larger group sizes (Rice, 1998).

2.8.3.1. Indo-Pacific bottlenose dolphin (*Tursiops aduncus*)

Characteristic features

T. aduncus has a large dorsal fin and a dark dorsal region with dark spots on the belly on many individuals (absent in *T. truncatus*) (Ross, 1984; Best, 2007). Average lengths are 2.38 m in females and 2.43 m in males, with this form is being less robust and smaller than *T. truncatus* (Cockcroft and Ross, 1990; Mann *et al.*, 2000). Births occur primarily in summer and autumn and calving intervals range from 3 to 6.2 years (Saayman *et al.*, 1973; Cockcroft *et al.*, 1992).

Range

Bottlenose dolphins are cosmopolitan species, found in a wide range of habitats in both tropical and temperate waters world-wide (Weigle, 1990; Defran and Weller, 1999; Wang and Yang, 2009). Despite this species being well studied, their taxonomy is still unclear (Ross, 1977; Ross, 1984; Rice, 1998). The Indo-Pacific bottlenose dolphin (hereafter referred to as bottlenose dolphin) is found in the temperate and tropical waters of the Indian Ocean basin, extending from east Africa, along south and south-east Asia to Japan and Australia (Figure 2.4) (Findlay *et al.*, 1992; Fury and Harrison, 2008). In South Africa, these dolphins are found all along the coastline from Cape Agulhas to Mozambique (Fury and Harrison, 2008). A seasonal movement along the South African coastline is thought to occur with the annual Sardine Run drawing these dolphins towards Kwa-Zulu Natal (KZN) (Ross, 1984). Movements between Plettenberg Bay and Algoa Bay have also been observed (Saayman *et al.*, 1972; Cockcroft *et al.*, 1992).

Habitat and ecology

Bottlenose dolphins commonly occupy coastal waters less than 30 m deep (within one kilometre from land) (Fury and Harrison, 2008). However, they are also known to utilise a wider range of habitats including deep ocean basins, lagoons and estuaries (Ross, 1984; Best, 2007). This species lives in fission-fusion societies that are comprised of short-term acquaintances that last several hours to a few days (Lusseau *et al.*, 2006). Thus, group sizes vary significantly. These animals are usually seen in groups of around 40 dolphins, with larger group sizes of approximately 140 animals, having been reported in the Eastern Cape (Cockcroft and Ross, 1990; Klinowska, 1991).

Plate 2.4. Bottlenose dolphins leaping out the back of a wave (Alexandria Dunefield in background). *Photo: B. Melly.*

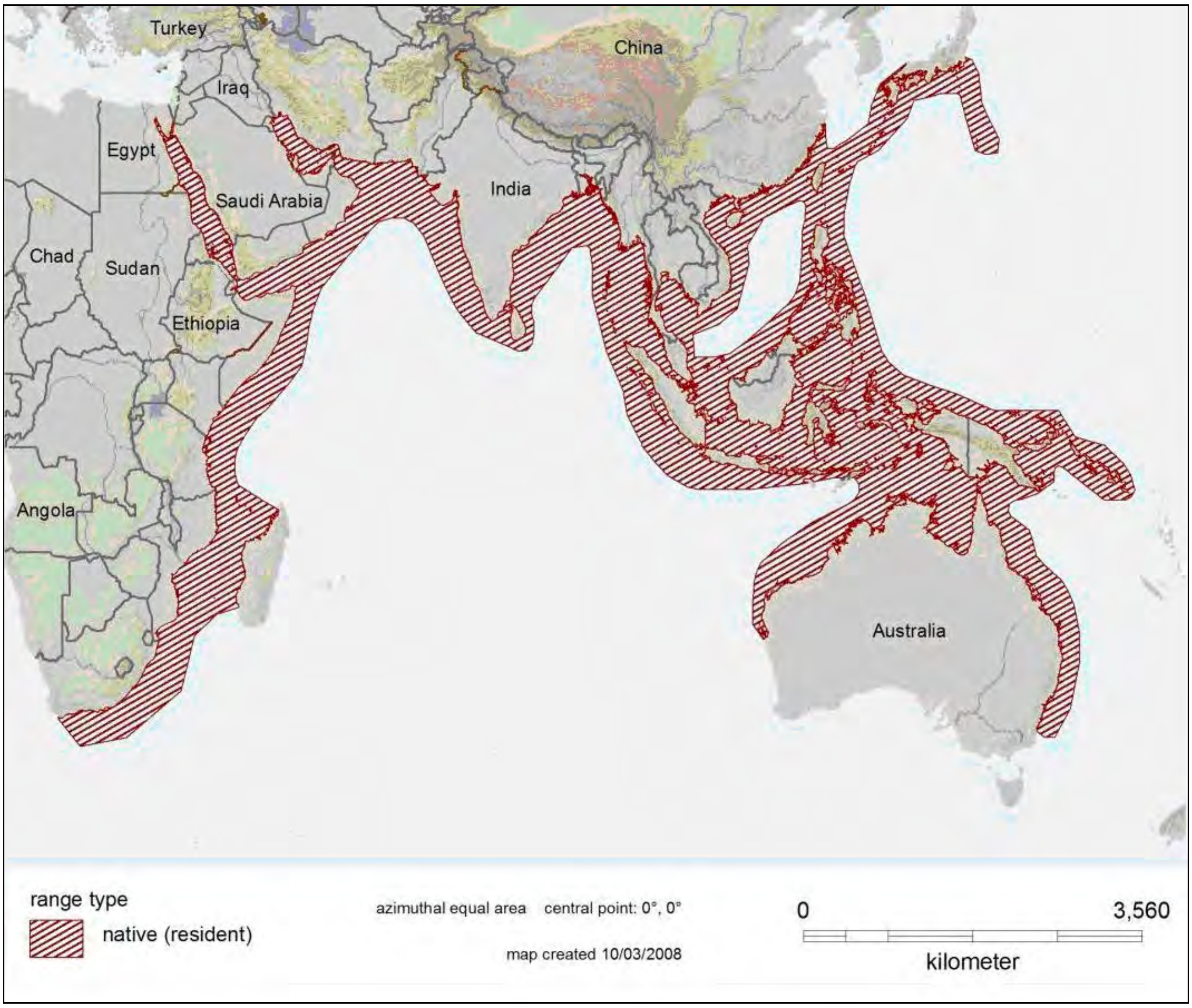

Figure 2.4. Worldwide range of Indo-Pacific bottlenose dolphins (Hammond *et al.*, 2008b).

Cooperative feeding has been observed in this species, where the group herds the prey, allowing individuals to feed (Lockyer, 1990; Acevedo, 1991; Constantine *et al.*, 2004). This is more common in deeper waters, with independent feeding predominating in more shallow waters (Klinowska, 1991). Bottlenose dolphins have also been observed interacting with other cetacean species, especially when foraging in baitballs (for example, with Bryde's whales and common dolphins) (Deakos *et al.*, 2010; O'Donoghue *et al.*, 2010b). They are also known to voluntarily interact with humans, but research has also illustrated distinct boat and human avoidance (Rice, 1998; Fury and Harrison, 2008).

Population status

Due to the many discrepancies between the various species, *Tursiops* spp. are listed as 'data deficient' by the IUCN, and *T. aduncus* is classified as 'vulnerable' in the Red Data book, with the migratory subpopulation being classified as 'endangered' in South Africa (Friedmann and Daly, 2004; Hammond *et al.*, 2008b). Population estimates are vague with estimates of between 520 (Ross *et al.*, 1989) and 900 individuals along the Natal coastline (Reisinger and Karczmarski, 2009). A photo-identification study carried out in the early 1990s estimated a population of 28 482 individuals off the Eastern Cape, suggesting that these dolphins inhabit a larger range along the South African coastline than what was originally estimated (Wells and Scott, 1999; Reisinger and Karczmarski, 2009).

2.8.3.2. Indo-Pacific humpback dolphin (*Sousa chinensis*)

Currently there is confusion over which *Sousa* species inhabits the south-east coast of South Africa (Best, 2007). On the west coast of South Africa, the Atlantic form is known as *Sousa teuszii* (Ross *et al.*, 1994). In the Indian Ocean, two populations exist, namely, the Indian humpback dolphin (*S. plumbea*) and Indo-Pacific humpback dolphin (*S. chinensis*) (Ross *et al.*, 1994; Best, 2007). Morphometrically there is little or no difference between these two populations (Ross and Best, 1989; Kaschner *et al.*, 2006b). For the purposes of this study, the species found off the south coast of South Africa is referred to as the Indo-Pacific humpback dolphin (hereafter referred to as humpback dolphin) based on literature and studies in the area (see: Durham, 1994; Ross *et al.*, 1994; Karczmarski, 1996; Rice, 1998; Jefferson and Karczmarski, 2001; Keith *et al.*, 2002; Guissamulo and Cockcroft, 2004; Best, 2007).

Characteristic features

Humpback dolphins show sexual dimorphism, with males being larger (average length of 2.79 m) than females (average length of 2.49) (Ross *et al.*, 1994; Best, 2007). These animals have a brownish-grey body, long beak, and a distinctive hump with a small, hooked dorsal fin (Ross *et al.*, 1994; Karczmarski *et al.*, 1999).

Range

Humpback dolphins are found in coastal areas of the Indian Ocean ranging from the south coast of South Africa, along the eastern coastline of Africa, south Asia, the Philippines and the associated islands in the ocean basin (Figure 2.5) (Ross *et al.*, 1994; Jefferson and Karczmarski, 2001; Friedmann and Daly, 2004). These animals are primarily found in bays, river mouths, and estuaries off South Africa, extending from False Bay to the KZN coastline and into East Africa. Females with calves tend to be resident within their habitat, with other individuals moving along the coastline to neighbouring bays (Karczmarski, 2000; Friedmann and Daly, 2004).

Habitat and ecology

Humpback dolphins are observed in waters less than 15 m in depth, and within one kilometre from land (Findlay *et al.*, 1992; Karczmarski, 1996; Keith, 1999). Group sizes are typically less than 25 individuals, with the average group size less than 10 animals (Karczmarski, 1999; Jefferson, 2000; Parra and Ross, 2009). Larger groups are generally associated with calves, with births peaking in summer along the southern African coastline (Karczmarski and Cockcroft, 1999).

Humpback dolphins feed individually on a variety of fish species in sandy-sheltered bays and along rocky shores (Keith *et al.*, 2002; Atkins *et al.*, 2004). A diurnal pattern of feeding has been previously observed in Algoa Bay, with peaks occurring in the early morning and late afternoon during the winter months (Karczmarski *et al.*, 2000a). These animals tend to use exposed and disturbed areas of water (for example, areas of high human activity) for travelling (Saayman and Tayler, 1979; Keith, 1999; Best, 2007).

Bottlenose dolphins and humpback dolphins are rarely seen integrating, despite very similar niches. However, single humpback dolphins have been seen within a group of bottlenose dolphins (Karczmarski *et al.*, 1997). Humpback dolphins also tend to avoid boats and human activities, and are known to increase dive times and disperse when approached by boats or humans (Ross *et al.*, 1994; Best, 2007). Like bottlenose dolphins, humpback dolphins display social behaviours such as leaping and chasing (Friedmann and Daly, 2004).

Plate 2.5. Humpback dolphin. *Photo: B. Melly.*

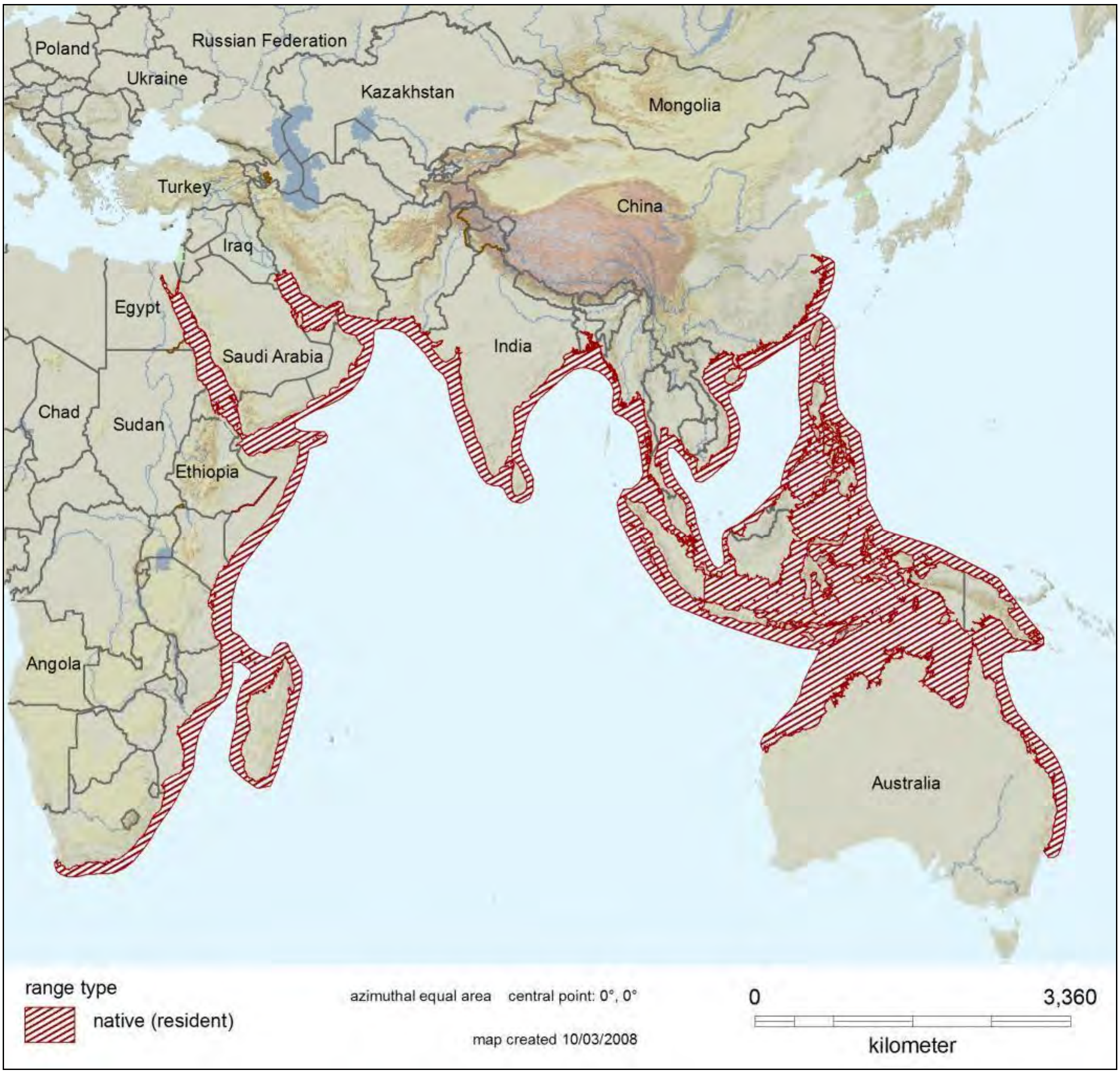

Figure 2.5. Worldwide distribution of Indo-pacific humpback dolphins (Reeves *et al.*, 2008).

Population status

Approximately 1000 individuals are present along the South African coastline and it is thought that the numbers are decreasing (Rice, 1998; Fury and Harrison, 2008; Reeves *et al.*, 2008). Best (2007), suggests a fluctuation in growth rates between -3% and 2%, which is suggestive of some stability. At a global level, this species is considered 'data deficient', and at a local level it is classified as 'vulnerable' (Friedmann and Daly, 2004) or 'near threatened' (Reeves *et al.*, 2008).

2.8.3.3. Long-beaked common dolphin (*Delphinus capensis*)

The taxonomy of the common dolphin is still unresolved (Rice, 1998). Currently, it is recognised that the short-beaked common dolphin (*D. delphis*) occupy mainly offshore areas off the South African coastline, compared to their long-beaked counterparts (*D. capensis*) which occupy more inshore habitats (Ross, 1984; Evans, 1994). Recently, it has been proposed that common dolphins could even be considered as one widely distributed 'super-species', with local differentiation between the various populations (International Whaling Commission, 2009).

Characteristic features

Long-beaked common dolphins (hereafter referred to as common dolphins) are slender and streamlined with yellow and grey 'hourglass' or 'v' shaped saddle markings on the side of their bodies (Ross, 1984; Ross and Best, 1989; Heyning and Perrin, 1994). They have a maximum length of 2.54 m in males and 2.22 m in females, being both larger and more streamlined than their short-beaked counterparts (Ross, 1984; Best, 2007). Neonates measure just under one metre, with the majority of births occurring in summer (Klinowska, 1991; Best, 2007). Sexual maturity in displayed in animals over 1.5 m in length, with a calving interval of approximately three years (Cockcroft and Peddemors, 1990; Evans, 1994).

Range

Common dolphins are a widely distributed species situated in tropical and temperate oceans, especially in South America, California, western and southern Africa, and south-east Asia (Figure 2.6) (Findlay *et al.*, 1992; Rice, 1998). Annual winter migrations along the east coast of South Africa are common, following the Sardine Run, which begins in the Eastern Cape and travels up to the north coast of KZN (Friedmann and Daly, 2004; Best, 2007; van der Lingen *et al.*, 2010).

Plate 2.6. Common dolphins porpoising. *Photo: B. Melly.*

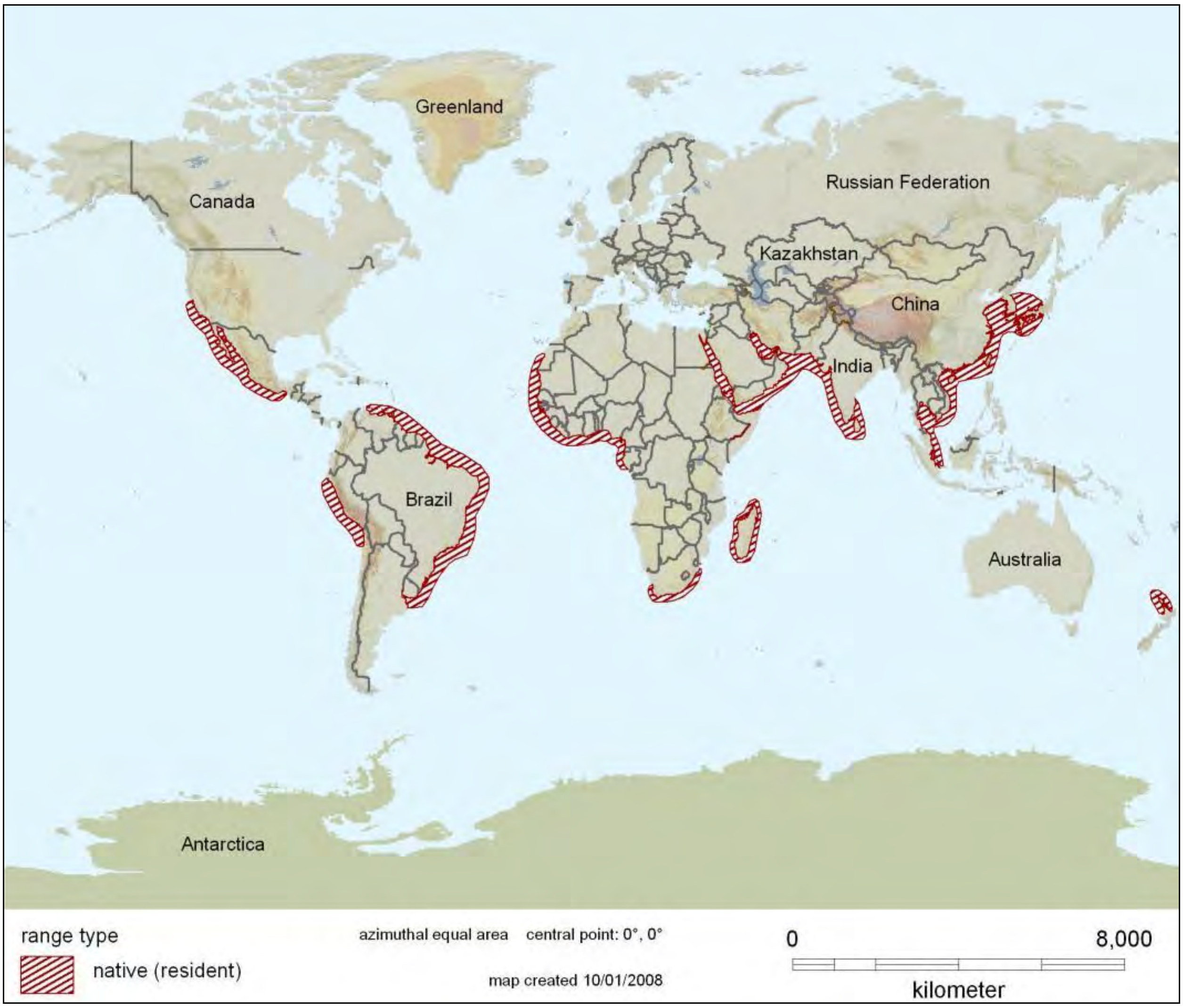

Figure 2.6. Worldwide distribution of common dolphins (Hammond *et al.*, 2008a).

Habitat and ecology

Group sizes vary from 100s to 1000s of individuals, with an average group size of 302 (Evans, 1994). However, they appear to have social units of around 30 animals (Evans, 1994; Barlow, 1995). Off South Africa, common dolphins occupy more coastal habitats of less then 500 m in depth, while short-beaked common dolphins are found further offshore (Findlay *et al.*, 1992; Peddemors, 1999).

These animals are known to travel along escarpments in search of prey, and therefore tend to have more offshore distributions compared to other delphinid species (Peschak, 2005; Samaai *et al.*, 2005; Filby *et al.*, 2010). They forage individually or use group herding strategies to feed on pelagic shoaling fish (Best *et al.*, 1984; Best, 2007). Several species have been reported in feeding associations with common dolphins, including Bryde's whales, bottlenose dolphins, fur seals, seabirds and sharks (Heyning and Perrin, 1994; Frantzis and Herzing, 2002; Best, 2007).

Population status

In 1988/ 89 15 000 to 20 000 common dolphins were estimated along the south-east coast of South Africa, which does not include the full range of the species (Würsig, 1989). Although this is outdated, no other estimates currently exist (Best, 2007). At a national level they have a status of 'least concern', with the IUCN classifying this species as 'data deficient' (Friedmann and Daly, 2004; Best, 2007; Hammond *et al.*, 2008a).

2.9. SUMMARY AND CONCLUSION

Table 2.1. Summary table of the cetaceans found within the inshore areas of Algoa Bay.

Common Name	Scientific name	IUCN Population status	Global range
Southern right whale	*Eubalaena australis*	Least concern	Circumpolar - temperate
Humpback whale	*Megaptera novaeangliae*	Least concern	Cosmopolitan
Bryde's whale	*Balaenoptera brydei*	Data deficient	Tropical - subtropical
Indo-Pacific humpback dolphin	*Sousa chinensis*	Near threatened	Tropical - warm temperate
Indo-Pacific bottlenose dolphin	*Tursiops aduncus*	Data deficient	Tropical - warm temperate
Long-beaked common dolphin	*Delphinus capensis*	Data deficient	Tropical - warm temperate

Table 2.1 provides a synopsis of the name, IUCN population status and range of the six cetacean species found within the inshore areas of the Algoa Bay, the knowledge of which is based on

previous studies. Two species, the dwarf minke whale (*Balaenoptera acutorostrata*) and killer whale (*Orcinus Orca),* which have been occasionally sighted in the bay, were not discussed as they were not observed during the time span of this study.

Despite continued research on cetaceans in South Africa, there are still a large number of questions related to the distribution and habitat use of these animals along this coastline, as well as the geographical variables affecting their distribution. In order for appropriate conservation and management strategies to be outlined and implemented for any cetacean species, these parameters need to be more accurately defined. Non-systematic line-transect sampling methods have proved to be useful in collecting cetacean sighting data. Spatial data analysis methods such as GIS and statistics have proven to be valuable in defining the spatial and temporal distribution and habitat of cetaceans. Consequently, this study uses a combination of these methods (discussed in Chapter Four) for researching cetacean species that inhabit the inshore areas of Algoa Bay.

CHAPTER 3: STUDY AREA

3.1. INTRODUCTION

This chapter provides a detailed description of Algoa Bay. Prominent geographical, hydrological and biological features have been delineated. Current activities that potentially affect cetacean distribution, as well as proposed future developments and conservation strategies, are also mentioned.

Algoa Bay is situated on the south Eastern Cape coastline of South Africa. It is bordered by two headlands, Cape Padrone (33°46’ S 26°28’ E) on the east and Cape Recife (34°02’ S 25°42’ E) on the western side of the bay (Figure 3.1). The coastline is approximately 135 km long, consisting mainly of sandy beaches, with rocky shores along Cape Recife. Three main rivers enter the western half of Algoa Bay: the Sundays, Swartkops and Coega Rivers. The Alexandria Dunefield borders about 50 km of the northern part of the bay from Sundays River to Cape Padrone. Port Elizabeth city is situated on the south-western corner of Algoa Bay.

Boat-based surveys were undertaken along the coastal waters between the two headlands of Algoa Bay, as well as along key geographical features within the bay. This includes two island groups and a shallow reef on the south-west border, which will be discussed in the following section.

3.2. GEOGRAPHICAL FEATURES

The coastline west of Algoa Bay consists of several relatively shallow bays with maximum depths of 100 m and average depths of less than 50 m; of which Algoa Bay is the largest with an area of approximately 3100 km^2 (Bremner, 1979a; Bremner, 1983; Bremner *et al.*, 1991). This bay has a planimetric shape with the appearance of a near perfect clockwise logarithmic spiral (Figure 3.1) (Bremner, 1979b; Ross, 1984). Approximately 45 km south of Cape Recife lies the continental shelf break at a depth of 150 m (Bremner *et al.*, 1991).

The Alexandria Dunefield borders the north and north-eastern boundaries of the bay, forming an extended sandy shore stretching from Sundays River to Woody Cape (Figure 3.1) (McLachlan, 1983; Illenberger, 1986). This dunefield is the largest in South Africa with an area of 120 km^2

extending across 50 km, with an average width of 2.2 km and consists mostly of unvegetated mobile dunes (Illenberger, 1986).

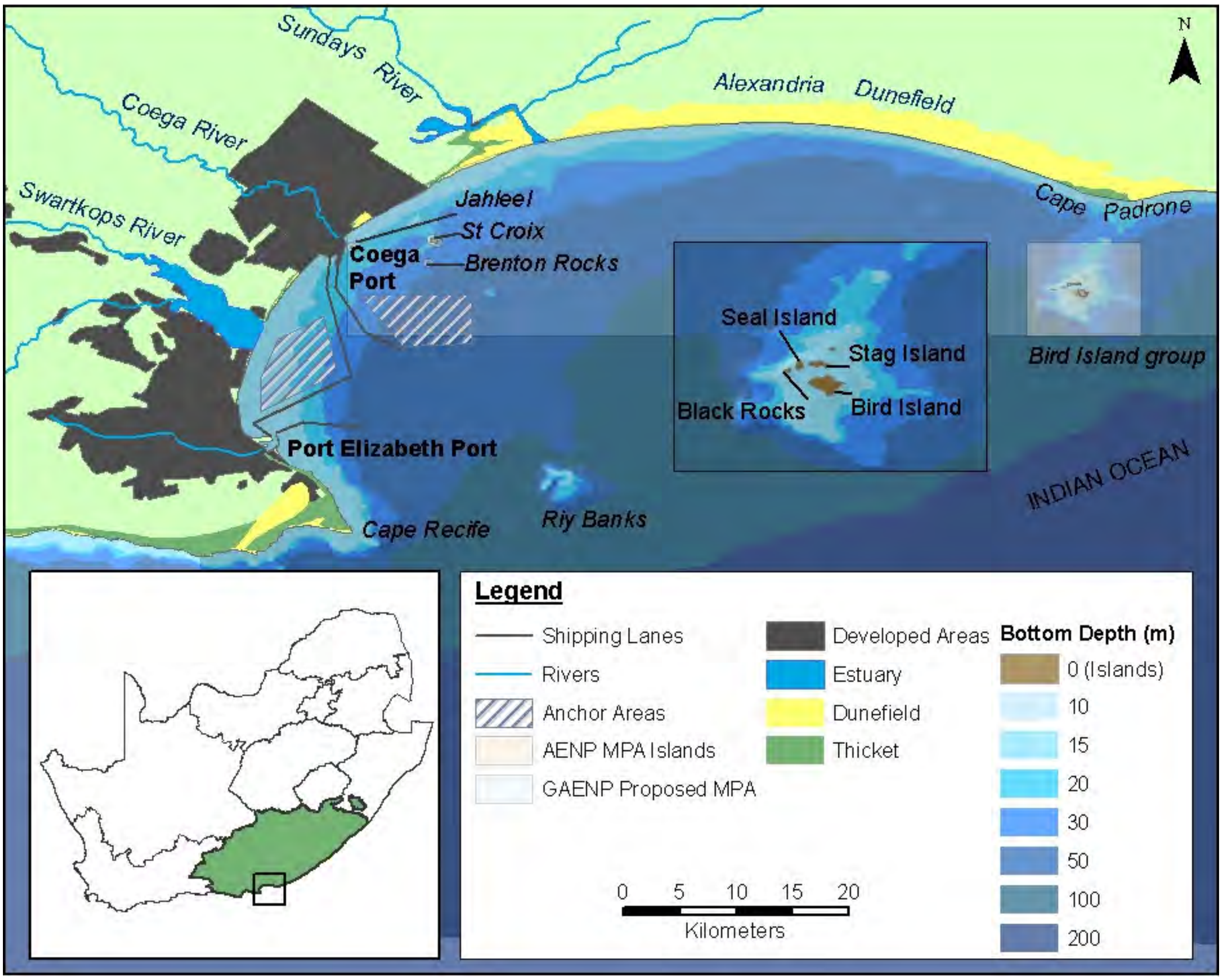

Figure 3.1. Features of Algoa Bay on the south Eastern Cape coastline of South Africa.

The Swartkops and Sundays Rivers are two large perennial systems with permanently open estuaries into Algoa Bay (Figure 3.1) (Bremner, 1983). The Sundays River has a catchment area of 20 729 km^2, with the estuary extending approximately 21 km inland, bordering the Alexandria Dunefield (Harrison and Whitfield, 1990). The Swartkops River has a catchment size of approximately 1 555 km^2 and is situated 10 km north-east of Port Elizabeth (Melville-Smith and Baird, 1980). The estuary is 16 km long and has evidence of elevated levels of heavy metals which are deposited in the sediments of the surrounding ocean floor (Melville-Smith and Baird, 1980; Binning and Baird, 2001). The seasonal Coega River is the next largest river entering the bay, supporting a salt-extraction works, with the Port of Ngqura (Coega Port) situated at the mouth of this non-perennial river (Figure 3.1) (Bremner, 1983). The Papkuils River and the

Baakens River are also small non-perennial streams, the latter, flowing into PE Port (Figure 3.1) (Bremner, 1983).

A reef and two island groups distinguishes Algoa Bay from other bays in South Africa (Figure 3.1). Riy Banks is a shallow reef situated approximately 20 km east-southeast of PE Port (Bremner, 1979a; Bremner *et al.*, 1991). The reef rises from a depth of approximately 50 m to depths between 12 and 15 m, forming a rough ovoid-shaped plateau of 24 km^2, making it a popular diving and spear-fishing site (Bremner, 1979a; Bremner *et al.*, 1991). The northern and western flanks of the outcrop are steep, with more gently sloping topography on the south and eastern flanks (Bremner *et al.*, 1991).

The Bird Island group, comprising of Bird Island, Black Rocks, Seal Island and Stag Island, is situated approximately eight kilometres south-southeast of Woody Cape and two to three kilometres south of Cape Padrone (Bremner *et al.*, 1991; World Bank, 2004). The Islands of the Cross (commonly reffered to as the St Croix Islands) consist of St Croix Island, Jahleel Island and Brenton Island, all of which border the eastern side of Coega port.

These features, along with the existence of large deposits of unconsolidated sand on land (from the Alexandra Dunefield), the introduction of sediment from the two largest rivers entering the bay, the prevailing wind patterns, groundswell and the Agulhas Current, have all contributed to the present shape of Algoa Bay (Bremner, 1979b). These geographical features have also influenced the nature and distribution of sediments on the sea-floor (Figure 3.2) (Bremner, 1979b). The sea-floor mainly consists of fine sand to sand sized sediment (Figure 3.2) (Bremner, 1979b). The two larger rivers deposit coarse sediment at the river mouths, and finer clay to silt-sized sediments across the central bay area, covering the predominantly sand-based sea-floor (Figure 3.2) (Bremner, 1979b).

Bremner (1979b) and Bremner *et al*. (1991) discuss the bathymetry of Algoa Bay in detail. In general, the sea-floor slopes towards the south-southeast at about 0.15^o with several islands, depressions and ridges disturbing this gradient locally (Bremner, 1979a; Karczmarski, 1996). St Croix Island, Jahleel Island and Brenton Island are three isolated outcrops forming a south-westward ridge known as the 'St Croix Ridge', and are surrounded by the generally smooth-sloping sea-floor (Bremner, 1979a). Between the two island groups lie a number of hill-like features that form shallow depressions and small uneven ridges along the north-east shoreline of the bay (Bremner, 1979a). Cape Recife, Riy Banks and the Bird Island group are three areas of extremely rough morphology that form a steep, sea-ward dipping, discontinuous ridge of exposed bedrock along the outskirts of the Algoa Bay (known as the 'Recife Bird Ridge'), where water depth quickly exceeds 50 m (Bremner, 1979a).

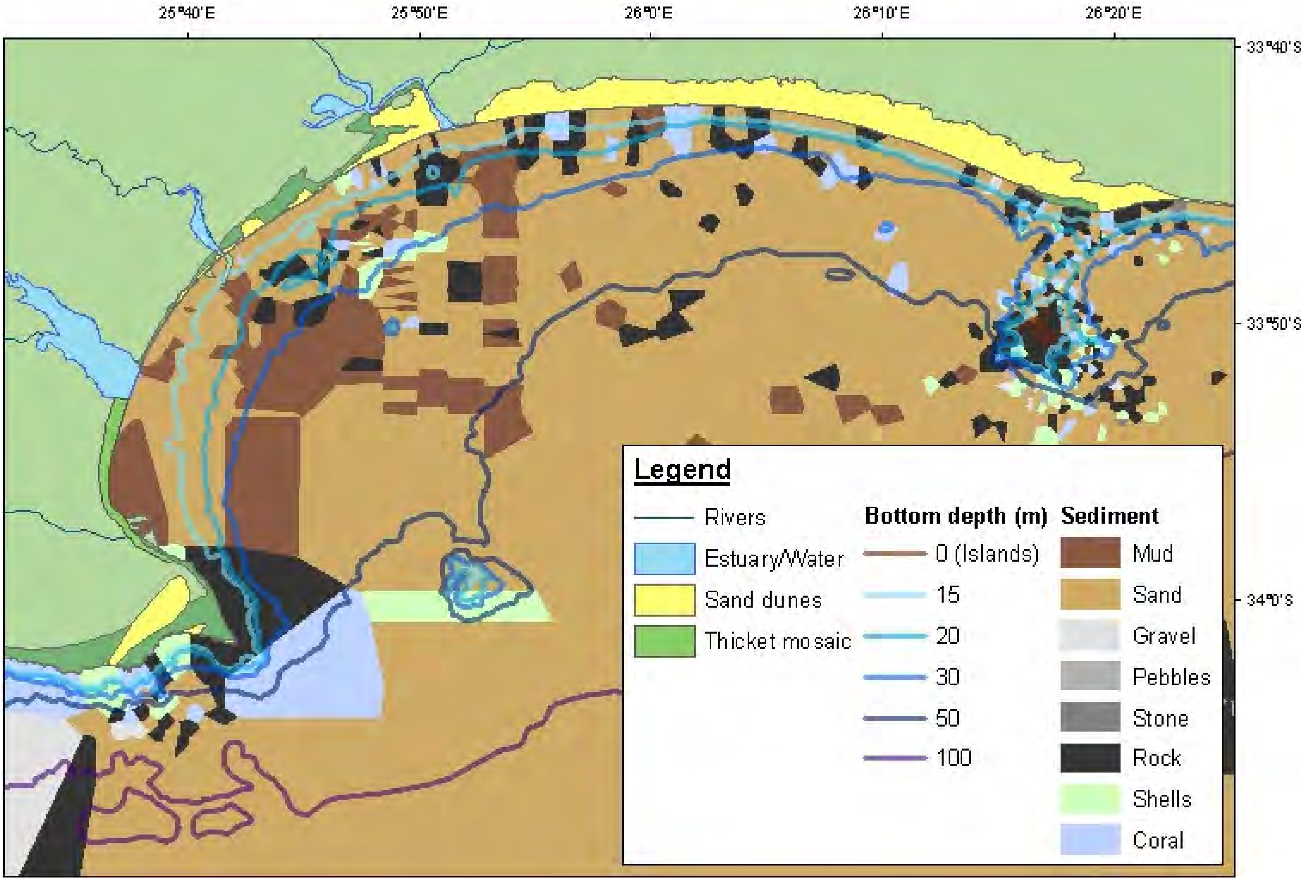

Figure 3.2. Interpolated sediment map of Algoa Bay derived from SANHO point sample data using Thiessen polygons (note: sparse data in the south-west region has led to the construction of large Thiessen polygons).

3.3. CLIMATE AND WEATHER PATTERNS

This large, relatively exposed bay is situated in the subtropical climate of the Eastern Cape Province of South Africa and faces the south-west Indian Ocean. The weather of Algoa Bay is predominantly controlled by high pressure systems as well as cold fronts and coastal lows (Goschen and Schumann, 1988). These fronts and coastal lows are associated with high winds, cloud cover and rainfall (Goschen and Schumann, 1988).

Algoa Bay falls in the transition zone between winter and summer maximum rainfall regions which are found on the west and east coast respectively, and experiences an overall winter maximum rainfall (Stone *et al.*, 1998). Raw weather data were obtained from the South African Weather Service (SAWS). Port Elizabeth receives approximately 545 mm of rainfall a year, with large amounts of intra and inter-annual variability (Figure 3.3). During the summer, Algoa Bay receives an average of 8.5 to nine hours of sunshine a day, while in winter this decreases to approximately 6.9 hours per day (Karczmarski, 1996; Stone *et al.*, 1998). Average daily air temperatures range from 13 to 23 ^{o}C (Figure 3.3).

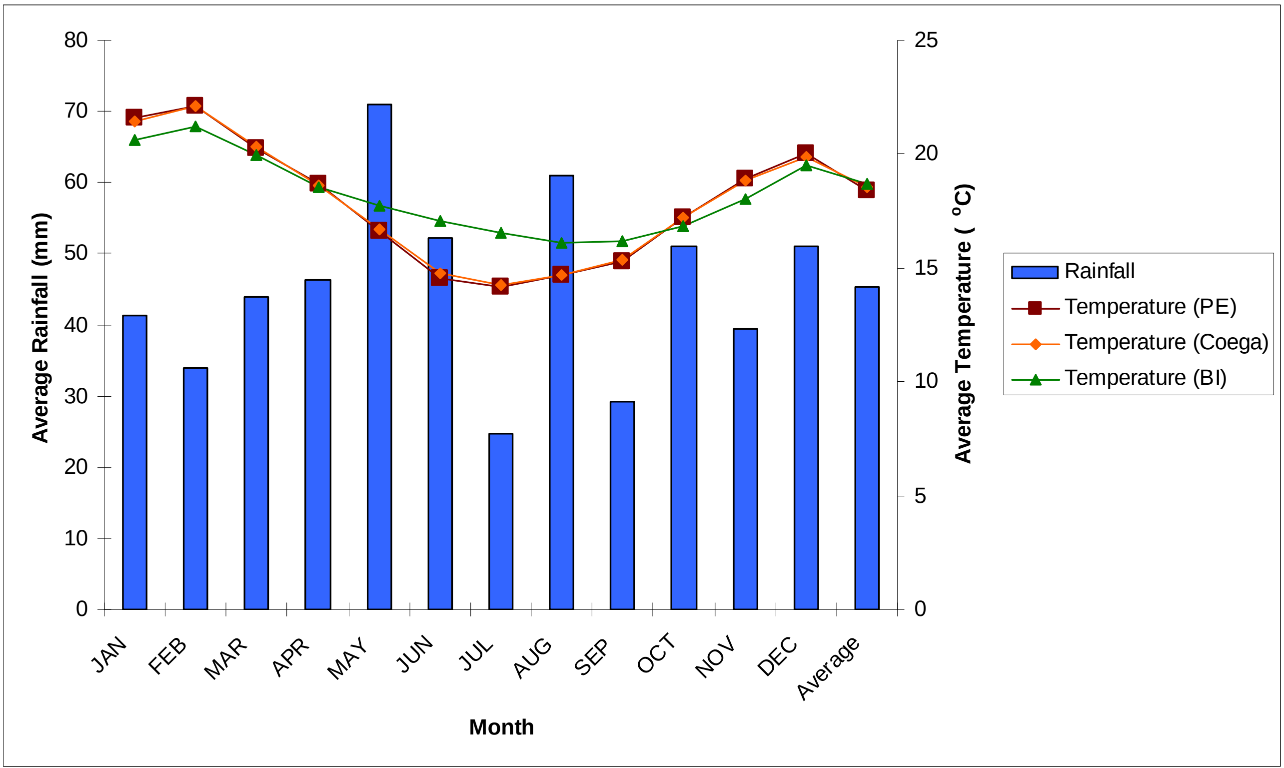

Figure 3.3. Mean monthly temperatures for all three stations in Algoa Bay, and mean monthly precipitation for Port Elizabeth. Temperatures recorded at PE airport, Coega Port and Bird Island.

Algoa Bay is dominated by west south-westerly winds, as well as south-westerly and westerly winds throughout the year, which coincides with the general orientation of the coastline (Figure 3.4) (Illenberger, 1986; Goschen and Schumann, 1988). Land and sea breezes also constitute an important component of local winds in the bay, generally intensifying in the afternoons (Beckley, 1977; Beckley and McLachlan, 1979; Karczmarski, 1996). During summer, easterly winds become more prominent and the average wind velocity increases (Goschen, 1991). Goschen

(1991) calculated that maximum wind speeds occurred between September and November, although this is thought to have shifted forward into January and February.

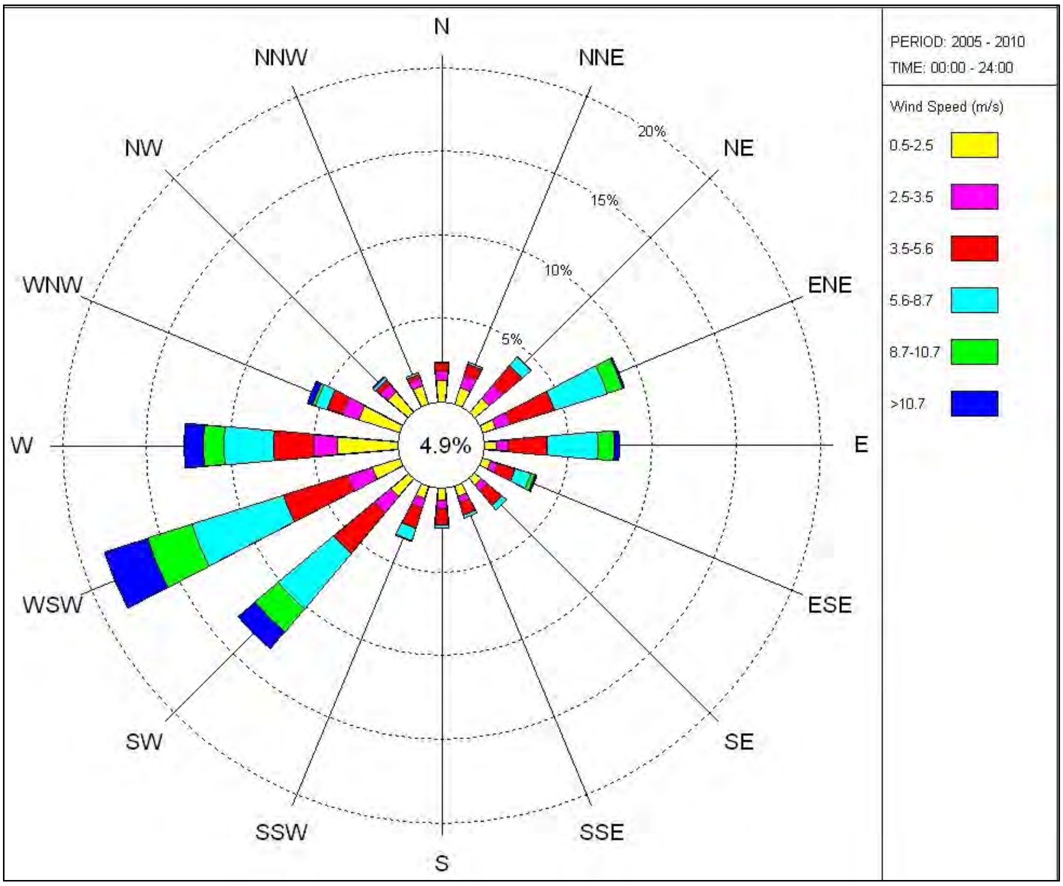

Figure 3.4. Wind rose for PE between 2005 and 2010. Data obtained from SAWS.

3.4. HYDROLOGICAL FEATURES

Wave direction and height in the bay is determined by local winds and distant storms combined with the underlying topography (Karczmarski, 1996). Swell height in the inshore zone of the bay is decreased by the dominant west south-westerly winds (Karczmarski, 1996). Conversely, due to Algoa Bay being exposed on the east, the easterly winds bring deep-sea waves which are unhindered by a headland and thus increase the swell height (Karczmarski, 1996). Taking into account that the sea state generally worsens throughout the course of the day, Karczmarski (1996) determined that the average monthly sea state corresponds to a Beaufort sea state of three.

The dominant oceanic feature associated with Algoa Bay is the warm Agulhas Current which flows between 44 and 60 km offshore of Cape Padrone and Cape Recife respectively (Goschen and Schumann, 1988). The current begins alongside Mozambique and flows close inshore down the east coast of South Africa along the continental shelf (Lutjeharms, 1981; Lutjeharms *et al.*, 2001). Around Algoa Bay the current begins to diverge from the coast as the continental shelf widens towards Cape Point (in the Western Cape) where it turns around and flows eastwards as the Agulhas Return Current (Ross, 1984; Lutjeharms *et al.*, 2001; Griffiths *et al.*, 2010). The current flows quickly at a velocity of approximately one metre per second (and can exceed speeds of 2.5 $m.s^{-1}$), with an average temperature of between 22 and 27 ^{o}C in August and March respectively (Ross, 1984). This current plays an important role in determining temperatures and smaller currents within Algoa Bay (Goschen and Schumann, 1988).

A cooler, more nutrient-rich counter current also affects the inshore waters of the bay (Beckley and McLachlan, 1979; Griffiths *et al.*, 2010). The water temperature in Algoa Bay is generally well mixed in winter, with little or no thermocline apparent, resulting in a vertical temperature difference of approximately one degree Celsius between bottom and surface water (Beckley, 1983; Schumann and van Heerden, 1988). The average water temperature in the bay is approximately 18.1 ^{o}C[1], but can fluctuate between 10.8 and 26.5 ^{o}C during upwellings and inshore meanders of the Agulhas Current respectively (Christensen, 1980; Lasiak, 1982).

Upwellings in Algoa Bay are generated by strong winds and the bottom boundary layer of the Agulhas Current (Schumann *et al.*, 1982; Beckley, 1983). Westerly winds produce upwellings north-east of Cape Recife, while easterly winds generate upwellings on the southern shores of the two headlands (Beckley, 1983; Goschen and Schumann, 1988). These upwellings bring up cold, nutrient-rich water that result in local changes to the physical environment, having distinct affects on the biota (Karczmarski, 1996). This is enhanced due to the lack of a thermocline, allowing the upward mixing of these nutrients (Karczmarski, 1996).

Semi-diurnal tides occur in Algoa Bay, with tidal ranges of 1.61 m and 0.51 m at spring and neap tide respectively (Beckley, 1977; Karczmarski, 1996). These tides form current speeds of over 30 $cm.s^{-1}$, insignificant to the general circulation pattern due to the overall bathymetry of the bay (Goschen and Schumann, 1988).

[1] Measured at Humewood Beach, Port Elizabeth (1973 – 1999) and Pollock Beach, Port Elizabeth (1999 – 2010). Data obtained from the South African Weather Service (SAWS).

3.5. THE BIOTA ASSOCIATED WITH HABITATS IN ALGOA BAY

3.5.1. Sandy beaches

The sandy shores of the Alexandria Dunefield produce a significant freshwater discharge into the corresponding surf zone providing a habitat for an important diatom, *Anaulus australis*, which accounts for over 95% of the primary production along the Alexandria Dunefield coastline (McLachlan, 1983; Illenberger, 1986; Webb and Wooldridge, 1990). This diatom is preyed upon by a wide variety of invertebrates and fish, forming a crucial producer base in the associated food web, which includes odontocetes as the apex predators (Webb and Wooldridge, 1990; CSIR, 2004; CSIR, 2007).

Several fish species are also common in the surf-zone associated with sandy beaches in the bay; namely, *Pomadasys olivaceum* (gorrie), *Liza richardsoni* (South African mullet), *Sarpa salpa* (streepie), and *Lithognathus mormyrus* (sand steenbras) (Lasiak, 1983). Fish biomass fluctuates daily, with two peaks in abundance, associated with low tide and twilight (Lasiak, 1982). Spawning takes place near the shoreline during the spring and summer months and these inshore waters provide a nursery ground for juvenile fish (Lasiak, 1983; Harrison and Whitfield, 1990). The permanently open Sundays River estuary also provides an important breeding and nursery ground for many fish species that have both recreational and commercial value along the Eastern Cape coastline (Harrison and Whitfield, 1990; Pattrick and Strydom, 2008).

3.5.2. Rocky shores

The south-western component of Algoa Bay consists of several small rocky reefs (Karczmarski, 1996). Rhodophyte seaweeds such as *Plocamium corallorhiza* and *Amphiroa ephedrae* predominantly cover shallow sub-tidal reefs of between zero to eight metres (Beckley and McLachlan, 1979; Beckley and Buxton, 1989; Karczmarski, 1996). The deeper reefs are primarily covered by Ascidians, Octocorals, Hydrozoans and Sponges, with *Pyura stolonifera* (red bait) dominating reef crests (Beckley and McLachlan, 1979; Beckley and Buxton, 1989; Karczmarski, 1996).

3.5.3. Reefs

The most recent survey on reef fish was done by Beckley and Buxton (1989) who identified 49 fish species during reef surveys conducted in the 1980s. The species composition of the most abundant ichthyofauna varies little intra-annually, with most species endemic to South Africa (Beckley and Buxton, 1989). Sparidae are the most dominant species on sub-tidal reefs (Beckley and Buxton, 1989). Several schooling species such as *Boopsoidea inornata* (dikoog), *Diplodus sargus capensis* (blacktail), *Spondyliosoma emarginatum* (steentjie), *Pachymetopon aeneum* (hottentot) and *S. salpa* were the most abundant fish on these sub-tidal reefs, with *B. inornata* observed on 98% of the dives (Beckley and Buxton, 1989). The inshore reefs, like tidal pools, estuaries and sandy shores, are an important nursery ground for juvenile fish (Beckley and Buxton, 1989).

The variety of habitats within Algoa Bay supports a diverse range of fish species which have resulted in Algoa Bay supporting a large commercial and recreational fishing industry, the main industry being the chokka squid fishery (Klages *et al.*, 1992; Pattrick and Strydom, 2008). This potentially plays a key role in determining foraging areas for cetaceans (Kenney *et al.*, 1997; Bearzi *et al.*, 2006; Nelson *et al.*, 2008).

3.5.4. Marine Protected Areas

St Croix Island supports the largest population of the endemic African penguin (*Spheniscus demersus*) (Shelton *et al.*, 1984; Coastal and Environmental Services, n.d.). A significant proportion of the total Cape gannet population (*Morus capensis*) breed on Bird Island, and many roseate terns (*Sterna dougallii*) and African black oystercatchers (*Haemotopus moquini*) utilise both island groups, feed in the surrounding waters during their breeding season (Klages *et al.*, 1992; Watson *et al.*, 1997; World Bank, 2004). This area is also well known for its vast Cape fur seal (*Arctocephalus pusillus*) population that inhabits Black Rocks, and the great white shark (*Carcharadon carcharias*), which is found in the adjacent waters (Randall *et al.*, 1988; Oosthuizen, 1991).

Several important geographical features make the proposed GAENP MPA a key habitat for several marine species, including the Sundays River and the Alexandra Dunefield. The dunefield is associated with a long stretch of sandy shores bordering the Algoa Bay coastline, providing a variety of habitats for marine animals, making this area an important breeding and nursery ground for numerous fish species and many endemic species (for example, the South African mullet and Cape gannet (*Morus capensis*)) (Illenberger, 1986; Pattrick and Strydom, 2008). Over 100 species of macroalgae and 86% of the endemic marine invertebrates are found in this area, as well as various ‘vulnerable’ and ‘threatened’ species such as the African penguin (*Spheniscus demersus*), great white shark (*Carcharadon carcharias*), and the diatom *A. australis* (Webb and Wooldridge, 1990; Klages *et al.*, 1992; World Bank, 2003; CSIR, 2007; Pattrick and Strydom, 2008; Coastal and Environmental Services, n.d.).

The GAENP MPA will potentially protect 95% of primary production in Algoa Bay, 38% of the endemic macroalgal species, 86% of South Africa’s endemic marine vertebrates, 45% of endemic marine invertebrate species, 34% of endemic fish species, and 23 species of seabirds, half of which are ‘vulnerable’, ‘threatened’ or ‘near-threatened’ and 15 of which breed in the bay (World Bank, 2003; Pattrick and Strydom, 2008; Coastal and Environmental Services, n.d.). The GAENP MPA will also set out to rebuild the collapsed fish stocks as well as protect nursery and spawning areas for other fish species and the chokka squid (Pattrick and Strydom, 2008).

3.5.5. Sardine Run

Sardines (*Sardinops sagax*) are a major contributor to pelagic fisheries off the coast of southern Africa (Beckley and van der Lingen, 1999; van der Lingen *et al.*, 2010). They are found in temperate, coastal and shelf waters along the South African coastline, including Algoa Bay (Beckley and van der Lingen, 1999). Most sardines spawn in spring and summer along the Agulhas Bank and migrate eastwards as large shoals during winter, moving inshore as the Agulhas Bank narrows in a phenomenon known as the Sardine Run (Beckley and van der Lingen, 1999; van der Lingen *et al.*, 2010). This migration occurs with the expansion of their temperature range, due to cooling air temperatures and upwellings along the coast as the warm Agulhas Current moves further offshore, and is thought to begin around Bird Island in Algoa Bay (Baird, 1971; Armstrong *et al.*, 1991; Beckley and van der Lingen, 1999). This run is known to attract a large number of marine predators, including cetacean species such as Bryde’s whales, bottlenose dolphins and common dolphins (O'Donoghue *et al.*, 2010a; O'Donoghue *et al.*, 2010b).

3.6. ANTHROPOGENIC ACTIVITIES

This study comes at a crucial time with several large scale industrial developments that have been proposed or are under construction, along with a general increase in anthropogenic activities. The role and influence of these developments and conservation strategies on cetaceans in Algoa Bay was reviewed on a broad-scale in Chapters One and Two, and will be further discussed in relation to the findings of this study in Chapter Six. A brief summary of the current activities in Algoa Bay are outlined below.

3.6.1. Industry

3.6.1.1. Port of Port Elizabeth

PE Port was established in 1825 serving local industries (especially agriculture and farming) and offers an alternative for container ships when Cape Town or Durban harbours are congested (Ports and Ships, 2010). The port has three container berths, two bulk berths and a tanker berth, with additional jetties available for tug, fishing, trawling and recreational vessels (Ports and Ships, 2010). However, all vessels are limited by the 14.5 m channel depth (Ports and Ships, 2010). The port has a total area of 115 HA with a breakwater length of 1.2 km (Ports and Ships, 2010). The shipping channel and anchoring areas for both PE and Coega Ports are illustrated in Figure 3.1[2].

Principal products handled include container shipping, manganese ore, petroleum products and cars (Ports and Ships, 2010). The regional commercial and recreational fishing industries also make extensive use of this port (Ports and Ships, 2010). Over 1 200 ships entered the port in the 2008/ 09 financial year, with over 10 million tons of cargo being handled during the 2005/ 06 financial year (Ports and Ships, 2010).

3.6.1.2. Port of Ngqura (Coega)

The deep-water Coega Port is situated approximately 20 km north-east of PE Port at the mouth of the Coega River and forms part of the 12 000 hectare Coega IDZ (Figure 3.1 illustrates the area)

[2] The delineation of the ship anchoring area and shipping lanes were obtained from the Algoa Bay Navigational Chart INT 7531 SAN 1024 (updated in August 2009).

(Ports and Ships, 2010). Harbour size, channel depth and the associated infrastructure in the PE Port have been unable to keep up with the increasing demands of shipping in South Africa, which motivated the building of this deep-water port. The port was completed and began commercial operations in October 2009 (Ports and Ships, 2010). The eastern breakwater, 2.7 km in length, is laid out such that it avoids the St Croix Islands exclusion zone situated on the east of the port (Ports and Ships, 2010). This port has a maximum channel depth of 18 m and a total of 32 berths, which will serve to re-direct vessels carrying manganese and other bulk ore for export, away from the city (Ports and Ships, 2010). At present, this port serves both dry and liquid bulk carriers and cellular container vessels (Ports and Ships, 2010).

Blasting, dredging and drilling were carried out to create the deep-water channel and port in the early 2000s. The effects of noise on marine mammals is described in Richardson *et al*. (1995) and Nowacek *et al*. (2007), with some of the proposed impacts being hearing loss (temporary or permanent), discomfort, displacement from habitat, stress, energetic consequences and various affects on an individual behaviours. Destruction of the physical habitat during the development of the Coega Port could have resulted in a decline or migration of prey species that are eaten by odontocetes (Clapham *et al.*, 1999; Friedmann and Daly, 2004). Other long term anticipated effects from an increase in shipping activity may be an increase in ship strikes, higher ambient noise levels from increased shipping traffic, increased environmental pollution (for example oil), and the disturbance of benthic habitats from the increased number of ships anchoring (Clapham *et al.*, 1999; Nowacek *et al.*, 2007).

3.6.1.3. Future developments in the bay

Several reports have suggested that there is a proposed waterfront development on the south side of PE Port and Kings Beach Precinct, which would have a construction period of approximately 20 years (SRK Consulting, 2007; Cull, 2010; NMBM, 2010). This development will be comprised of a number of key features including an international conference centre, leisure and tourism services, a number of residential and retail areas, and possibly, an expansion of the allocated area for auto and container terminals, and for the fishing industry (SRK Consulting, 2007; Cull, 2010; NMBM, 2010). Alongside the many profitable aspects of these project (job creation and commodity value), there are a number of potential well-known environmental risks and impacts involved in the various stages of construction and implementation of these projects, which were delineated earlier (section 3.6.1).

An oil refinery is planned for the Coega IDZ, with construction occurring between 2012 and 2015, and operations beginning in 2016 (de Bruyn, 2010; Kernohan, 2010). The refinery will be approximately 1 000 ha in size and will produce 400 000 barrels of oil a day at peak capacity (de Bruyn, 2010; Kernohan, 2010). There are several risks involved with the establishment of an oil refinery, which start from the exploration phase, to the various stages of oil collection (the drilling and extraction phase) and the transporting and refining of the oil (O'Rourke and Connolly, 2003; Nowacek *et al.*, 2007). These risks and impacts include: oil spills (which have significant environmental consequences), the physical alteration and disruption of the marine environment (in the case of offshore exploration), and chemical contamination of the water (O'Rourke and Connolly, 2003; Nowacek *et al.*, 2007).

3.6.2. Commercial exploitation of marine resources

Algoa Bay supports a variety of west and east coast fish species which have been heavily exploited over the last 50 years, with 19 of the 27 commercially exploitable line fisheries having collapsed (CSIR, 2004; Pattrick and Strydom, 2008). Thus, fishing for recreational, commercial or illegal purposes, has had a major impact on fish diversity, abundance and distribution of these prey species in the bay (CSIR, 2004; Pattrick and Strydom, 2008). The chokka squid (*Loligo vulgaris reynaudii*) fishery in Algoa Bay is an important industry in the Eastern Cape, possibly the fourth largest fishing industry in the country at present, illustrating the significance of these fishing activities (Karczmarski *et al.*, 1998; Coastal and Environmental Services, n.d.). Overfishing could results in the loss of a prey base, and consequently potentially increases the competition for prey species (Friedmann and Daly, 2004).

3.6.3. Recreational and tourism activities

A number of anthropogenic activities take place along the beachfront of Port Elizabeth which pose potential threats to cetaceans, namely swimming, snorkelling, scuba diving, paddling (surf skiing and kayaking), surfing, kite surfing, windsurfing, shore angling, urban and industrial pollution, the development of the coastal zone, and destruction of coastal habitats (for example, through the establishment of ports and dolosse) (Karczmarski *et al.*, 1998; Friedmann and Daly, 2004; SRK Consulting, 2007).

There has been a rise in recreational boating activities, especially jet skis which are used in the surf zone, an important area for several cetacean species (Karczmarski *et al.*, 1998; Friedmann and Daly, 2004; SRK Consulting, 2007). Boats have been reported following cetaceans at a very close range, which also poses a potential threat. Some operators do not have permits and are not properly educated as to the potential effects of boating activities around these animals, which increases the potential impact (Karczmarski *et al.*, 1998). This has been observed in several studies which have indicated that fast approaching boats, loud engines and improper manoeuvring of a vessel can affect group dynamics and behaviour (Karczmarski *et al.*, 1998; Van Parijs and Corkeron, 2001; Constantine *et al.*, 2004; Lusseau and Higham, 2004).

Marine eco-tourism is also on the rise in South Africa, and in Algoa Bay, where a whale-watching permit set to be released in 2010/ 2011 (Government Gazette, 2009a; Government Gazette, 2009b). Whale-watching is defined as boat- or land-based tourism that is informally or formally organised, with some commercial aspect, in order to observe and/ or swim with any of the cetacean species (Hoyt, 2001). Two benefits of whale-watching are generating revenue for the local community (some of which could be fed back into research), and changing people's attitudes towards the environment (Karczmarski *et al.*, 1998; Hoyt, 2001). However, these benefits also need to be weighed up against the potential impact that this activity has on cetaceans, both in the short- and long-term, in order for this activity to be sustainable in the future (Wilson *et al.*, 1997; Constantine *et al.*, 2004; Hoyt, 2005; Bejder *et al.*, 2006).

3.6.4. Conservation strategies

3.6.4.1. Marine Protected Areas

Two MPAs currently exist in Algoa Bay around the two island groups: the Bird Islands, which lie two to three kilometres south of Cape Padrone, and St Croix Islands, which lie north-east of the Coega River (Figure 3.1) (World Bank, 2004). Both of these groups of islands have an exclusion zone of 100 to 300 m (Bremner *et al.*, 1991; World Bank, 2004).

The proposed GAENP MPA will adjoin the existing Addo Elephant National Park to create a contiguous MPA incorporating these two island groups (Figure 3.1). This area will extend from the Coega River to beyond Cape Padrone and seawards along the shoreline, to create a MPA of approximately 120 000 ha (CES, n.d.; World Bank, 2004). The GAENP aims to prevent further ecosystem degradation by creating a mega-biodiversity conservation area where terrestrial, aquatic and marine ecosystems are protected, while creating employment and contributing to poverty reduction (World Bank, 2004). Although there has been no recent development on the implementation of the MPA in Algoa Bay, SAN Parks are still planning to expand the GAENP MPA in the near future (Oosthuizen, 2010: Pers. Comm.).

3.6.4.2. Proposed humpback dolphin marine sanctuary

After a population study on the humpback dolphins in Algoa Bay in the early 1990s, it was proposed that a humpback dolphin marine sanctuary be established in order to protect this species along the Eastern Cape coastline (Karczmarski, 1996; Karczmarski *et al.*, 1998). This is due to their low population numbers and their inshore distribution, which make this species particularly vulnerable to the effects of anthropogenic activities prominent in this region (Karczmarski *et al.*, 1998). Humpback dolphins are known to prefer inshore, shallow reefs, such as those found on the south-west corner of Algoa Bay (Karczmarski, 1996). This area is actively used by these animals, especially as a primary feeding ground (Karczmarski, 1996). They are therefore susceptible to the destruction of this important habitat and vulnerable to the potential threat of increasing anthropogenic activities in this area (Karczmarski, 1996; Karczmarski *et al.*, 1998). As mentioned previously, the main threat identified is the inshore powerboat traffic, including jet skis and inflatables (rubber ducks, zodiacs) (Karczmarski *et al.*, 1998; Klages, 2006). The proposed humpback dolphin sanctuary therefore aims to protect this species by establishing an exclusion zone for these inshore powerboats, extending southwards from Hobie Beach to Cape Recife (Karczmarski *et al.*, 1998; Klages, 2006). The demarcated area would be approximately 800 m wide (roughly following the 10 m isobath) and seven kilometres alongshore (Klages, 2006).

3.7. CONCLUSION

This chapter provided a detailed overview of the prominent geographical features of Algoa Bay, and a synopsis of the current activities in the bay, with proposed developments and conservation strategies. A thorough knowledge of the geography of the study area is required to accurately interpret biological data (Chapter Six), and to produce relevant and more precise recommendations and guidelines (Chapter Seven).

CHAPTER 4: METHODS

4.1. INTRODUCTION

The research design, methods, the associated techniques, and the tools used to achieve objectives one to five, are examined in detail in this chapter. The framework from which this was established has been outlined in Chapter One. This is based on the aim of the research which is to determine the spatial and temporal distribution, and habitat preference of the cetaceans in Algoa Bay. The research matrix outlined below (Table 4.1) indicates how the five objectives, and their associated methods, have been used to achieve this aim. The primary data were collected during dedicated boat-based surveys, with GIS and statistics being used to conduct the data analysis.

4.2. OBJECTIVE ONE (A): DEDICATED BOAT-BASED SURVEYS

4.2.1. Introduction

Dedicated boat-based surveys were performed within Algoa Bay, including within the proposed MPA, between March 2009 and July 2010. The location of various cetacean species, individual and group dynamics and behaviour, were all recorded. The surveys were carried out on a monthly basis on an 8.5 m semi-rigid boat with two outboard Evinrude engines (115 HP each). A predetermined course was followed using a bearing, or by following the coastline behind the surf zone (150 to 250 m offshore) with GPS points being taken at the beginning and end of a course change (see Appendix One for the Effort Form). Approximately four survey days (or alternatively, up to eight half days) were carried out in a month depending on weather conditions. Surveys were only carried out during daylight hours with favourable weather conditions and the tracks were recorded using a Garmin GPSMAP 76CSx GPS, which computed the boat's position every five minutes.

Table 4.1. Research Matrix.

Objectives	Research question	Data required	Data acquisition tools	Data source	Method of analysis
1. To collect data on cetacean location, behaviour and other attribute information	Which cetaceans are found in Algoa Bay?	Spatial data and associated attribute information	Dedicated boat-based surveys	Primary	Data input and preparation into a database for further analysis
		Spatial data and associated attribute information	Opportunistic sightings	Secondary	
2. To acquire secondary spatial and non-spatial data on geographical and anthropogenic variables	Can these geographical and anthropogenic variables be used to explain cetacean distribution?	Spatial, geographical and anthropogenic data	Dedicated boat-based surveys	Primary	Data input and preparation into a database for further analysis
			Relevant literature, maps and other secondary sources	Secondary	
3. To determine the spatial and temporal distribution, and behaviour of the different cetacean species in Algoa Bay	a) Where and when are cetaceans located in Algoa Bay? b) Does the behaviour of the animals help explain this distribution?	Results from previous analysis			Data analysis in Excel and spatial analysis in ArcGIS
4. To relate the distribution and behaviour of cetaceans to geographical and anthropogenic variables	a) Are there associations between cetacean distribution and these variables? b) Where are potential key habitats for each of the cetacean species?	Relevant literature and results from previous analysis			Data analysis in Excel, ArcGIS, and R. Compare data to relevant literature
5. To produce a set of recommendations and guidelines for improved management, conservation and research	How can the outcomes of this research be used to form a baseline for future research, conservation and development strategies?	Relevant literature and results from previous analysis			Addressing existing and potential problems through reviewing results and existing literature

4.2.2. Survey design

In general, biological surveys collect data on organisms to assess the status of the resource (Mann, 1999). Marine mammal surveys are defined as encounters with groups of animals or individuals along a predetermined trackline, and staying with these animals for a brief period of time (less than 30 min) before continuing along the track (Mann, 1999). Thus, surveys provide a snapshot view of the animals in question in order to answer population level questions such as distribution (Mann, 1999). In this study, a boat-based survey was conducted in Algoa Bay, in order to obtain information on the cetaceans in the area.

4.2.2.1. Survey field procedures

Survey outline

A systematic design with equal coverage is necessary to assess absolute cetacean abundance with unbiased distribution patterns (Dawson *et al.*, 2008). Logistical constraints such as unfavourable wind and sea conditions, prohibited this form of survey, a common problem in cetacean research (Cañadas *et al.*, 2005; Dawson *et al.*, 2008; Hammond, 2009). Instead, the relative abundance (a measure of the relative number of animals in an area), and more importantly, the baseline spatial and temporal distribution patterns of the cetaceans, were determined. Thus, a stratified search effort (as used by Aragones *et al*. (1997) and Dawson *et al*. (2008)) was carried out during the dedicated boat-based surveys, focusing on the coastal areas of the bay, with three main tracks being carried out monthly (Figure 4.1). The first track went from PE Port to St Croix Island, around the island, to the Sundays River mouth, and coastwise back to PE Port (going around Coega Port) (Figure 4.1). The second track followed the coastline from the PE Port to Cape Recife. Weather permitting, after completing this track, the boat continued along different bearing towards Riy Banks (a shallow reef on the outskirts of the bay) or headed straight back to the port (Figure 4.1). The third track begun at Black Rocks, passing through the Bird Islands, to the headland and then coastwise along Woody Cape/ Alexandria Dunefield to Sundays River (Figure 4.1). Consequently, the entire coastline of Algoa Bay was surveyed in this study. The offshore tracks were harder to carry out as sea conditions generally declined with increasing distance from shore. Therefore, if weather permitted, priority was given to more exposed tracks.

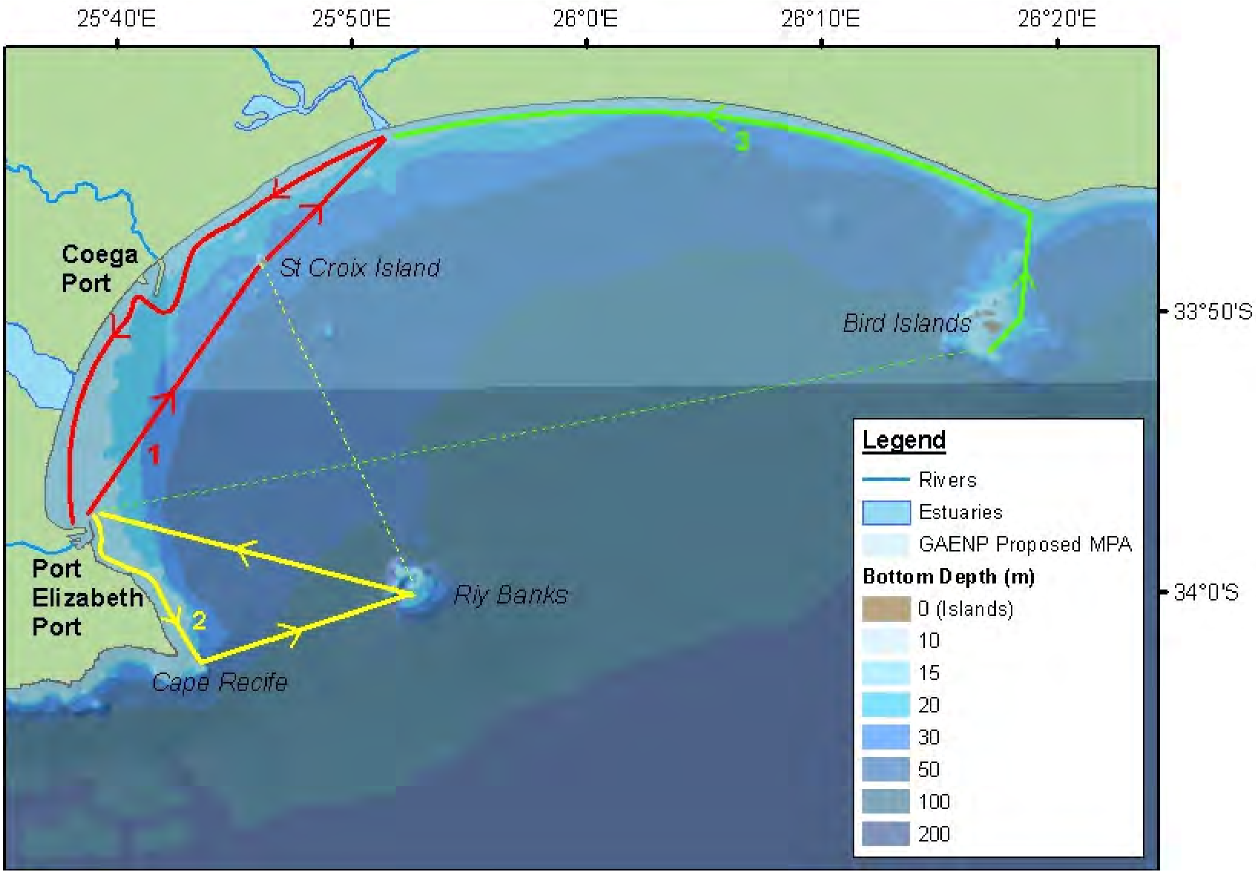

Figure 4.1. Outline of survey tracks performed in Algoa Bay. Tracks 1, 2 and 3 are described in the text. Dashed lines represent opportunistic tracks covered during surveys.

Survey observation technique

Cetacean detection is influenced by a number of variables that need to be controlled as far as possible. These variables include: Beaufort sea state, speed of the vessel, number of observers, observer experience and eye height of observer (Evans and Hammond, 2004; Dawson *et al.*, 2008; Hammond, 2009). Four to five crew members, with a minimum of two trained observers, acted as observers, scanning the sea 360˚ around the survey platform from the horizon to the boat, perpendicular to the trackline, and in front and behind of the line. Trained observers were those who have a background in marine biology and were experienced in dedicated boat-based surveys.

Sighting probability was greatly reduced when conditions deteriorated to a sea state higher than Beaufort four; therefore surveys were conducted in calm sea conditions only. Suitable conditions were Beaufort sea states of four or less, good visibility, a swell of less that two meters (and preferably less than 1.5 m), and no rain. The surveys in this study were carried out at a speed of six knots to ensure that the search effort was relatively consistent and that all individuals along a trackline were spotted, including species with longer dive times (see: Wilson *et al.*, 1997; Davis *et al.*, 2002; Dawson *et al.*, 2008). If the sea state declined to a high Beaufort four/ five, search effort was stopped until the vessel moved to a more protected area, or the survey was called off (in accordance with: Selzer and Payne, 1988; Dawson *et al.*, 2008). In good weather conditions and calm seas (Beaufort zero or one), speed was sometimes increased to a maximum of 8.9 kn. This speed is still below other survey speeds reported by Weigle (1990), Reilly and Fiedler (1994), Wilson *et al*. (1997), and Bearzi *et al*. (2009).

4.2.3. Cetacean sightings data

Table 4.2. Definitions for cetacean sightings.

Term	Definition	Citation
Group	A group is all individuals within a 100 m radius, moving in the same general direction and performing similar behaviours, i.e. with some form of interaction between the individuals.	Campbell *et al*., 2002; Cañadas *et al*., 2002
Sighting	A sighting is a group of cetaceans, including any solitary animals observed. Two separate sightings were recorded if the individuals in an area showed no signs of interacting, were performing different behaviours, and/ or had distance greater than ten metres separating the two groups. However, if the individuals interacted (including inter-species interactions), or participated in similar behaviours, this was noted as one sighting.	Karczmarski *et al*., 1999; Chilvers and Corkeron, 2003, Balmer *et al*., 2008
Group size	Group size is estimated through counting and recounting the number of individuals observed throughout the duration of the sighting, with three final figures: maximum, minimum and best estimate.	
Group composition	The number of calves, juveniles and adults.	
Calf	A calf has a small body size (less then half of adult size), lighter colouration, the occasional presence of foetal folds (if newly born), immature swimming patterns, and the constant association with an adult female i.e. swimming in the 'calf position'.	Weigle, 1990; Smolker *et al*., 1992; Campbell *et al*., 2002
Juvenile	Juveniles range in size from large calves to small adults, and do not consistently travel in close association with an adult female.	Smolker *et al*., 1992
Adult	Adults are full-sized individuals.	Smolker *et al*., 1992

4.2.3.1. Field procedures for sightings

The terms used in the collection of sighting data are explained in Table 4.2. When an individual animal or group was 'sighted' (either directly or through a cue such as a blow, splash or feeding seabirds) within 1.5 nm of the trackline, the track was stopped and the boat headed towards the sighting (Dawson *et al.*, 2008). This was recorded as 'time seen'. If cetaceans were sighted further than two nautical miles away from the trackline, the boat did not head towards the sighting, as search effort along the track would have been compromised (Barlow, 1995). Therefore, only the approximate position, and any other relevant information that could be collected from a distance, were recorded for these sightings before continuing with the survey.

Upon arrival at a sighting, the 'time closed' was noted. During the sighting, the time and position were recorded using the onboard GPS (M52i S/GPS Compact Fish finder). Several environmental variables were also documented including sea surface temperature (SST), bottom depth, Beaufort sea state, wind direction and cloud cover.

The group size, composition and surface behaviour, along with any other relevant information, was observed and recorded (further detail given below). Cetaceans were identified to the lowest taxonomic level based on descriptions in field guides and literature such as Best (2007), Perrin *et al*. (2009), and Skinner and Chimimba (2005). Bottom depth and SST were also noted using the onboard GPS. Upon leaving, the 'time left', GPS position as well as other standard environmental variables were recorded (see Appendix Two for the Sighting Form).

The boat approached the sighting slowly and was manoeuvred carefully in order to reduce any potential impact on the animals' behaviour (Weigle, 1990; Constantine *et al.*, 2004). To avoid variation in the data collected, all final decisions regarding species, group size, composition, and behaviour were made by the researchers. If there were any discrepancies on the validity of the data (especially the number of individuals and group composition in very large groups), this was noted. Very brief sightings, where the individual could not be found again (i.e. no 'time closed'), were marked as 'unconfirmed' sightings. Unconfirmed sightings were not used in further, more-detailed analysis. At the end of a sighting, the boat went back to the position at 'time seen', and continued with the track (Dawson *et al.*, 2008).

4.2.3.2. Behaviour

Table 4.3. Behavioural terms for mysticetes and odontocetes.

Term	Definition	Citation
Socialising	High levels of 'playful' activity, and is recorded in both mysticetes and odontocetes. Socialising in odontocetes includes surfing waves, breaching, jumping, chasing and tail-slapping. In mysticetes calf-suckling was considered a 'socialising' behaviour.	Shane *et al*., 1986; Balance, 1992; Karczmarski *et al*., 2000a
Mating	Belly-to-belly contact between two individuals of the same species.	Karczmarski *et al*., 1997
Foraging	Any effort to capture and consume prey which can be seen through direct evidence (prey in the mouth), or indirect observations. Foraging in mysticetes is indicated by lunging or circular, horizontal movements just below the surface of the water (in order to trap prey). In odontocetes, chasing prey at the surface of the water, frequent and asynchronous dives in one location with loud exhalations, or rapid sharp turning/ circular swimming on the surface, are indicative signs of foraging. There is usually no contact between individuals, although they are known to feed cooperatively.	Constantine *et al*., 2004; Shane *et al*., 1986; Balance, 1992; Karczmarski *et al*., 2000a; Friedmann and Daly, 2004; Best, 2007
Slow travel	Persistent one-directional movement of the whole group at speeds of less than three knots.	Constantine *et al*., 2004
Travelling	Persistent one-directional movement of the whole group at speeds of at least three knots.	Balance, 1992; Constantine *et al*., 2004
Fast travel	Fast travelling involves porpoising, where the dolphins leap clear of the water while moving in a particular direction.	Constantine *et al*., 2004
Milling	Non-directional, relaxed movements in a confined area. This behaviour is frequently seen in conjunction with other behavioural states such as foraging and socialising.	Shane *et al*., 1986; Constantine *et al*., 2004
Resting	In odontocetes, this was identified by the dolphins engaging in extremely slow movements (and almost no forward movement), while surfacing very close together (clumped). Odontocetes will surface together then sink slowly as a group, and at times the group appears to be stationary (floating on the surface). In mysticetes this was characterised by slow surfacing and then sinking, afterwards re-surfacing at the same place a few minutes later.	Shane *et al*., 1986; Balance, 1992; Karczmarski *et al*., 2000a; Constantine *et al*., 2004
Other	In mysticetes: breaching, fluking, flipper slapping, sailing and spy hopping, as it is not unequivocally known why they perform these activities. It is thought that these activities could be for 'fun', to remove parasites, or for thermoregulation. 'Other' was also used for ambiguous activities in both odontocetes and mysticetes.	Cummings, 1985a

Field procedures for behavioural data

The definitions for the different behaviours are outlined in Table 4.3. The method used to determine behaviour in this study was *ad libitum* sampling, where observations of interest were noted, as well as the predominant behaviour (Mann, 1999). An additional method was used 10 times for each species, in order to determine whether the research boat was having an impact on the animals in a sighting (Acevedo, 1991; Constantine *et al.*, 2004). This method is defined as 'focal group' sampling by Mann (1999), where the predominant group activity (greater than 50% of the individuals) was recorded at three minute intervals, in order to better define the behavioural patterns (Mann, 1999). If the animal/ group were submerged at the three minute interval, no behaviour was recorded, and upon surfacing the behaviour was noted. Throughout the study, an effort was also made to determine the behaviour of the animals as the boat approached the group ('initial behaviour'). In addition, the behaviour upon the arrival of the boat (at 'time closed') as well as any changes in behaviour during the sighting was noted.

4.3. OBJECTIVE ONE (B): OPPORTUNISTIC DATA

Several studies have indicated that shore-based monitoring of coastal cetaceans provides valuable information on the species such as recording habitat use, and determining the temporal variation in occurrence at study sites (Saayman *et al.*, 1972; Bristow *et al.*, 2001; Pierpoint *et al.*, 2009). Although this study does not include formal shore-based monitoring of cetaceans, the value of this data were realised and therefore collected on an 'opportunistic' basis (Table 4.1).

Data from opportunistic shore-based sightings were collected by both trained and untrained individuals throughout the duration of the study period. Trained observers noted the time, approximate location, species, group size and behaviour, while untrained observers provided the same information excluding behaviour. GPS positions were acquired from Google Earth © using landmarks and 'distance from land' estimates provided by the observer. Opportunistic sightings were often reported by members of the general public, using the beaches for recreation.

Boat-based opportunistic sightings provided a platform for data collection and for supplementing the data collated from dedicated boat-based surveys. As with shore-based sightings, boat-based opportunistic sighting data were provided by both trained and untrained individuals, collecting information on time, species, group size and behaviour (depending on level of training). The GPS position, SST and depth were captured using the onboard GPS/ navigator which all vessels are required to have. As sightings were generally brief; group size, composition and behaviour were not as detailed as dedicated surveys. Opportunistic boat-based sightings were supplied by recreational boat users in the bay such as fishermen, divers and yachtsmen. All sightings were carefully checked for inconsistencies and accuracy before being included in the final dataset.

4.4. OBJECTIVE TWO

Environmental and anthropogenic variables that could potentially affect sighting effort or the distribution and behaviour of cetaceans were identified through observations, literature and interviews. Landmarks and other key geographical features including harbours, rivers, important coastal features (such as a dunefield), and bathymetry, were downloaded or taken from topographical maps and other existing maps of the region, and used as data layers (Table 4.4).

Table 4.4. Description of the spatial data files used in this research. 'Manipulation' indicates whether further processing was done on the file in preparation for spatial analysis.

Spatial data file name	Type	Manipulation	Source of data
Algoa Bay (coastal) outline	Line vector file	No	STEP database
Coastal vegetation, developed areas	Polygon vector file	No	Topographical maps 3325 DC, DA, DB and 3326 CA, CB and CD
Bathymetry	Line vector file	Yes	SAEON
Existing MPAs and proposed GAENP MPA	Polygon vector files	No	SAN Parks
Shipping areas	Polygon and line vector files	No	Algoa Bay Navigational Chart INT 7531 SAN 1024 (updated in August 2009)
Sea-floor substrate	Point vector files	Yes	SANHO
Effort and sighting data	Point vector files	Yes	Boat-based surveys and opportunistic sightings

4.5. OBJECTIVES THREE AND FOUR

4.5.1. Introduction

GIS was used to integrate sighting information with environmental data. Using the positions and other attribute data obtained during dedicated boat-based surveys, maps were created illustrating the spatial and temporal distribution of each species. The overall distribution as well as the spatial and temporal distribution of the cetaceans were displayed and contrasted to the surrounding environmental and anthropogenic variables using a range of data layers which were identified through objective two.

Spatial analyses were done using a Geographic Information System (GIS), ArcMap 9.3 with the spatial analyst extension (ESRI® Inc., 2008). Further spatial analysis required the use of the Geospatial Modelling Environment (GME) tool (Beyer, 2010), which requires two statistical packages to run, StatConn and R (Baier, 2009; The R project for statistical computing, 2010). Statistical analyses were conducted in both R and Microsoft Excel 2003 (Microsoft® Office Excel, 2003; The R project for statistical computing, 2010). The tracklines and sighting positions as well as the associated attribute data acquired from the dedicated boat-based surveys were entered into Excel and imported into ArcMap 9.3. In order to conduct the spatial analysis in ArcMap, the data was projected to Transverse Mercator central meridian 25 and referenced to the Hartebeesthoek 94 datum.

4.5.2. Overview of the environmental parameters

For the purposes of this study, conventional austral seasons were used. Seasons were therefore grouped into three month periods, with autumn between the months of March and May, winter between June and August, spring between September and November, and summer between December and February. Prefixes 'early', 'mid' or 'late' were added to the season to indicate the month (for example, early summer = December).

Several environmental parameters were also collected during boat-based surveys. Beaufort sea state, wind direction, cloud cover, SST and bottom depth were collected every half an hour, and/or at the beginning and end of each sighting, depending on the length of time between sightings. As an indicator of the survey conditions throughout the study, these variables were averaged for each month and graphed so that the conditions throughout the year could be viewed, including data collected when search effort was 'off'. The display of effort data is discussed in the GIS analysis section.

4.5.3. Search effort

To determine the search effort throughout the duration of the study, the total time spent 'on effort' (where all criteria were met for suitable survey conditions) was calculated for each day of the study (Barlow, 1995; Cañadas and Hammond, 2008). The total length of tracks covered 'on effort' for each survey, was also totalled across the months.

A search effort grid of the total length of tracklines within each grid cell (one square kilometre) was calculated using the Intersect Analysis tool in ArcMap. All the tracks were "intersected" with the grid and "dissolved" using the cell ID field, in order to determine the sum of the track lengths for each one square kilometre cell in Algoa Bay. This dissolved effort layer was then "joined" to the grid such that the grid layer contained information on the total length of tracks within each cell, representing a measure of effort per grid cell.

4.5.4. Generating a grid for Algoa Bay

No formal method of choosing an appropriate grid size was found in an extensive search of the cetacean literature. Most cetacean studies used cell sizes ranging from 25 km^2 to 2 860 km^2, depending on the size of the study area (for example: Cañadas and Hammond, 2008; Gómez de Segura *et al.*, 2008; Weir *et al.*, 2009; Becker *et al.*, 2010; Santora *et al.*, 2010). Thus, a combination of factors taken from the available literature, were considered.

A paper by Hengl (2006) discussed the methodology in selecting an appropriate grid resolution for output maps for land-based vegetation and hydrological datasets, based on some of the intrinsic properties of the data points. This includes an inherent factor that a larger resolution grid results in the aggregation of data (and visa versa), and as a result, affects the accuracy and display of the output map (Hengl, 2006; Seo *et al.*, 2009). Therefore, there is an optimum grid size that best represents spatial variability while taking into account spatial autocorrelation (Qi and Wu, 1996; Guisan and Thuiller, 2005; Hengl, 2006; Seo *et al.*, 2009). Spatial autocorrelation is defined as values that are less or more alike (negative or positive correlation) than would otherwise be expected from random processes (Legendre, 1993).

Various studies place importance on these aforementioned aspects where the models are used for predicting present and future patterns of species distributions (Qi and Wu, 1996; Guisan and Thuiller, 2005; Seo *et al.*, 2009; Becker *et al.*, 2010). As the grid in this study was used to illustrate track distances and density of sightings, it was deemed more important to choose a grid size that was cartographically suitable (easy to visualise spatial patterns), and one that represented highly mobile animals, rather than for the use of statistical analysis and predictive modelling of distribution patterns. Several grid sizes were tested (taking into account spatial autocorrelation) with the final result being largely subjective. Thus, a grid size of one square kilometre was created (using the Geospatial Modelling Environment (GME) tool), which incidentally has also been used to illustrate other land-species distributions (Socioeconomic Data and Applications Centre, 2010).

To determine whether the grid size was suitable, a Moran's I test for spatial autocorrelation was conducted using R (Azzellino *et al.*, 2008; Paradis, 2010). Values range from '-1' to '+1', indicating perfect dispersion to perfect correlation, with a value of '0' indicating a random spatial pattern (Booth, 2004; Azzellino *et al.*, 2008). Significant p-values signify very weak or no spatial autocorrelation, which would indicate whether the grid chosen was a suitable size (Booth, 2004; Azzellino *et al.*, 2008; Paradis, 2010). The Moran's I test for spatial autocorrelation is defined as:

$$I = \frac{N \sum_i \sum_j W_{i,j}(X_i - \overline{X})(X_j - \overline{X})}{(\sum_i \sum_j W_{i,j}) \sum_i (X_i - \overline{X})^2}$$

where N is the number of units, X_i is a variable at a particular location, X_j is a variable at another location, $\bar{x}$ is mean of the variables and W_{ij} is a matrix of spatial weights.

4.5.5. Overview of sightings

The total number of sightings for each species was calculated and displayed for each month (Bearzi *et al.*, 2009). The mean number of sightings per survey and sighting frequency (Ballance, 1992; Bearzi *et al.*, 2009) was calculated using the two equations below:

$$S_{Ave} = S_T / S_u$$

where S_{Ave} is the mean number of sightings per survey, S_T is the total number of sightings for each species and S_u is total number of surveys, and

$$S_F = S_T / H_T$$

where S_F is the sighting frequency ($S.hr^{-1}$) and H_T is the total search effort time in hours.

The mean and range of group sizes were determined for each species throughout the duration of the study, using the minimum, maximum and best estimates for the sizes of each group (Campbell *et al.*, 2002). The total time spent with each species throughout the duration of the study was quantified by subtracting 'time closed' from the 'time left' in each sighting, and totalled for all species (Bearzi *et al.*, 2009). The mean time spent with each sighting was also calculated for each species by dividing the total time by the total number of sightings.

4.5.5.1. Spatial distribution of sightings

An initial map provided an overview of all the sightings recorded in Algoa Bay throughout the duration of the survey, including those collected opportunistically. A suite of maps were then created to represent the spatial distribution of each species separately, with any opportunistic sightings included. This was done to provide a clearer picture of where each species was found. A map was also created with the locations of humpback whale and southern right whale mother-calf pairs to determine whether there were any differences in the spatial distribution between sightings with and without calves present.

4.5.6. Spatial sightings per unit effort

Sightings per unit effort (SPUE) is defined as the number of sightings observed during 100 km of search effort. SPUE provides an indication of the number of animals observed in an area or during a particular time-frame (see next section), taking into account the search effort in that area (or during a period of time) (Barendse *et al.*, 2010). The same process used in calculating the total effort in each grid cell was used to establish the number of sightings for each species per cell. The table formed was then "joined" to the effort grid layer so that the number of sightings could be compared to the effort in each one square kilometre cell. The cells were then grouped into four classes: search effort with no sightings, low SPUE, medium SPUE and high SPUE. These classes were established using geometric intervals which are designed to handle and display continuous data (ESRI Inc., 2007). Classes contain approximately the same number of values and have intervals that are relatively constant (ESRI Inc., 2007). Four classes were also defined for individuals per unit effort (IPUE). Maps for each species, depicting these categories, were then created to determine whether there were key areas with a high number of sightings that have been corrected for the intensity of search effort.

4.5.7. Temporal sightings per unit effort

In order to determine whether SPUE exhibited changes throughout the year, the total number of sightings (overall and for each species) per 100 km effort, per month, was calculated using the following equation:

$$SPUE = (S_T / TL_{MT}) \times 100$$

where TL_{MT} is the total track length for a month.

This index provides a graphical representation of the relative abundance overall, and for a particular species in each month of the year (Findlay *et al.*, 1994; Mullin *et al.*, 1994; Keiper *et al.*, 2005). This was used to clarify whether species were more prevalent in the bay in certain months of the year (Elwen *et al.*, 2009). The overall mean SPUE was calculated by taking the average of all the SPUE for each month of the year and was displayed as a horizontal line on the graph (Keiper *et al.*, 2005; Barendse *et al.*, 2010).

4.5.8. Group dynamics and relative density

The total number of calves, juveniles and individuals were calculated for each species. Frequency of individuals was determined using the same equation as sighting frequency, to provide an indication of how often an individual from a particular species was observed (Baumgartner *et al.*, 2001; Bearzi *et al.*, 2009; Gilles *et al.*, 2009). The relative density of each species in Algoa Bay was also calculated using the following equation:

$$RD = I_T / TL_T$$

where RD is the relative density (Indiv.km^{-1}), I_T is the total number of individuals observed throughout survey and TL_T is the total length of tracks completed throughout survey (km).

4.5.9. Observed behaviour of the cetaceans

The predominant behaviour for each sighting was used to establish the behavioural budget for each species observed, both overall and per season. This was done by enumerating the number of times a particular behaviour occurred and dividing it by the total number of sightings for that species, to indicate how much time a species spends doing a particular activity compared to other behaviours (Bearzi *et al.*, 2009). As behavioural observations of 'mating' in bottlenose dolphins were often intermingled with other socialising activities, no differentiation was made, and the overall behaviour was assigned as 'socialising'. The behavioural budget was also extrapolated for each species per season.

4.5.10. Cetacean relative densities

Kernel density is an interpolation function which fits a smooth surface to each point (sighting) in order to visualise the density of sightings per unit area (Silverman, 1986; Fotheringham *et al.*, 2000). It is therefore an effective tool for determining key areas/ critical habitats, and to visualise trends over large areas (Bailey and Gatrell, 1995; Fotheringham *et al.*, 2000). Kernel density was estimated for each species using the Kernel density tool in ArcMap. This feature took into account the number of individuals in each sighting. An output cell size of approximately 130 map units and a search radius of 4 000 m were used to create the final raster features. These maps were then visually compared to the SPUE maps in order to determine whether certain areas of the bay had higher relative densities compared to others.

4.5.11. Sightings and environmental variables

Boxplots were created for several environmental parameters to determine the relationship between each species and a habitat type/ environmental parameter (Baumgartner *et al.*, 2001; Elwen *et al.*, 2009; Weir *et al.*, 2009). The bottom depth and SST recorded at each sighting was graphed as a boxplot in R with the median, upper and lower quartiles displayed as the box.

Whiskers represented the data within 1.5 times the inter-quartile range, and points were used to indicate any outliers. To determine the extent to which the results for the bottom depths were a construct of the depths surveyed, the distribution of depth classes covered during the survey, were calculated. This was done by overlaying the survey grid with the bathymetry. The number of cells within each depth class was totalled and multiplied by the total length of tracks within the depth class. The proportion of surveys conducted within each depth class was then graphed.

A boxplot was also created to elucidate the median and mean distance from land and from the nearest river, for each species. The distances were measured using the Spatial Join Analysis Tool in ArcMap by creating a spatial join between the species sightings and the Algoa Bay coastline. The match option "closest" was used to calculate the closest distance of each sighting, from the land or river (in kilometres). The relevant data was then tabulated and a boxplot was created.

A one-way ANOVA was then conducted on these environmental variables in R, to establish whether there was a significant difference in means of each of these variables, among the different species (Townend, 2003; McKillup, 2006). If a significant difference was found, a post-hoc Tukey HSD test was conducted to indicate which species had significant differences between their means (Moore *et al.*, 2000; Redfern *et al.*, 2006). The mean bottom depth and distance from land for humpback whale and southern right whale mother-calf pairs were also calculated and compared to the rest of the sightings for that species, using the Student's T-test.

Substrate data for Algoa Bay was only available in point data form. Thus, in order to determine what substrate each sighting was associated with, the point data layer was 'coded' by giving each substrate type a number, and then converted into thiessen polygons. Thiessen polygons contain one point within each polygon, with all points within the polygon being closer to that point than to the point of any other polygon (ESRI Inc., 2007). As the results were based on the best available data (with some large data gaps), the final sediment map was potentially not the most accurate representation of the sediment distribution on the sea floor.

The Spatial Join function was used to determine which sightings were associated with the different sea-floor substrates. The proportion of each type of bottom substrate for each species was then graphed and compared to the other species, to examine these associations (Bearzi and Politi, 1999; Allen *et al.*, 2001).

4.5.12. Sightings and anthropogenic variables

Four areas were defined for the shipping zones in Algoa Bay (see Figure 3.1). The two shipping approaches (channels) for each port were delineated and named the Port Elizabeth and Coega channels. Two anchoring areas also exist for these two ports: an inshore anchoring area and an offshore anchoring area, which have also been illustrated in Figure 3.1. To determine the number of sightings for each species that were found in each of these zones (and thus indicate potential areas of conflict), the Intersect Analysis tool was used to establish which observations were attributed to each of these zones. The proportion of sightings for each species within a zone was then extrapolated and graphed.

As mentioned previously, mysticetes are known to select certain areas along the subtropical and tropical coastline during austral winter, to breed and calve (Shane *et al.*, 1986; Ingram and Rogan, 2002). Thus, there are potentially certain areas within Algoa Bay that are particularly suited to these groups of animals. The number of mysticete calves and juveniles found both within and outside the proposed GAENP MPA was therefore calculated using the Intersect Analysis tool, between the sightings layer and the proposed MPA polygon layer. The purpose was to illustrate the potential importance of this proposed MPA in protecting these more 'vulnerable' individuals in the cetacean population.

4.6. SIGHTING RATE AND RELATIVE ABUNDANCE MODELLING

Statistical models are a set of probability distributions (in the form of mathematical equations) that describe the relationship between a set of independent and dependent variables (McCullagh, 2002). Thus, these models can be used to explain animal population distribution patterns (Barry and Welsh, 2002). In addition to GIS techniques which were used to display spatial and temporal distribution patterns, statistical models were used to further explain the relationship of the different cetacean species to their surrounding environment. The first step to understanding these relationships was to perform exploratory data analysis using descriptive statistics and visualising the data. After which, several variables were further analysed using Generalised Additive Models (GAMs), Generalised Linear Models (GLMs) and Zero-altered conditional models, also known as hurdle models.

4.6.1. Exploratory data analysis

Pairwise-scatterplots were constructed in R to investigate possible relationships between the presence of the different cetacean species and the geographical/ environmental factors in Algoa Bay (Swartzman *et al.*, 1994; Fotheringham *et al.*, 2000; McKillup, 2006). Variables included group size, Beaufort sea state, SST, bottom depth, seasonality, distance from land, and distance from the nearest river. Seasonality, being cyclic, was included in the models using the angular transformation of the month of the year (January = 0, December = 11) in the form sin ($\pi \times$ month/12) and cos ($\pi \times$ month/12). Both trigonometric identities were required to determine the peak of the cycle (the month of the year).

4.6.2. Generalised models

Statistically significant correlations identified in the scatterplots were further analysed using both GAMs and GLMs to gain ecological insight into the relationship between the response variable and the selected explanatory variables (Becker *et al.*, 2010).

GLMs are an extension of linear models with greater flexibility, which allows for non-constant variance structures in the data and any error structure within the exponential family of distributions (Nelder and Wedderburn, 1972; Redfern *et al.*, 2006; Becker *et al.*, 2010). In GLMs, the linear model is to be related to the response variable, *y*, via a link function, $\eta(\cdot)$, and is modelled as a sum of the explanatory variables ($x_1, x_2, \ldots, x_p$) each corresponding to linear coefficient ($\beta_1, \beta_2, \ldots, \beta_k$) , such that:

$$\eta(y) = \mu = \alpha + \sum_{i=1}^{k} \beta_i x_i$$

GAMs are non-parametric extensions of GLMs (Hastie and Tibshirani, 1990) in that the linear coefficients are replaced by any parametric or non-parametric function, denoted as $f_i(\cdot)$, of the explanatory variables such that:

$$\eta(y) = \mu = \alpha + \sum_{i=1}^{k} f_i(x_i)$$

A distinct advantage of using GAMs over GLMs is that GAMs have the ability to deal with non-linear and non-parametric relationships between the response and explanatory variables (Hastie and Tibshirani, 1987; Hastie and Tibshirani, 1990; Guisan *et al.*, 2002; Agenbag *et al.*, 2003). In both GLMs and GAMs, the coefficients are estimated by minimising the appropriate negated log-likelihood function, $\ln L$. Akaike's Information Criterion (AIC: Akaike, 1973) was used in the GLMs and GAMs as the basis for selecting the most parsimonious model that explained the most variance with the fewest number of parameters. Thus, linear, polynomials (second through forth order) denoted as $poly(\cdot)$, and smoothing splines denoted as $s(\cdot)$, were included in a stepwise forward/backward variable selection procedure. The most parsimonious model had the lowest AIC. A χ^2 test, indicated the importance of the effect of each of the explanatory variables in the final model (McKillup, 2006). To determine the fit of the model, a pseudo-coefficient of determination was calculated using the following equation:

$$\text{Pseudo} - R^2 = 1 - \frac{\text{Residual deviance}}{\text{Null deviance}}$$

where $\text{residual deviance} = \sum_{i=1}^{n} \left[\ln L(\mu_i; y_i) - \ln L(y_i; y_i)\right]$ and

$$\text{null deviance} = \sum_{i=1}^{n} \left[\ln L(\mu_i; \bar{y}) - \ln L(y_i; y_i)\right]$$

with y_i being the observed response, $\bar{y}$ the mean response and μ_i the model predicted response.

This value, which falls between zero and one, is used as a substitute for the classical R^2, with a good fit defined by a small overall residual deviance (Swartzman *et al.*, 1994; Millar, 2000; Maunder and Punt, 2004). Due to the large number of zeros in count data, a Poisson distribution was used in the GAM models (Millar, 2000; Becker *et al.*, 2010).

Five explanatory variables were considered for all the analyses in order to construct parsimonious models. The selection of variables was based on existing literature, data availability and data limitations. Consequently, the explanatory variables used were Beaufort sea state, SST, depth and seasonality in the form of the two trigonometric identities.

4.6.3. Hurdle models

A characteristic feature of animal abundance/ occurrence data, is that it is often zero-inflated when the data contains more zeros than would be expected (Barry and Welsh, 2002; Zuur *et al.*, 2009). Thus, to empirically model such data, it has been suggested that the data are modelled using zero-altered conditional models (Mullahy, 1986; Welsh *et al.*, 1996; Zuur *et al.*, 2009).

Zero-altered conditional models, also known as hurdle models, are two-component GLMs. The first component models the presence/ absence of a species using the whole dataset with a binomial GLM (Mullahy, 1986; Welsh *et al.*, 1996). The second component determines the magnitude of the presence data from the positive values in the dataset (Gurmu, 1997; Dalrymple *et al.*, 2003; Cunningham and Lindenmayer, 2005). The hurdle model defines each observation's contribution to the likelihood as:

$$\Pr(Y = y) = \begin{cases} \pi_0 & y = 0 \\ (1 - \pi_0)\dfrac{f(y)}{1 - f(0)} & y > 0 \end{cases}$$

where $f(y)$ and $f(0)$ are the probabilities, from an appropriate probability density function for a positive and zero observation, respectively. The denominator, $1 - f(0)$, conditions the probability to observing at least one animal. In this study, a negative binomial probability density function was used to account for possible over-dispersion of the data (Cunningham and Lindenmayer, 2005; Bilgic and Florkowski, 2007; Zuur *et al.*, 2009).

Hurdle models have the advantage that they can take two ecological processes into account that could influence cetacean distribution and relative abundance in the bay. The first process is presence-absence, and the second, if cetaceans are present, what is the mean abundance. A stepwise procedure, as applied to a GLM or a GAM, was used to determine which predictor variables were significant.

4.7. DEFINING KEY HABITATS FOR CETACEANS IN ALGOA BAY

The fifth objective is to produce a set of recommendations and guidelines for management. To achieve this objective it is necessary to define potential key habitats for the cetaceans in Algoa Bay. The term 'key habitats' was used to identify areas that were *potential* critical habitats, however, more long-term data would be needed to verify this. Important locations and activities have already been identified as mother-calf pair sightings for the mysticetes, and key behaviours (mating, resting and foraging) for all cetacean species. Thus, this data was combined to determine the location of the key habitats.

Each point (representing a location of one of these important locations and activities) was assigned a value of 'one'. This data were then converted into a raster feature, with a cell resolution of one kilometre for both mysticetes and odontocetes. The value of each cell was then determined by the total number of key behaviours, or the number of mother-calf pairs, in each cell. These cells were then combined using the Raster Calculator in Spatial Analyst (with equal weightings). In order to display areas where these habitats were located, the raster layer was converted back into a shape file. A map was then created illustrating the positions of these key habitats over a kernel density map for mysticetes and odontocetes. The two kernel density layers were reclassified into six classes, with the top two classes representing areas of highest density, in order to easily visualise these areas. As a result, the final maps provided an indication of areas where there was a high density of sightings, as well as indicating whether these areas were places that were utilised for important activities such as foraging, resting or calving.

4.8. CONCLUSION

This chapter examined the various methods applied in conducting this research, and the analyses applied to the data. The approaches used in this study provided the means of achieving the objectives set out in Chapter One, the results of which are detailed in the following chapter. Based on these results, key habitats in Algoa Bay are defined in Chapter Six, which will be used to formulate appropriate recommendations for future research, conservation and management strategies in Chapter Seven.

CHAPTER 5: RESULTS

5.1. INTRODUCTION

The findings of this research, conducted in Algoa Bay between March 2009 and July 2010, are presented in this chapter. An overview of the baseline data collected in the study, which was used for further data analysis, is addressed at the outset. A large portion of the chapter is dedicated to the spatial and temporal distribution of the cetaceans in Algoa Bay, and is represented in graphical and cartographic format. The sightings per unit effort (SPUE) and behaviour is provided, in order to further explain the spatial and temporal differences in the sighting rates for each species. Density maps are also displayed. The sightings are subsequently compared to some geographical and anthropogenic variables, forming a foundation for the explanatory modelling of cetacean distribution. These results are then used to establish key habitats for each of the cetacean species in the bay.

5.2. OVERVIEW OF ENVIRONMENTAL PARAMETERS RECORDED

The mean sea state for the study period was Beaufort two ('on' and 'off effort'), with no overall trend observed in the sea state over the study period (Figure 5.1). An increase in cloud cover was generally associated with calmer conditions, and therefore a slight decrease in sea state, this being most common in the summer months (Figure 5.1).

Fluctuations in sea surface temperatures (SST) corresponded with changes in seasons, with 22.5 ^{o}C recorded during March (after summer) and the lowest mean temperature of 16.8 ^{o}C during July (during winter) (Figure 5.2). The mean SST for the duration of the study was 19.2 ^{o}C.

5.3. SEARCH EFFORT

Dedicated boat-based surveys were conducted in Algoa Bay on 57 days between March 2009 and July 2010. Overall, 365 hours were spent at sea, of which 291 hours were spent 'on effort'. A sum total of 2 866 km of tracks were completed during this period. These were predominantly carried out in the western half of the bay between Cape Recife and St Croix Island (Figure 5.3). In addition, surveys were carried out along the Alexandria Dunefield coastline (between Bird Island and Sundays River) (Figure 5.3).

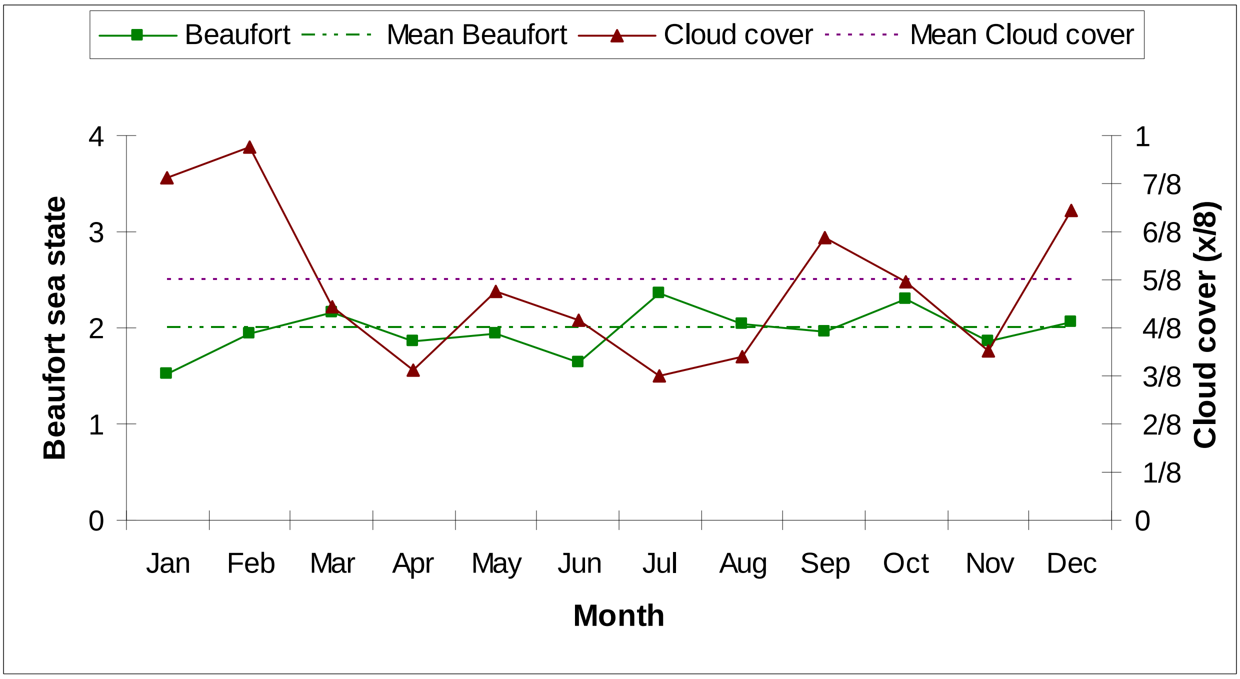

Figure 5.1. Beaufort sea state and cloud cover measured at sea for the duration of the study. Dashed lines represent the mean sea state (Beaufort 2) and cloud cover (5/8).

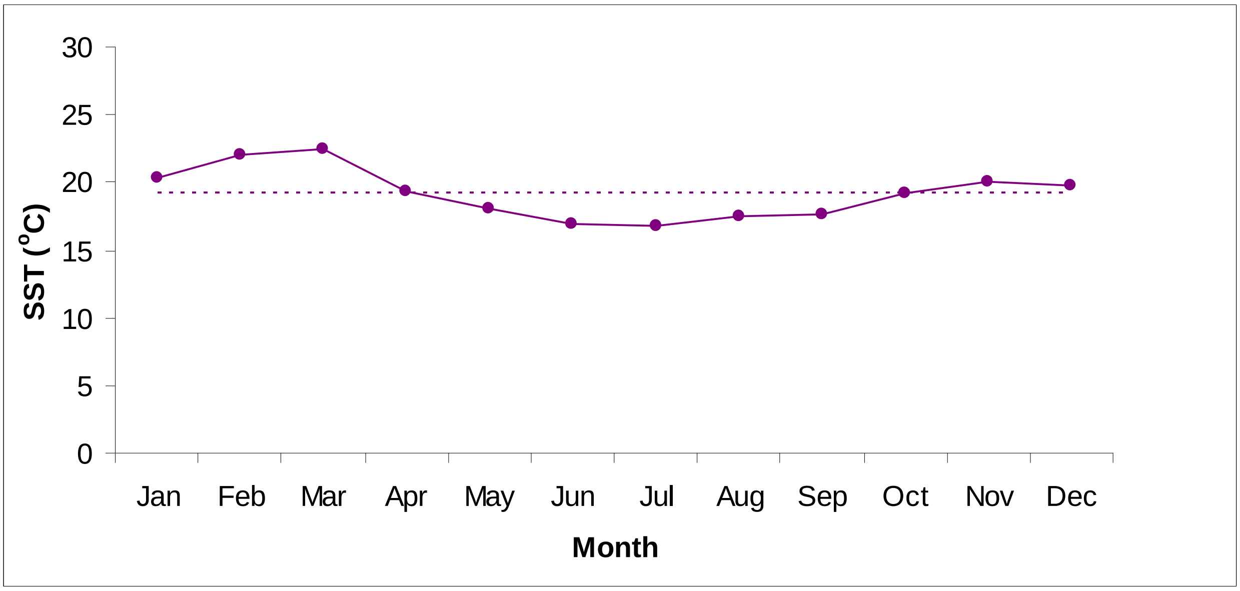

Figure 5.2. Sea surface temperature (SST) recorded at sea for the duration of the study. Dashed line represents the overall mean SST of 19.2 ^{o}C.

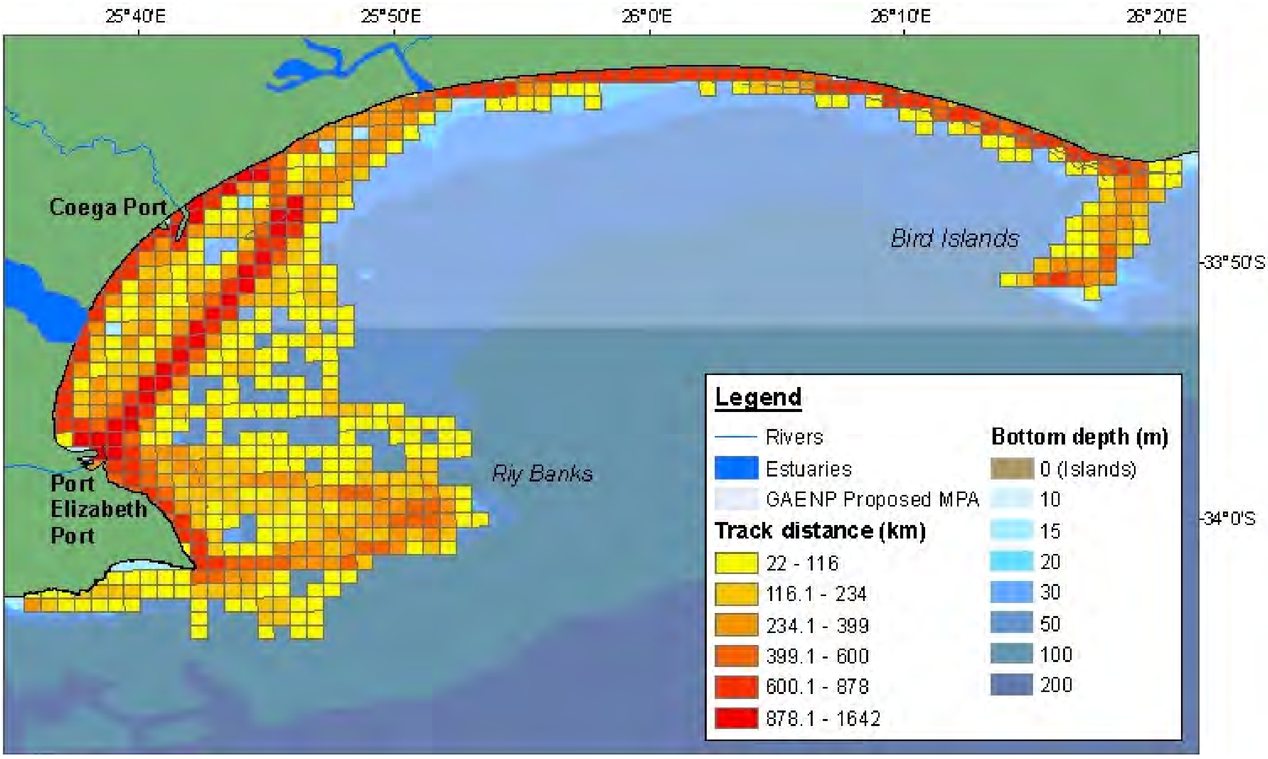

Figure 5.3. Survey tracks completed during boat-based surveys. A one square kilometre grid was used, displaying the total distance of tracks covered within each block, to illustrate intensity of effort. Track distance also includes the paths covered in sightings. Moran's I test detected no spatial autocorrelation ($p < 0.05$).

5.4. CETACEAN SIGHTINGS

5.4.1. Overview of sightings

Cetaceans were sighted 353 times in Algoa Bay; six sightings were of unidentified whales, and one sighting of an unidentified dolphin, a total of 346 confirmed sightings (Table 5.1). Six species were observed over 67 hours of search effort (Table 5.1). The most common species observed were the bottlenose dolphin (odontocete) and the humpback whale (mysticete) (Table 5.1). The other cetaceans observed in the bay were two mysticete species, the southern right whale and the Bryde's whale, and two odontocete species, the humpback dolphin and common dolphin (Table 5.1).

Opportunistic sightings were collected during the same time period as the dedicated boat-based surveys. This data came from both shore-based and boat-based observations with a total of 308 sightings comprised of the same six cetacean species (Table 5.1). The most common species observed opportunistically was the bottlenose dolphin followed by the humpback whale (Table 5.1).

Table 5.1. Summary of sightings for the six cetacean species observed in Algoa Bay. The results are based on the dedicated boat-based surveys unless otherwise stated.

Species	Total opportun-istic. sightings	Total survey sightings	Sightings per survey	Sighting frequency ($S.hr^{-1}$)	Mean group size (min/max)	Total time (hh:mm)	Mean time per sighting (hh:mm)
Southern right whale	35	37	0.65	0.13	2.4 (1/8)	09:01	00:15
Humpback whale	44	64	1.12	0.22	2.3 (1/6)	14:10	00:14
Bryde's whale	7	27	0.47	0.09	1.2 (1/2)	05:41	00:18
Bottlenose dolphin	192	183	3.21	0.63	57.8 (1/500)	28:13	00:09
Humpback dolphin	22	28	0.49	0.10	3.3 (1/23)	07:58	00:17
Common dolphin	8	7	0.18	0.03	343.0 (1/800)	02:02	00:17
Total (Mean)	**308**	**346**	**6.12 (1.02)**	**1.20 (0.20)**		**67:05**	**(00:15)**

The mean number of sightings, the sighting frequency, and the total number of sightings per survey, provide an indication of the prevalence of each of the species (Table 5.1). Bottlenose dolphins were sighted most frequently, with a high number of sightings also recorded for humpback whales. The least common species observed was the common dolphin which was seen approximately once every eight surveys.

Group sizes varied extensively among the different species, with common dolphins having the largest groups, with a mean of 343 individuals per sighting (Table 5.1). Groups as large as 500 to 800 animals were observed in bait balls. On two occasions a single common dolphin was seen within a group of bottlenose dolphins, and thus was not included in this group average. Bottlenose dolphins had widely ranging group sizes between one and 500 individuals (Table 5.1). Small groups of one to eight humpback dolphins were observed, with the exception of one sighting consisting of 23 individuals in June 2010 (Table 5.1).

Mysticetes had smaller group sizes as compared to the odontocetes (Table 5.1). Bryde's whales were generally observed singularly, with groups of two to three individuals seen in humpback whales and southern right whales (Table 5.1). Larger groups of up to eight southern right whales were recorded during mating or surface active groups (SAGs). Maps of the spatial pattern of group sizes for each species were created. However, these maps did not show any discernable patterns and are therefore found in Appendix Three.

5.4.2. Spatial distribution of sightings

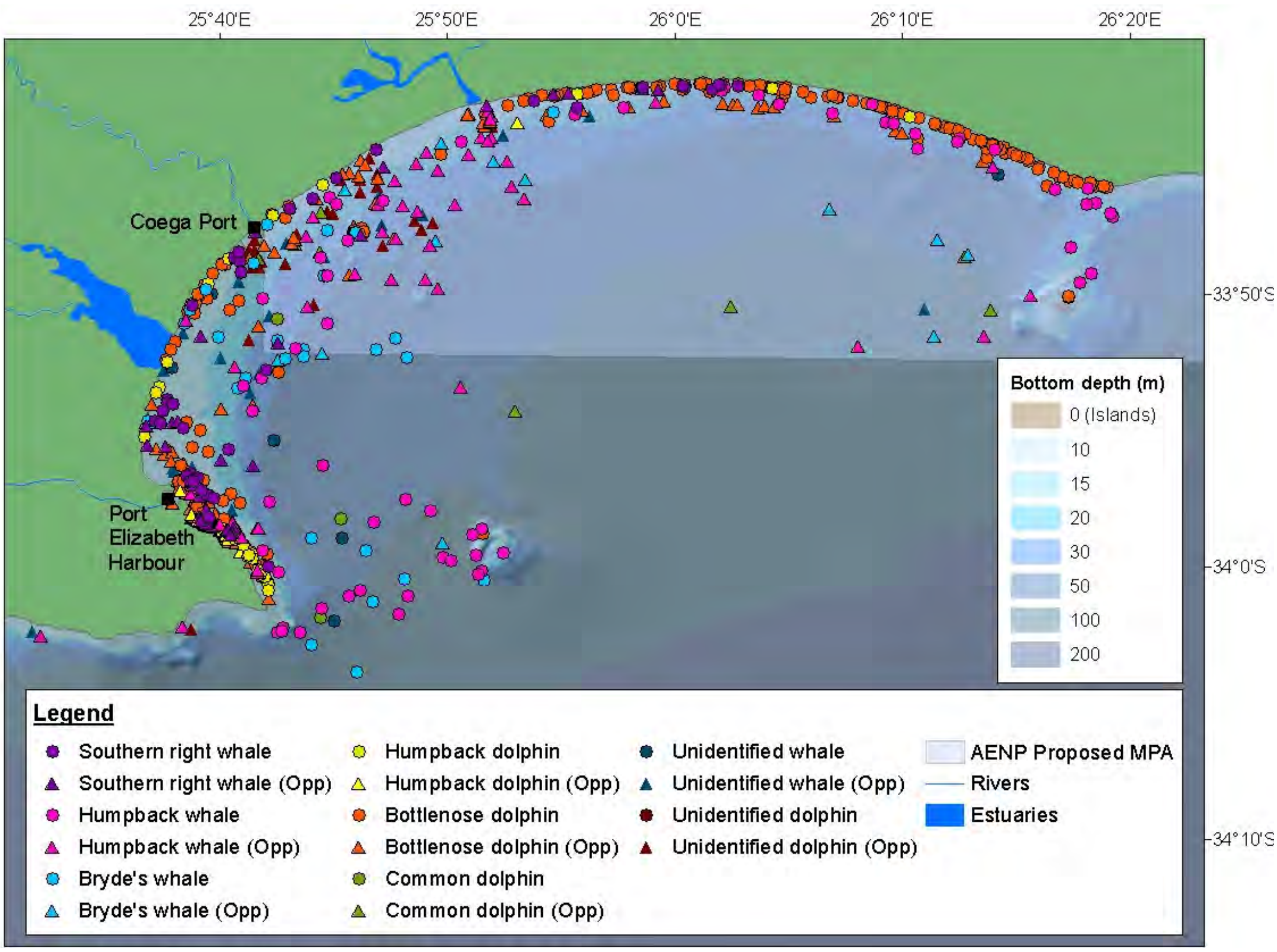

Figure 5.4. Sightings in Algoa Bay between March 2009 and July 2010. Sightings observed opportunistically are also displayed.

Cetaceans were sighted throughout the survey area (Figure 5.4). Opportunistic sightings illustrate similar distribution patterns, with mysticetes also observed in areas not covered by the survey, i.e. offshore of the Alexandria Dunefield (between PE Port and Bird Islands) (Figure 5.4). Cetacean sightings were associated with all major geographical features of the bay, including rivers/

estuaries, the two ports, Riy Banks, and the two island groups. Moreover, a large number of sightings were located in the area that corresponds with the proposed GAENP MPA (Figure 5.4). There was a notable lack of sightings along a stretch of coastline west of the Sundays River (Figure 5.4).

Southern right whales were sighted in the sheltered, inshore areas of Algoa Bay between PE Port and past the Sundays River (Figure 5.5). Only one sighting was observed in the rocky shore area of Cape Recife, and no southern right whales were seen beyond 26.05 ^{o}E. These animals appeared to avoid the areas around Swartkops and Sundays estuaries, with the majority of sightings found south of the Swartkops River, especially around PE Port.

Humpback whales were recorded throughout the survey area, including Riy banks, and the two island groups (Figure 5.5). A number of inshore sightings were observed between PE Port and Cape Recife, and off the Alexandria Dunefield coastline. In contrast to southern right whales, no sightings were seen in the inshore area between the two ports. The opportunistic sightings of humpback whales further illustrated that this species occurred in the offshore area between PE Port and the Bird Islands.

Bryde's whales were predominantly observed in the offshore areas of the western half of the bay, with opportunistic sightings recorded offshore of the Alexandria Dunefield and the Bird Islands (Figure 5.5). Unlike humpback whales, Bryde's whales were not closely associated with the island groups or Riy Banks. Four inshore sightings of Bryde's whales were recorded between Swartkops River and Coega Port, and a large portion of offshore sightings were located seawards of the same area.

Bottlenose dolphins were observed extensively in the inshore areas of Algoa Bay (Figure 5.5). The majority of sightings were recorded between PE Port and Cape Recife, and along the Alexandria Dunefield (beyond Sundays River). Two sighting gaps were observed between PE Port and Swartkops River, and between Coega Port and Sundays River. However, some opportunistic sightings were recorded between Coega Port and north of St Croix. Sightings were also observed around the reef and islands.

Humpback dolphins showed a similar distribution pattern to southern right whales. However, all sightings were exclusively located in the shallow, inshore waters of the bay (Figure 5.5). The majority of sightings were observed in the rocky shore area between PE Port and Cape Recife. In contrast to other species, humpback dolphins were also frequently sighted on either side of the Swartkops River.

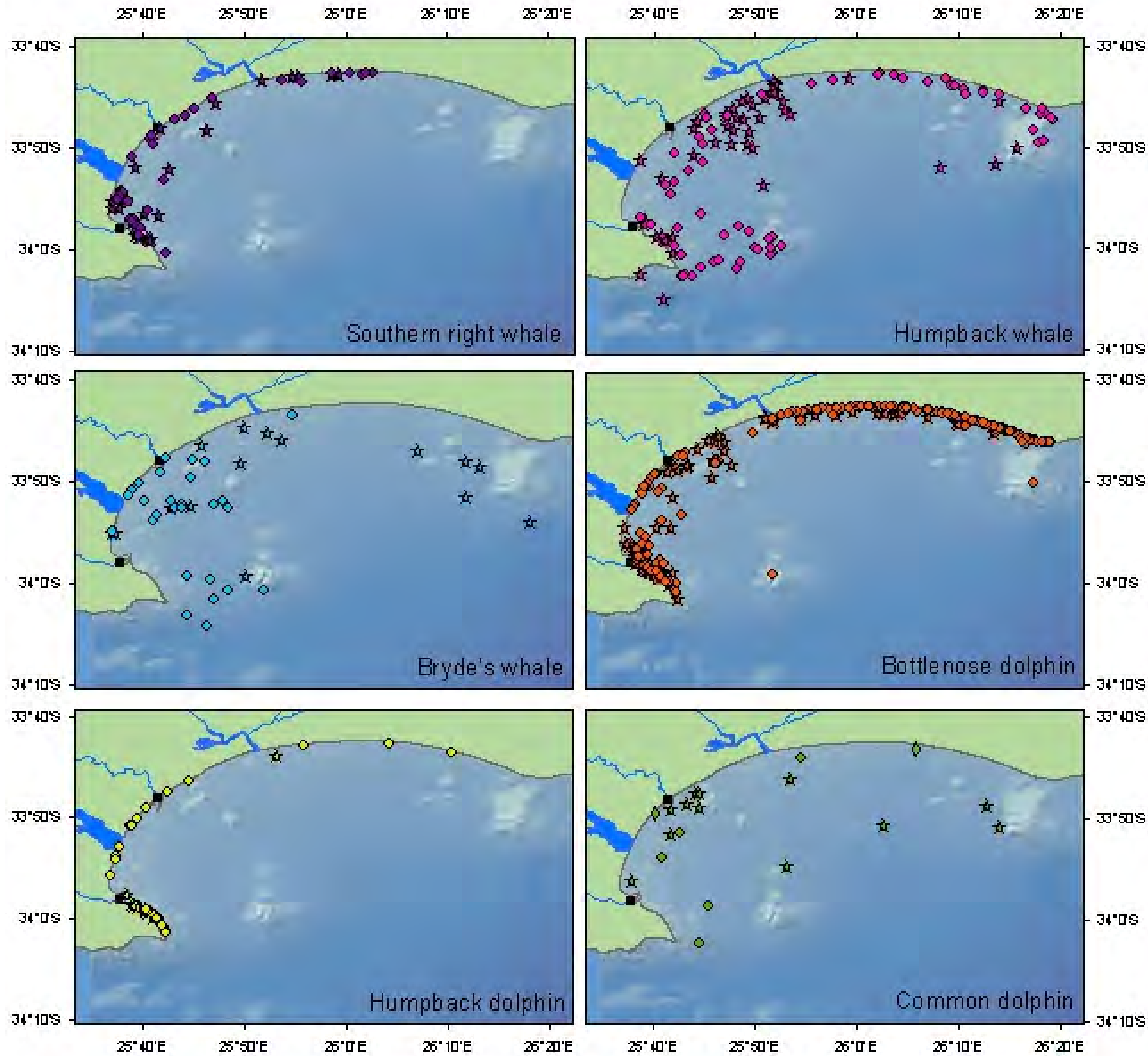

Figure 5.5. Distribution of sightings for each species observed in Algoa Bay March 2009 to July 2010. Data collected during dedicated boat-based surveys is represented by circles and opportunistic data with stars.

Common dolphins were not often sighted in Algoa Bay. This species was observed in the offshore and exposed areas of Algoa Bay, with opportunistic sightings recorded around St Croix and in the offshore areas of the eastern half of the bay (Figure 5.5). Two sightings of a single common dolphin were briefly observed off the Alexandria Dunefield and east of Coega Port within a large group of bottlenose dolphins. Due to the brevity of these sightings, and without genetic sampling, it was not established whether these two animals were common dolphins or hybrids, and for this reason, were excluded from further data analysis.

5.4.3. Spatial sightings per unit effort (SPUE)

The following maps illustrate the spatial distribution of sightings, corrected for search effort, providing a more meaningful indication of potential key areas for the cetaceans in Algoa Bay. Maps of the number of individuals per unit effort (IPUE) were also created, but as they illustrated similar trends to the SPUE maps, they are not shown in the result but are included in Appendix Four.

Overall, there was no significant pattern of the cetacean SPUE, although a slightly higher cetacean SPUE was found along the rocky shores south of PE Port and along the coast east of 26^{o}12’ E (Figure 5.6). High SPUE were found in some offshore areas, where search effort was comparatively lower than the coastal areas. Despite a relatively high search effort along the coastline between the PE Port and Sundays River, the cetacean SPUE was low in this area, especially between Coega Port and Sundays River (Figure 5.6). Riy Banks, St Croix Island and the Bird Islands all had a medium SPUE.

The highest SPUE of southern right whales was recorded south of the Swartkops River (Figure 5.7). Humpback whales showed no distinct pattern of high and low SPUE areas. However, lower SPUE areas did appear to be located further inshore, while higher SPUE areas were observed offshore (Figure 5.8). Higher SPUE areas were also recorded closer to land along the Alexandria Dunefield coastline compared to the western side of Algoa Bay (Figure 5.8). Bryde’s whales, like humpback whales, had a higher number of SPUE in the offshore survey areas (at bottom depths greater than 30 m), with the highest SPUE for Bryde’s whales illustrated in a group of three high cells located offshore of St Croix Island and Swartkops River (Figure 5.9). Low Bryde’s whale SPUE areas were observed along the coastline between PE and Coega Port (Figure 5.9).

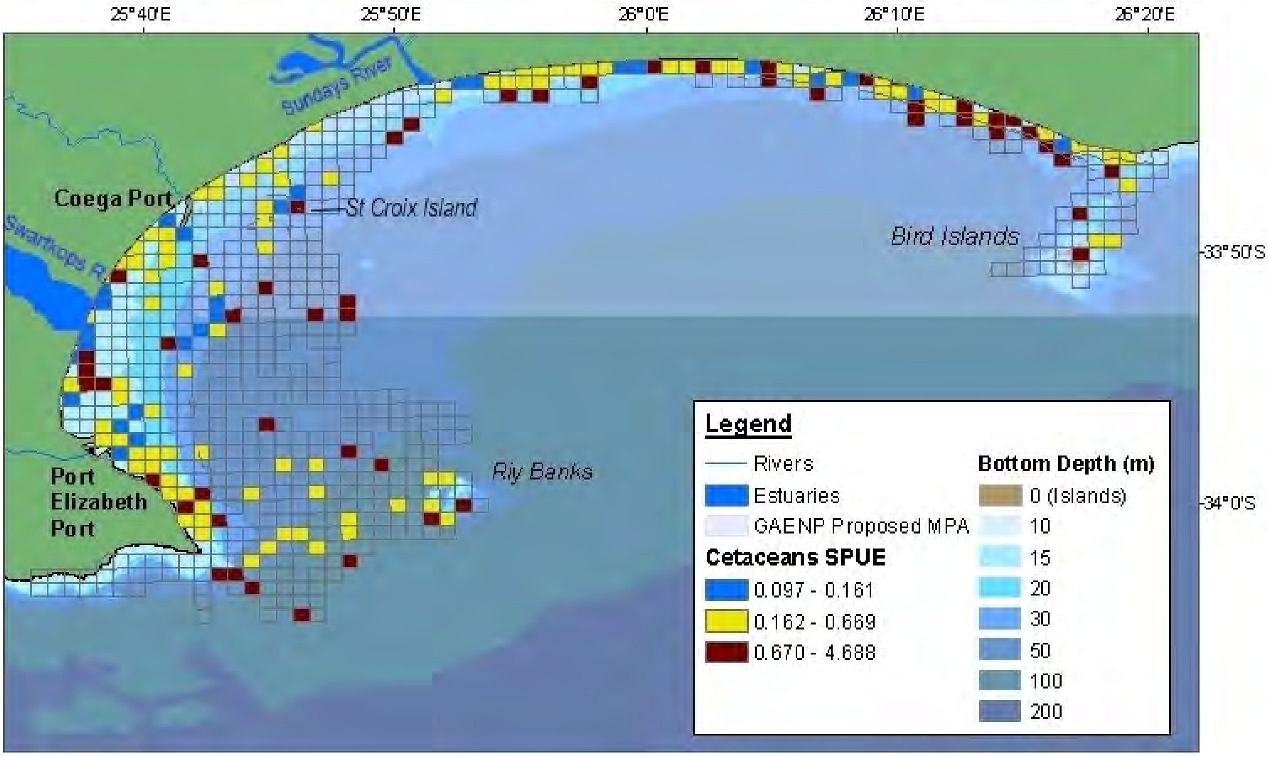

Figure 5.6. Spatial distribution of cetacean SPUE. Four levels of cells were used: empty cells, where search effort was carried out without any sightings recorded, and three coloured cells to represent low, medium and a high SPUE. Note: low, medium and high SPUE is a relative value defined for each species and is therefore not directly comparable across the different species.

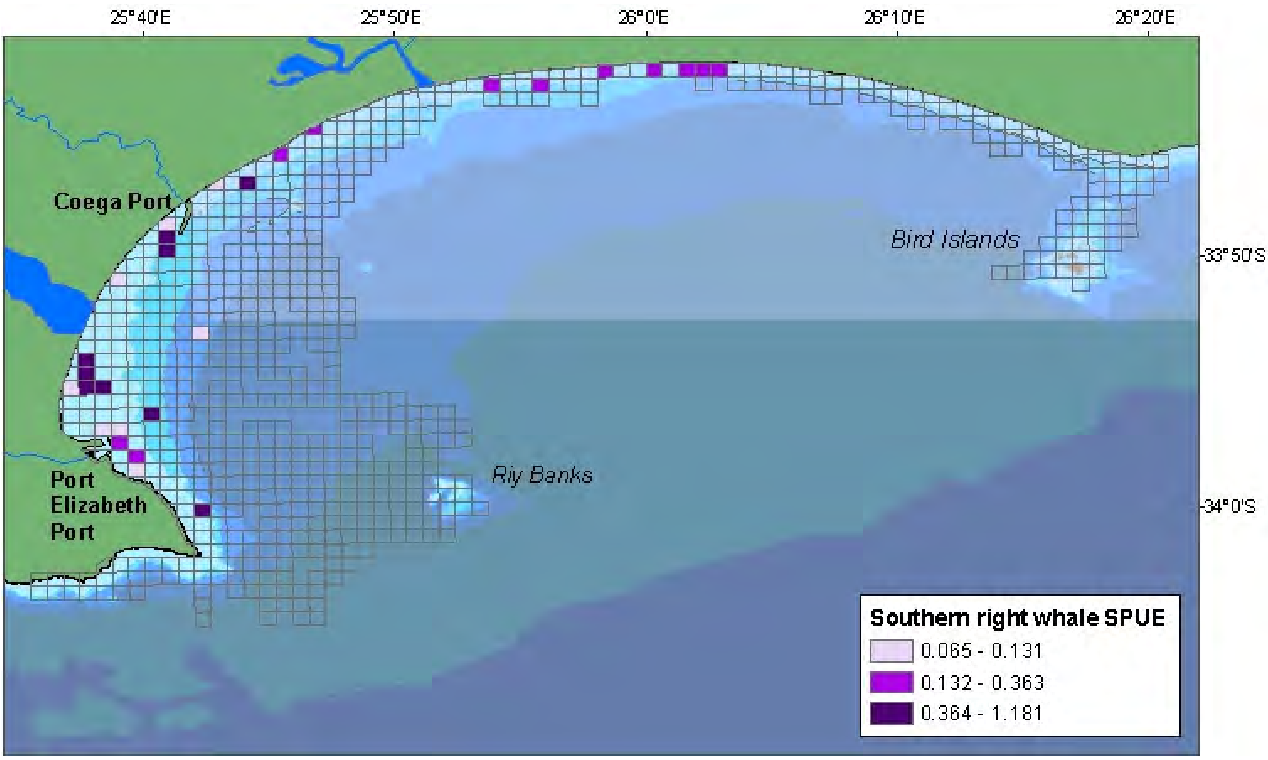

Figure 5.7. Spatial distribution of southern right whale SPUE.

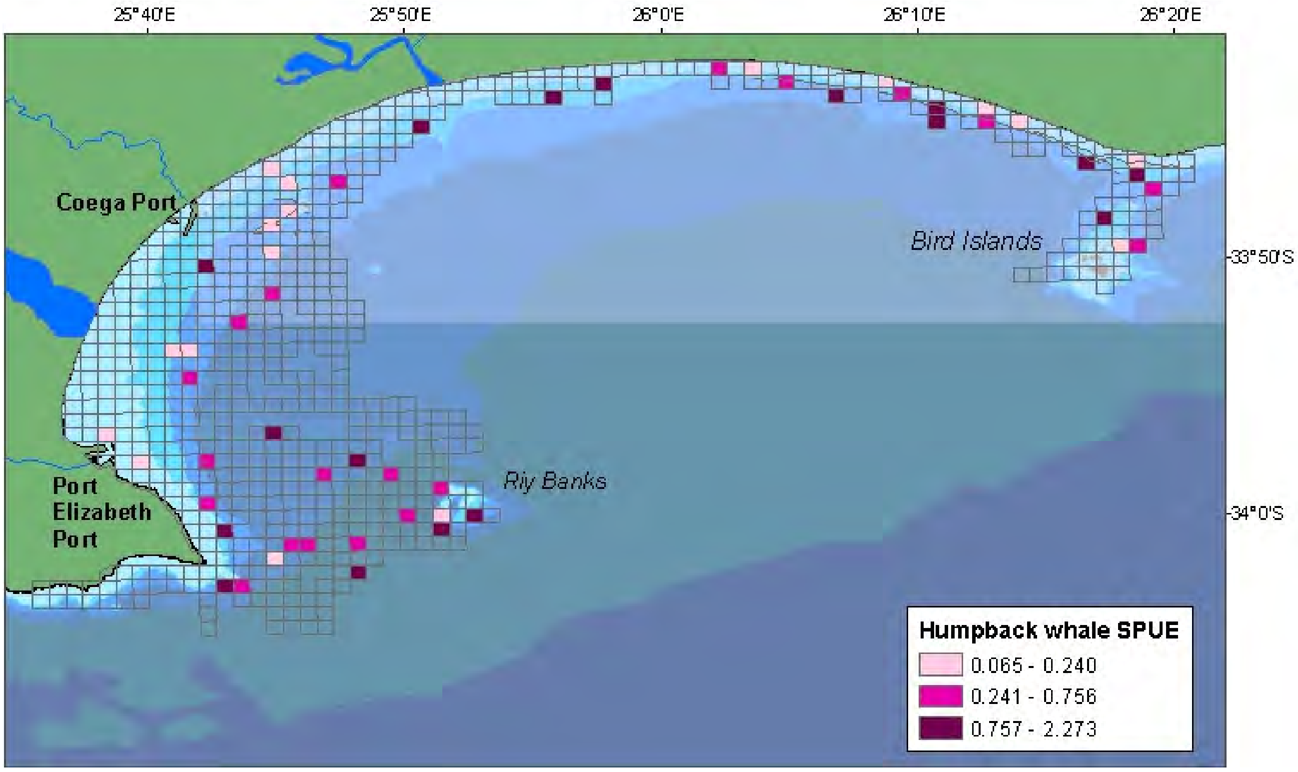

Figure 5.8. Spatial distribution of humpback whale SPUE.

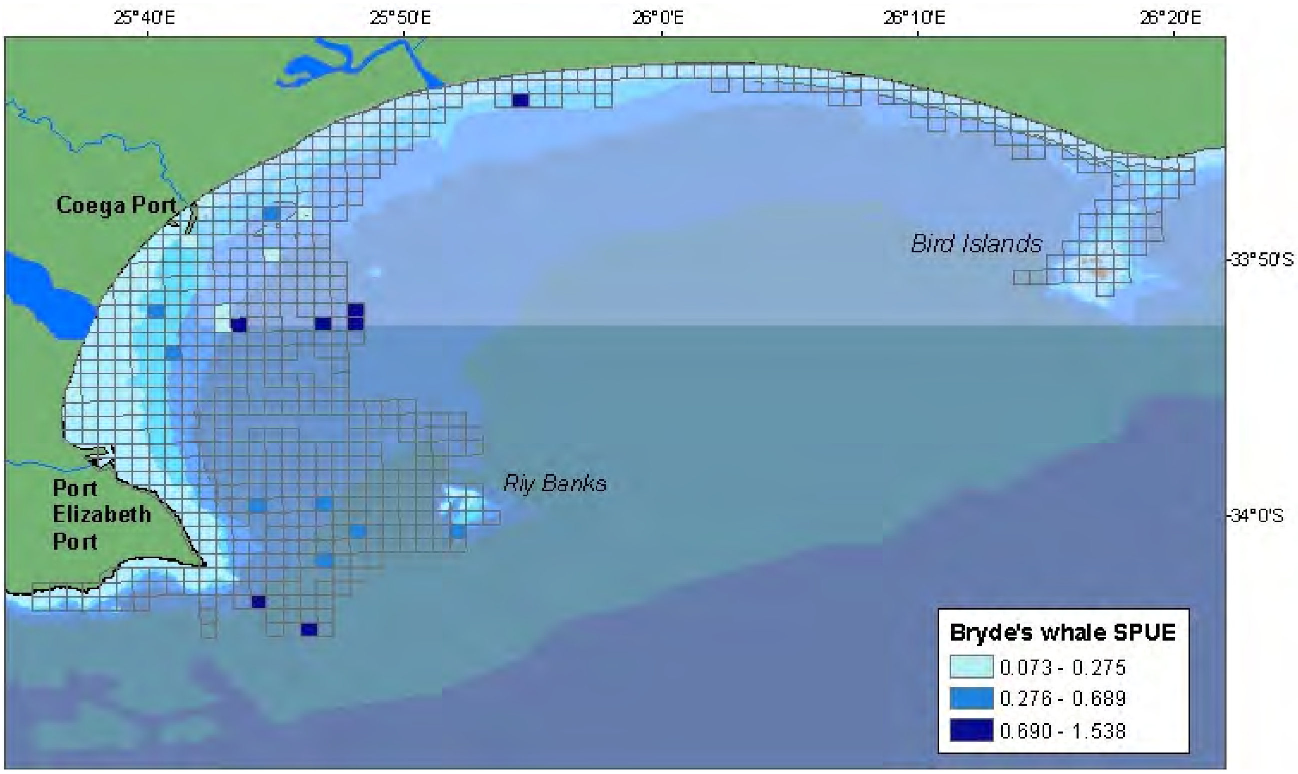

Figure 5.9. Spatial distribution of Bryde's whale SPUE.

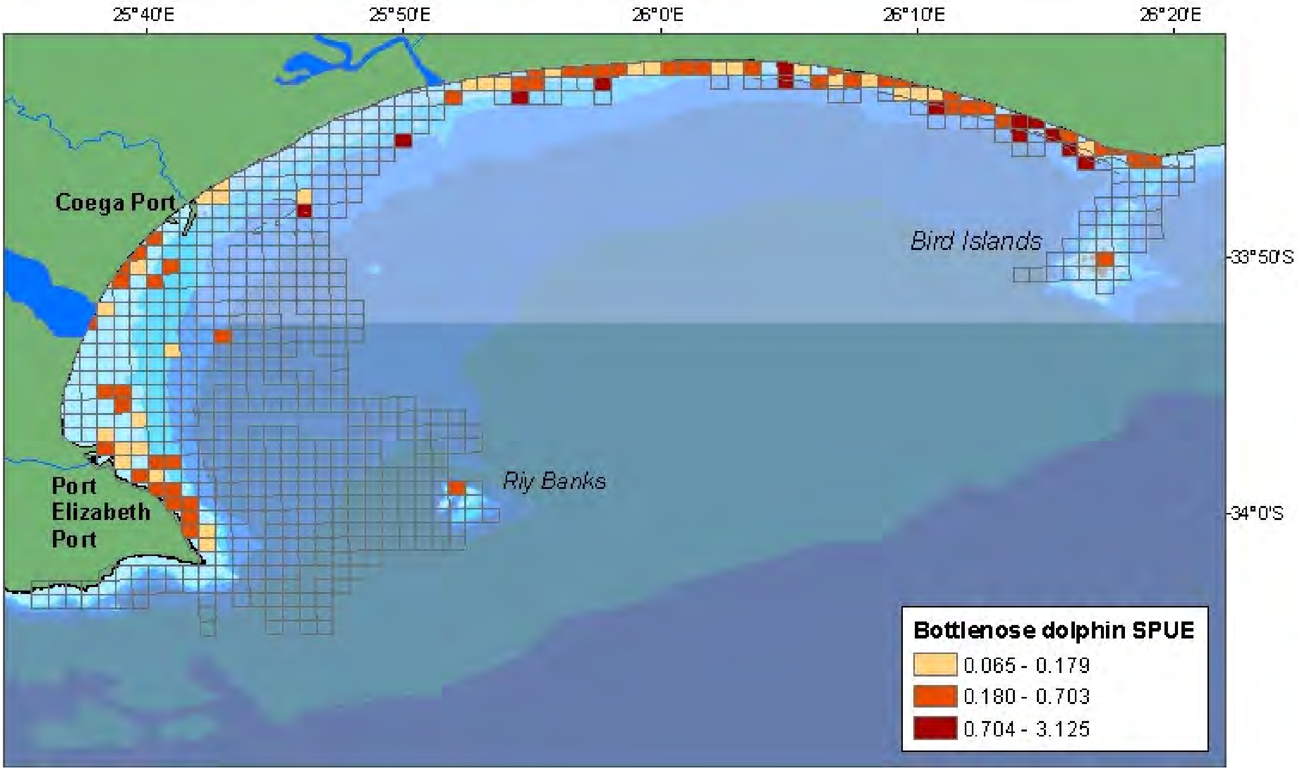

Figure 5.10. Spatial distribution of bottlenose dolphin SPUE.

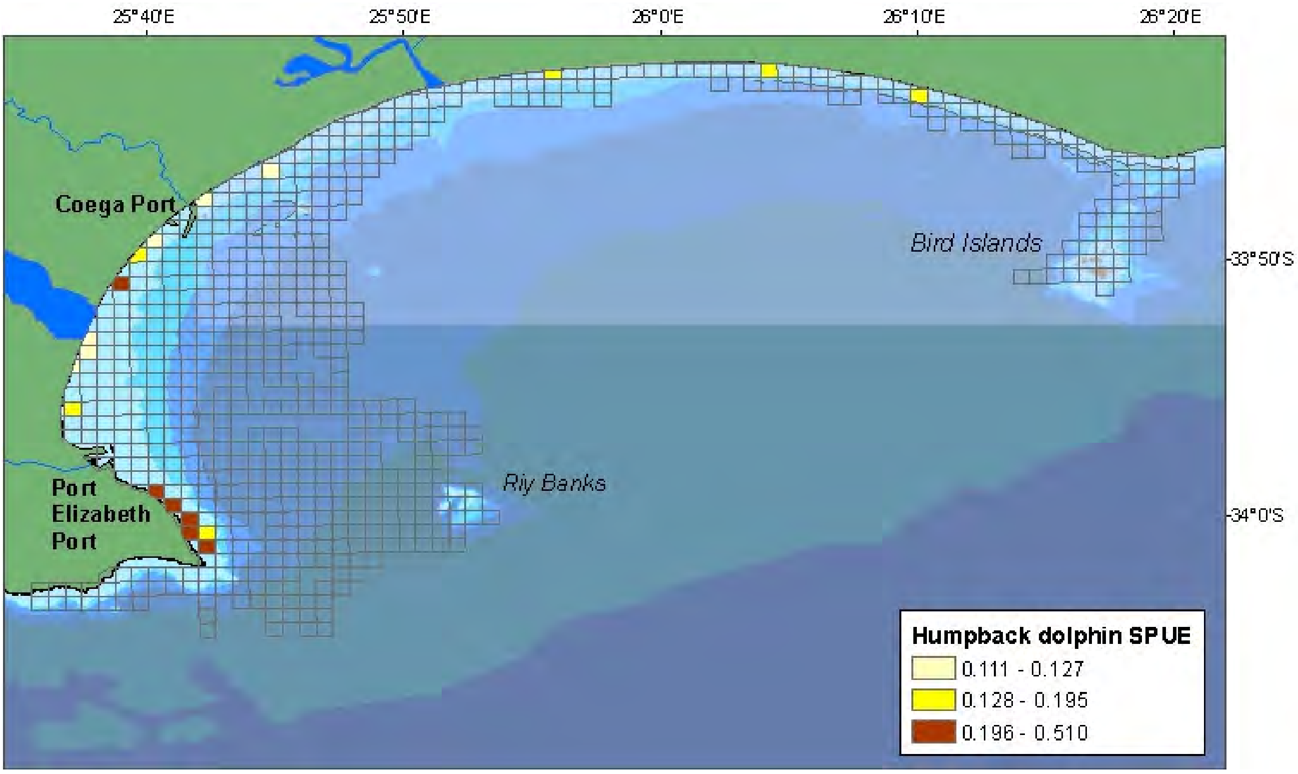

Figure 5.11. Spatial distribution of humpback dolphin SPUE.

Bottlenose dolphins were seen in relatively high numbers in the coastal areas of Algoa Bay, with the highest SPUE for this species observed east of Sundays River (Figure 5.10). The higher SPUE for humpback dolphins were found south of PE Port, with low SPUE seen throughout the rest of their range in Algoa Bay (Figure 5.11). Due to the low number of common dolphin sightings, a SPUE map for this species was not created.

5.4.4. Temporal sightings per unit effort (SPUE)

Search effort varied during the study period depending on the environmental conditions, with a mean distance of 169 km per month, ranging from 314 km in April 2009 to only 41 km in July 2009 (Figure 5.12). On average 8.6 sightings were observed every 100 km, with a distinct peak in sightings occurring in October 2009 (21.1 SPUE) and June 2010 (27.3 SPUE), with July 2009, November 2009 and February 2010 also having an above average SPUE (Figure 5.12). The lowest number of sightings observed occurred in March and June 2009.

The seasonality of sightings was displayed per month so that the arrival and departure of the two migratory whale species could be more accurately displayed. Southern right whales had an annual mean of 1.3 SPUE (Figure 5.13). This species was first sighted in the bay in winter (August 2009 and June 2010), with a peak in sightings in October (spring) of 9.6 SPUE. No sightings of southern right whales were observed in summer and early autumn.

Humpback whales showed a similar seasonal distribution pattern to southern right whales. They were first observed in Algoa Bay from late May, with an average winter peak SPUE of 2.8 in June (Figure 5.13). After which there was a decline in numbers for the rest of winter/ early spring. A sharp rise in numbers was seen in November and December, with a SPUE of 10.2 and 10.7 respectively. The mean SPUE for humpback whales was 1.9 throughout the year.

Bryde's whales were seen year-round in Algoa Bay, with the exception of late winter and spring (July to November) (Figure 5.13). High numbers were observed in autumn, with the highest SPUE of 3.4 and 3.3 occurring in May 2009 and June 2010 respectively. Bryde's whales had a mean SPUE of one for the duration of the study.

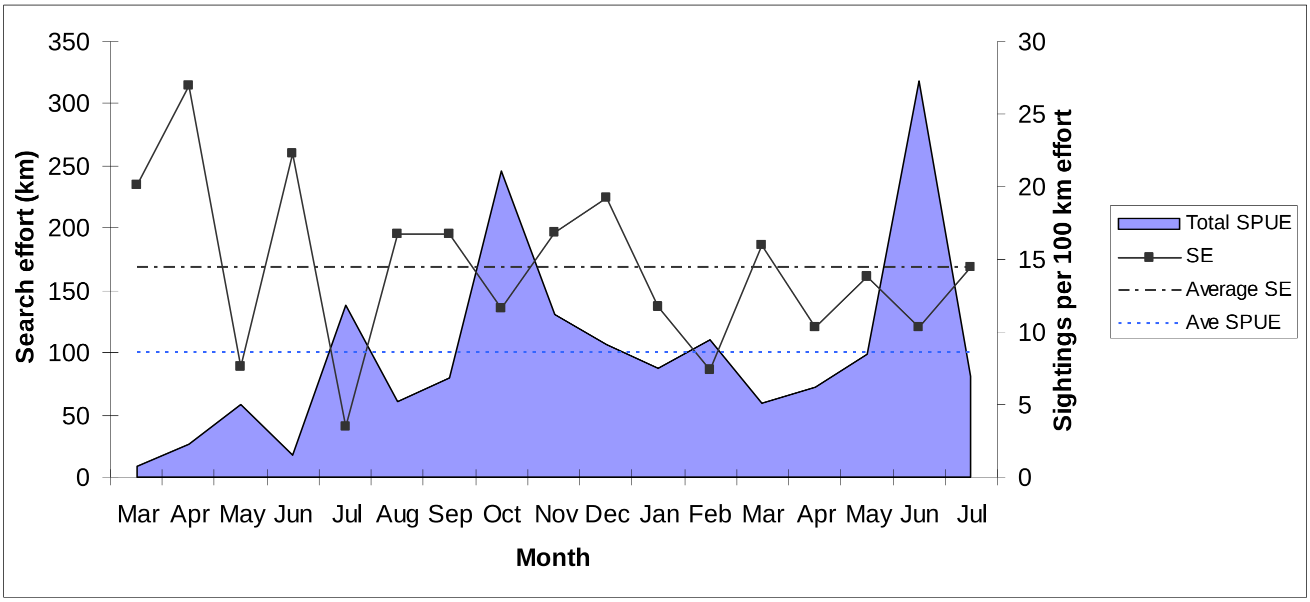

Figure 5.12. Sightings per 100 km search effort (SPUE) for all species, and search effort (SE) per month, for the duration of the study. Dashed line represents the mean SPUE (8.6) and the mean SE (169 km).

Bottlenose dolphins were the only species recorded in every month of the year with a mean of 6.6 SPUE (Figure 5.13). This species illustrated bimodal annual peaks in the SPUE, with the highest peaks occurring in October 2009 with 14.7 SPUE and in June 2010 with 22.3 SPUE. Lower sighting numbers were recorded during autumn in both 2009 and 2010.

Humpback dolphins had a mean sighting rate of 1.2 SPUE (Figure 5.13). The highest number of sightings was observed in February with a SPUE of 3.5. In autumn, very low numbers of humpback dolphins were recorded, with no sightings observed in May in either year. No sightings were recorded in September 2009.

Common dolphins were not frequently observed in Algoa Bay, with an overall average of 0.3 SPUE (Figure 5.13). Sightings were recorded once in September, May and June and twice in February. No sightings of common dolphins were recorded in late winter and early spring, or in early summer. Due to the low number of sightings, it was difficult to determine any general trends in occurrence.

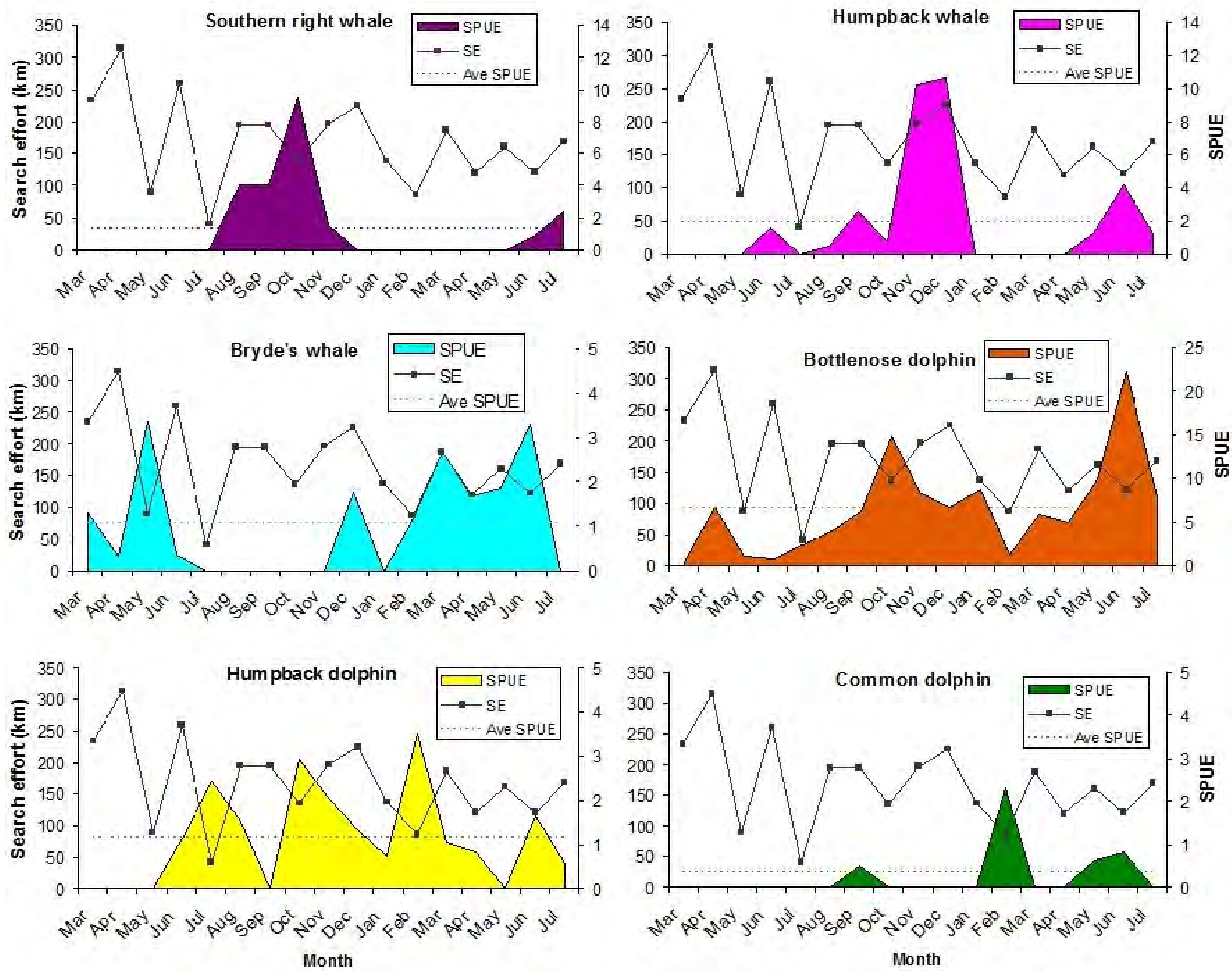

Figure 5.13. Sightings per 100 km effort (SPUE) for each species, and search effort per month. Dashed line represents the mean SPUE.

5.5. GROUP DYNAMICS AND RELATIVE DENSITY

Bottlenose dolphins and common dolphins constitute over 97% of the overall number of cetacean individuals observed, contributing significantly to the overall relative density of cetaceans in Algoa Bay (Table 5.2). Considerably lower relative densities were detected in the other species, with the lowest observed in Bryde's whales. Across all six species, a mean of 31.47 indiv.hr^{-1} and 3.22 indiv.km^{-1} was recorded (Table 5.2).

Bryde's whales were the only species where no calves or juveniles were observed (Table 5.2). Calves were present in 40.5% of southern right whale sightings and 67% humpback whale sightings, throughout their observed ranges in Algoa Bay (see Figure 5.14 for locations). On two occasions a calf or juvenile (possibly a yearling) humpback whale were observed alone. A large number of calves and juveniles were identified in bottlenose dolphin groups compared to common dolphins, where only 11 calves and juveniles were seen in total. No seasonality was observed in the number of calves and juveniles for bottlenose dolphins and humpback dolphins.

Table 5.2. Group dynamics and relative density of the cetaceans in Algoa Bay.

Species	Total number calves	Total number of Juveniles	Total number of individuals	Individual frequency (indiv.hr^{-1})	Relative individual density (indiv.km^{-1})
Southern right whales	15	2	87	0.22	0.02
Humpback whales	43	6	143	0.35	0.04
Bryde's whales	0	0	32	0.08	0.01
Bottlenose dolphins	464	275	10 170	25.14	2.57
Humpback dolphins	6	7	91	0.22	0.02
Common dolphins	8	3	1718	4.25	0.43
Total (Mean)	**536**	**293**	**12 241**	**31.47 (5.25)**	**3.22 (0.54)**

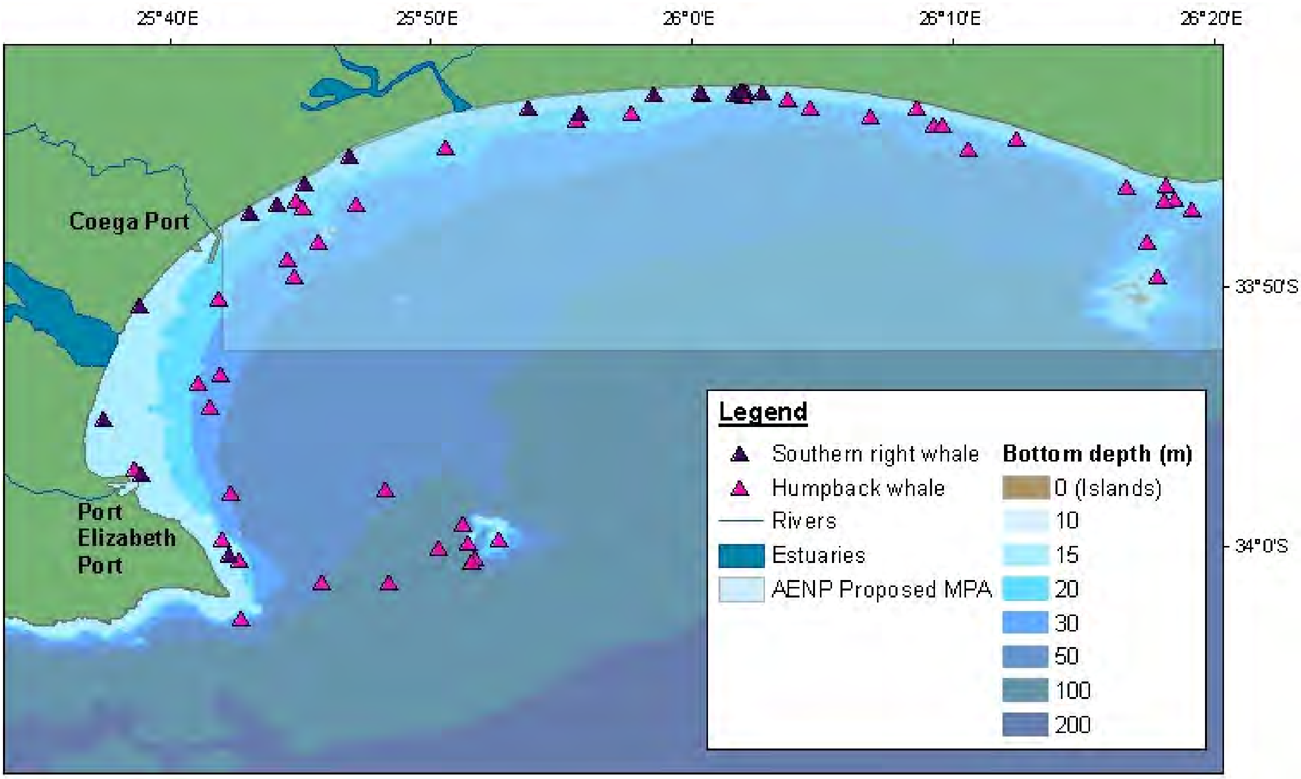

Figure 5.14. The locations of mother-calf pairs for southern right whales and humpback whales.

5.6. OBSERVED BEHAVIOUR OF THE CETACEANS

Each cetacean species utilised Algoa Bay differently (Figure 5.15). Southern right whales spent the majority of their time during winter and spring either milling (49%) or mating (24%), the latter was only recorded during spring (Figures 5.15 and 5.16). This activity was almost exclusively observed around PE port (Figure 5.17).

Humpback whales spent a larger proportion of their time travelling (48%), as well as milling (16%), the latter was observed in increasing measures as the number of calves and juveniles increased towards the end of their wintering season (late spring to early summer), before migrating back to their polar feeding grounds (Figures 5.15 and 5.16). Breaching, flipper slapping and other behaviours defined as 'other' were also frequently observed. The large proportion of 'other' behaviour in autumn is based on two sightings, where breaching and flipper slapping were recorded. Humpback whales were observed resting in the inshore areas of the remote Alexandria Dunefield coastline, especially around Cape Padrone (Figures 5.17). Four instances of foraging occurred during spring, where sharp, fast turns (in a 'zigzag' fashion) were observed just below the surface of the water or at the surface. In three of these sightings, gannets and dolphins were seen foraging in the same area.

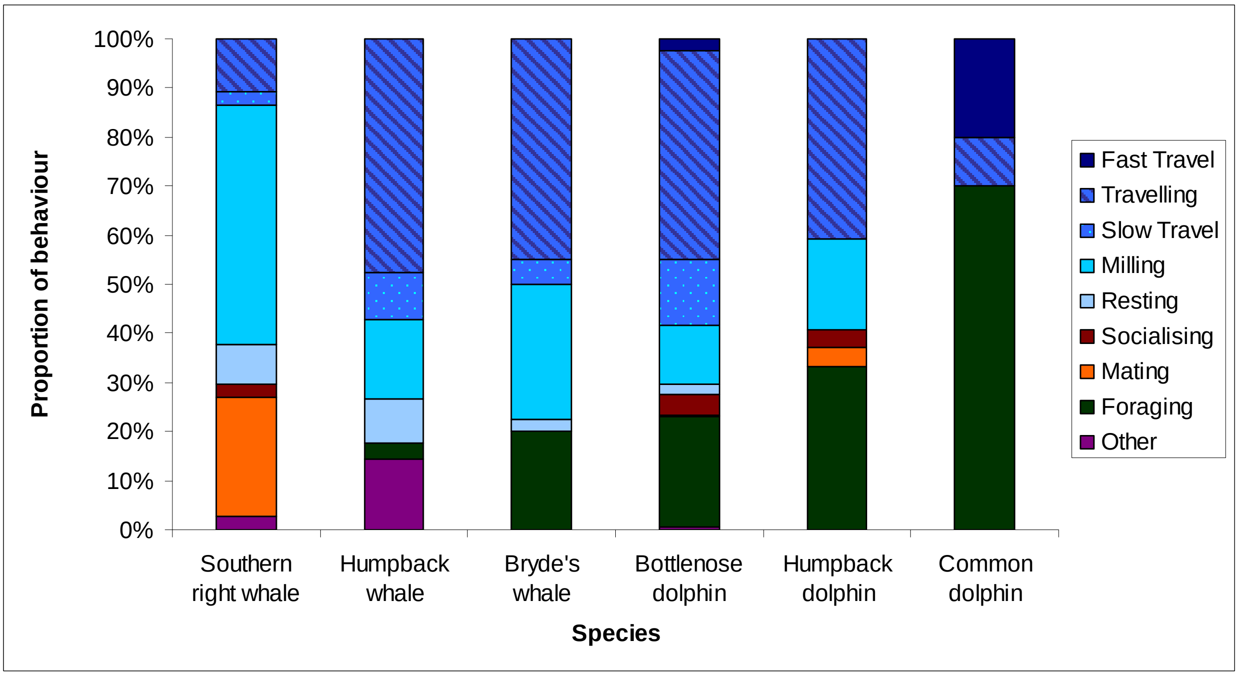

Figure 5.15. Behavioural budget for each cetacean species. Note: 'mating' behaviour in bottlenose dolphins was classed as socialising, as these behaviours were closely related in the field.

Bryde's whales were predominantly sighted travelling (45%), milling (28%) and foraging (20%) (Figures 5.15 and 5.16). During one sighting, the behaviour could not be determined as the whale appeared to be attracted to the research vessel. It would approach the vessel and pass sideways underneath, turning around to repeat the behaviour. This continued for the entire duration of the sighting. Most foraging behaviour consisted of horizontal lunges below the surface of the water, with only one instance of vertical lunge feeding observed in a single animal in autumn.

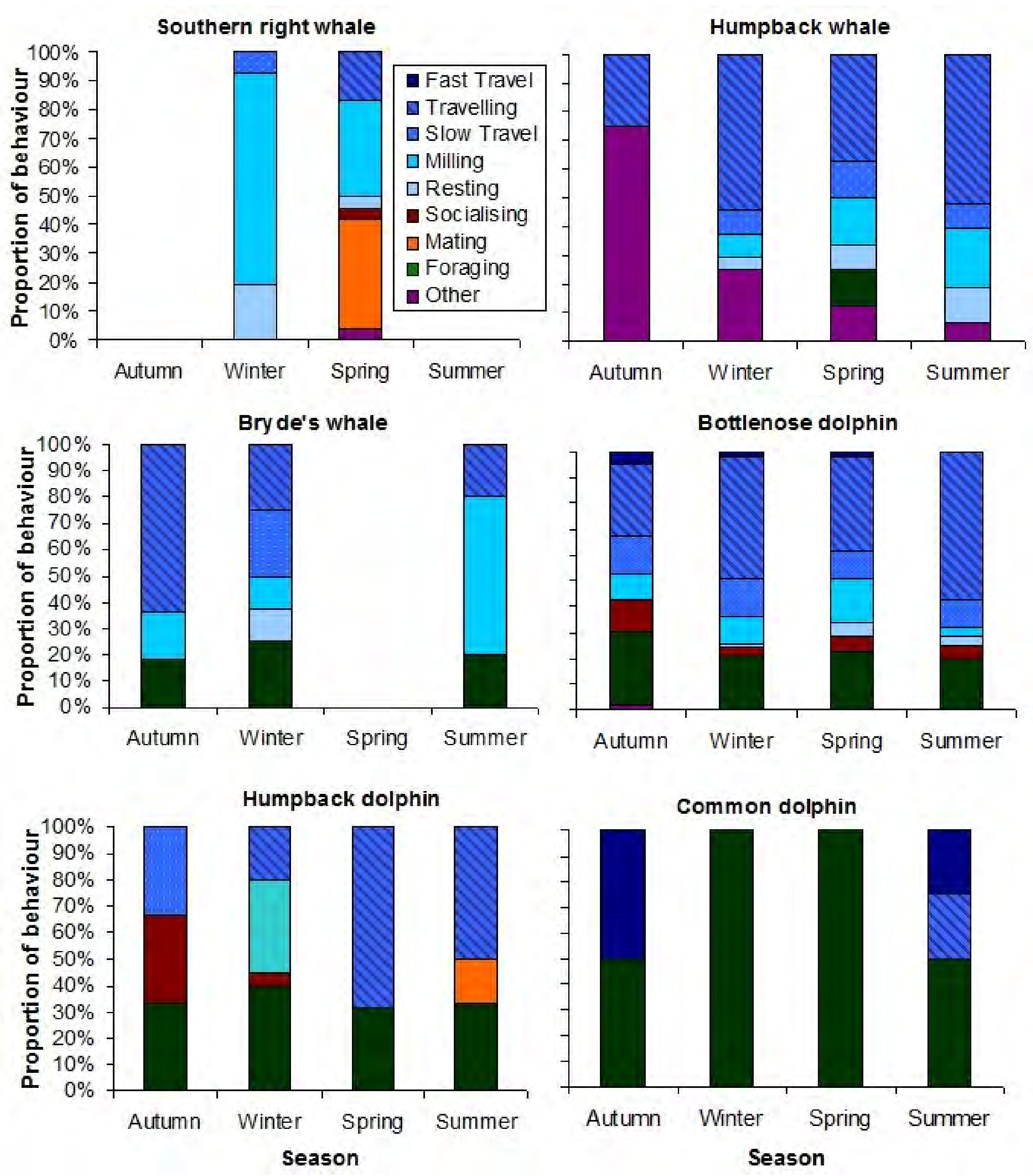

Figure 5.16. The seasonal behavioural budget for the different cetacean species.

Bottlenose dolphins spent the majority of their observed time travelling (43%) and foraging (23%), with little change in their behaviour between seasons (Figures 5.15 and 5.16). Foraging took place along the entire shoreline especially east of Sundays River and south of PE Port, as well as being observed by Riy Banks reef and the two island groups (Figure 5.18). Socialising activities recorded were: tail slapping, breaching, jumping, mating, surfing waves, chasing another individual, fluking (including some observed sailing), aerial somersaults, playing with food (throwing fish into the air), and on one occasion it appeared that a mother was teaching a calf how to forage for food. Socialising activities were often observed in conjunction with travelling or foraging behaviour.

Humpback dolphins were primarily seen foraging (33%) and travelling (41%) throughout the study period (Figures 5.15 and 5.16). Foraging was mainly observed south of PE Port and around the Swartkops River (Figure 5.18). Milling and slow travel were recorded during autumn and winter, along with socialising. Socialising activities observed were: tail-slapping, jumping and spy-hopping. Mating was observed once during December south of PE Port (Figure 5.18).

Common dolphins were predominantly observed foraging in bait balls (70%), or fast travelling (20%) to or from a foraging area (Figures 5.15 and 5.16). Bait balls consisted of gannets circling and diving in the area, and sometimes other marine birds (such as African penguins and roseate terns) and Cape fur seals, as well as other cetacean species such as Bryde's whales and bottlenose dolphins.

5.7. CETACEAN RELATIVE DENSITIES

Several high density areas for cetaceans were recorded in Algoa Bay (Figure 5.19). The highest was along the inshore areas of the Alexandria Dunefield, around 26^{o}10' E, and east of Sundays River. A high number of cetaceans were also observed around St Croix Islands and PE Port.

A high density area for southern right whales was seen around PE Port (Figure 5.20), compared to humpback whales which were found on Riy Banks, around both headlands, and east of 26^{o}10' E along the Alexandria Dunefield coastline (Figure 5.21). The high density area for Bryde's whales was offshore of the Swartkops River (Figure 5.22).

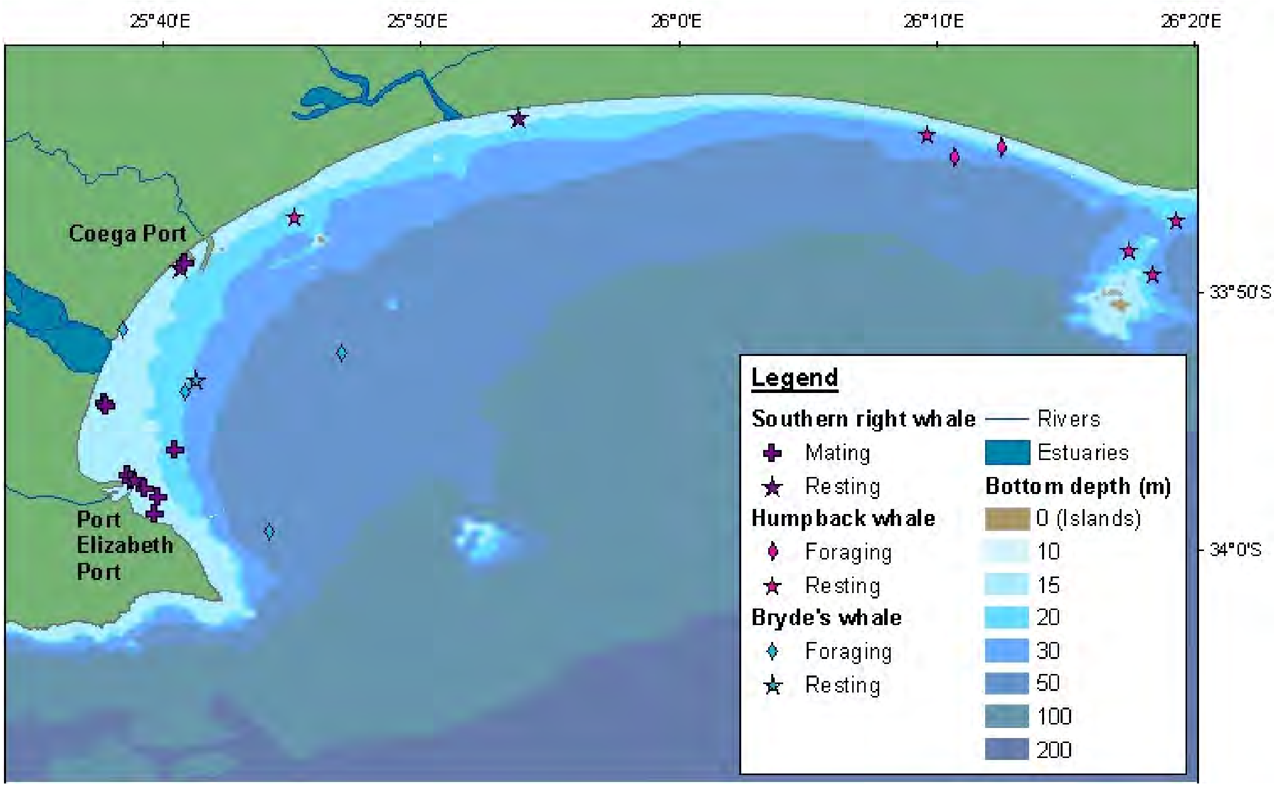

Figure 5.17. Key behaviours for the three whale species observed in Algoa Bay.

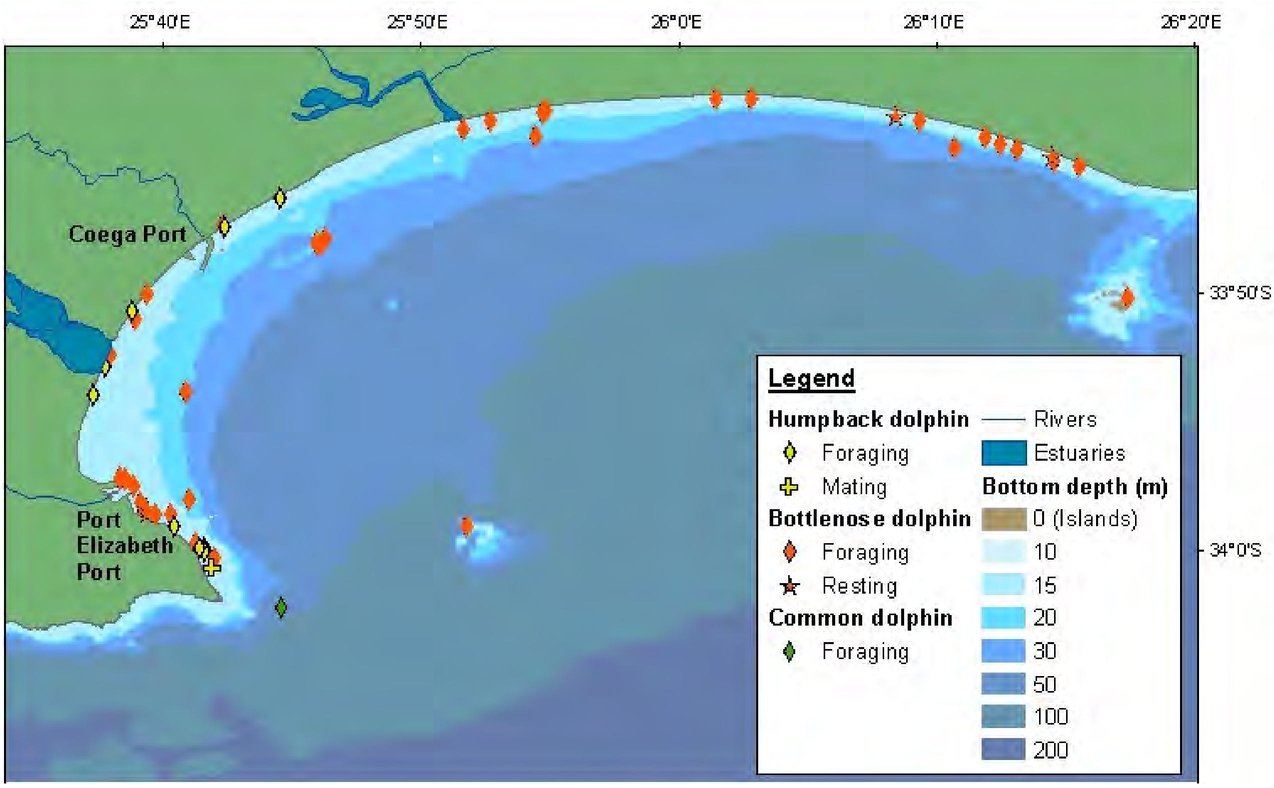

Figure 5.18. Key behaviours for the three dolphin species observed in Algoa Bay.

Bottlenose dolphin kernel density mapping revealed one key area located approximately 26°15' E on the Alexandria Dunefield coastline (Figure 5.23). Other relatively densely populated areas were recorded along the entire coastline, with lower densities around the two estuaries and Coega Port. A high density area for humpback dolphins was observed along the coastline of the south-west corner of the bay (south of PE Port) (Figure 5.24) in between the two high density areas for southern right whales and humpback whales. Kernel density mapping was not carried out for common dolphins due to the low number of sightings.

The kernel density maps illustrate similar key areas as the SPUE maps for the respective cetacean species. These two sets of maps take into account both the number of individuals in a sighting as well as the search effort in the area, and thus provide a good indication of key areas for each cetacean species within Algoa Bay.

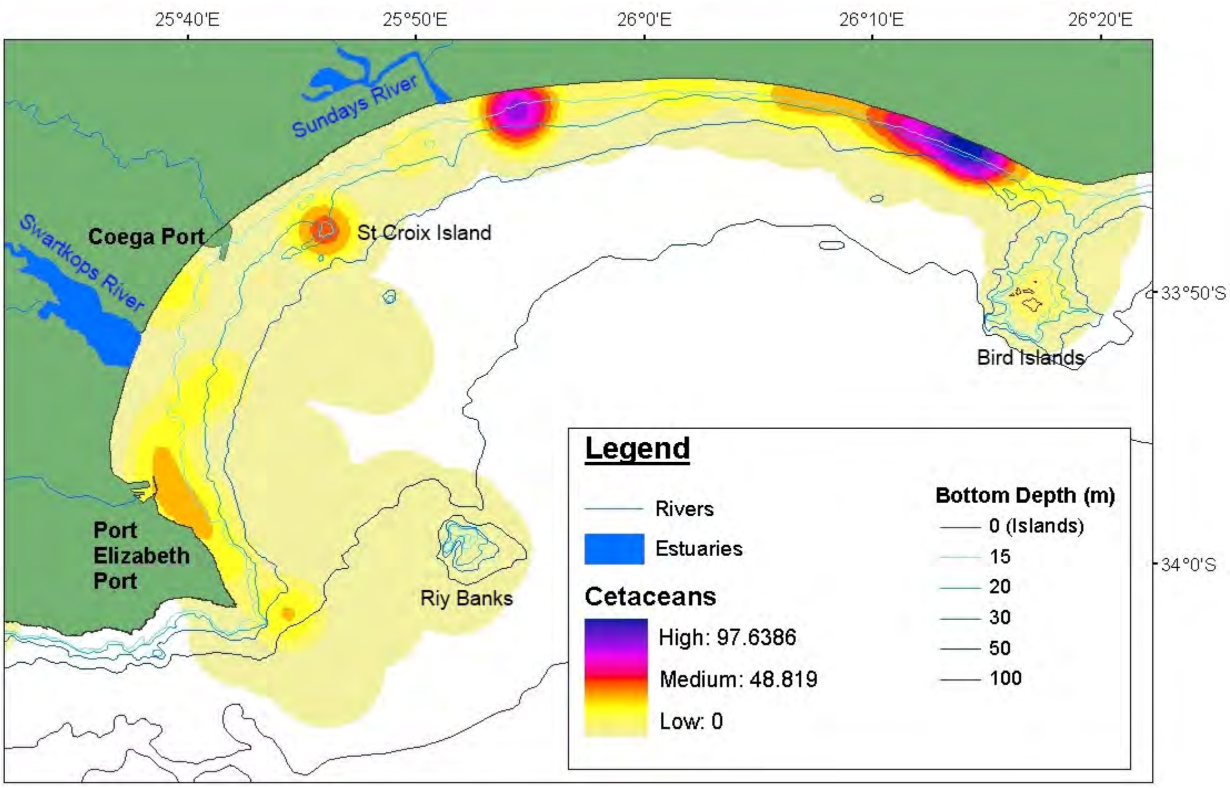

Figure 5.19. Kernel density map of the six cetacean species observed in Algoa Bay. Density estimates take into account the number of individuals in a sighting (i.e. values represent the number of individuals per square kilometre).

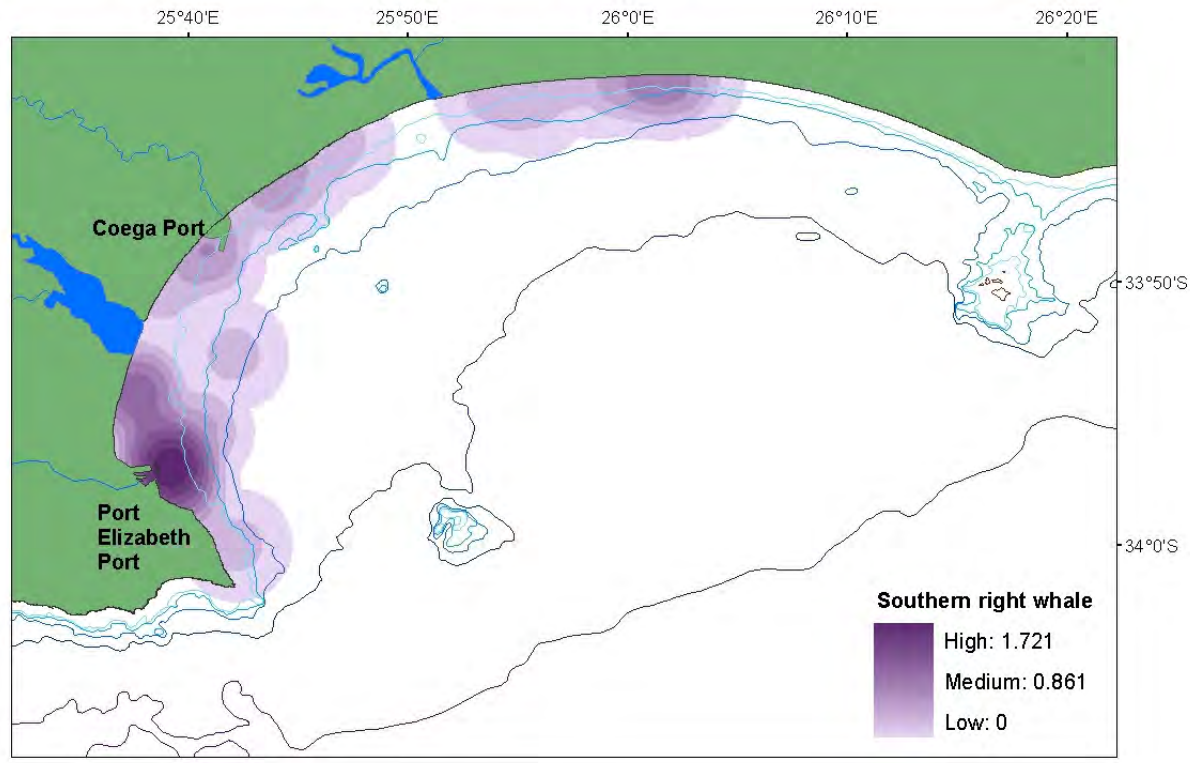

Figure 5.20. Kernel density map of the southern right whales in Algoa Bay. Density estimates take into account the number of individuals in a sighting.

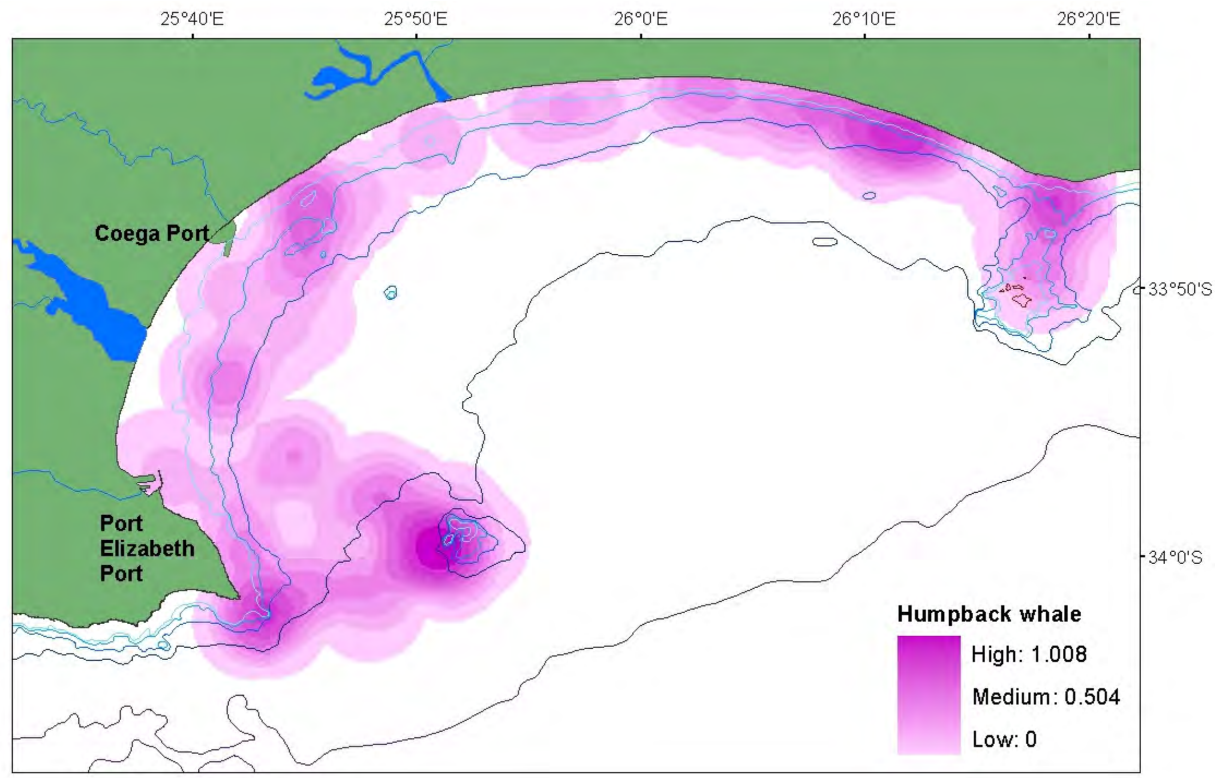

Figure 5.21. Kernel density map of the humpback whales in Algoa Bay. Density estimates take into account the number of individuals in a sighting.

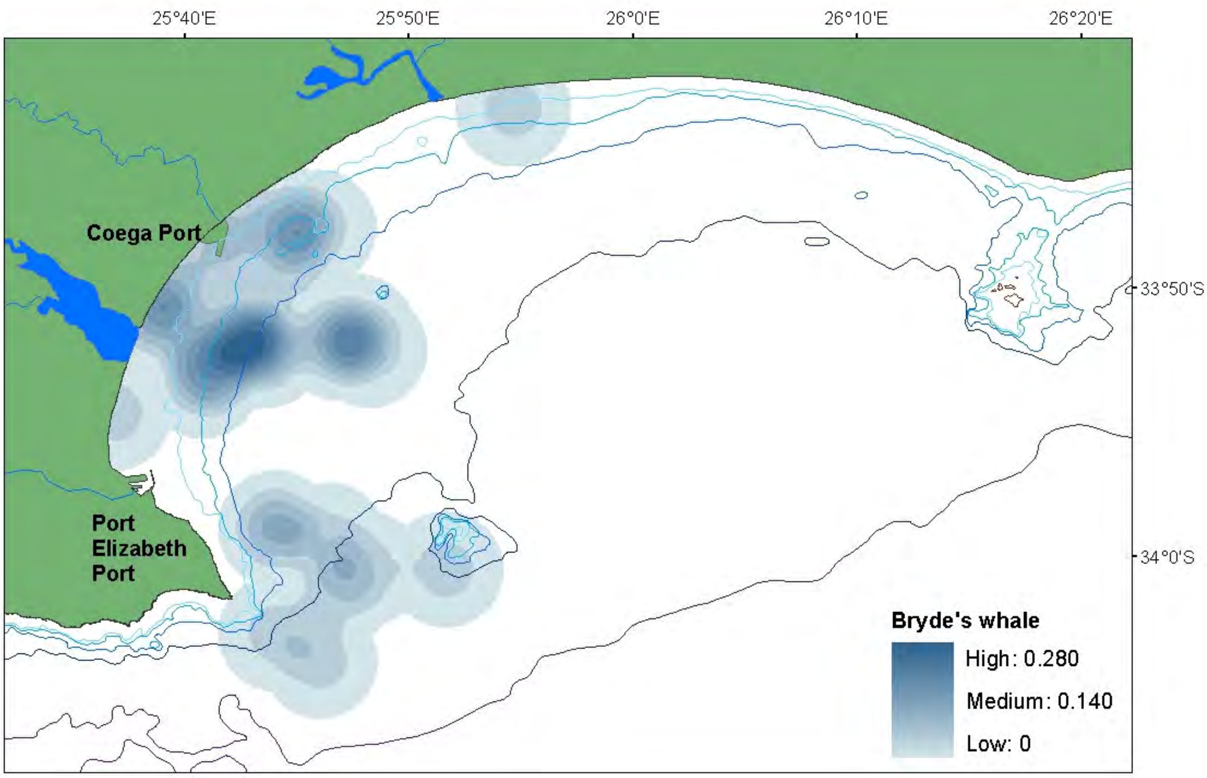

Figure 5.22. Kernel density map of the Bryde's whales in Algoa Bay. Density estimates take into account the number of individuals in a sighting.

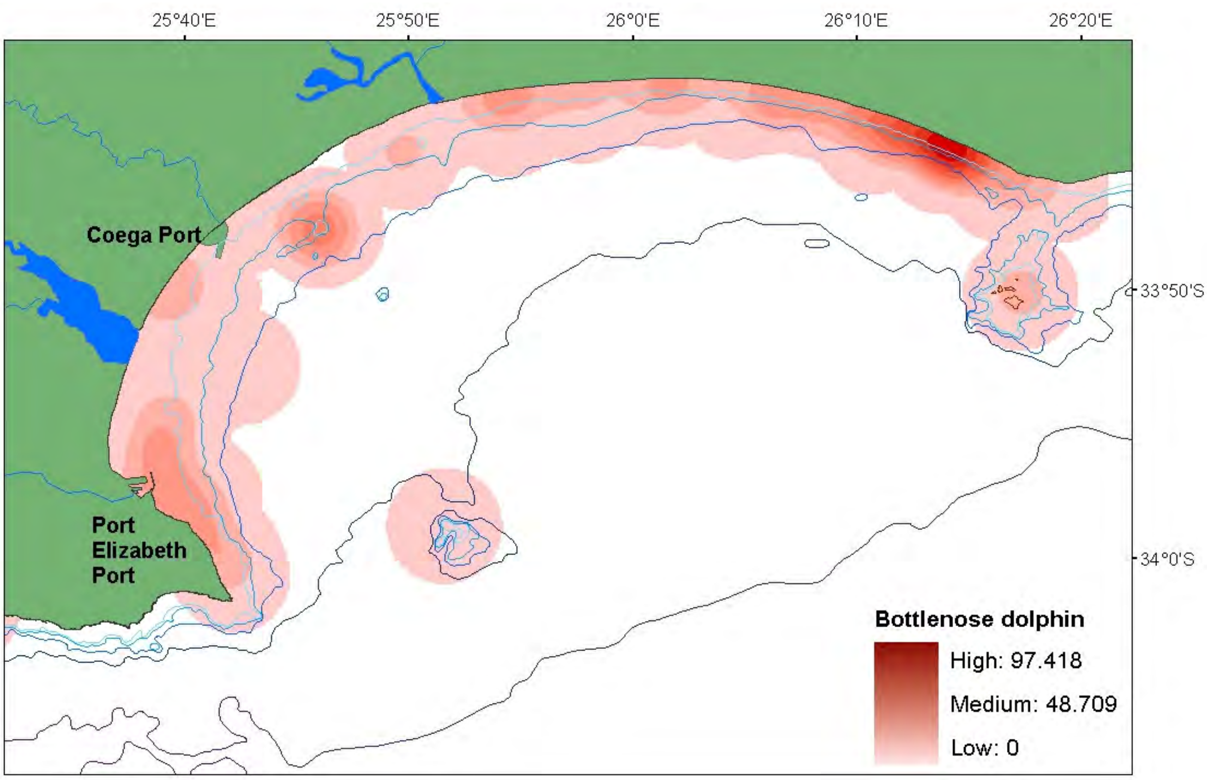

Figure 5.23. Kernel density map of the bottlenose dolphins in Algoa Bay. Density estimates take into account the number of individuals in a sighting.

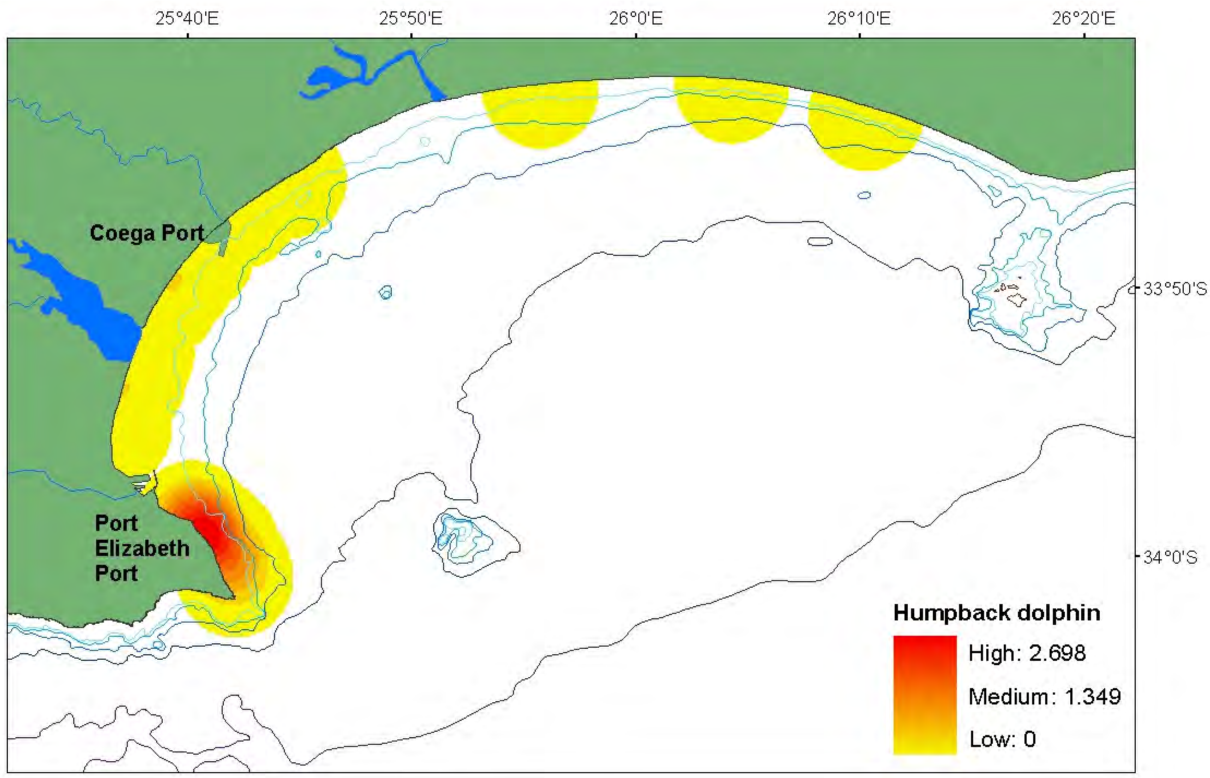

Figure 5.24. Kernel density map of the humpback dolphins in Algoa Bay. Density estimates take into account the number of individuals in a sighting.

5.8. SIGHTINGS AND ENVIRONMENTAL VARIABLES

Sightings were recorded in waters with SST between 13.5 and 24.8 ^{o}C, the full range of SST recorded during surveys (Figure 5.25). However, most sightings were observed between 17 and 21 ^{o}C. Overall, there was no significant difference between the mean SST for the six cetacean species (ANOVA, df = 5, F = 1.195, p > 0.1).

Sightings were observed in waters with bottom depths of 2.3 to 90.6 m (Figure 5.26). Southern right whales were mostly recorded in waters between 11 and 15 m deep, compared to humpback whales and Bryde's whales which were observed in deeper waters of 18 to 45 m. Bottlenose dolphins were predominantly sighted in bottom depths of zero to 15 m however, they were also observed in bottom depths of 30 m. Humpback dolphins were recorded in shallow waters of less than 15 m deep, which is in contrast to common dolphins which were observed in waters between 11 and 44 m deep. Despite the majority of boat-based surveys being conducted in waters less than 15 m deep (60%), some of the species were still predominantly observed in deeper waters (Figures 5.26 and 5.27). This indicates that the 'inshore' species were well surveyed, while the 'offshore' species with median bottom depths above 15 m (humpback whales, Bryde's whales and common dolphins), were possibly not as well covered during boat-based surveys.

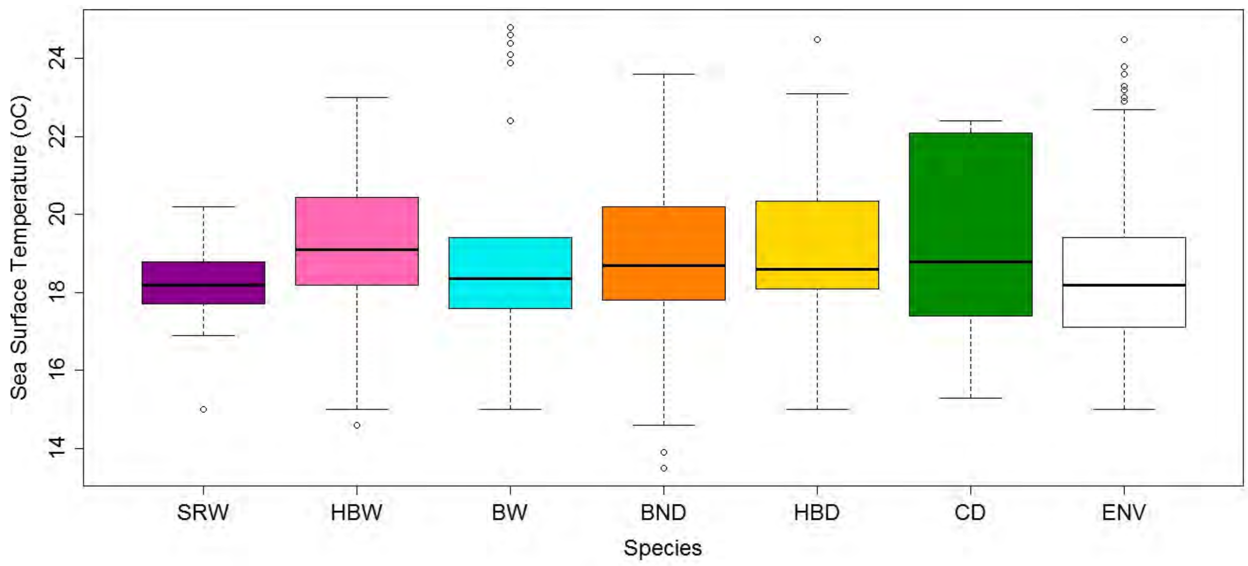

Figure 5.25. The median sea surface temperature (SST) and standard deviation for each species observed in Algoa Bay. Outliers are represented by open circles. Environmental (ENV) data was data collected both 'on' and 'off' effort during boat-based surveys.

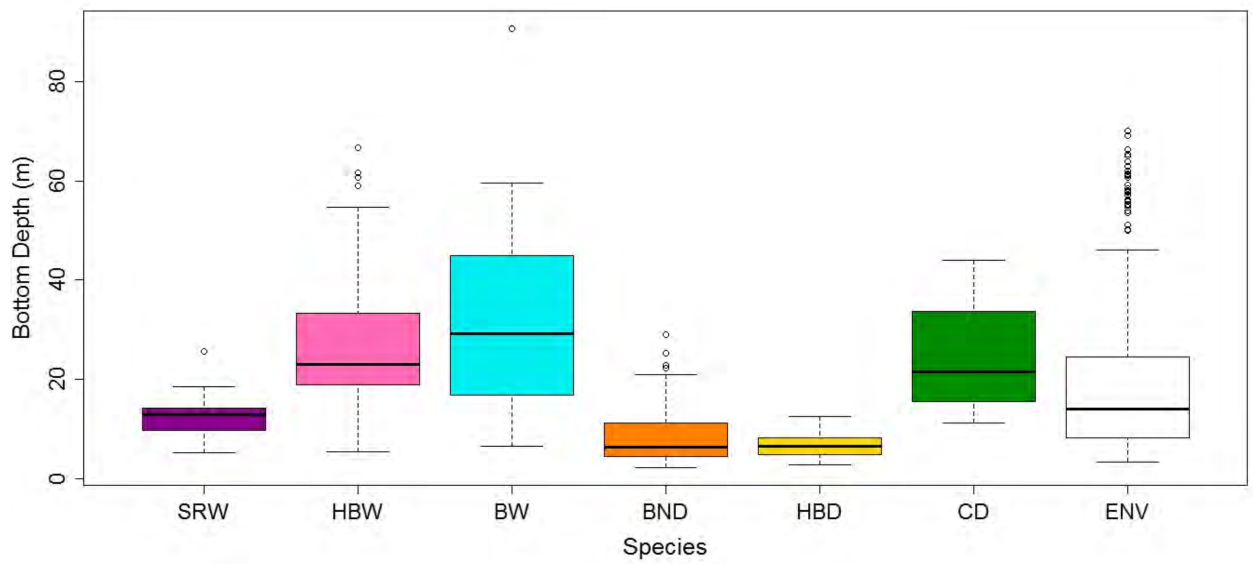

Figure 5.26. The median bottom depth and standard deviation for each species observed in Algoa Bay. Outliers are represented by open circles. Environmental (ENV) data was data collected both 'on' and 'off' effort during boat-based surveys.

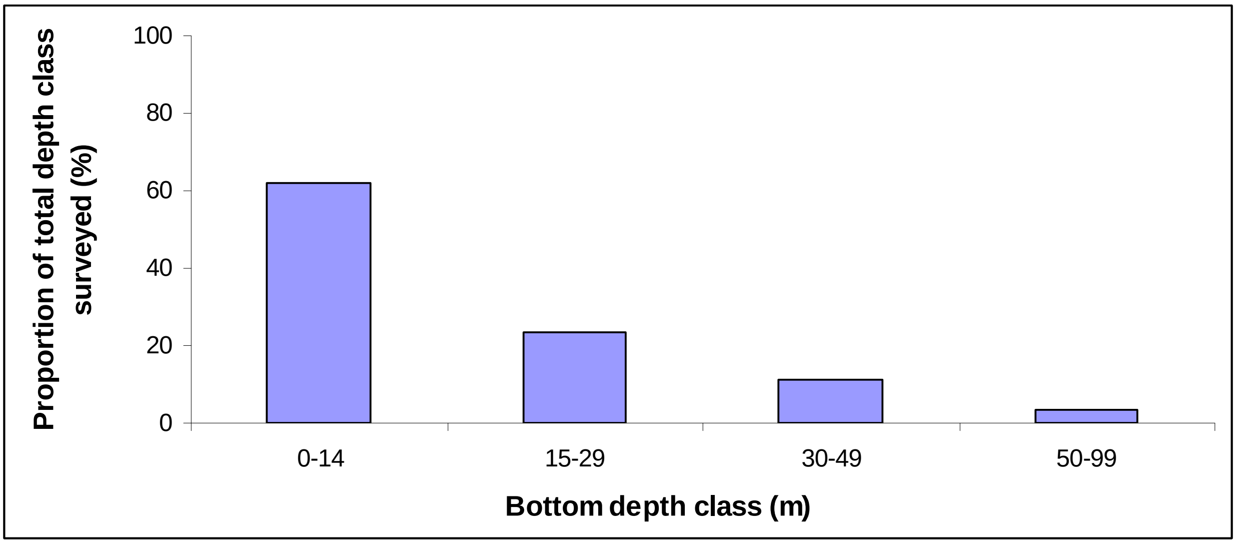

Figure 5.27. The proportion of depth classes surveyed in Algoa Bay.

There was a significant difference in the mean bottom depths among the cetacean species (ANOVA, df = 5, F = 59.622, $p < 0.05$). A Post-hoc Tukey HSD test illustrated highly significant differences in the mean depths between several species (see Table 5.3). The significant difference in depths suggest that there are two groups of cetacean species in Algoa Bay, 'offshore' species (humpback whales, Bryde's whales and common dolphins) that are found in deeper waters, and 'inshore' species (southern right whales, bottlenose dolphins and humpback dolphins). These trends are also illustrated spatially in the distribution maps (Figures 5.4 and 5.5).

Table 5.3. The significant differences in mean depths (white blocks) and mean distances from land (grey blocks), between the different cetacean species.

	Southern right whale	Humpback whale	Bryde's whale	Bottlenose dolphin	Humpback dolphin	Common dolphin
Southern right whale		p < 0.001	p < 0.001			
Humpback whale	p < 0.001			p < 0.001	p < 0.001	
Bryde's whale	p < 0.001			p < 0.001	p < 0.001	
Bottlenose dolphin		p < 0.001	p < 0.001			p < 0.05
Humpback dolphin		p < 0.001	p < 0.001			p < 0.001
Common dolphin				p < 0.05	p < 0.001	

The distance from land data was log-transformed to remove heteroscedasticity (uneven scatter). The distance from land for each species (Figure 5.28) illustrated a similar trend to their associated depths (Figure 5.26). Sightings ranged between 0.1 km and 16.4 km from land (Figure 5.28). A one-way ANOVA revealed a highly significant difference between the log mean distance from land for each species (df = 5, F = 11.171, $p < 0.05$). A post-hoc Tukey HSD test revealed highly significant differences in the log distances from land between several species, the same significant differences as the mean depths (Table 5.3). These trends are also illustrated spatially in the distribution maps (Figures 5.4 and 5.5).

The mean distance from land and bottom depths were also calculated for mother-calf pairs, for both southern right whales and humpback whales (Figures 5.29 and 5.30). This was compared to sightings without the presence of calves. Southern right whales were observed significantly closer to land and at shallower depths compared to non mother-calf pairs ($t(35) = 4.78$, $p < 0.05$ and $t(35) = 2.21$, $p < 0.05$). However, there was no significant difference in mean bottom depths and distance from land between humpback whale mother-calf pairs and non-calf groups ($t(62) = 0.736$, $p > 0.1$ and $t(62) = 1.16$, $p > 0.1$).

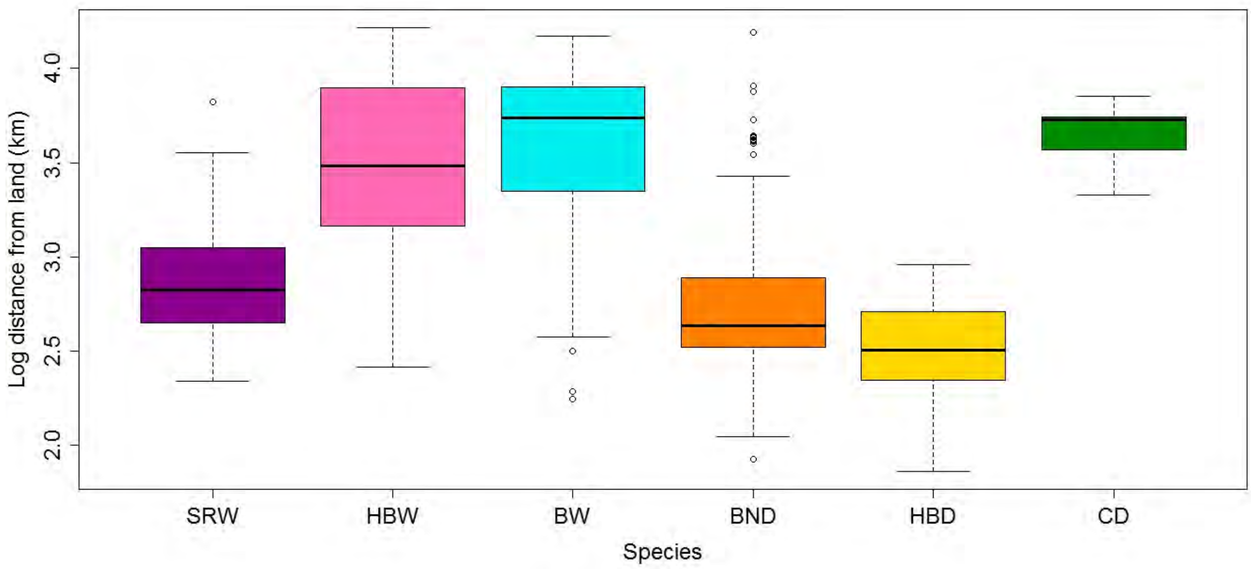

Figure 5.28. The log distance from land, and standard deviation for each species observed in Algoa Bay. Outliers are represented by open circles.

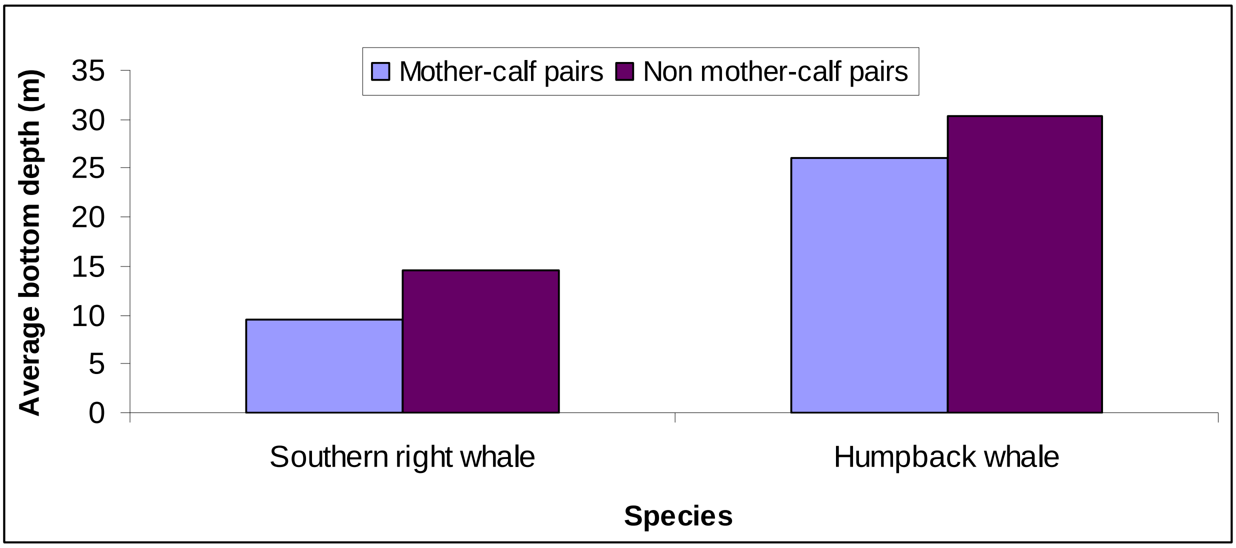

Figure 5.29. Mean bottom depth (m) for two mysticete species comparing sightings of mother-calf pairs and non mother-calf pairs.

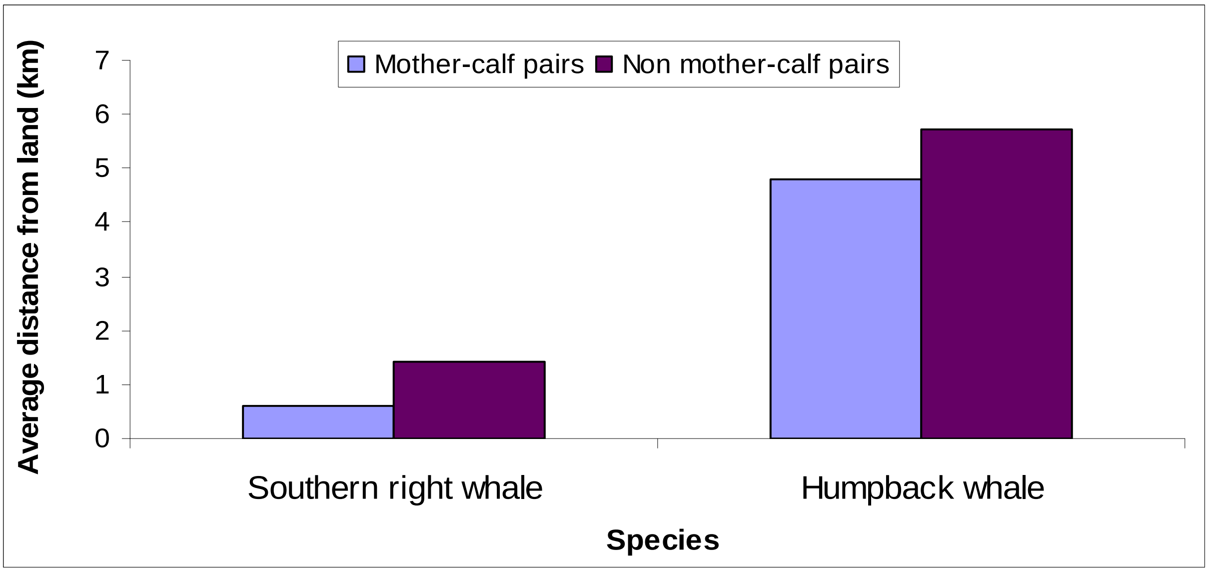

Figure 5.30. Mean distance from land (km) for two mysticete species comparing sightings of mother-calf pairs and non mother-calf pairs.

The distance to rivers data was log-transformed to remove heteroscedasticity. The log distance to rivers for each species illustrated a similar trend to the log distance from land (Figure 5.28), with sightings ranging from 500 m and 23.6 km to the nearest river (Figure 5.31). A one-way ANOVA revealed a significant difference between the log distance to rivers for each species (df = 5, F = 7.897, $p < 0.05$). A post-hoc Tukey HSD test indicated that humpback whales were observed significantly further from rivers than southern right whales, bottlenose dolphins and humpback dolphins ($p < 0.05$).

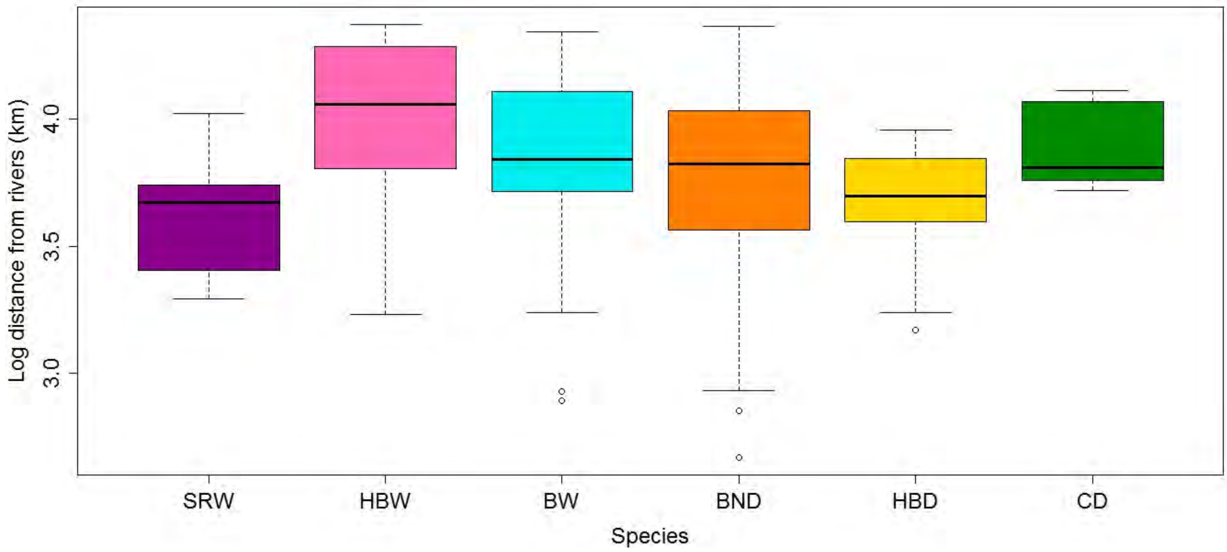

Figure 5.31. The log distance from rivers and standard deviation for each species observed in Algoa Bay. Outliers are represented by open circles.

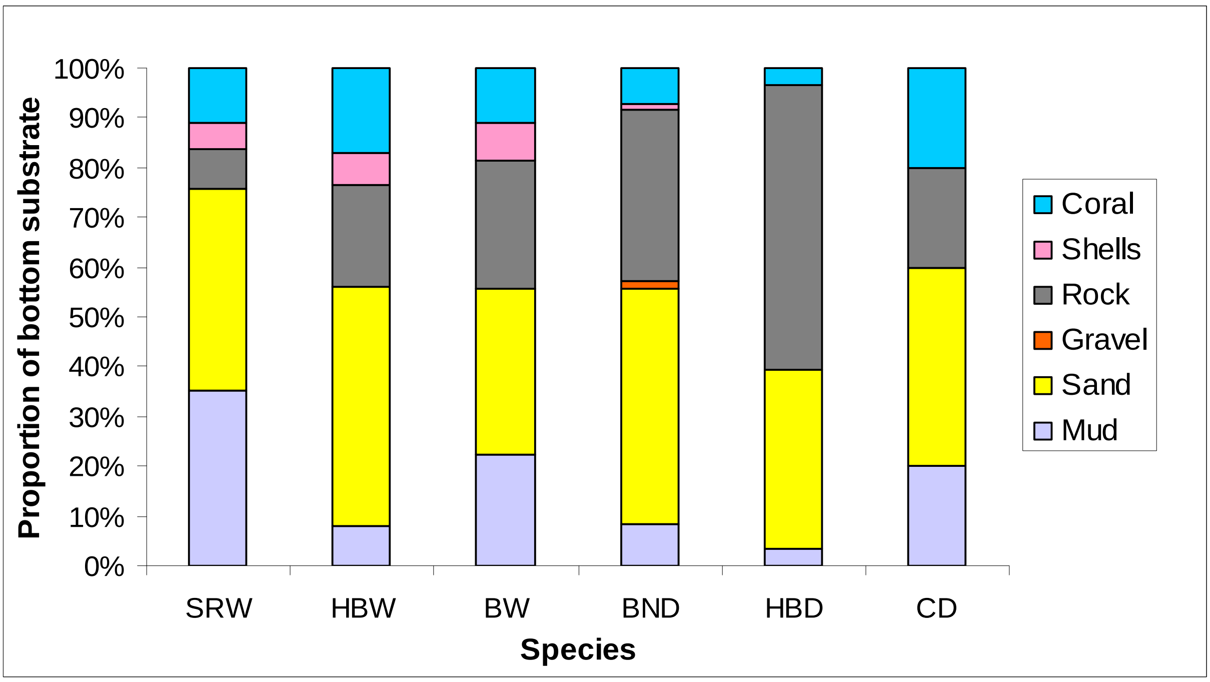

Figure 5.32. The proportion of sea-floor substrate associated with each species. Substrate data was made available by SANHO.

There were few noteworthy trends between each cetacean species and the type of sea-floor substrate (Figure 5.32). Five cetacean species were predominantly associated with a mud and sand substrate, with southern right whales utilising the largest proportion of mud substrate (Figure 5.32). Humpback dolphins were the only species which were predominately associated with a rocky substrate (57%) (Figure 5.32). Furthermore, coral and shells, which are linked to reef habitats, were associated with most species, with the exception of humpback and common dolphins (Figure 5.32).

5.9. SIGHTINGS AND ANTHROPOGENIC ACTIVITIES

Southern right whales were seen in three of the four shipping zones, with three sightings in the PE channel (Figure 5.33). No mother-calf pairs for this species were sighted in any of the shipping zones. One humpback whale sighting was recorded in each of the four shipping zones, with calves seen in the all of the zones, except in the offshore anchoring zone (Figure 5.33). Over 20% of Bryde's whales were observed within the shipping areas, more than any other species (Figure 5.33). Only nine of the 183 bottlenose dolphin sightings were seen within a shipping zone, the most (six sightings), being recorded in the PE channel (Figure 5.33). No humpback dolphin sightings were observed within any of the shipping areas, and one common dolphin sighting was recorded in the inshore anchoring area (Figure 5.33).

Southern right whales and humpback whales were recorded in Algoa Bay during austral winter and spring, using the coastal areas as calving and nursing grounds. Both species were seen with calves and juveniles in the bay during this period (Figure 5.14). A significant proportion of these sightings were observed within the proposed GAENP MPA, with 76% of the southern right whales and 63% humpback whales sighted in this area (Figure 5.34).

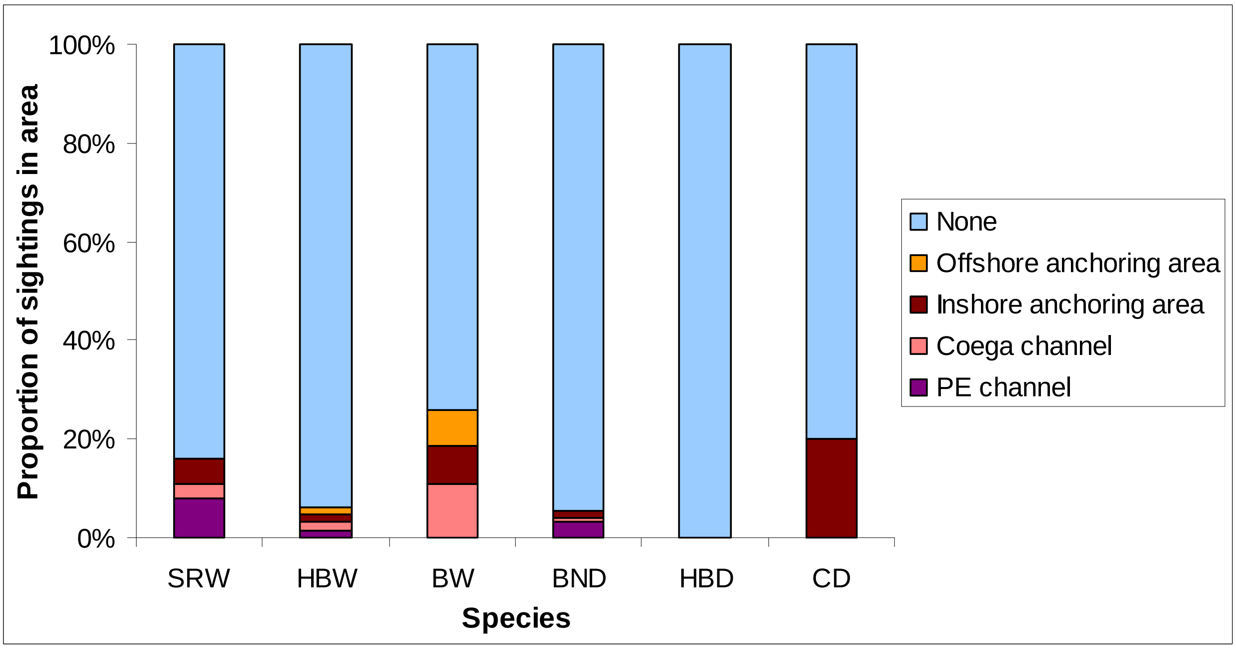

Figure 5.33. Proportion of cetacean sightings within the shipping zones.

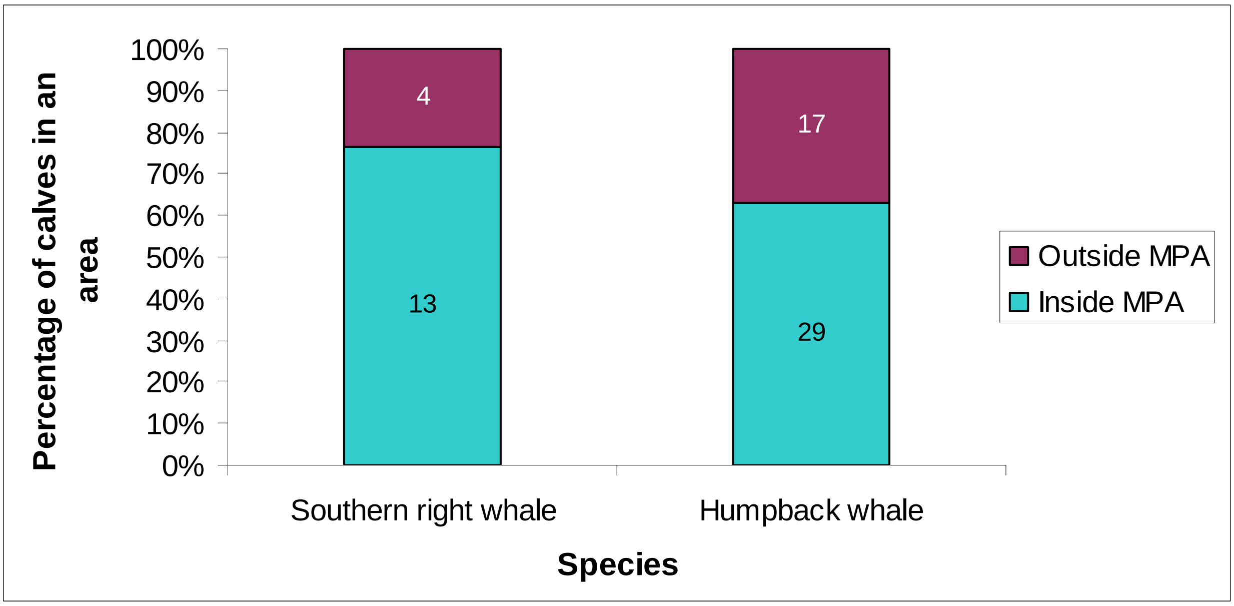

Figure 5.34. Proportion of mother-calf pairs inside and outside the proposed GAENP MPA (numbers in histogram represent actual number of sightings).

5.10 SIGHTING RATE AND RELATIVE ABUNDANCE MODELLING

5.10.1. Introduction

This next section describes the results of statistical analyses conducted on the data. Exploratory data analysis (EDA) in the form of scatterplots was constructed for each of the cetacean species, using several explanatory variables. Further analysis was conducted using GAMs and GLMs to determine cetacean distribution in relation to Beaufort sea state, SST, bottom depth and seasonality. Stepwise forwards/ backwards procedures were conducted on both sets of models, with the final model (lowest AIC) being reviewed. All GAMs performed better than the GLMs (Table 5.4). Hurdle models were then constructed to ascertain whether these variables are also affecting the relative abundance of the different cetacean species in Algoa Bay. As this dataset was restricted by sample size and the limited time-scale of the study, the results should be explored in more detail in future studies. Due to the extremely small number of common dolphin sightings, this species was excluded from the statistical analysis.

5.10.2. Southern right whales

The scatterplots presented in Figure 5.35 reveal significant relationships between southern right whales and several environmental parameters. This species was primarily observed in spring. An increase in sightings were observed in water temperatures ranging between 17 and 19 ^{o}C, and at depths of approximately 15 m. Larger groups were observed in colder water temperatures of less than 17 ^{o}C. Most sightings were also recorded within two kilometres from land. There was no clear relationship between group size and their proximity to the rivers entering the bay.

The most parsimonious GAM indicates the relationship between southern right whales and their environment and is best described by *Group size = s(Beaufort) + s(SST) + Depth + Season*. No variables were statistically significant ($p > 0.05$) (Table 5.4 and Figure 5.36). Nonetheless, the model did explain 54% of the variability within the data. Southern right whales were primarily associated with winter and spring, with no sightings observed in the first half of the year (Figure 3.56). The range in Beaufort sea state of one to four and SST between 16 and 20 ^{o}C, had an equal influence on the occurrence of southern right whales in the bay (Figure 5.36). This species was more prevalent in shallow waters below 20 m, with no sightings found above 25 m (Figure 5.36). The hurdle model indicated that seasonality and SST strongly influenced the presence of these animals in the bay, with bottom depth ($p < 0.05$) and seasonality ($p < 0.05$), significantly influencing the estimated number of animals observed (Table 5.5).

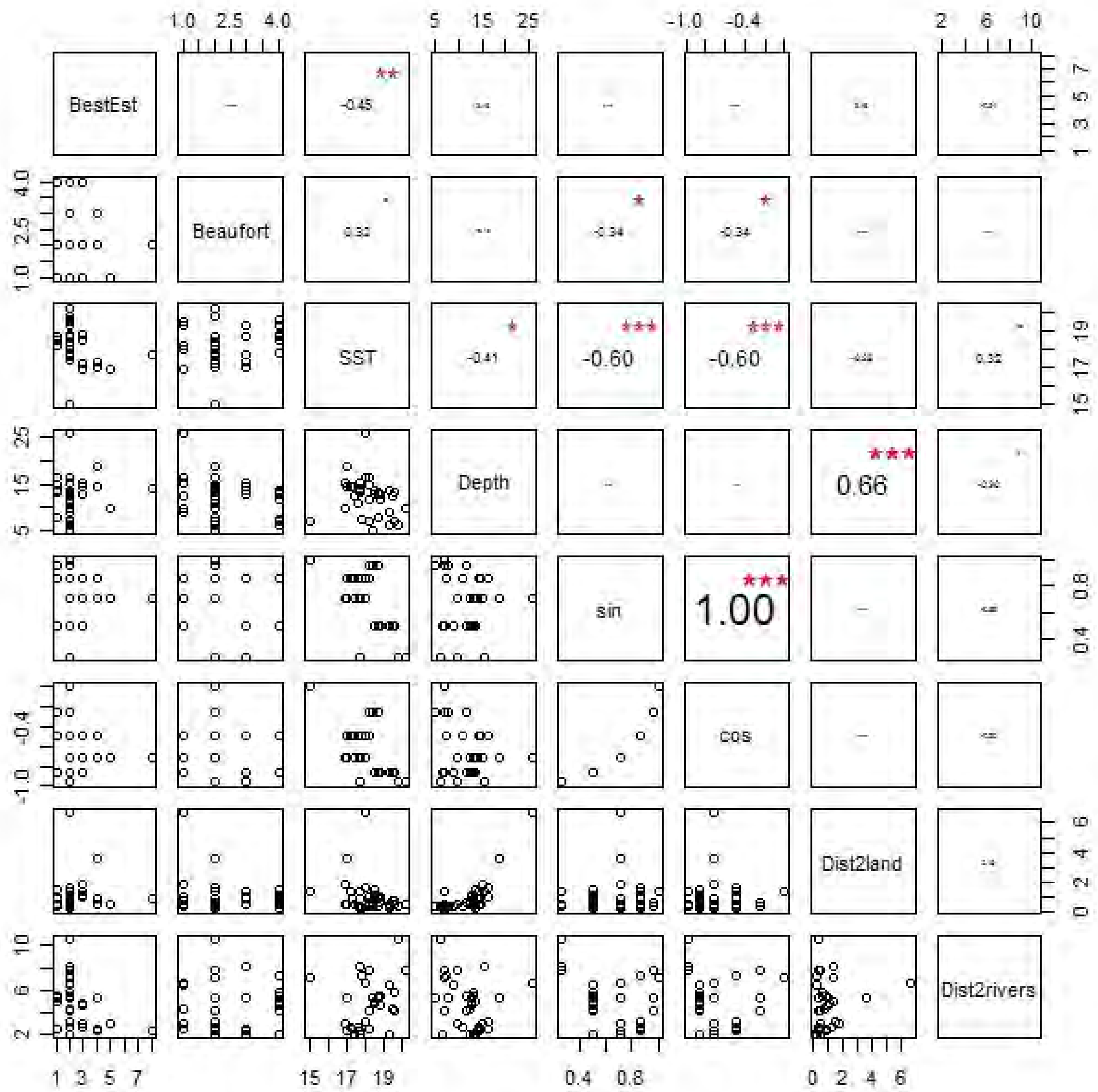

Figure 5.35. Scatterplots showing the relationship between southern right whale group size (BestEst) and Beaufort sea state, SST, bottom depth, seasonality, distance from land and distance from the nearest river. The lower panel contains the scatterplots, and the upper panel provides the results of a Spearman correlation, which illustrates the degree of statistical dependency between two variables.

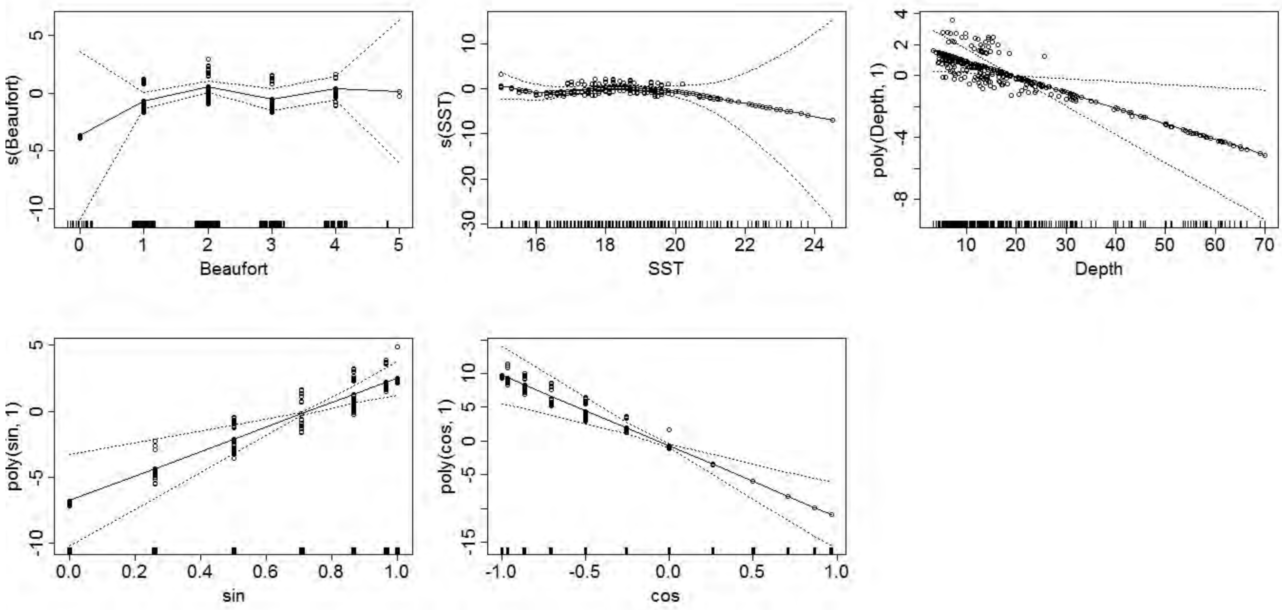

Figure 5.36. The results of a GAM for southern right whales as a function of Beaufort, SST, bottom depth and seasonality. Results are shown for the best-fit model after a stepwise-selected GAM was completed. Dashed lines represent the two standard error bands. Tick marks (rugs) on the x-axis show the location of data points.

5.10.3. Humpback whales

Humpback whales revealed significant relationships with several environmental parameters (Figure 5.37). This species illustrated a slight preference for warmer waters over 18 ^{o}C (Figure 5.37). They were observed in a wide range of bottom depths (mostly less than 40 m) and generally within 10 km from land (Figure 5.37). However, several sightings were noted further offshore, in deeper waters. Two peaks in sightings were observed in Algoa Bay, one in winter and also at the beginning of summer (July and December).

The GAM for humpback whales demonstrated that the relationship between these animals and the environment is best described by *Group size = p(SST, 4) + s(Depth) + Season* (Figure 5.38). This model explained 49% of the variability within the data (Table 5.4). Most sightings were observed between 15 and 21 ^{o}C, with a slight increase in sightings in warmer waters, which was also seen in the scatterplot (Figures 5.37 and 5.38). Depth was a highly significant variable in the model (Table 5.4, χ^2 = 29.891, df = 3, p < 0.05), with a steep increase in sightings with increasing depth, and a peak of observations between 20 and 30 m (Figure 5.38). Seasonality also played a significant role in the presence of humpback whales in the bay (Table 5.4, $\chi^2 = 17.856$, df = 3, p < 0.05), with a decrease in sightings in late spring, and the highest sighting rates in both winter/ early spring and late spring/ early summer, and no sightings observed between late summer and mid-autumn (Figure 5.38). The hurdle model indicated that bottom depth and seasonality also had a highly significant influence (p < 0.05) on the estimated number of humpback whales observed (Table 5.5).

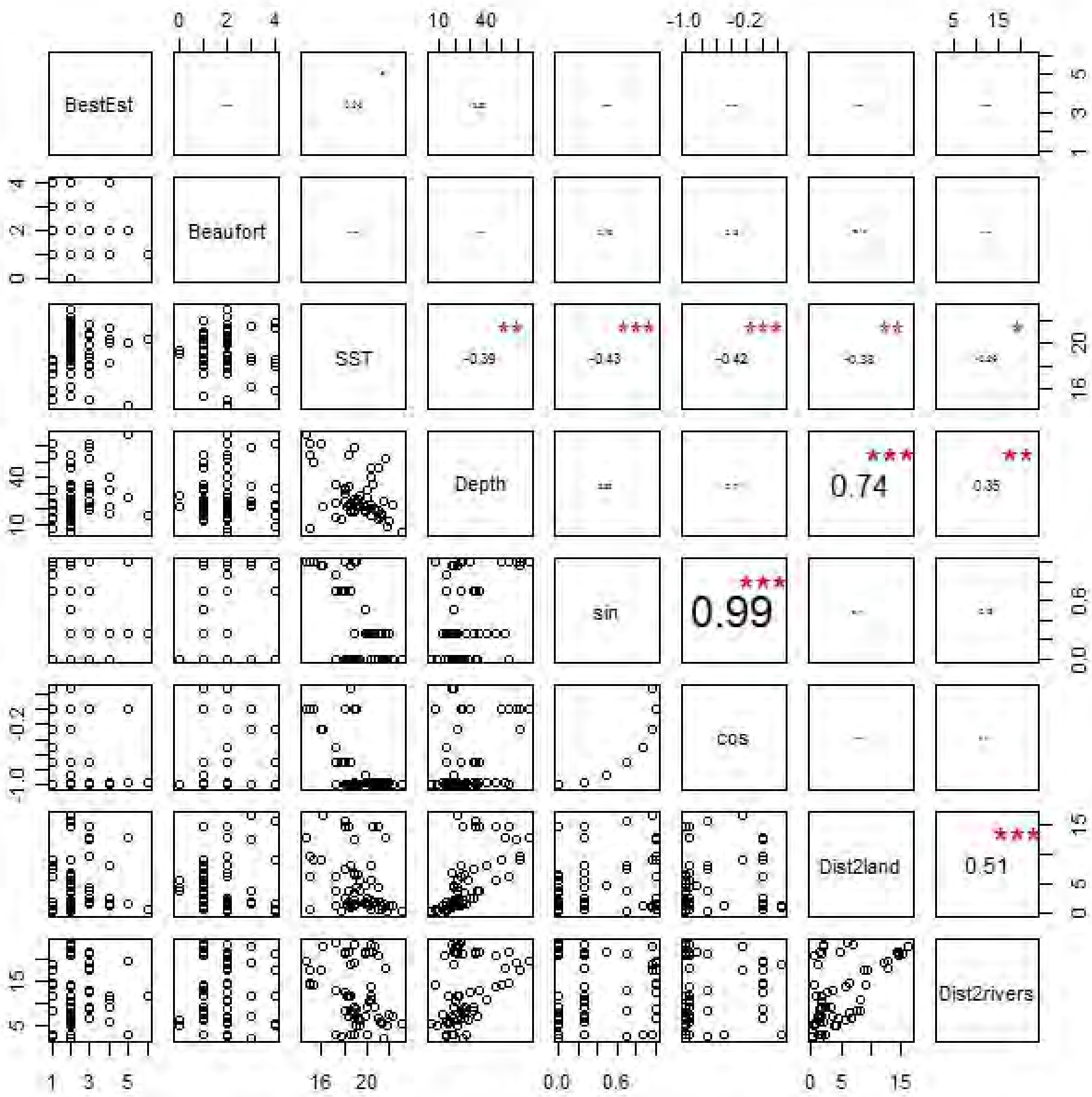

Figure 5.37. Scatterplots showing the relationship between humpback whales and Beaufort sea state, SST, bottom depth, seasonality, distance from land and distance from the nearest river.

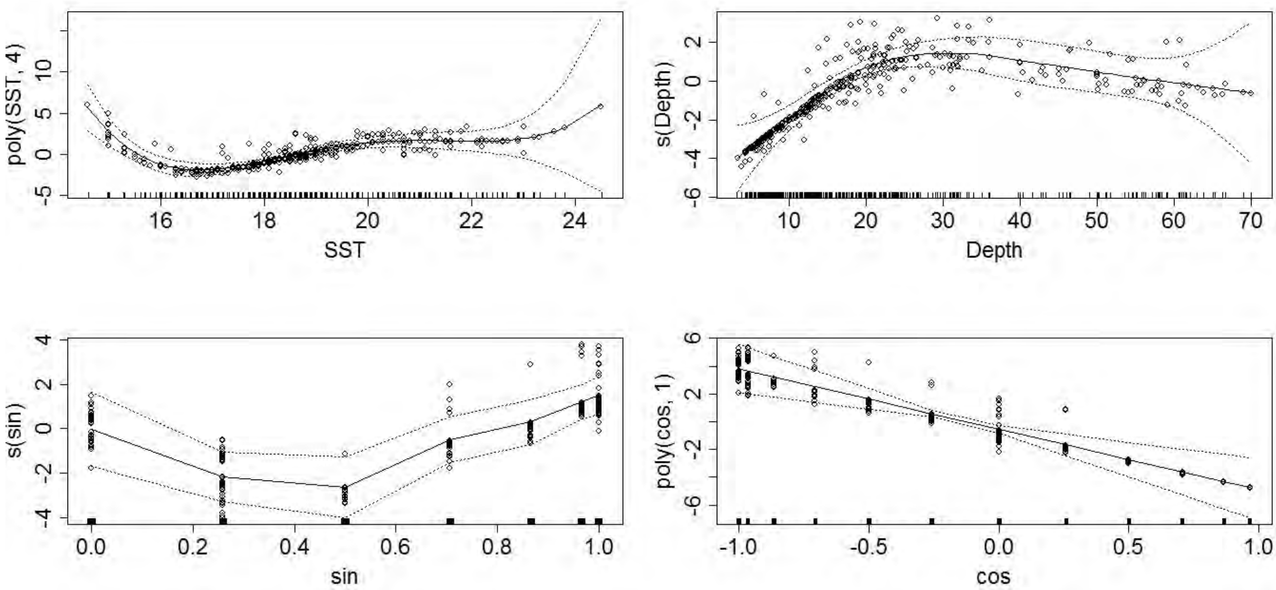

Figure 5.38. The results of the GAM for humpback whales as a function of SST, bottom depth and seasonality. Results are shown for the best-fit model after a step-wise-selected GAM was completed.

5.10.4. Bryde's whales

The scatterplots for Bryde's whales (Figure 5.39) illustrate the relationships between sightings and environmental parameters. This species was primarily observed in late autumn/ early winter with no sightings recorded between July and November (Figure 5.39). This species was observed in a wide range of SST and depths, with most Bryde's whale sightings occurring in water less than 60 m deep (Figure 5.39).

The results of the GAM indicate that the relationship between Bryde's whales and the environment is best described by *Group size = p(SST, 4) + p(Depth, 4) + Season* (Figure 5.40). Like southern right whales, none of the environmental variables for Bryde's whales were statistically significant ($p > 0.05$) (Table 5.4). Bryde's whales were observed across all depths and SST, with an apparent increase in sightings in waters above 23 ^{o}C (Figure 5.40). Sighting rates appeared to be highest during early-winter and early-summer, similar to humpback whales (Figure 5.40). In contrast to the other two mysticete species that were found in Algoa Bay, Bryde's whales were not generally observed in the second half of the year (Figure 5.40). The hurdle model indicated that SST and depth played a significant ($p < 0.05$) role in determining the estimated number of animals observed (Table 5.5).

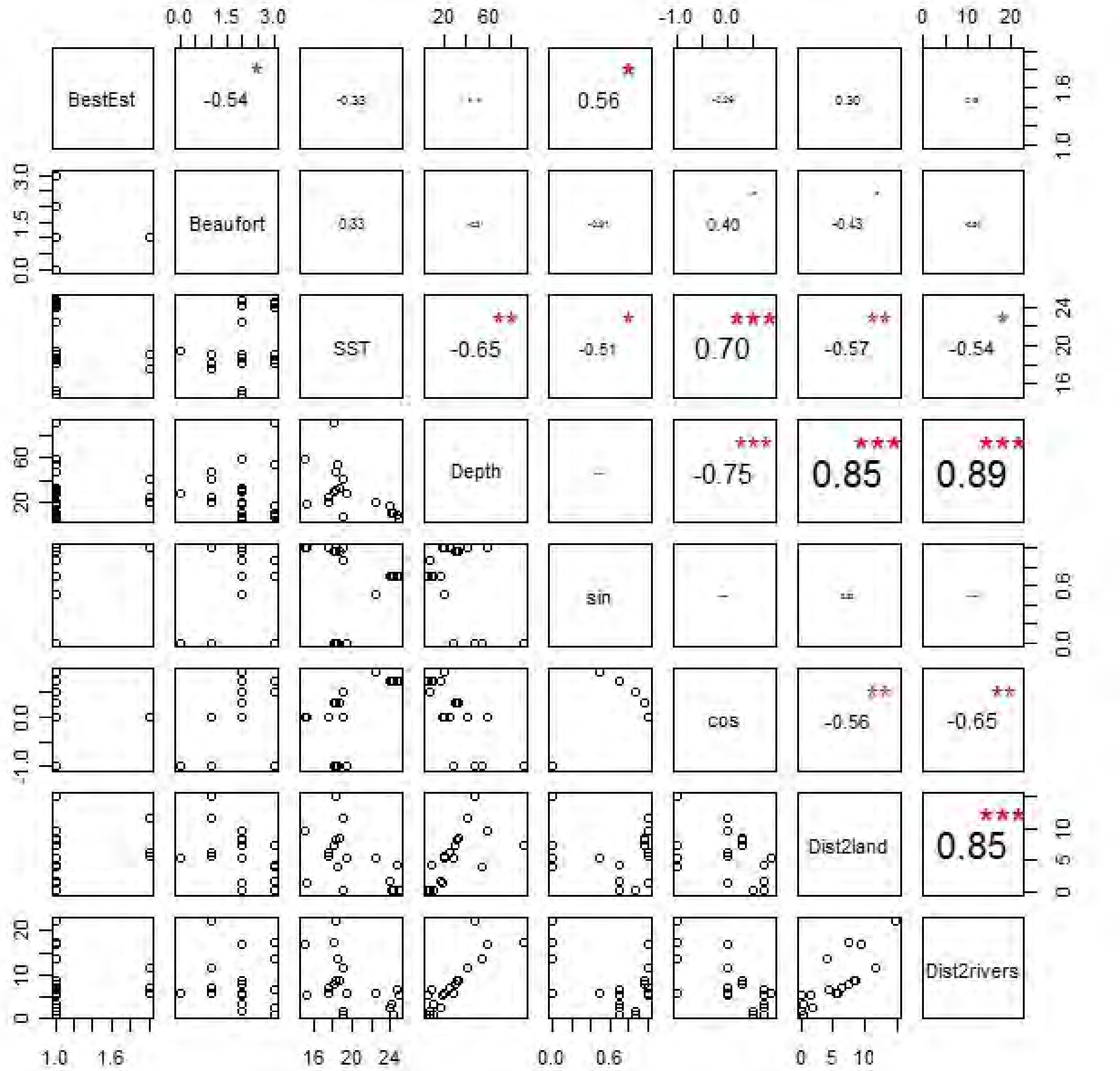

Figure 5.39. Scatterplots showing the relationship between Bryde's whales and Beaufort sea state, SST, bottom depth, seasonality, distance from land and distance from the nearest river.

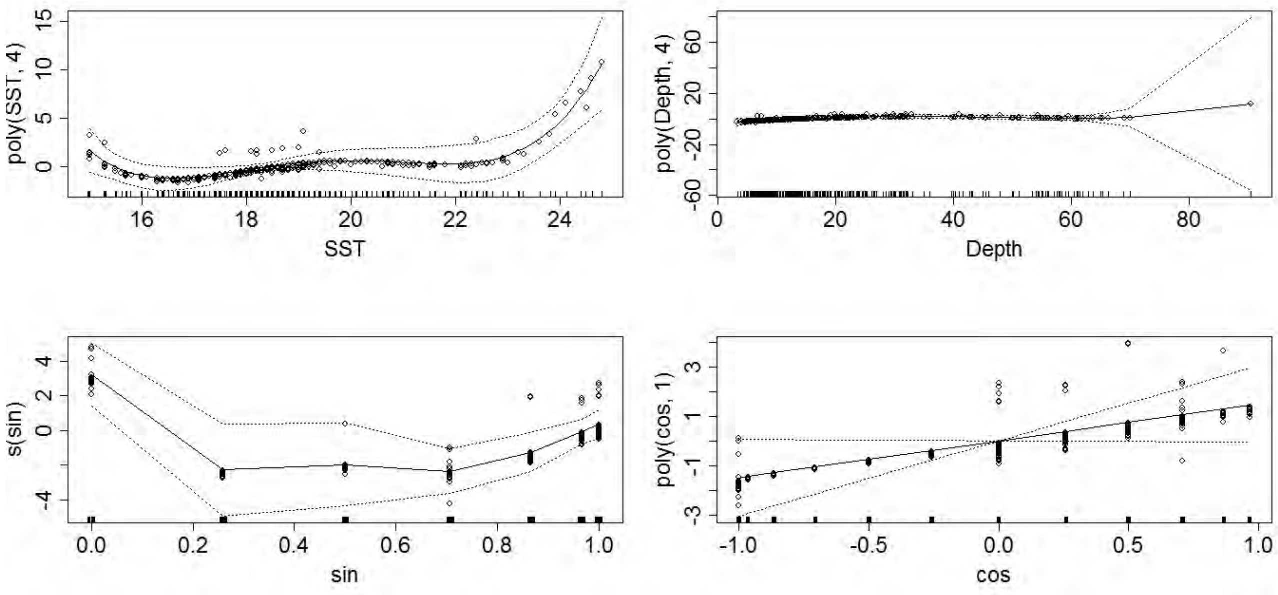

Figure 5.40. The results of a GAM for Bryde's whales as a function of SST, bottom depth and seasonality. Results are shown for the best-fit model after a step-wise-selected GAM was completed.

5.10.5. Bottlenose dolphins

The scatterplots presented in Figure 5.41 reveal several relationships between bottlenose dolphins and the environmental parameters. This species was observed year-round in the bay, with a peak in sightings during winter and spring (Figure 5.41). They were recorded in a wide range of SST, with a slight preference for warmer waters over 18 ^oC (Figure 5.41). Bottlenose dolphins were generally found in shallow waters less than 20 m deep and within two kilometres from land (Figure 5.41).

The most parsimonious GAM for bottlenose dolphins indicates the relationship between bottlenose dolphins and their environment and is best described as *Group size = s(Beaufort) + p(SST, 4) + p(Depth,4) + Season*, with 66% of the variability explained by the data (Figure 5.42, Table 5.4). Seasonality had a highly significant influence on this model (Table 5.4, $\chi^2 = 16.135$, df = 3, $p < 0.05$), with an increase in sightings during the second half of the year (Figure 5.42), which coincides with the prevalence of southern right whales and humpback whales in the bay. To some extent, more sightings were observed at a Beaufort sea state of zero or one, however the number of sightings at a sea state of 4 was only fractionally smaller than Beaufort zero and one (Figure 5.42). There also appeared to be an increase in occurrence of bottlenose dolphins with an increase in temperatures, between 16 and 22 °C (Figure 5.42). Figure 5.39 illustrates that the distribution of bottlenose dolphins was significantly influenced by bottom depths ($\chi^2 = 6.315$, df = 3, $p < 0.05$), with these animals only being observed between three and 30 m, despite surveys being conducted in deeper waters (Figure 5.42 and Table 5.4). The results of the hurdle model demonstrated that depth and seasonality played a highly significant role ($p < 0.05$) in the overall estimated relative abundance of bottlenose dolphins in the bay, with higher numbers seen during the second half of the year and in waters less than 20 m deep (Table 5.5).

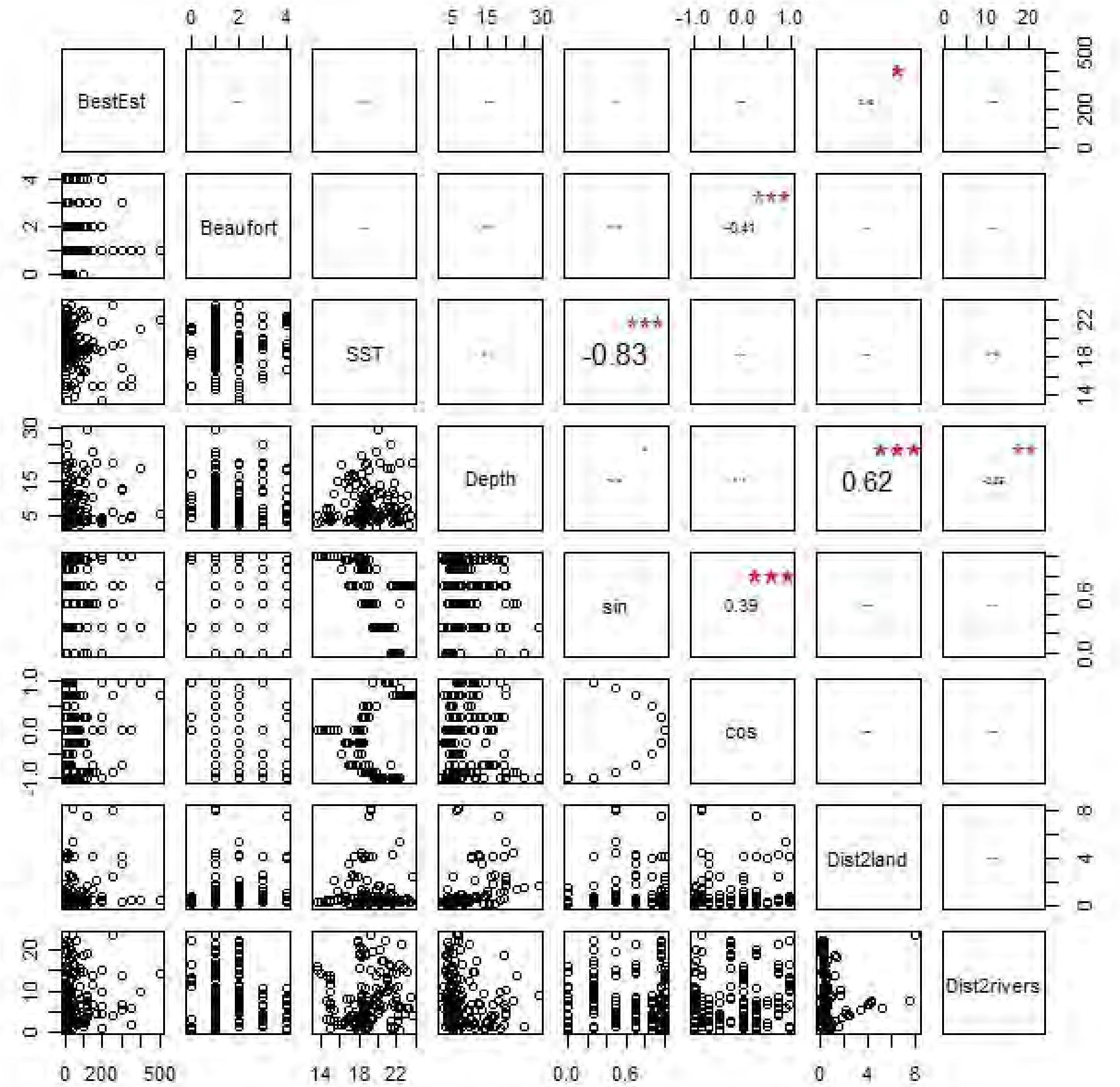

Figure 5.41. Scatterplots showing the relationship between bottlenose dolphins and Beaufort sea state, SST, bottom depth, seasonality, distance from land and distance from the nearest river.

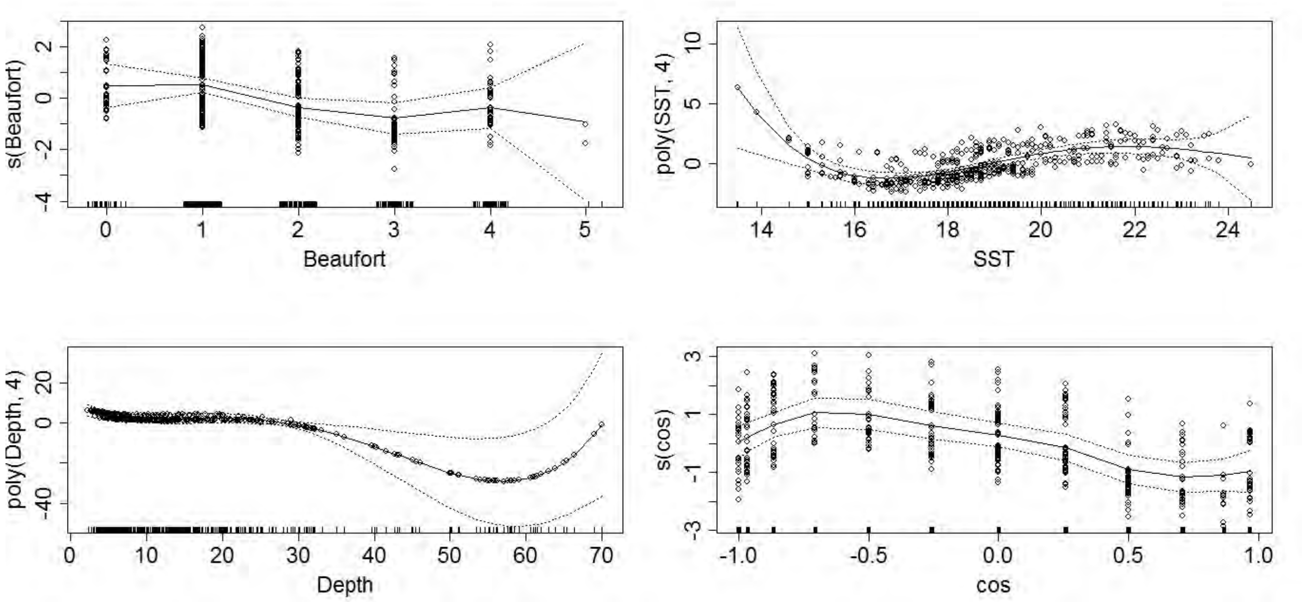

Figure 5.42. The results of a GAM for bottlenose dolphins as a function of Beaufort, SST, bottom depth and seasonality. Results are shown for the best-fit model after a step-wise-selected GAM was completed.

5.10.6. Humpback dolphins

The last set of scatterplots illustrates the relationship between humpback dolphins and several environmental parameters (Figure 5.43). More humpback dolphins were observed between 18 and 22 ^{o}C (Figure 5.43). Most of the sightings were also found in extremely shallow waters (less than 10 m deep) and close to shore, within 600 m (Figure 5.43).

The results of the GAM indicate that the relationship between humpback dolphins and their environment is best described by *Group size = p(Beaufort, 3) + p(Depth, 4) + Season* (Figure 5.44). Like southern right whales and Bryde's whales, none of the environmental variables for humpback dolphins were statistically significant in the most parsimonious GAM (Table 5.4). However, the GAM did explain 59% of the variability within the data (Table 5.4). No significant trend was seen between the presence of humpback dolphins and Beaufort sea state, with a slight decrease in sightings observed at Beaufort zero (Figure 5.44). This species was only observed in waters less than 15 m deep, and in this narrow band of shallow water, there was no upward or downward trend of humpback dolphin occurrence (Figure 5.44). Humpback dolphins were seen throughout the year, with the lowest numbers in late autumn and highest numbers during winter (Figure 5.44). The hurdle model indicated that depth was a very good explanatory variable for both the presence of humpback dolphins ($p < 0.05$) as well as the relative abundance ($p < 0.05$) of these animals in Algoa Bay (Table 5.5).

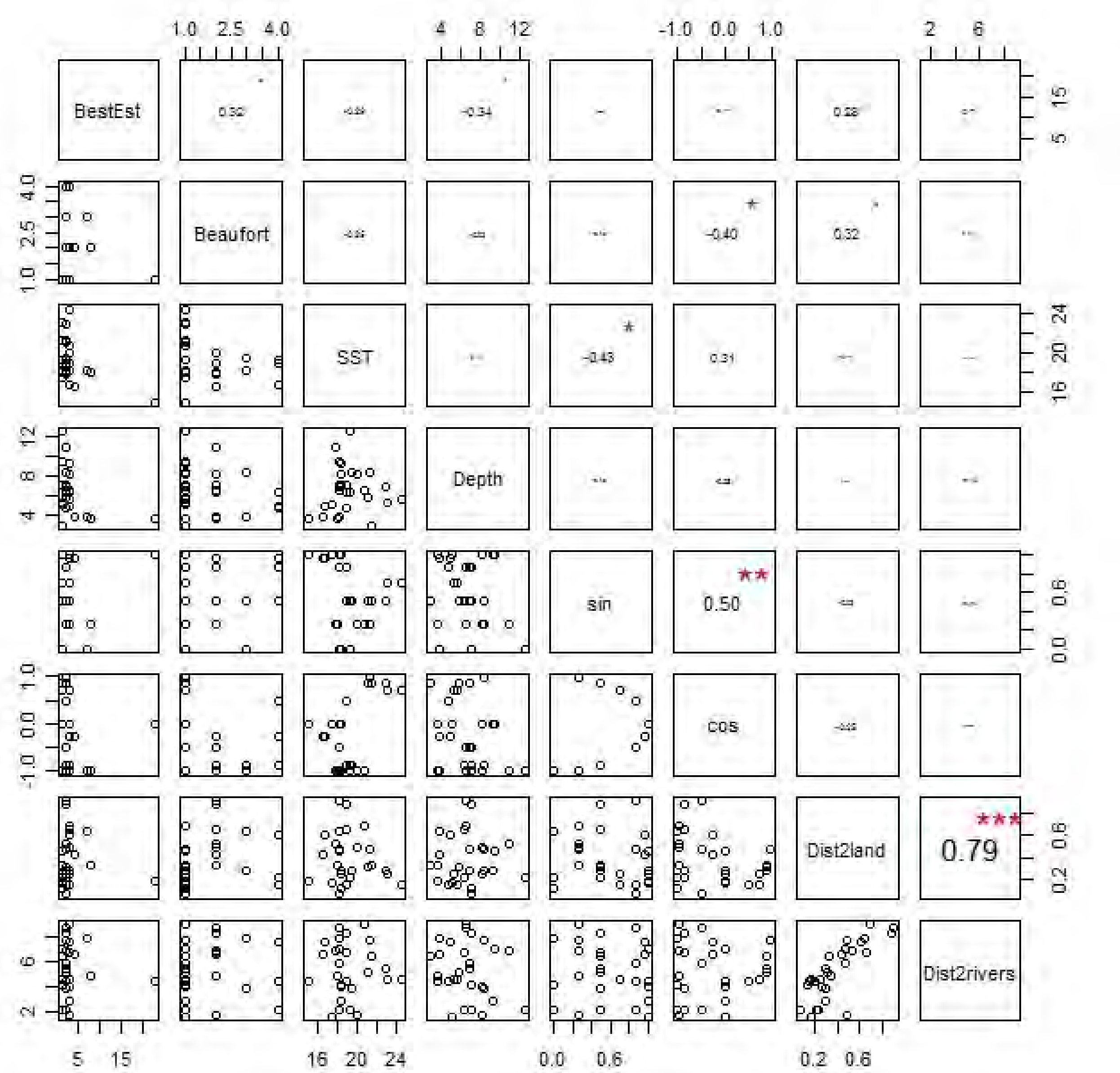

Figure 5.43. Scatterplots showing the relationship between humpback dolphins and Beaufort sea state, SST, bottom depth, seasonality, distance from land and distance from the nearest river.

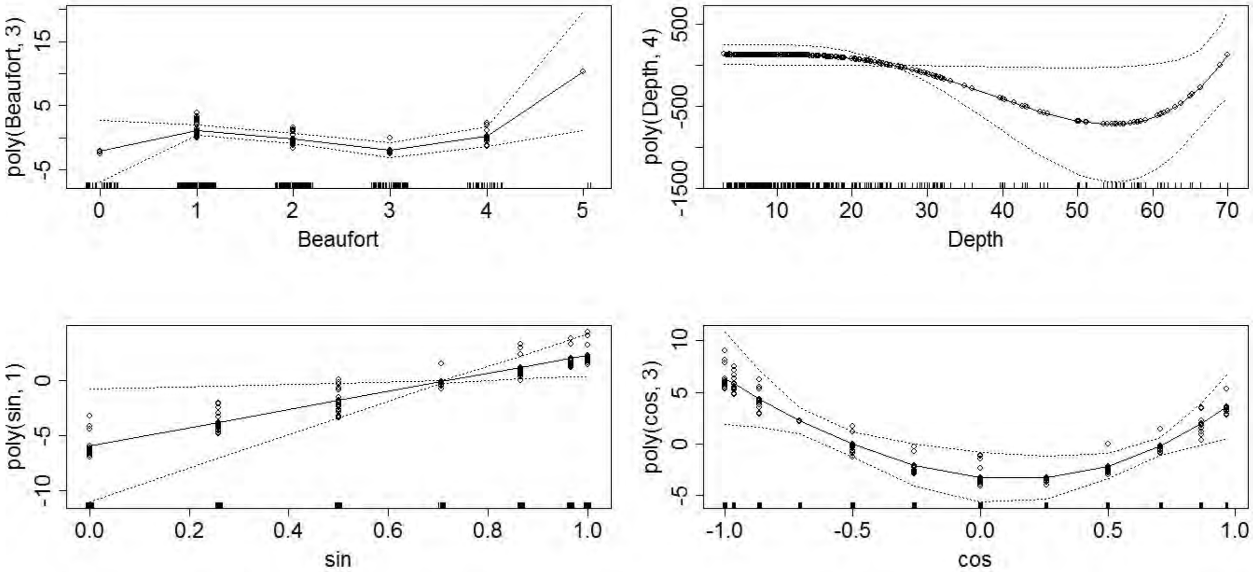

Figure 5.44. The results of a GAM for humpback dolphins as a function of Beaufort, bottom depth and seasonality. Results are shown for the best-fit model after a step-wise-selected GAM was completed.

Table 5.4. Comparison of the variables included in the final sighting rate models (GAMs and GLMs) for each species. Linear fits are represented by 'L 1', smoothing splines by 'S #', and polynomial fits by 'P #', where '#' indicates the associated degrees of freedom. The pseudo R^2 value represents a goodness-of-fit measure. P-values were displayed if some level of significance was shown: 0 '***' 0.001 '**' 0.01'*' and 0.05 '.'.

Species	Model	Explanatory variables					Pseudo R^2	AIC
		Beaufort	SST	Depth	sin	cos		
Southern right whale	GAM	S 3 0.066.	S 3 0.064.	L 1	L 1	L 1	0.54	150.57
	GLM	-	-	0.007**	0.000***	0.000***	0.62	152.14
Humpback whale	GAM	-	P 4	S 3***	S 3 ***	L 1	0.49	194.05
	GLM	0.000***	-	-	0.065.	0.000***	0.72	250.47
Bryde's whale	GAM		P 4	P 4	S 3 0.080.	L 1	0.61	121.05
	GLM	-	0.002**	0.008**	-	-	0.91	144.28
Bottlenose dolphin	GAM	S 1 0.097.	P 4	P 4	-	S 3 0.001**	0.66	430.05
	GLM	0.003**	0.015*	0.000***		0.000***	0.78	476.01
Humpback dolphin	GAM	P 3	-	P 4	L 1	P 3	0.59	138.02
	GLM	0.143	0.028*	0.000***	-	0.003**	0.69	144.08

Table 5.5. Outcomes of the hurdle models for the different cetacean species. Only variables that were significant in the two stages of the model were noted with their appropriate levels of significance (0 ‘***’ 0.001 ‘**’ 0.01’*’ and 0.05 ‘.’).

Hurdles	Stage	Explanatory variables				
		Beaufort	**SST**	**Depth**	**sin**	**cos**
Southern right whale	1	-	0.0195*	-	-	0.05.
	2	-	-	0.008**	0.000***	0.000***
Humpback whale	1	-	-	-	-	-
	2	-	-	0.000***	-	0.000***
Bryde's whale	1	-	-	-	-	-
	2	-	0.007**	0.008**	-	-
Bottlenose dolphin	1	-	-	-	-	0.063.
	2	0.003**	0.026*	0.000***	-	0.000***
Humpback dolphin	1	-	0.329*	0.007**	-	-
	2	-	0.050*	0.000***	-	0.017*

5.10.7. Summary of the statistical models

The results of the exploratory data analysis, GAMs, GLMs and the hurdle models indicated that bottom depth and seasonality were the key explanatory variables (that having the greatest effect on the mean response) in determining sighting rate and group size of cetaceans in Algoa Bay, confirming statistically what was illustrated in previous analyses in this chapter. In summary, more mysticetes and odontocetes were observed in the second half of the year, from mid-winter to early summer (July to December). Cetacean species also appeared to utilise and favour different depth classes, with distinctions between inshore and offshore species. Beaufort sea state did not appear to significantly influence the number of sightings for each species directly. However, the inclusion of Beaufort sea state into most of the final models suggests that this variable is correlated with other factors that influence cetaceans, such as seasonality.

5.11. DEFINING POTENTIAL KEY HABITATS FOR THE CETACEANS IN ALGOA BAY

Key habitats (potential critical habitats) were defined by looking at high density areas, places where key behaviours occurred (foraging, resting and mating), and the location of mother calf pairs. As the data for this research was only captured over a relatively short-period of time, these maps (Figures 5.45 and 5.46) provide only a preliminary insight into the key habitats for the mysticetes and odontocetes in Algoa Bay.

For mysticetes, five areas (A, B, D, E and G) were identified as key habitats (Figure 5.45). Areas C and F have lower densities, but were considered relatively important in two variables (Figure 5.45). This map can be interpreted further when taking into account all the geographical variables that have been compared to cetacean distribution in this chapter, including bottom depth, which was an important factor in the cetacean distribution in the statistical models. Area B (in bottom depths less than 20 m) was considered to be the key habitat for southern right whales (Figure 5.45). This area also possibly extends north-westwards towards the Swartkops River, with a high number of sightings and mating activities observed here (Figure 5.45). A secondary, smaller key habitat for southern right whales falls within area E, where a high number of mother-calf pairs for this species was located (Figure 5.45). In contrast to this, key habitats for humpback whales were located along the more exposed edges of the bay in A, F and G, with area A being the farthest offshore (Figure 5.45). Areas D and E were also moderately utilised by this species (Figure 5.45). As the total number of Bryde’s whales was comparatively low compared to the other two mysticete species, along with the lack of calves present in sightings, it was more difficult to establish a key area for Bryde’s whales. However, Bryde’s whales were seen relatively often in area C, while foraging and resting (Figure 5.45).

The high number of sightings for bottlenose dolphins and the significantly lower number of sightings for common dolphins, make it more difficult to distinguish key areas for the odontocete species (Figure 5.46). Nevertheless, several locations are more extensively used by odontocetes compared to other areas in Algoa Bay (Figure 5.46). The coastal nature and shallow habitats for both bottlenose dolphins and humpback dolphins has been revealed in various ways. Although area H is not the most densely populated area, a number of key activities were located here, all of which were associated with bottom depths of less than 15 m (Figure 5.46). In addition, a significant proportion of humpback dolphin sightings were located in area H. This, as well as the presence of important activities such as mating and foraging along these rocky shores, makes this area very important for humpback dolphins (Figure 5.46). Bottlenose dolphins extensively utilised the sandy, shallow waters along the Alexandria Dunefield coastline (east of Sundays River). Additionally, two key areas (K and L) where a very high number of sightings, as well as foraging activities, were located within this region (Figure 5.46). These areas were also associated with shallow waters; primarily within bottom depths of less than 20 m (Figure 5.46). Areas J (St Croix Island), and to a lesser extent, I, have also been considered important as a relatively large amount of foraging was recorded there (Figure 5.46).

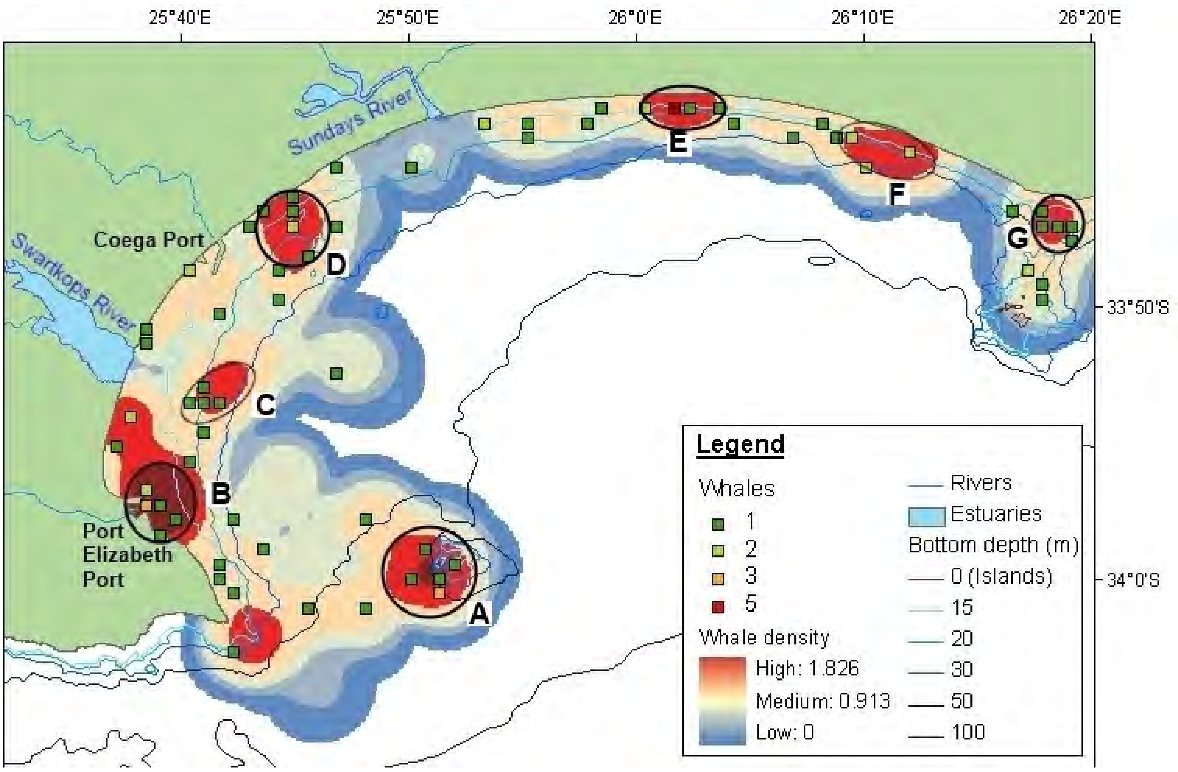

Figure 5.45. Potential key habitats (A – G) for the mysticetes in Algoa Bay.

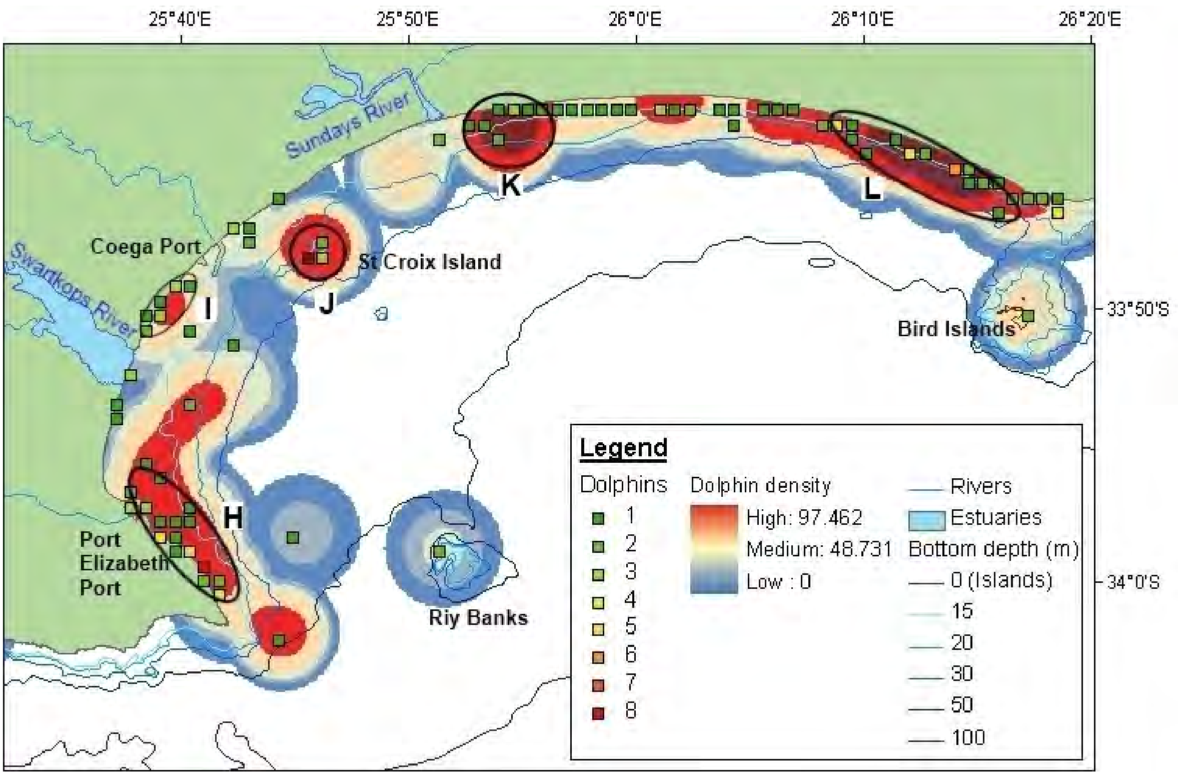

Figure 5.46. Potential key habitats (H – L) for the odontocetes in Algoa Bay.

5.12. SUMMARY OF FINDINGS

Six cetacean species were observed in Algoa Bay during dedicated boat-based surveys and opportunistic data collection between March 2009 and July 2010. A total of 346 sightings were recorded, with over 12 000 individuals observed, including calves and juveniles. Mother-calf pairs for the two migratory whale species were seen throughout their range in the bay, with significantly higher numbers in the proposed GAENP MPA. A number of behaviours were recorded in the different species, including behaviours such as foraging and mating, which are indicative of potential key habitats. Some sightings were recorded within the various shipping zones.

Southern right whales were only recorded during winter and spring, with a peak in sightings during spring, where mating was the most observed behaviour. This species was recorded in the sheltered, inshore (shallow) areas between the two ports, with the associated substrate primarily consisting of sand and mud.

Humpback whales were the second most observed species in the bay, with all sightings recorded between June and December. Two peaks of observations were noted in June and November/ December. This species was seen throughout the survey area, and was recorded opportunistically offshore of the Alexandria Dunefield. Humpback whales were the least closely associated with rivers compared to the other species, and were generally found over sand, rock or coral substrate. These animals were frequently observed breaching, with some opportunistic foraging observed.

Bryde's whales were observed in Algoa Bay during the austral summer and autumn, with a peak of sightings occurring in May. These animals were recorded in the inshore waters between the two ports, and in the offshore zone, where sand, rock and mud substrate dominates. Within these two zones, they were found intermittently within the Coega channel and the two anchoring areas. Bryde's whales, in comparison to the other species, were located in the deepest waters of Algoa Bay, with no calves and juveniles recorded. This species was predominantly observed travelling, milling and foraging.

Bottlenose dolphins were the most common species recorded in Algoa Bay, with the highest number of individuals, calves and juveniles observed. This species was recorded year-round, with peaks in sightings during winter and spring, and a decrease in sightings during autumn. They were sighted throughout the study area, with a greater inshore distribution compared to humpback whales. The highest number of sightings for this species was recorded in the coastal zone of the Alexandria Dunefield, which is primarily comprised of sandy substrate. Bottlenose dolphins were predominantly observed travelling, milling and foraging.

Humpback dolphins were recorded in the coastal zone of the western half of the bay, with the majority of sightings observed along the rocky shores south of PE Port. This species was recorded closest to the shore out of the six cetacean species, with all sightings occurring in depths of less than 15 m. The lowest number of sightings was observed during autumn, with increased numbers noted in winter and early summer. Group sizes consisted of approximately four individuals, with one sighting of 23 humpback dolphins. This species was most often observed travelling and foraging, with socialising occurring in autumn and winter.

Common dolphins were only recorded seven times in Algoa Bay, two sightings of which were of single individuals within a group of bottlenose dolphins. However, this species contributed to the second highest number of individuals in the bay due to their large group sizes. These dolphins were predominantly observed foraging in bait balls with other marine species in the offshore and exposed areas of the bay.

In conclusion, this chapter presented the findings through the use of tools such as GIS and statistics. These results address objectives three and four, which were to map and investigate the spatial and temporal distribution and behaviour of the cetacean species, and to relate this distribution to the environmental and anthropogenic variables. The following chapter will further develop and explain these findings.

CHAPTER 6: DISCUSSION

6.1. INTRODUCTION

Six cetacean species were observed throughout the surveyed area in Algoa Bay, displaying a number of different spatial and temporal distribution patterns. These distribution patterns, together with the influence of group dynamics such as the predominant behaviour, will be discussed in order to meet objective three, which was to determine the spatial and temporal distribution and behaviour of the cetacean species. These patterns indicate habitat preferences for each species within the bay. The relationship between these habitat preferences and the surrounding physical environment is addressed through the outcomes of objective four, which relates the spatial and temporal distribution and behaviour of the cetaceans to these environmental and anthropogenic variables.

Existing literature is referred to, to demonstrate the present state of knowledge, and compare the measured biological and geographical variables, to cetacean distribution within Algoa Bay. Each species is discussed separately, with an overview of the general spatial and temporal distributions of the different cetacean species occurrences in the bay. This is followed by the discussion of more specific group dynamics and behaviours which influence their distribution patterns. The final section for each species builds on these two previous aspects in order to identify their habitat preferences within Algoa Bay and how this relates to general habitat preferences within their range. Anthropogenic activities that have affected, or may potentially affect the distribution of cetaceans are also discussed for mysticetes and odontocetes. This discussion is intended to form the foundation of a more comprehensive framework for future management, conservation and research decisions.

6.2. SOUTHERN RIGHT WHALE

6.2.1. General spatial and temporal distribution patterns

Previous data on the southern right whale's utilisation of the South African coastline was obtained from aerial surveys conducted between 1970 and 2000 (Best, 2000; Elwen and Best, 2004). These surveys established that this species was primarily recorded on the south and west coasts of the country, especially between Walker Bay and Plettenberg Bay, with very few sightings east of Cape Padrone (Best, 1990; Elwen and Best, 2004). The results of this study indicate that this situation has changed over the last decade, with a greater number of southern right whales recorded in Algoa Bay. However, as this is a local study, it is not evident whether the presence of these animals in the bay is a result of a shift in distribution away from other areas, or whether it is a result of their large population growth recorded by Best *et al*. (2001), that has resulted in an expansion of their range along the coast (Figure 6.1) (Best, 2010: Pers. Comm.).

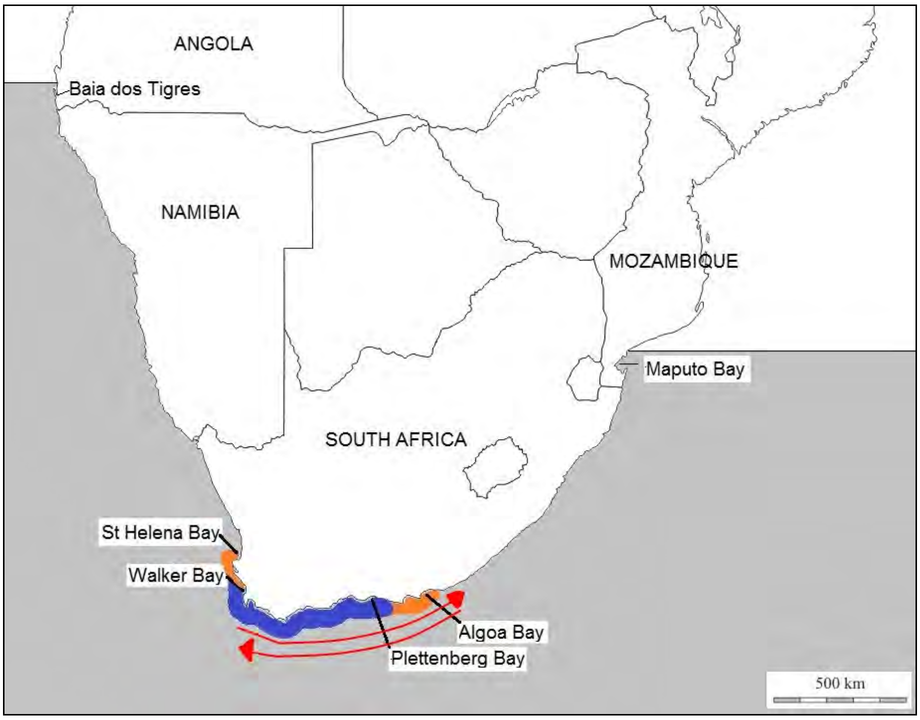

Figure 6.1. Diagram illustrating the distribution of southern right whales in southern Africa. The grey area represents the previously known limits (Baia dos Tigres to Maputo Bay). The blue and orange areas illustrate the previous core distribution and the current range expansion, respectively. The arrows represent the eastward and westward movement of this species at the beginning and end of their wintering season.

During the 'whaling' period, southern right whales were caught along the entire coastline of South Africa, within their winter range which extended from Baia dos Tigres, Angola, in the west, to Maputo Bay, Mozambique, in the east (Figure 2.1) (Best, 2007; Reilly *et al.*, 2008b). Therefore, the recent increase in numbers at the end of their modern day range suggests that, with the population growth over the last three decades, this species is extending beyond its present day range to its previously known limits (Figure 6.1) (Belgrano *et al.*, 2008; Mate *et al.*, 2010).

Patterns of range expansion for this species have already been observed up the west coast of South Africa (Best, 1990), and off the Península Valdés in Argentina (Rowntree *et al.*, 2001).

In this study, southern right whales were recorded in Algoa Bay between June and December, throughout the duration of their previously known wintering months off the coast of South Africa (Figure 5.13) (see: Best, 1990; Best *et al.*, 2003). This is comparable to other subtropical breeding grounds in the southern hemisphere such as Argentina, Uruguay, Australia and New Zealand, where sightings are recorded in winter and spring (Burnell and Bryden, 1997; Rowntree *et al.*, 2001; Patenaude, 2003; Costa *et al.*, 2005; Belgrano *et al.*, 2008).

The sighting frequency for southern right whales was 0.13 $s.hr^{-1}$. This frequency is relatively high compared to the other species, particularly since this species is only being observed five to six months of the year (Table 5.1). A intensive shore-based study in Saldanha Bay (which had more hours ‘on effort’), calculated a sighting frequency of 0.37 $s.hr^{-1}$ (Barendse *et al.*, 2010), which is almost three times higher than what was recorded in Algoa Bay. The results of these two studies could again indicate that the number of sightings in this region have increased in recent years, which is indicative of range expansion and an increase in numbers within this range.

6.2.2. Group dynamics and behaviour

The mean group size for southern right whales was 2.4 individuals (Table 5.1), slightly larger than those recorded by Best (1990a), who estimated an average of 1.51 individuals per sighting. Groups of two or more individuals are common in the subtropical breeding grounds (Best, 1990; Costa *et al.*, 2005), which is in contrast to their Antarctic feeding grounds where only 15.4% of sightings consist of more than one individual (Best *et al.*, 2003).

Aerial surveys between 1969 and 1987 recorded no mother-calf pairs in Algoa Bay, only adults (Best, 2000). This is in sharp contrast to what was observed in the bay during the present study, which recorded mother-calf pairs in 40% of the sightings (Table 5.2). In this study, a peak in sightings occurred approximately two months after the previously estimated peak birthing time (August) for southern right whales observed off the South African coastline (see: Best, 1994; Best, 2007) (Figure 5.13). A large portion of these sightings during October were mother-calf pairs, which suggests that these animals move into the bay after giving birth. This was confirmed by field observations, where slightly larger calves (six to seven metres in length) were recorded.

Studies in the region have indicated a westward movement along the south coast (Figure 6.1) (Best, 2000; Mate *et al.*, 2010), which would imply that these animals were born east of Algoa Bay, and slowly moved westwards during the season, before returning to their summer feeding grounds at the beginning of summer. However, three extremely small calves were also seen in the bay in June and July 2010 (approximately four to five metres in length), one with neonatal folds, indicating that some of the observed calves were probably born in Algoa Bay.

A large proportion of socialising behaviour observed in spring was a result of an increase in mating activities, often linked to 'surface active groups' (SAGs) (Figure 5.16). SAGs are groups of between two and ten animals that perform a variety of behaviours including splashing, spy-hopping, rolling, and exposing of their bellies and flippers at the surface of the water (Best *et al.*, 2003; Patenaude, 2003). Such activities were seen five times in the bay, with a maximum group size of eight individuals. The seasonality of these larger groups was also shown to be significant in the final hurdle model ($p < 0.05$; Table 5.5). Although these socialising/ mating behaviours are relatively common on their wintering grounds, this is in sharp contrast to the activities of these animals in their polar feeding grounds, where almost no socialising has been observed (except between a mother and calf) (Best *et al.*, 2003).

6.2.3. Description of the habitat preference within Algoa Bay

Southern right whales were recorded in the sheltered and sandy areas of Algoa Bay (Figures 5.32 and 3.2). This is comparable to findings in other studies which also noted the favouring of similar habitats along the South African coastline, with this species avoiding the more exposed and rocky shores (Figure 5.5) (Best *et al.*, 2001a; Elwen and Best, 2004). The lack of sightings along the rocky shore region on the south-west corner of the bay could also be attributed to the steeper bathymetry in this area, as these animals tend to prefer a gentle sloping/ flat sea-floor (Best *et al.*, 2001a). The high proportion of sightings associated with sand and mud could also explain why southern right whales, out of all the species, were the most closely associated with river mouths (Figure 5.31), which tend to have finer sediments and gentle gradients around them. Most sightings were found near the two ports, both of which have rivers that enter them (Figure 5.5). The long harbour walls create a buffer to the ocean, and result in a sheltered area from the wind and swell, providing an ideal habitat for this species.

Best (2000) suggested that 'nursery' and 'mating' areas existed in separate patches along the south coast of South Africa, and previous data did not indicate that Algoa Bay served as either (Best, 1990; Elwen and Best, 2004). The results of this study suggest that this bay now has both nursery and mating areas (Figure 5.17), with a mating area existing around the PE Port, and the presence of mother-calf pairs recorded throughout their observed range in Algoa Bay (Figure 5.14). Most of the mother-calf pairs (76%) were observed in the proposed GAENP MPA (Figure 5.34). Recent shifts in nursery and mating grounds have also been seen in other regions, such as off the coast of Valdés, Argentina (Rowntree *et al.*, 2001). However, the results of this study does not suggest a well defined segregation between a nursery and mating area in the bay as suggested in previous studies (Payne, 1986; Best, 1990; Elwen and Best, 2004), with mother-calf pairs in Algoa Bay overlapping with the core mating area (Figures 5.14 and 5.17).

The results of this research were similar to Elwen and Best (2004), with mother-calf pairs being located both closer to shore and in shallower depths compared to sightings consisting of only adults ($p < 0.05$; Figures 5.29 and 5.30). One hypothesis is that the mother-calf pairs utilise the shallow surf zone to avoid predation by killer whales (which are occasionally observed along the coastline of South Africa), as the waves mask the noise of these animals, and the shallow water prevents an attack from below (Thomas and Taber, 1984; Sironi *et al.*, 2008). Southern right whales could also utilise the more shallow areas to avoid interactions with other animals of the same species, which could resulting in possible injury to the calf or interruption of suckling (Elwen and Best, 2004).

Southern right whales were mainly observed at depths of ten to 15 m (Figure 5.26), and approximately 700 m from land (Figure 5.28). This is similar to other findings for this species in the region (Payne, 1986; Best, 1990; Elwen and Best, 2004). These habitat preferences were explored further with the use of a hurdle model which indicated that depth did play a significant role in the relative abundance of southern right whales in Algoa Bay ($p < 0.05$; Table 5.5).

6.3. HUMPBACK WHALE

6.3.1. General spatial and temporal distribution patterns

Humpback whales are known to use subtropical coastlines as a migratory corridor to their main wintering areas, which exist from Angola and Mozambique northwards (Dawbin, 1966; Best, 2007). Although these animals have a cosmopolitan distribution (Figure 2.2) (MacLeod *et al.*, 2005), humpback whales exhibited a distinct seasonality in Algoa Bay, similar to the southern right whales, with a slightly longer season extending from May to December (Figure 5.14). Studies from different regions in the world have also shown a strong seasonality in humpback whale sightings (see: Winn and Reichley, 1985; Jefferson and Schiro, 1997). In South Africa, a shift in peak sightings, was recorded along the different latitudes (Best *et al.*, 1998; Barendse *et al.*, 2010). These peaks occurred in August at Cape Vidal (east coast), October at Saldanha Bay, and December at Knysna (south coast), for the southward migration of these whales (Figure 6.2) (Best *et al.*, 1998). The tropical limit of their east coast wintering ground is thought to be around central Mozambique (Findlay *et al.*, 1994; Barendse *et al.*, 2010).

Humpback whale sightings increased towards the end of their wintering season, with a lower peak of sightings in June, and the highest number of sightings recorded during November and December (Figure 5.13). This trend is possibly due to the initial arrival of this species at the beginning of the season, resulting in a winter peak of abundance in June, before they continue up the coastline to the tropical areas (Best *et al.*, 1998; Best, 2007). The continuation of sightings throughout the season mainly consisted of adults, which indicates that they might not travel the full extension of their migratory route, and instead, remain along the South African coastline. The sharp increase in sightings in November and December (ten times the SPUE recorded during July and October), mark the end of the winter breeding season, and the southward movement of these animals (Figure 5.13) which coincides with previous studies in the region (see: Best *et al.*, 1998; Best, 2007).

A sighting frequency of 0.22 $s.hr^{-1}$ was recorded for humpback whales in this study (Table 5.1), which is higher than the total frequency of 0.12 $s.hr^{-1}$ recorded by Best *et al*. (1998) in coastal and offshore surveys off southern Africa between 19 and 53 ^{o}E (Knysna to East Madagascar). In contrast to Algoa Bay, humpback whales in Saldanha Bay were also observed less frequently (0.16 $s.hr^{-1}$) (Barendse *et al.*, 2010). This shows that they are found in varying numbers around South Africa and possibly indicates that Algoa Bay is an important site.

The mean SPUE for humpback whales (1.9) was high (Figure 5.13), considering they were not observed in the bay between January and late May. The SPUE for these whales ranged from 0.7 to 10.2. In contrast, the SPUE measured for humpback whales in Mozambique was approximately 1.25 between August and September (Findlay *et al.*, 1994). When taking into account the actual number of individuals observed and the distance covered during the survey, the relative density of humpback whales is low (0.04 $indiv.km^{-1}$; Table 5.2) compared to a relative density of 0.185 $indiv.km^{-1}$ recorded for this species in Madagascar by Best and Sekiguchi (1996). However, the high SPUE in Algoa Bay does indicate that this area is potentially important for these animals along the migratory route.

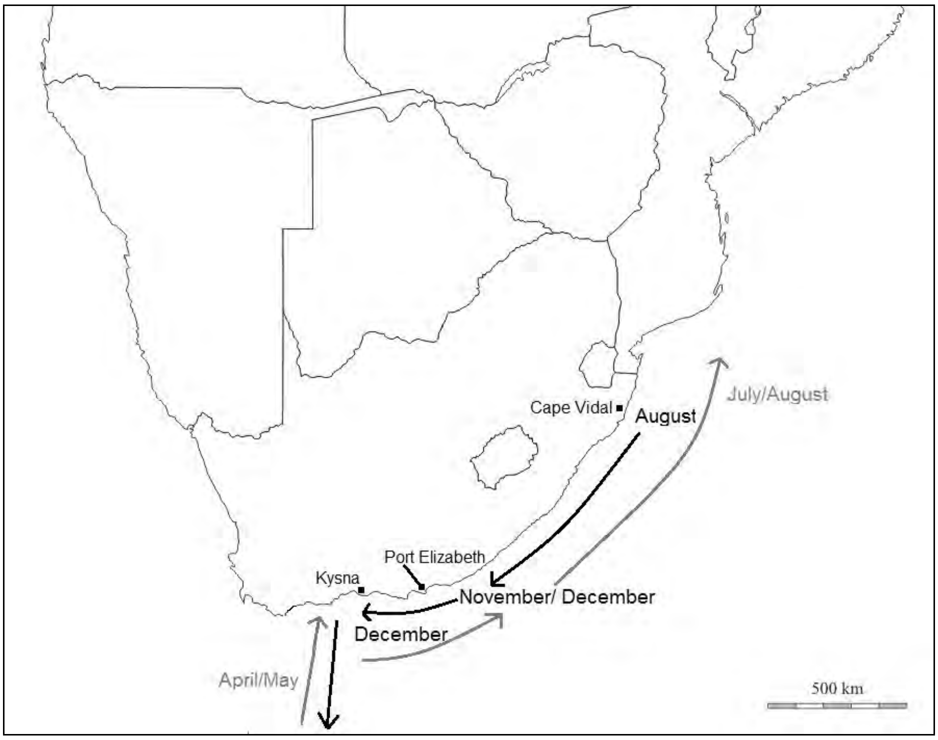

Figure 6.2. Migratory route of humpback whales on the east coast of South Africa. The grey and black arrows represent the north and southward migratory route, respectively. Months where peak sightings occur are displayed in the diagram.

6.3.2. Group dynamics and behaviour

Group sizes were between one and six individuals, with a mean of 2.4 (Table 5.1). This is similar to records in the wintering grounds of 1.4 to 2.2 animals (Mignucci-Giannoni, 1998; Best *et al.*, 1999; Barendse *et al.*, 2010). Group sizes at the beginning of the season were between one and three individuals with very few mother-calf pairs. This is in sharp contrast to the end of the season, where groups were larger (up to six individuals), and most of which contained at least one calf. Barendse *et al.* (2010) also established that group sizes change with season, with larger groups observed in mid-spring and early summer. These observations were further clarified by the results of the hurdle model which illustrated that seasonality played a significant role in both the occurrence and the number of animals in the bay ($p < 0.05$; Table 5.5).

This change in group size and composition could be a result of the sequence of migration that these animals undertake. Humpback whales are believed to migrate between their feeding and breeding grounds in a particular order, with females with yearlings generally migrating northwards first, followed by young and mature adults, and lastly, the pregnant females (Dawbin, 1966; Best, 2007). A similar sequence is thought to occur on the southwards migration, with the females with new calves leaving last (Dawbin, 1966; Barendse *et al.*, 2010). This could explain the changes in group composition throughout the austral winter.

However, this does not explain the high number of mother-calf sightings observed in Algoa Bay (over 60%; Table 5.2). This was much higher than studies in Puerto Rico, where calves were present in 12% of the sightings, and 3.7% of the sightings in Madagascar (Best and Sekiguchi, 1996; Mignucci-Giannoni, 1998). Two sightings in Algoa Bay were also of very small calves (five to six metres), one of which had neonatal folds. This suggests that some humpback whale births could be occurring off the south coast of South Africa.

The presence of humpback whale mother-calf pairs in Algoa Bay (Figure 5.14) suggests that they utilise the relatively protected habitat that a bay provides, which are not found on the east coast of the country (Bremner, 1983), until their calves are large or strong enough to migrate back to their summer feeding grounds in Antarctica. It is not known whether these animals would then continue travelling westwards along the south coast of the country, or whether they migrate directly south (Best, 2007).

Alongside the change in group sizes and composition, they appear to change their behaviour on the return route along South Africa (Figure 5.16). At the beginning of their wintering season, breaching, flipper slapping and other similar ‘play’ behaviours were dominant at sightings. Towards the end of the season, greater time was spent travelling, milling and resting. The decrease in highly active behaviours and the increase in milling and resting (especially in groups with small calves), is possibly due to these animals conserving energy before migrating back to their polar feeding grounds.

Three instances of foraging were observed during November (all with calves), two of which were in large groups (four to six individuals) (Figure 5.16). Dolphins and gannets were also recorded foraging in the area with the latter two groups. Laws (1977) suggested that opportunistic foraging could be due to appropriate food being available, and is therefore consumed to store up extra blubber reserves for suckling and migrating. All groups showed similar behaviours with spurts of travelling in a zigzag fashion (sharp, sudden turns), with milling/ slow travel in between, which according to Best, P.B. (2010: Pers. Comm.) is suggestive of feeding. Similar observations have been recorded in Saldanha Bay and Cape Columbine (Findlay and Best, 1995; Best, 2007; Barendse *et al.*, 2010).

6.3.3. Description of the habitat preference within Algoa Bay

Humpback whales were sighted throughout Algoa Bay, in both coastal and more offshore areas, with a preference for certain habitats (Riy Banks, along Woody Cape and at Cape Padrone) (Figures 5.5. 5.8 and 5.21). However, this preference for certain habitats within the bay was not as noticeable as other studies, where only one or two key areas were occupied within the study area (Mignucci-Giannoni, 1998). In Algoa Bay, this species was associated with the major reef (Riy Banks) and the two island groups. They were also sighted at the two headlands bordering the bay. These areas have relatively steep bottom topography (i.e. greater changes in bathymetry). The oceanic ridge ('Recife Bird Ridge') extends between the two headlands and Riy Banks could provide a path for navigation as the humpback whales migrate along the coastline (Figure 6.3). Looking at the behaviour of the animals along the ridge confirms this idea, as a number of animals were observed between Cape Recife and Riy Banks, travelling in the direction of the reef. The observed behaviour of humpback whales on the reef was also different, with most animals seen milling and breaching, before moving away.

Unlike humpback whales in Puerto Rico which were primarily recorded in sheltered areas (Mignucci-Giannoni, 1998), a high number of sightings in this study were observed along the exposed Woody Cape coastline. A significant proportion (63%) of the observed mother-calf pairs were located on the eastern coastline of the bay (inside the GAENP MPA) (Figure 5.34), an area which experiences some of the largest waves in the bay (Pers. Obs.). The hypotheses as to why mother-calf pairs utilise shallow, surf zones was outlined previously with regard to southern right whales.

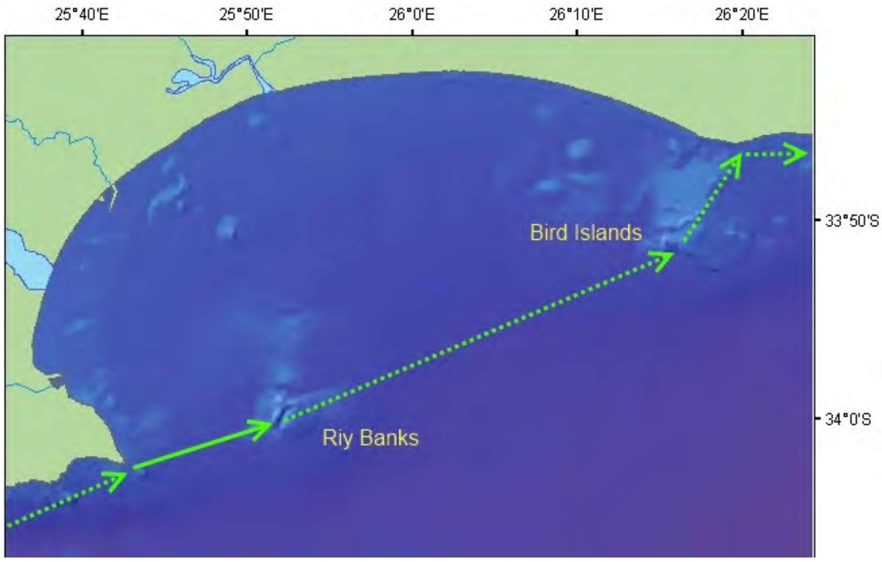

Figure 6.3. Postulated movement of humpback whales in the Algoa Bay region.

The distance from land recorded for humpback whales ranged from 1.5 to 7.8 km (Figure 5.28). This is similar to the ranges observed at Cape Vidal, and Saldanha Bay (Best *et al.*, 1998; Barendse *et al.*, 2010). Humpback whale mother-calf pairs, like southern right whales, were also found slightly closer inshore than the other sightings of the same species. However, this was not significant ($p > 0.1$; Figure 5.30). Mother-calf pairs have been observed closer to land in other areas such as the São Tomé and Príncipe archipelago and Puerto Rico (Mignucci-Giannoni, 1998; Picanço *et al.*, 2009).

The distance from land also relates to the depth at which this species was sighted. In Algoa Bay, most sightings were detected in waters greater than 20 m deep, with a mean bottom depth of 27.6 m (Figure 5.26). This is similar to the distribution of humpback whales in Mozambique which were generally observed in waters greater than 18 m deep (Findlay *et al.*, 1994). Depth was also considered a significantly important variable for presence of humpback whales in the bay ($p < 0.05$; Table 5.4) and their relative abundance ($p < 0.05$; Table 5.5) in the GAM and hurdle models. These results suggest that perhaps the coastal nature of this survey has only recorded a relatively small percentage of the total population that are utilising the Algoa Bay region.

6.4. BRYDE'S WHALES

6.4.1. General spatial and temporal distribution patterns

Bryde's whales were predominantly observed in the western half of the bay during boat-based surveys, with a few opportunistic sightings off the Bird Islands. This included offshore sightings between Cape Recife and Riy Banks, and more inshore sightings between Swartkops River and St Croix Island (Figure 5.5). These animals are very elusive in nature (O'Callaghan and Baker, 2002), and it was difficult to observe their head or pectoral flippers. This would have confirmed whether all the sightings were Bryde's whales, or whether some consisted of minke whales (*B. acutorostrata*) or sei whales (*B. borealis*), which are thought to occur in the region, and are very similar morphometrically (Best, 1985; Best, 2001; Kato and Perrin, 2009). However, the few rostrums that were observed had the characteristic three ridges for Bryde's whales described by Best (1977) and Best (2007). For the purposes of this study, all Bryde's whales and like-Bryde's whales were grouped together.

The inshore form of Bryde's whales is thought to be located along the west and southern coastlines of South Africa within the 200 m isobath (Best *et al.*, 1984; Best, 2001). This species occupied Algoa Bay in summer and autumn/ early winter (Figure 5.13). Bryde's whales along the west coast of South Africa are observed during autumn and winter, before migrating downwards towards the south coast during spring (proposed migratory pattern is illustrated in Figure 6.4) (Best *et al.*, 1984; Best, 2001). Small-scale migrations to warmer waters along either the west or the east coast of South Africa, including migrations with the annual Sardine Run, have previously been proposed by Best (2001) and O'Donoghue *et al*. (2010b). The lack of sightings in Algoa Bay during late winter and spring indicates that the animals observed in this study could undergo similar migrations (Figure 6.4). Although little information has been scientifically recorded for the Sardine Run until recently, it is thought to begin east of Algoa Bay during winter, and move up the east coast, continuing into spring (van der Lingen *et al.*, 2010). Other marine mammals such as bottlenose dolphins and common dolphins have been associated with this phenomenon (O'Donoghue *et al.*, 2010b; van der Lingen *et al.*, 2010). This small-scale seasonal movement of Bryde's whales is probably governed by the distribution of their prey, which undergo migrations at a similar spatial scale along the coast of South Africa (Omura, 1959; Best, 1977; O'Callaghan and Baker, 2002; Penry, 2010).

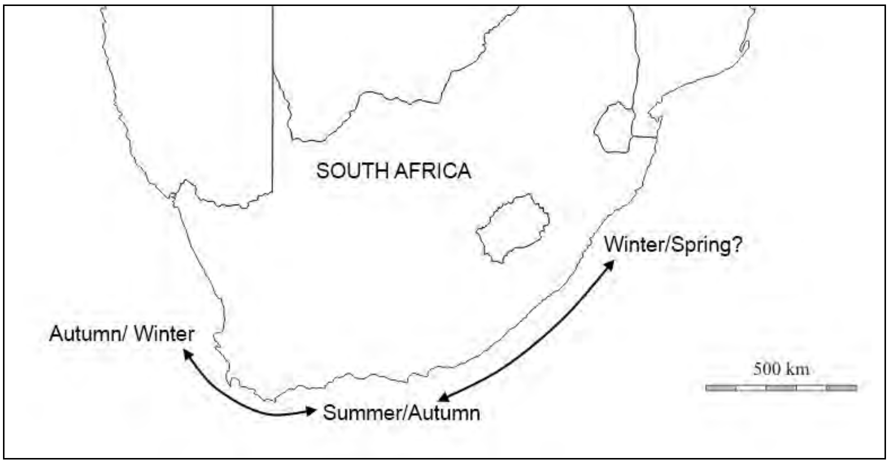

Figure 6.4. Proposed movement of Bryde's whales along South Africa.

The absence of sightings during late winter and spring could be a result of the short time-span over which this study took place, although, numbers are expected to be considerably lower during this period. A similar trend in the seasonal fluctuations of Bryde's whale sightings was observed in Plettenberg Bay, where highest numbers occurred during autumn, with a significant drop in sightings during winter (Penry, 2010). Similar patterns were also observed along the Brazilian coastline and in the Hauraki Gulf in New Zealand (Zerbini *et al.*, 1997; Wiseman, 2008).

Bryde's whales had a low number of sightings compared to the other two mysticete species observed in this study (Table 5.1). The sighting frequency for these animals was 0.09 $s.hr^{-1}$, higher than the 0.03 $s.hr^{-1}$ that was recorded in the Hauraki Gulf, New Zealand (O'Callaghan and Baker, 2002). In Algoa Bay, this species had a mean SPUE of one, which is higher than the SPUE of 0.02 recorded in the north-central Gulf of Mexico (Mullin *et al.*, 1994). The relatively small number of sightings for this species in several surveys (including the present study) could be attributed to the coastal nature of most studies which only cover a small portion of the Bryde's whale habitat. Consequently, if Bryde's whales are utilising the more inshore areas of Algoa Bay, for activities such as foraging, this would explain the higher sighting frequencies and SPUE.

6.4.2. Group dynamics and behaviour

The absence of Bryde's whale calves in this study is similar to other studies of these animals along the coastline (Table 5.2) (Penry, 2010). The low numbers of calves could reflect a low birth rate, or that there are key areas for mother-calf pairs which have not been identified (Penry, 2010). In general, little is known about the reproductive seasonality of this species and whether they prefer certain areas for mating and calving (Kato and Perrin, 2009; Penry, 2010). However, calves have been observed year round in places such as the Hauraki Gulf, New Zealand and it is therefore thought to be a nursery ground for that local population (Wiseman, 2008).

Few sightings of more than one Bryde's whale were recorded in Algoa Bay (Table 5.1). This is comparable to other studies in the Hauraki Gulf, New Zealand, and in South Africa (Best *et al.*, 1984; O'Callaghan and Baker, 2002; Penry, 2010). Most of the sightings which consisted of two animals were described as foraging in bait balls, with several marine bird species, and on two occasions, with bottlenose dolphins and common dolphins. This has been recorded in other regions with up to five animals seen foraging in bait balls with other marine mammals (Zerbini *et al.*, 1997; Wiseman, 2008; Penry, 2010).

6.4.3. Description of the habitat preference within Algoa Bay

Bryde's whales were observed furthest from land (2.3 to eight kilometres) and in the deepest waters (mean 31.9 m) compared to other cetacean species in Algoa Bay (Figure 5.26 and 5.28). This is typical of this species which have also been recorded in waters greater than 50 m deep in the Hauraki Gulf (O'Callaghan and Baker, 2002; Wiseman, 2008). SST over 23 ^{o}C ($p < 0.05$) and depth ($p < 0.05$) were considered important explanatory variables when modelling the relative abundance of this species (Figure 5.40 and Table 5.5). A study conducted in Plettenberg Bay also established that SST was a significant variable in the statistical models (Penry, 2010). This was thought to be due to the relationship between SST, Chlorophyll-a concentration and seasonality, all of which affected primary short- and long-term productivity in the region and therefore resulted in an increased occurrence of prey (Penry, 2010). Groups of two animals were primarily associated with foraging in Algoa Bay, which according to Wiseman (2008) suggests that prey distribution is affected by SST and depth, and thus determines where and when foraging can occur.

Bryde's whales indicated two areas of preference within Algoa Bay, between Cape Recife and Riy Banks, and offshore of Swartkops River (Figures 5.9 and 5.22). Few studies have specifically looked at physical habitat in relation to Bryde's whale distribution. As these whales forage year-round and undergo small-scale migrations to follow prey distribution (O'Callaghan and Baker, 2002; Penry, 2010), this is likely the determining factor for the choice of habitat in Algoa Bay. According to the sediment data (supplied by SANHO), the area east of Cape Recife consists of an underlying substrate of coral and rock (see Figure 3.2). This substrate, alongside the relatively steep bottom topography could contribute to higher prey densities in the area (Tynan, 1996; Baumgartner, 1997; Robinson *et al.*, 2009).

The area offshore of the Swartkops River consists of mud and sand sediment (Figure 3.2). Several bait balls were recorded here, including ones where Bryde's whales were foraging. This region was calculated to have the highest density of this species, and therefore should be considered an important area for these animals. It is not clear what causes shoals of fish to enter this area and further more in-depth studies are needed of the water currents in Algoa Bay, as well as the movement of sediment and nutrients from the Swartkops River, in order to establish what factors lead to the formation of these bait balls (Goschen and Schumann, 1988; Binning and Baird, 2001).

6.5. BOTTLENOSE DOLPHIN

6.5.1. General spatial and temporal distribution patterns

The bottlenose dolphins observed in this study were generally thought to be consistent with the inshore form of this species (*T. aduncus*). However, there were two distinct 'forms' observed during dedicated surveys: a smaller and darker form with a contrasting colouration along the side of the body which was observed between autumn and spring, and a larger, lighter form with a longer beak, seen throughout the year. These features would indicate that both *T. aduncus* and *T. truncatus* are present in Algoa Bay (Ross, 1977; Findlay *et al.*, 1992; Peddemors, 1999). A lack of quantitative records on which form was observed during the dedicated surveys and the absence of genetic data, make it difficult to group sightings according to these forms. Thus, for the purposes of this study, all sightings were classed as one species, *T. aduncus* (based on: Ross *et al.*, 1987; Findlay *et al.*, 1992; Peddemors, 1999; Best, 2007).

Bottlenose dolphins were the most prevalent species in Algoa Bay (Table 5.1). They were seen extensively along the inshore areas of the bay, which forms part of the south-west limit of their range around the Indian Ocean, the westward extent of which occurs around Cape Agulhas (according to: Rice, 1998; Wells and Scott, 1999; Wang and Yang, 2009). This species is thought to be part of a large 'open' population with an extensive range along the South African coastline

(Karczmarski, 1996; Reisinger and Karczmarski, 2009). Similar large ranges have been observed in other locations around the world (Ballance, 1992; Wilson *et al.*, 1997; Merriman *et al.*, 2009).

Bottlenose dolphins were sighted six times more frequently (0.63 $s.hr^{-1}$) than the other cetacean species, and had the highest overall relative density of 2.57 $individuals.km^{-1}$ (Tables 5.1 and 5.2). This compares with frequencies recorded in Marlborough Sounds, New Zealand (Merriman *et al.*, 2009). However, the dolphins in Algoa Bay had much higher sighting frequencies than what has recorded in other regions by Bristow *et al*. (2001), Bearzi *et al*. (2009) and Picanço *et al*. (2009), emphasising the prevalence of this species in the region.

6.5.2. Group dynamics and behaviour

Bottlenose dolphins live in a fission-fusion society, in which individuals associate in small groups that change frequently in composition and size (Lusseau *et al.*, 2006). In Algoa Bay, these animals were recorded to have a wide range of group sizes from one to 500 individuals, with a mean group size of 57.8 animals (Table 5.1). The wide range in group sizes was similar to other observations recorded in the Eastern Cape, where a mean group size of 140 bottlenose dolphins has been recorded (see: Saayman *et al.*, 1972; Ross, 1984). Significantly smaller groups have been observed in other parts of the world, with an average of two to 27 individuals (Weigle, 1990; Mullin *et al.*, 1994; Cañadas *et al.*, 2005; Pierpoint *et al.*, 2009).

Calves and juveniles were associated with most bottlenose dolphin sightings, and were observed throughout the year (Table 5.2). This is a common occurrence for this species worldwide, with evidence of some seasonal fluctuations in numbers (Wells and Scott, 1999; Campbell *et al.*, 2002; Bearzi *et al.*, 2009). The presence of calves throughout the year in Algoa Bay is indicative of their ability to utilise the wide range of inshore habitats available along the Eastern Cape coast (Cockcroft and Ross, 1990; Best, 2007).

Bottlenose dolphins exhibited a wide variety of behaviours in Algoa Bay (Figures 5.16 and 5.18). These behaviours did not appear to change significantly over the different seasons, with foraging and travelling predominating throughout the year, a common occurrence for this species throughout their cosmopolitan range (Ballance, 1992; Hanson and Defran, 1993; Bristow *et al.*, 2001; Lusseau and Higham, 2004).

Several observations of bottlenose dolphins included other cetacean species. They were twice observed foraging in bait balls with Bryde's whales and common dolphins, and on another two occasions they were observed foraging with humpback dolphins by Cape Recife. In addition, they were also recorded travelling with humpback whales (coming within two metres of these whales). These multi-species interactions have been recorded in other areas, and vary in their function (Saayman *et al.*, 1972; Mignucci-Giannoni, 1998; Deakos *et al.*, 2010). An example of a positive 'playful' interaction between bottlenose dolphins and humpback whales was observed in Hawaiian waters, where the whale appeared to repeatedly lift the dolphin out of the water (Deakos *et al.*, 2010).

6.5.3. Description of the habitat preference within Algoa Bay

Bottlenose dolphins were commonly observed in shallow waters of five to 11 m deep (mean of 9.2 m) and generally 300 to 800 m from land (Figures 5.26 and 5.28). This is comparable to findings in KwaZulu-Natal (KZN) where this species was located within one kilometre from land (Ross *et al.*, 1989). However, aerial surveys conducted in Algoa Bay in the 1980s recorded the majority of sightings within six kilometres of the land, and the majority of these more 'offshore' sightings were located between PE Port and St Croix (Ross *et al.*, 1987), which was also observed to some extent in the present study. The presence of bottlenose dolphins in Algoa Bay, has been described as part of a 'coastal corridor' of sightings up to a depth of 30 m, throughout their range (Defran and Weller, 1999; Stensland *et al.*, 2006; Bearzi *et al.*, 2009). Sightings located further offshore, are associated with canyons and escarpments in other studies (Bearzi *et al.*, 2009), comparable to the observations in this study where sightings were observed in the region of Riy Banks and the two island groups (Figure 5.5). This is probably due to these features, as well as estuaries/ rivers, being optimal locations for a local abundance of prey (Hui, 1979; Ross *et al.*, 1987; Ballance, 1992; Baumgartner *et al.*, 2001). On the whole, depth was considered an important variable in the final hurdle model ($p < 0.05$; Table 5.5), which is comparable with other findings where depth has been considered significant in determining the distribution patterns of bottlenose dolphins (see: Baumgartner *et al.*, 2001; Cañadas *et al.*, 2005; Cañadas and Hammond, 2006).

In other studies, bottlenose dolphins have illustrated a more clumped distribution, with areas of higher densities and lower densities within their coastal corridor (Ross *et al.*, 1989; Wilson *et al.*, 1997). However, in Algoa Bay they were observed extensively throughout the coastal zone with two 'gaps' noted in their distribution. The lack of sightings between PE Port and Swartkops River, as well as between Coega Port and Sundays River is worthy of comment (Figure 5.6). A map of the sightings recorded during an aerial survey in the 1980s showed similar observations, although, it was not explicitly commented on by the author (Ross *et al.*, 1987). It was thought that these dolphins travelled across from Cape Recife to PE Port, to the Swartkops/ Coega Rivers and then offshore to St Croix Island, with some dolphins taking more direct routes (Ross *et al.*, 1987). The direction of movement for bottlenose dolphins was not recorded in the current survey but these proposed movements towards established 'foraging areas' would explain the distribution of inshore and more 'offshore' sightings on the western half of the bay (Figure 5.5). Similar foraging areas were observed in this study (Figure 5.18).

The highest density of sightings in Algoa Bay was observed east of Sundays River, especially past 26.17 ^{o}E where the groups were dispersed (Figures 5.10 and Figures 5.23). Bottlenose dolphins are known to utilise group size and structure to achieve maximum foraging efficiency (Wells and Scott, 1999; Campbell *et al.*, 2002), and the coastal waters associated with the Alexandria Dunefield (along Woody Cape) are considered to be areas of high productivity (McLachlan, 1983; Illenberger, 1986; Webb and Wooldridge, 1990). In some surveys, dolphins were seen frequently over several kilometres, with no distinguishable beginning or end to a group. Thus, the large group sizes and high relative abundance of bottlenose dolphins observed could be due to an adequate and predictable supply of food in this region, which has been noted by Ross (1984) as a likely explanation. These sightings were most common in winter and spring, which is possibly due to the higher abundance of suitable prey during these months.

Bottlenose dolphins were also most commonly associated with sand (33%) and rock (20%) substrate, which coincides with the dominant substrates along the inshore areas (Figures 5.32 and 3.2). These species utilise the wide variety of inshore habitats to forage opportunistically on a range of prey that is available in the different habitats (Wells and Scott, 1999; Best, 2007).

6.6. HUMPBACK DOLPHIN

6.6.1 General spatial and temporal distribution patterns

Humpback dolphins were predominantly found in the inshore areas of the western half of Algoa Bay (Figure 5.5). This falls within their range which occurs along the east and south coasts of

South Africa, as well as within their entire range which extends around the Indian Ocean (as defined by: Ross, 1984; Karczmarski *et al.*, 2000b; Jefferson and Karczmarski, 2001; Kaschner *et al.*, 2006b).

No seasonal distribution patterns were obvious (Figure 5.13). The absence of sightings in September and the low number in January could be a result of the limited time period over which this study took place, and more long-term studies would confirm if these changes in sighting frequency are an annual pattern. However, the near-absence of these dolphins during autumn is noteworthy. Boat- and shore-based surveys on the western half of Algoa Bay were conducted in the early 1990s, when this species was found in the bay throughout the year, with distinct seasonal variations (Karczmarski, 1996; Karczmarski *et al.*, 1999). Both of the previous and present studies recorded a greater number of sightings during late summer (Karczmarski, 1996). Similar observations have been made along the Eastern Cape coastline (Saayman *et al.*, 1972). Another lower peak of sightings was observed in spring during the early 1990s (Karczmarski, 1996), and the current study suggests that this peak has shifted into winter.

The sighting frequency for humpback dolphins (0.1 $s.hr^{-1}$) was similar to Bryde's whales (Table 5.1). This is relatively low considering the coastal nature of this survey and these animals. For example, in Cleveland Bay and the Great Barrier Reef Marine Park, Australia, the sighting frequency for humpback dolphins was approximately 0.2 $s.hr^{-1}$ (Parra, 2006; Parra *et al.*, 2006). A higher sighting frequency of 0.34 $s.hr^{-1}$ was recorded in Richards Bay (Atkins *et al.*, 2004). These surveys recorded more than double the frequency of sightings compared to what was observed in Algoa Bay. Overall, this species was also observed less often than bottlenose dolphins (Table 5.1). This is in contrast to shore-based observations along the south Eastern Cape coastline in the early 1970s, where humpback dolphins were sighted more frequently (Saayman *et al.*, 1972).

These animals are thought to immigrate and emigrate into and out of the bay across the seasons, possibly even moving extensively along the coastline, depending on prey availability (Karczmarski, 1996; Karczmarski *et al.*, 1999; Keith *et al.*, 2002). However, it is difficult to determine the scale at which this occurs. Nonetheless, identified animals have been observed both in Algoa Bay and St Francis Bay, suggesting movements of greater than 100 km, and less than 1 000 km (Karczmarski, 1996). It is unlikely that distribution of humpback dolphins is continuous in the Indian Ocean; it is more expected that their distribution consists of many subpopulations that should be treated as separate management units (Durham, 1994; Karczmarski, 1996; Keith, 1999; Karczmarski, 2000).

6.6.2. Group dynamics and behaviour

In Algoa Bay group sizes of humpback dolphins were much smaller compared to the other two delphinid species (Table 5.1). The mean group size of 3.3 individuals was similar to that observed in Hong Kong waters (Jefferson, 2000), half the size of what had been observed in the bay previously (Karczmarski, 1996), and smaller compared to other locations along the southern African coastline (Durham, 1994; Guissamulo and Cockcroft, 2004). Most of the groups observed in the recent survey consisted of less than four individuals, with three larger groups of seven, eight and 23 individuals observed once respectively. This is in contrast to previous observations in the bay which estimated a mean group size of seven individuals (Saayman and Tayler, 1979; Findlay *et al.*, 1992; Karczmarski, 1996; Karczmarski *et al.*, 1999), and significantly different to observations on this species in Maputo Bay where a mean group size of 14.2 individuals was recorded (Guissamulo and Cockcroft, 2004).

Only one calf or juvenile was observed in the majority of sightings, with one exception of a group of 23 humpback dolphins consisting of three calves and four juveniles in June 2010 (Table 5.2). Relatively few calf sightings were observed in summer, which was previously associated with the peak calving season (Karczmarski, 1996). Overall, the lower number of calves present in this study could indicate that the birth rate has decreased.

Humpback dolphins were primarily observed foraging (33%), with mating and socialising seen in summer and autumn respectively (Figures 5.15 and 5.16). These findings are similar to that of Karczmarski (1996) and Parra (2006). However, foraging also occurred south of Swartkops River, and east of Coega Port (Figure 5.18). This behaviour predominantly occurred along the rocky shores on the south-west corner of the bay, which is in accordance with previous sightings where humpback dolphins have frequently been observed foraging along rocky shores in the Eastern Cape, and in large estuarine systems in KZN (Saayman *et al.*, 1972; Durham, 1994; Karczmarski, 1996; Karczmarski *et al.*, 2000a; Atkins *et al.*, 2004).

Two humpback dolphin sightings were associated with bottlenose dolphins, consisting of three and two individuals, respectively. In the first sighting, both species were observed foraging, with one instance of a bottlenose dolphin tail-slapping a humpback dolphin. Non-aggressive interactions between these two species have been occasionally observed in the bay (Saayman *et al.*, 1972; Karczmarski *et al.*, 1997) and aggressive interactions between these two species in the region have also been reported (Saayman *et al.*, 1972; Saayman and Tayler, 1979). An incidental observation of humpback dolphins interacting with southern right whales in August 2009 was also observed, both species were recorded as socialising. This has been observed previously in the region by Saayman and Tayler (1979).

6.6.3. Description of the habitat preference within Algoa Bay

Humpback dolphins were generally observed within 500 m of land (median of 300 m), at a mean depth of 6.6 m, and within ten kilometres of the nearest river mouth (Figures 5.26, 5.28 and 5.31). This is very similar to the findings from the early 1990s, where 87% of sightings were observed within 400 m of land, and almost all the sightings were in waters less than 15 m deep (Karczmarski, 1996; Karczmarski *et al.*, 2000a). Other studies have also established that humpback dolphins commonly occur within one kilometre of the coast in waters less than 50 m deep, and generally within the surf zone (Ross *et al.*, 1994; Atkins *et al.*, 2004; Parra, 2006). In Richards Bay, humpback dolphins were seen at a mean depth of 13.2 m, with a maximum depth of 31.8 m (almost five kilometres from land) (Keith, 1999), which was much deeper and further offshore than what was observed in this study. This is most probably due to the wide, shallow Tugela bank which results in the 15 m isobath being positioned further offshore (Durham, 1994). In northern Queensland, Australia, humpback dolphins were also found further offshore (mostly less than five kilometres from land), in waters less than 15 m deep (Parra *et al.*, 2006). The inclusion of depth as a significant explanatory variable in both stages of the final hurdle model ($p < 0.05$) further confirms the influence this variable has in determining the limit of humpback dolphin distribution throughout their range (Table 5.5).

The highest densities of sightings were found along the inshore areas between PE Port and Cape Recife (Figures 5.11 and 5.24). This is the same area identified previously as a key habitat for humpback dolphins in Algoa Bay (Karczmarski, 1996; Karczmarski *et al.*, 1998). Whereas previously, almost all of the sightings were found south of PE Port (Karczmarski, 1996), a number of sightings in this study were found between the two ports. An incidental sighting was even observed in the Swartkops Estuary. Sightings have also been recorded in other estuaries in Mozambique and Australia (Parra, 2006; Parra and Ross, 2009).

Humpback dolphins were to some extent more closely associated with estuaries and rivers in the bay compared to other cetaceans (Figure 5.31). Parra *et al*. (2006) also established that humpback dolphins were found within 20 km of the nearest river. In Richards Bay, a high proportion of sightings and foraging occurred around the harbour, a dredged estuary (Atkins *et al.*, 2004). Thus, along with the rocky shores, estuaries could provide an important foraging ground for this species (Ross *et al.*, 1994; Atkins *et al.*, 2004). This would account for the incidental sightings of these animals in the Swartkops Estuary.

Unlike the other cetacean species observed in Algoa Bay, a significant proportion (57%) of humpback dolphin sightings were associated with a rocky substrate found along the south-west corner of the bay (Figures 5.32 and 3.2). This is in accordance with other records of humpback dolphins (Saayman *et al.*, 1972; Ross *et al.*, 1994; Karczmarski *et al.*, 2000a). Overall, this area of the bay also had the highest incidence of foraging behaviour (Figure 5.18). The high density of sightings and foraging observations occurring within this relatively small area indicate that this region is a key habitat for this species (Figure 5.18 and 5.24).

6.7. COMMON DOLPHIN

6.7.1. General spatial and temporal distribution patterns

Common dolphins were the least frequently observed cetacean species in Algoa Bay, and due to the paucity of sightings, it was difficult to determine whether there are any patterns in their spatial and temporal distribution. In both dedicated boat-based surveys and opportunistic sightings, common dolphins were primarily observed in the offshore areas (Figure 5.5). Although, several sightings were observed more 'inshore' around the Swartkops River and around Coega Port. This was in a similar location to where Bryde's whales were observed.

Common dolphins are generally considered to be 'offshore' species and enter the bay opportunistically in search of shoals of fish (Reilly, 1990; Samaai *et al.*, 2005; Best, 2007). Thus, the sightings recorded in Algoa Bay only represented a small sample at the edge of their extensive range. These dolphins were found in the bay in late summer, winter and in spring.

Common dolphins have long been known as the principal predators in the annual Sardine Run (Cockcroft and Peddemors, 1990; O'Donoghue *et al.*, 2010b; van der Lingen *et al.*, 2010). The peak in sightings in late summer is expected as common dolphins are thought to inhabit the Eastern Cape coastline during this season, moving to the Natal coastline during winter (Ross, 1984; Cockcroft and Peddemors, 1990). Although, aerial surveys carried out between Port Elizabeth and East London in the late 1980s detected common dolphins in low densities throughout the year (Cockcroft and Peddemors, 1990). Thus, the presence of common dolphins in the bay at the beginning of winter (Figure 5.13) is probably closely linked to the distribution and movement of their prey along the Eastern Cape coastline (Cockcroft and Peddemors, 1990). The sightings in both May and June in 2010 were most likely a result of the dolphins moving into inshore waters at the start of the Sardine Run to feed off small and localised bait balls that had formed in the bay, before following the migration of the sardines up the east coast. However, this movement of common dolphins towards KZN does not necessarily involve the entire population (Cockcroft and Peddemors, 1990), which would account for the presence of common dolphins in Algoa Bay during spring 2009.

6.7.2. Group dynamics and behaviour

Common dolphins were observed in large groups of up to 800 animals, with a mean of 343 individuals (Table 5.2). Two smaller groups were observed travelling in shallow areas. This species is known to have extremely large group sizes in comparison to their other delphinid counterparts (Saayman *et al.*, 1972; Barlow, 1995; Weir *et al.*, 2009). These large groups were also consistent with other findings in South Africa, which had mean group sizes of 302 to 619, with one group of approximately 10 000 individuals observed in an aerial survey between Port Elizabeth and Richards Bay (Cockcroft and Peddemors, 1990; Findlay *et al.*, 1992; Best, 2007; O'Donoghue *et al.*, 2010b). The group sizes appear to be slightly larger than other locations such as the Minch in Scotland where common dolphins had a mean group size of 135 (Weir *et al.*, 2009). Common dolphin groups in south Australia were also observed in small groups of approximately five animals (Filby *et al.*, 2010).

Common dolphins were either seen foraging, or travelling (porpoising) to and from foraging areas in Algoa Bay (Figure 5.15 and 5.16). While following the group, they were frequently observed bow-riding, a common behaviour with this species (Best, 2007). However, no other socialising or ‘play’ behaviours were observed. Foraging activities were observed in ‘bait balls’, with a number of other marine predators such as Cape gannets, Bryde’s whales and bottlenose dolphins. This is a frequent observation for common dolphins in South Africa (Saayman *et al.*, 1972; Best *et al.*, 1984; O'Donoghue *et al.*, 2010b).

Two sightings of single animals were seen within a group of bottlenose dolphins. However, there were no photos taken of the individuals, which would have assisted in determining whether the animal was a common dolphin or a hybrid (see: Reyes, 1996; Zornetzer and Duffield, 2003). Common dolphins have been associated with other cetacean species such as striped dolphins (*Stenella coeruleoalba*) and Risso's dolphins (*Grampus griseus*) (Cañadas *et al.*, 2002; Frantzis and Herzing, 2002; Cañadas and Hammond, 2008).

6.7.3. Description of the habitat preference within Algoa Bay

Common dolphins were sighted at depths of 16 to 38 m and 4.5 to six kilometres from land, which was similar to the humpback whales and Bryde's whales (Figure 5.26 and 5.28). Other studies have also observed common dolphins at similar depth/ distances from land (Filby *et al.*, 2010; O'Donoghue *et al.*, 2010b), but there are many areas where a number of sightings have been observed on the continental slope (100 to 200 m deep) (Selzer and Payne, 1988; Findlay *et al.*, 1992; Cañadas and Hammond, 2008). The small number of sightings in Algoa Bay suggests that common dolphins in this region prefer more offshore habitats of less than 500 m deep (Findlay *et al.*, 1992; Peddemors, 1999).

6.8. ANTHROPOGENIC INFLUENCES AND IMPACTS ON CETACEANS IN ALGOA BAY

Based on the knowledge gained from this survey on the spatial use of the bay and cetacean behaviour, threats and issues identified in the literature can now be considered for Algoa Bay (objective four). The predominant threat to mysticetes in the past was whaling, which began in 1775, and almost exhausted several large mysticete stocks, including the species observed in this study (International Whaling Commission, 1986; Best, 2007). Now, several organisations have been established to protect these species from commercial whaling (Friedmann and Daly, 2004). However, there are a number of current and potential future threats that could influence the full recovery of these populations. These were discussed in detail in Chapter Two.

Understanding the spatial and temporal distribution patterns as well as identifying key habitats of a cetacean species is imperative if the favoured environment for these animals is going to be correctly managed in the future (Wilson *et al.*, 1997; Hastie *et al.*, 2003; Cañadas and Hammond, 2008). Coastal dolphins are some of the most threatened cetacean species due to their close proximity to anthropogenic activities (Thompson *et al.*, 2000). With the expanding use of the coastal zone for recreational and commercial activities, it is necessary to monitor these impacts.

With the increase in shipping activities in the bay (associated with the new Coega Port), it is important to monitor the associated impacts in order to mitigate any potential negative affects in the future. A brief summary of the potential threats to cetaceans, in the context of the results of this study, are outlined in Table 6.1 below.

6.9. DEFINING POTENTIAL KEY HABITATS FOR THE CETACEANS IN ALGOA BAY

Several potential key habitats were identified for mysticetes and odontocetes as illustrated in Figures 5.45 and 5.46. Possibly the hardest area to monitor is Riy Banks (A) where humpback whales are prominent. This reef is more difficult to manage as it is located more than 20 nm offshore of PE Port, and it is frequently utilised by commercial fisheries. The dynamics of the fishing activities in this area are not well known, and combined with limited data on the movement of animals in this area, make it difficult to implement appropriate conservation measures.

The south-west corner of the bay is a key habitat for both mysticetes and odontocetes. Southern right whales were seen extensively around PE Port (B), where a large proportion of mating was observed (Figure 5.45). Another key habitat lies south of PE Port (H) for both bottlenose dolphins and humpback dolphins (Figure 5.46). This area corresponds with the proposed humpback dolphin marine sanctuary (Klages, 2006). The sanctuary is set to exclude inshore motorised vessel activities, with the exception of two launch corridors within this exclusion zone (Klages, 2006). The sanctuary will create an 800 m wide buffer for the dolphins, which roughly corresponds with the ten metre isobath. Although the key habitat (H) almost extends to the 20 m isobath, the proposed sanctuary is a realistic and achievable plan which takes into account both development and conservation measures, and should therefore be implemented.

Table 6.1. Outline of the anthropogenic threats facing cetaceans in Algoa Bay.

Threats	Species	Observations in the field	Supporting observations in the literature	Level of concern for Algoa Bay
Ship strikes (collisions with vessels) and various shipping/ boating activities	Southern right whales	Slow moving animals which do not show strong boat avoidance behaviour. A moderate proportion of sightings were recorded in shipping areas.	Calves are particularly vulnerable to ship strikes (Klinowska, 1991; Best *et al.*, 2001a).	A healthy population growth rate suggests that this would not have a significant impact at a population level (Clapham *et al.*, 1999; Best *et al.*, 2001a).
	Humpback whales	Small proportion of sightings within the main shipping areas. Scars and fresh wounds from propellers observed.		Probably not significant in Algoa Bay due to small percentage of sightings observed within key shipping areas and an overall healthy population size.
	Bryde's whales	High proportion of sightings within shipping areas.	Population is considered 'data deficient' or 'vulnerable' (Friedmann and Daly, 2004; Reilly *et al.*, 2008a).	Potential threats to Bryde's whales have not been well assessed, therefore it is difficult to determine whether this activity could potentially significantly affect this species (Best, 2007; Penry, 2010).
	All odontocetes	Small proportion of sightings within the main shipping areas. Scars and fresh wounds from propellers observed (including cut-off dorsal fins).	Humpback dolphins are classified as 'vulnerable' or 'near-threatened' (Friedmann and Daly, 2004; Reeves *et al.*, 2008)	Odontocetes are highly mobile, and thus ship strikes are not considered to be a major threat. However, it could impact the small humpback dolphin population.
Entanglement in stationary/ floating objects (e.g. anchor lines)	Southern right whales, humpback whales, bottlenose dolphins and humpback dolphins	Scars and fresh wounds from fishing lines on many animals.	This threat is associated with various fishing and shipping activities that are known to occur throughout the bay (Rice, 1998; Best *et al.*, 2001a; Friedmann and Daly, 2004).	Scars and fresh wounds suggest that this threat is already having an impact on the animals. However, the extent of the impact is unknown.

Table 6.1. Continued

Whale-watching/ harassment by vessels	Southern right whales, humpback whales, bottlenose dolphins and humpback dolphins	Changes in behaviour have been observed when vessels (including fishing, pilot and research vessels) approached the animals.	Less mobile animals are particularly vulnerable (such as mother-calf pairs). Noise associated with vessel disturbance is known to result in short-term behavioural changes however, little is known about the long-term negative effects of this activity (Constantine *et al.*, 2004; Corkeron, 2004; Friedmann and Daly, 2004).	Changes in behaviour have been observed, indicating a potential impact, especially to certain individuals in a population (e.g. mother-calf pairs).
Pollution and the destruction/ alteration of coastal zone	Humpback dolphins	Not directly assessed or observed during this study	These animals have a relatively limited distribution (along coastal areas) with distinct key areas where foraging occurs (Karczmarski, 1996).	Possibly very important due to the small population size in the region.
	Bottlenose dolphins	Not directly assessed or observed during this study		Less of a threat to this species due to their larger home ranges and use of a wide variety of habitats within their range.

Although prominent behavioural activities and densities are relatively low between Coega Port and PE Port there are a number of important findings related to this area. This includes the foraging activities by humpback and bottlenose dolphins around Swartkops River (especially north of the river) (I), and an offshore area (C) where a number of Bryde's whales were observed foraging in bait balls. The Swartkops River is known to be highly polluted, with elevated levels of heavy metals which are deposited in the sediments on the surrounding sea-floor (Melville-Smith and Baird, 1980; Binning and Baird, 2001). The coastal zone between these two ports is also highly modified with a large amount of industrial activity taking place, and the presence of anti-erosion dolosses. A search through the literature revealed no studies which have determined the impact pollution is having on the surrounding marine fauna (such as a decrease in prey density). Thus, it is difficult to determine whether these anthropogenic activities have already resulted in cetaceans avoiding this area or whether this area has always been less occupied.

The outline for the proposed GAENP MPA potentially protects several of the key habitats that have been described in this study. This incorporates areas where a large proportion of mother-calf pairs were observed for southern right and humpback whales, as well as opportunistic foraging by humpback whales, delineated by areas D to G and J to L in Figures 5.45 and 5.46. Bottlenose dolphins were recorded in very high numbers in the proposed MPA where a large proportion of the foraging behaviour was exhibited by this species (Figures 5.23 and 5.18). Since the exact boundary of the MPA has not been confirmed, it is suggested that the MPA should *at least* extend from Sundays River to Cape Padrone up to the 30 m isobath. This would incorporate most of the southern right whales and bottlenose dolphins, as well as a large proportion of the humpback whales.

The two island groups are already exclusion zones for fishing activities, which protects an important foraging area for the bottlenose dolphin (area J; Figure 5.45). If the MPA includes both island groups, it will incorporate a relatively important area (D) for the mother-calf pairs, which lies between St Croix Island and the coastline.

Therefore, the proposed protected areas for Algoa Bay could play an important role in conserving cetaceans in Algoa Bay, with a large proportion of the key habitats, falling within these protected areas. However, the area offshore of Swartkops River and Riy Banks both should be examined in more detail, in order to determine the degree of importance of these habitats.

6.10. IMPLICATIONS FOR CONSERVATION AND MANAGEMENT

This study provides an important foundation for understanding the spatial and temporal distribution patterns of the cetacean species utilising Algoa Bay. In order to study cetacean distribution and habitat preferences, knowledge on the location, relative abundance/ frequency and behaviour of a species is required. Analytical tools such as GIS and statistical analysis which were used in this study, have aided in defining and quantifying these distribution patterns. To date, little is known about the role cetaceans play in the marine ecosystems around South Africa, and whether the populations and critical habitats of these species are adequately protected under the various national and international legislation (Harwood, 2001; Cañadas *et al.*, 2005). This type of baseline study would provide input to understanding this broader context.

Distribution studies at a variety of spatial scales are useful tools in monitoring the distribution of animals and identifying critical habitats (Hastie *et al.*, 2003). Once these important areas have been established, further development can take into account these areas, and where possible, work around them to establish corridors where key species, such as cetaceans, are able to move to their important habitats to perform essential activities for survival (Hastie *et al.*, 2003). For example, Karczmarski *et al.* (1998) suggested establishing the humpback dolphin marine sanctuary in Algoa Bay. A conservation priority area was marked on the south-west corner of the bay, extending from Humewood Beach to Cape Recife (Karczmarski *et al.*, 1998). Although the full extent of the this sanctuary is unlikely to be implemented, a significant portion of this zone is under review (Klages, 2006). However, if the proposed King's beach development is implemented, this could result in this key habitat for three cetacean species, being impacted. Thus, this study has reiterated the necessity for this sanctuary, as the results of the present study and recent literature indicate that the humpback dolphin population may be under more stress than it was in the early 1990s.

Another example of managing critical habitats would be the establishment of MPAs, which are located at various places along the coastline of South Africa. These are fundamental in the conservation of cetaceans, but research must be done to determine the role these areas play in actually protecting the species concerned as well as the other biota in the marine environment (Rice, 1998; MacLeod, 2009). According to the data collected during this survey, the proposed GAENP MPA in Algoa Bay has the potential to be an important area for a wide variety of species, including southern right whales, humpback whales and bottlenose dolphins. A large proportion of the most vulnerable individuals (mysticete mother-calf pairs) sighted in the bay were located within the proposed MPA during the study. Consequently, this area would protect these individuals from several threats outlined in section 6.8.

6.11. CONCLUSION

Table 6.2. A summary of the key findings associated with each of the cetacean species.

Species	Key findings
Southern right whale	Mating activities focused around PE Port during spring
	Potentially a new calving/nursery area as a significant proportion of sightings were of mother-calf pairs, especially within the proposed GAENP MPA
	Located in shallow (bottom depths of ten to 15 m) and sandy areas
Humpback whale	High number of sightings
	Strong seasonality linked to migration patterns along the continental coastline during austral winter
	High proportion of mother-calf pairs (and therefore potentially an important nursery area)
	Associated with reefs and island habitats
	Opportunistic foraging observed along the Alexandria Dunefield
Bryde's whale	Elusive, offshore species
	Predominantly sighted offshore of Swartkops River during summer and autumn (foraging in bait balls)
Bottlenose dolphin	Widespread throughout shallow waters in bay, throughout the year
	Exhibited a wide-variety of behaviours and group dynamics (sizes)
	Higher densities located along Alexandria Dunefield
Humpback dolphin	Inshore species (mean bottom depth of 6.6 m)
	Limited distribution with most sightings located in the south-west corner of the bay
	Associated with rocky shores which is probably linked to prey distribution patterns
	A noteworthy decline in sightings and group size since 1990s
Common dolphin	Only offshore odontocete species
	Extremely large group sizes (up to 800 individuals)
	Distribution strongly associated with prey in Algoa Bay (primarily observed foraging)

The key findings of this research are displayed in a simplified map (Figure 6.5) and in a summary table (Table 6.2). Cetaceans in Algoa Bay illustrated distinct and varying patterns in their spatial and temporal distributions, with a number of key habitats identified (objective three). The location of these key habitats was influenced by a number of geographical and biological variables such as relative density, behaviour, the presence of mother-calf pairs, bottom depth, distance from land, sea-floor substrate, SST and seasonality (objective four) (Table 6.2). The aforementioned variables, along with anthropogenic activities and proposed conservation strategies, play an important role in understanding the present distribution patterns of these cetaceans (objectives four and five). Based on the results of this study, some of the threats facing these animals have been outlined. This forms a framework on which the relative importance for each of the key habitats can be defined. This was done to provide recommendations for future research, management, and conservation strategies, which outlined in the following chapter.

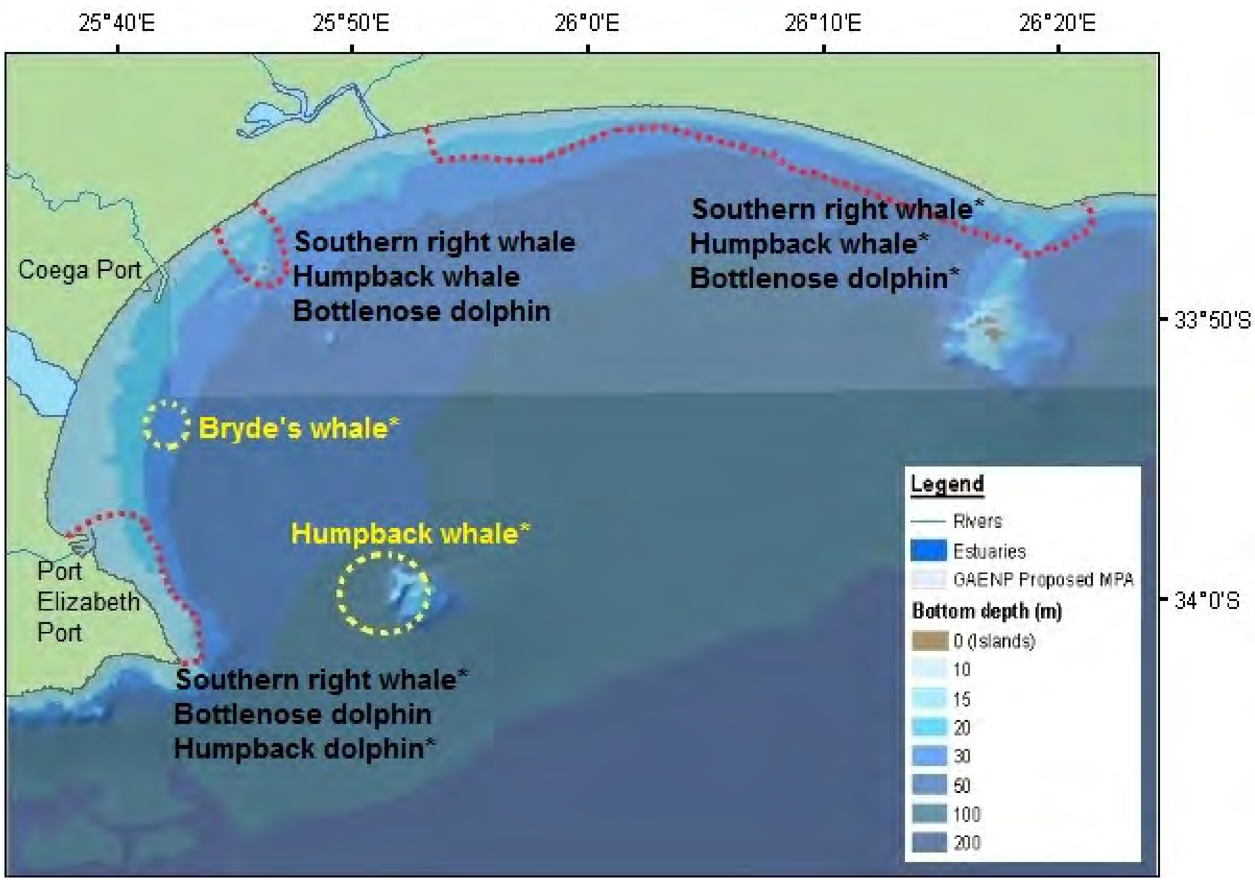

Figure 6.5. Summary map of the key habitats for the different cetacean species in Algoa Bay. Red areas are important coastal key habitats, with the yellow areas representing key habitats that are located offshore (and which need to be researched further). A star indicates that the area is potentially the most important key habitat for the species in Algoa Bay.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1. INTRODUCTION

This final chapter will summarise the key findings of this research and provide conclusions, in relation to the aim and objectives outlined in Chapter One. The caveats of this research are addressed initially, followed by a summary of the most significant findings per species, leading into recommendations for management, conservation and research.

7.2. POTENTIAL CAVEATS

There are several problems that could affect the quantity and quality of the data captured and analysed in cetacean research, including this study. The short time-span of this research made it difficult to extrapolate long-term spatial and temporal distribution patterns and the habitat preference of these long-lived, wide-ranging animals, as these patterns may have been caused by spurious intra-annual patterns that do not represent their true biogeography. Thus, all results and discussion should be treated as preliminary indications of these trends. However, this study has established potential areas of interest (key habitats) that should be further researched and taken into consideration for future management and planning.

Logistical and financial constraints are the most prominent limiting factors affecting cetacean studies, and this study was no exception. Poor weather conditions during this study resulted in irregular sampling during certain times of the year, where all tracks were not covered. This particularly affected surveys in the more exposed areas of Algoa Bay (Riy Banks and Bird Islands). This was compounded by boat availability being, for the most part, restricted to ten days per month. Thus, some boat-based surveys were partially carried out in less then ideal circumstances (Beaufort sea state three and above), which may have affected search effort, with swell and white caps potentially reducing the ability to sight animals.

Opportunistic sightings (land- and boat-based) are useful in providing attribute information to supplement the primary dataset. However, the same level of detail is not obtained and may not be as accurate as survey data (for example, GPS position, group size and dynamics). Therefore, the opportunistic data collected during the study period were not utilised to the same extent as dedicated surveys. Nevertheless, opportunistic sightings in this study did reinforce trends observed in the boat-based surveys, and assisted in filling 'data gaps' where a high intensity search effort could not be carried out.

This study did not take into account several geographical, biological and anthropogenic variables that could have potentially improved the understanding of the dynamics of the cetaceans in the bay. A suitable resolution of Chlorophyll-a data, which is an important indicator for primary productivity, was difficult to obtain and could not be processed due to logistical limitations. Data on prey distribution was also not available for Algoa Bay, which could provide valuable information on one of the primary factors affecting cetacean distribution.

Pollution, noise, and interactions with vessels (recreational, fishing etc.) are some of the prominent anthropogenic influences that could be affecting the cetaceans in the bay. The inclusion of these variables, as well as other variables measured in this study, could have potentially resulted in the construction of more robust statistical models, which would improve the explanation of the observed distribution patterns. However, parsimonious statistical models are much easier to interpret ecologically and can provide an indication of what analysis should be done on a larger and more long-term dataset in the future.

There are a number of challenges faced when dealing with spatial datasets. There are limitations within the programs used (such as ArcGIS), which then need to be supplemented by other programs (for example, Hawth's tools and R) that use a different interface. This increases the time taken to perform tasks and often leads to overlay problems with the different sources of data. In this study, the lack of remote sensing data and complex analysis of raster data combined with vector data was a result of these limitations in the data and the programmes. However, the increasing compatibility of different programs (that handle spatial data), significantly improves the range of analytical techniques that can be conducted on a wide range of data.

7.3. CONCLUSIONS

The aim of this research was to determine the spatial and temporal distribution and habitat preference, of the cetaceans in Algoa Bay. This included areas within and outside the proposed GAENP MPA. In addition, this study aimed to relate this distribution to various geographical parameters. Five objectives were laid out in Chapter One, in order to achieve this aim. A summary of the key findings and conclusions in relation to each objective and research question is outlined below.

The first objective was to collect primary data on cetacean location, behaviour and other related environmental variables via different survey and opportunistic techniques. The principal method for obtaining this data came from dedicated boat-based surveys which were carried out monthly in Algoa Bay, between March 2009 and July 2010 (Chapter Four). As no boat-based surveys had addressed all cetacean species in the bay previously, the first research question was to determine which cetacean species were observed in Algoa Bay. In both the dedicated boat-based surveys and opportunistic data collection, six cetacean species were observed: southern right whales, humpback whales, Bryde's whales, bottlenose dolphins, humpback dolphins and common dolphins. These results were described in Chapter Five.

The second objective was to acquire spatial and non-spatial data of geographic and anthropogenic variables in order to determine whether these variables could be used to explain cetacean distribution. Geographical data such as Beaufort sea state, SST, and bottom depth were collected throughout the dedicated surveys, both during and in-between sightings (while 'on effort'). Secondary data came primarily from reviewing the literature (Chapter Two) as well as other marine and coastal studies in the region (Chapter Three). Secondary data were collected on the bathymetry of the bay, sea-floor substrate, shipping areas and MPAs.

The third and fourth objectives were to determine the spatial and temporal distribution and behaviour of the different cetacean species, and to relate these patterns to the geographic and anthropogenic variables delineated in objective two. The results of this analysis show that, the six cetacean species illustrated distinct differences in their spatial and temporal distribution patterns. These patterns were displayed and discussed in detail in Chapters Five and Six. The key findings for each species are represented spatially on a map (Figure 7.1) and can be summarised as follows:

Southern right whales were primarily observed in inshore waters (bottom depths of ten to 15 m) of the western half of the bay, during austral winter and spring, especially around PE Port. These sheltered and sandy areas were used for mating and calving (both in and outside of the proposed GAENP MPA). However, these two areas (for mating and calving) did not appear to be as segregated, as suggested in other studies. Mating activities were primarily observed in spring, around PE Port, and coincided with the peak in sightings for this species. The presence of calves in a large proportion of sightings, most of which occurred within the proposed MPA, indicates that there has been a notable change in the distribution patterns of this species along the South African coastline.

Humpback whales were seen extensively in Algoa Bay between June and December. Two peaks in sightings were noted, a winter peak in June associated with their northward migration of this species, and a peak at the end of their wintering season, in December, associated with the southward movement of these animals. These animals occupied a wide range of habitats, with high relative densities associated with the coastal waters off the Alexandria Dunefield, and the islands and reefs in the bay, especially Riy Banks. These whales potentially use the ‘Recife Bird Ridge’, in order to navigate along the coastline. These animals exhibited a wide range of behaviours, including breaching and flipper slapping, with opportunistic foraging observed three times during November, within the proposed GAENP MPA.

Bryde’s whales were the most elusive species observed. They were predominantly recorded in summer and autumn in the western half of the bay. The lack of sightings during winter and spring could be due to seasonal migrations along the South African coast, associated with the movement of their prey in a natural phenomenon known as the Sardine Run. A higher relative density of Bryde’s whales was observed offshore of the Swartkops River, where a number of foraging activities were recorded.

Bottlenose dolphins were the most prolific species in Algoa Bay. They were observed year round in the inshore waters, with a peak in sightings during winter and spring. This species exhibited a wide variety of behaviours and were associated with most of the geographical features in the bay. These animals also had large and highly variable group sizes. However, higher densities were predominantly observed along the Alexandria Dunefield (in the proposed MPA). These dolphins were also observed interacting with other cetacean species. This included foraging in bait balls with Bryde’s whales and common dolphins, as well as foraging with humpback dolphins along the south-west corner of the bay. Social interactions between bottlenose dolphins and humpback whales and humpback dolphins, were also recorded.

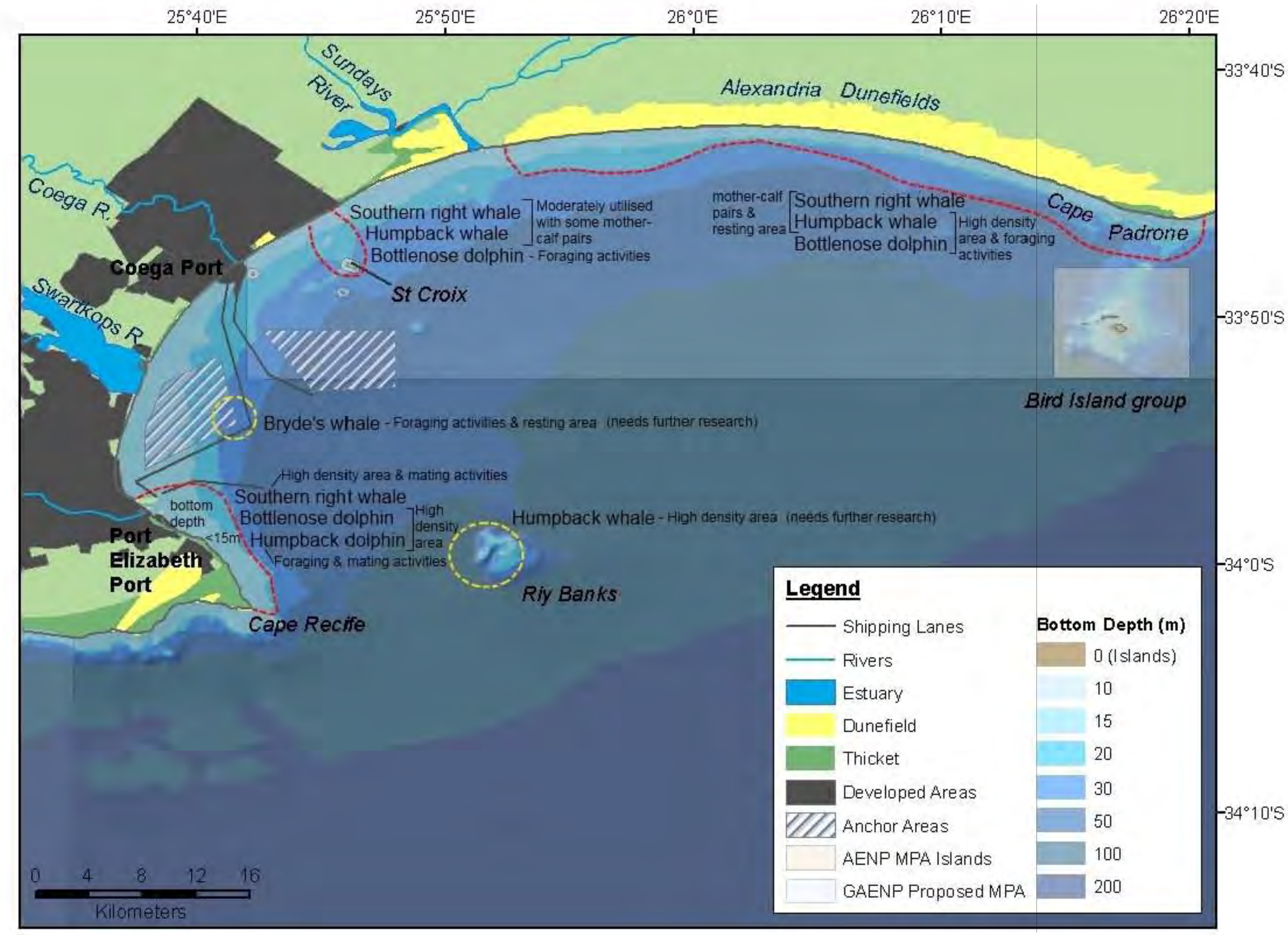

Figure 7.1. Annotated map of the potential key habitats for cetacean species. Two offshore key habitats (in yellow) need further research in order to determine the extent of the importance of this area.

Humpback dolphins were sighted in very shallow waters, with most sightings occurring within 500 m of land, with a mean bottom depth of 6.6 m. Despite their inshore distribution, these animals were not observed as frequently as some of the other cetacean species, with the lowest number of sightings observed during autumn. Group sizes were much smaller than what was recorded in a study in the early 1990s (Karczmarski, 1996). However, like the previous study, these dolphins are still strongly associated with the rocky shores along the south-west corner of Algoa Bay.

Common dolphins were the only offshore odontocete species sighted during this study. They were observed in extremely large groups of up to 800 individuals which were generally associated with bait balls, along with other marine fauna. Due to the paucity of sightings (and low number of offshore surveys), it was difficult to determine whether these animals utilise the bay opportunistically, or on a seasonal basis (in search of prey), where their occurrence would be part of an established pattern of movement along the South African coastline. However, it is known that these animals are the principle predators in the annual Sardine Run. Thus, these animals follow the Sardine Run, which is thought to begin east of Algoa Bay during winter, before moving up the coast towards KZN.

The final objective is to establish some recommendations and guidelines. By way of conclusion, through consideration of the information collected on cetacean behaviour, together with identified threats (Chapter Six) and the knowledge of the spatial habitat preferences of these animals, some recommendations are put forward in the following section.

7.4. RECOMMENDATIONS FOR MANGEMENT, CONSERVATION AND RESEARCH

Based on the results of this research, cetacean distribution in Algoa Bay was associated with several environmental parameters, such as sea-floor substrate, bottom depth, SST and other geographical variables. With reference to these findings, the information derived from this study could be considered in future management strategies. The potential management areas where this information might be used are outlined below. These ideas should be considered in conjunction with the annotated map (Figure 7.1) which represents the key cetacean habitats.

1. With regard to shipping lanes and anchoring, in the event that these areas are changed, critical areas for cetaceans can be taken into consideration and avoided. Consequently, the integrity of the associated habitats in these critical areas would be maintained. This is especially relevant as a potential key habitat was identified in a shipping/ anchoring area for Bryde's whales (Figure 7.1).

2. With regard to urban planning, more informed decisions can be made about where to place new infrastructure such as waste pipelines, as they can alter sea-floor characteristics (habitat loss) and could change prey distribution patterns through this loss or alteration in habitat. This would potentially affect the distribution of odontocetes, which is linked to their prey distribution (Bristow *et al.*, 2001). Calving areas for all the cetacean species could be affected/ changed, as the distribution of these calving areas correspond with the optimal habitat conditions associated with this activity, and thus they would be affected by a disruption in the habitat (Bristow *et al.*, 2001). In terms of Algoa Bay, a number of anthropogenic activities are situated in the south-west corner, coinciding with a potential key habitat for three cetacean species (Figure 7.1).

3. With regard to MPA planning, the present and proposed MPAs need to be re-evaluated with a long-term dataset, in order to determine whether the proposed boundaries adequately protect the critical habitats or if they need to have more fluid boundaries that shift across time (Hastie *et al.*, 2003), i.e. that the summer and winter boundaries are slightly different to account for seasonal distribution shifts in a species. This study has illustrated that St Croix Island and the proposed GAENP MPA are both considered potential key habitats for three cetacean species that utilise Algoa Bay, and therefore the proposed MPA should be implemented (Figure 7.1). Further research should also be conducted on the marine fauna that utilise Riy Banks, as this reef is potentially an important habitat for cetaceans and other animals, and should therefore be carefully monitored (Figure 7.1).

4. With regard to legislation, Karczmarski *et al.* (1998) identified inshore powerboat traffic (especially jet skis) as a large disturbance to humpback dolphins. Current legislation outlaws any disturbance to cetaceans (Government Gazette, 2008), however, this is not effectively implemented. Boat traffic should be prohibited in important inshore areas, limiting the negative impact on these dolphins. The establishment of the proposed humpback dolphin marine sanctuary has the potential to help manage these disturbances for a significant proportion of the humpback dolphin habitat situated in the south-west corner of Algoa Bay (Figure 7.1). However, guidelines on approaching these animals and the time spent around a group of animals, need to be carefully

outlined and closely monitored to avoid excessive disturbance of these cetaceans, which could possibly have short- and long-term effects (Richardson *et al.*, 1995; Karczmarski *et al.*, 1998).

5. With regard to future research, Hastie *et al*. (2003) illustrate the need for a multi-scale approach in identifying geographic, biological and anthropogenic factors that determine the distribution patterns of a particular cetacean population. Although this study only provides baseline data on broad-scale patterns on the cetacean species, this is required to direct further studies in asking the 'right' questions, to better conserve and manage these cetacean populations and the marine ecosystem as a whole.

This study falls under the auspices of a three year research project on the cetaceans in Algoa Bay, after which further long-term monitoring needs to be established. This will ensure that the trends observed are characteristic of the species, allowing for more refined/ established key habitats that can be monitored and conserved effectively. This will also aid in determining the effects of large-scale influences, such as climate change, on cetacean distribution (Simmonds and Eliott, 2009).

The shipping zones were the main anthropogenic activity observed in this study. However, there are many other anthropogenic influences that indirectly or directly influence cetacean distribution and their habitat preference, for example, chemical and noise pollution, and the effects of the presence of recreational and commercial (fishing) vessels, on cetacean behaviour. Thus, the extent of these threats needs to be established in further research, to determine how these factors could be controlled.

Future research should also include genetic sampling, prey analyses, larger-scale surveys (covering the entire Algoa Bay up to the continental shelf) and behavioural studies. Genetic sampling, combined with photo-identification work, would aid in determining the population dynamics and further the understanding of the spatial and temporal distribution patterns. This would be especially interesting for the bottlenose dolphins observed in this study where two distinct forms were observed, possibly indicative of two species. Some preliminarily photo-identification analysis has been done on the humpback dolphins in Algoa Bay by the author, and this should be continued, along with more detailed behavioural studies. This would determine the significance of the key habitat (in the south-west corner of the bay) for this species, and mitigate any potential impacts which could negatively affect this population in the future.

A wide range of analytical techniques have been applied in this study. The integration of the variables used along with remote sensing images, and further spatial analysis and statistics, on a more long-term dataset, will refine these trends and allow for better inference from the results. This would form a foundation from which explanatory and predictive statistical models, of the spatial distribution of the cetacean species, could be constructed.

In conclusion, this dissertation has made a valuable contribution to current knowledge of cetaceans in Algoa Bay. This study has provided insight on local-scale cetacean distribution, behaviour and habitat use, making an important contribution to research on cetaceans in the coastal waters of South Africa. The findings of this research demonstrate the value of a site-specific study, which takes into account a multitude of species, and identifies key habitats. Additionally, it forms a foundation from which future research and management decisions, which are beneficial and sustainable in terms of conservation strategies and anthropogenic activities, can be made.

APPENDIX 1: EFFORT FORM

Date:	Observers:
Vessel: *Honckenii*	
Launch site: *PEDSAC*	

Sightability (1-5)

Survey #		

Weather check: Beaufort scale/ sea state (B1-4), wind direction, cloud cover (x/8), water temp (^{o}C) & water depth (m), mist/haze?
SE = search effort. Course change (cc): destination, speed and bearing/direction.

Time																				B	Wind	/8	^{o}C	m	Comments
																									Engines on
											S								E						
											S								E						
											S								E						
											S								E						
											S								E						
											S								E						
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											S								E						
											S								E						

APPENDIX 2: SIGHTING RECORD

SIGHTING RECORD SHEET - ALGOA BAY

Form #	Date (day, month, year)	General Location	Recorder	Sighting #

Time seen	Time closed	Initial GPS reading	Beaufort	SST	Depth
		S E	0 1 2 3 4	°C	m

Time left	Closest Dist	Average Dist.	Photos by	Frame no. start - end	Photo Notes
	m	m		-	

Final GPS reading	Beaufort	SST	Depth	Wind Dir	Cloud cover
S E	1 2 3 4	°C	m		

Species	Max No.	Min No.	Best est.	Calves	Juv.	✓	Dominant behaviour	Group dynamics
							Travelling Milling Socialising Foraging Resting	Clumped / Dispersed

Time	Behaviour
Seen	
Closed	
3	
6	
9	
12	
15	
18	
21	

Response to boat: (avoid / neutral / boat friendly)
Comments:

APPENDIX 3: MAPS OF GROUP SIZES

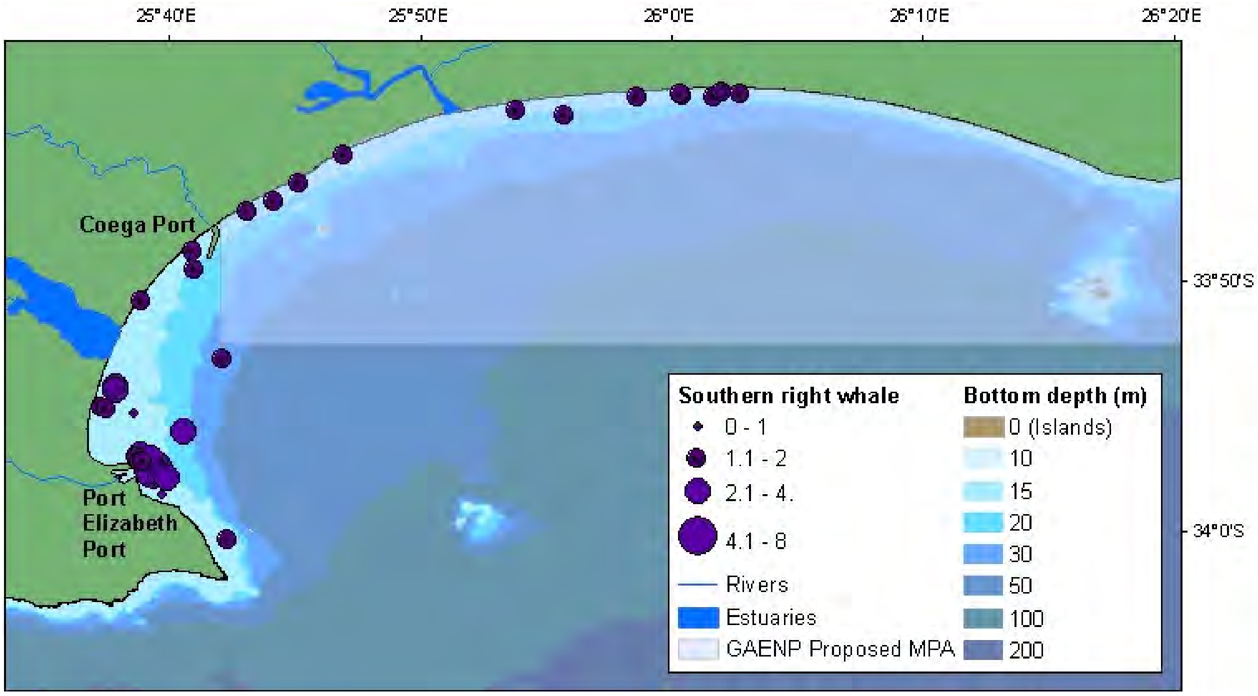

Figure A3.1. The spatial distribution of southern right whales with the size of the points representing the different group sizes.

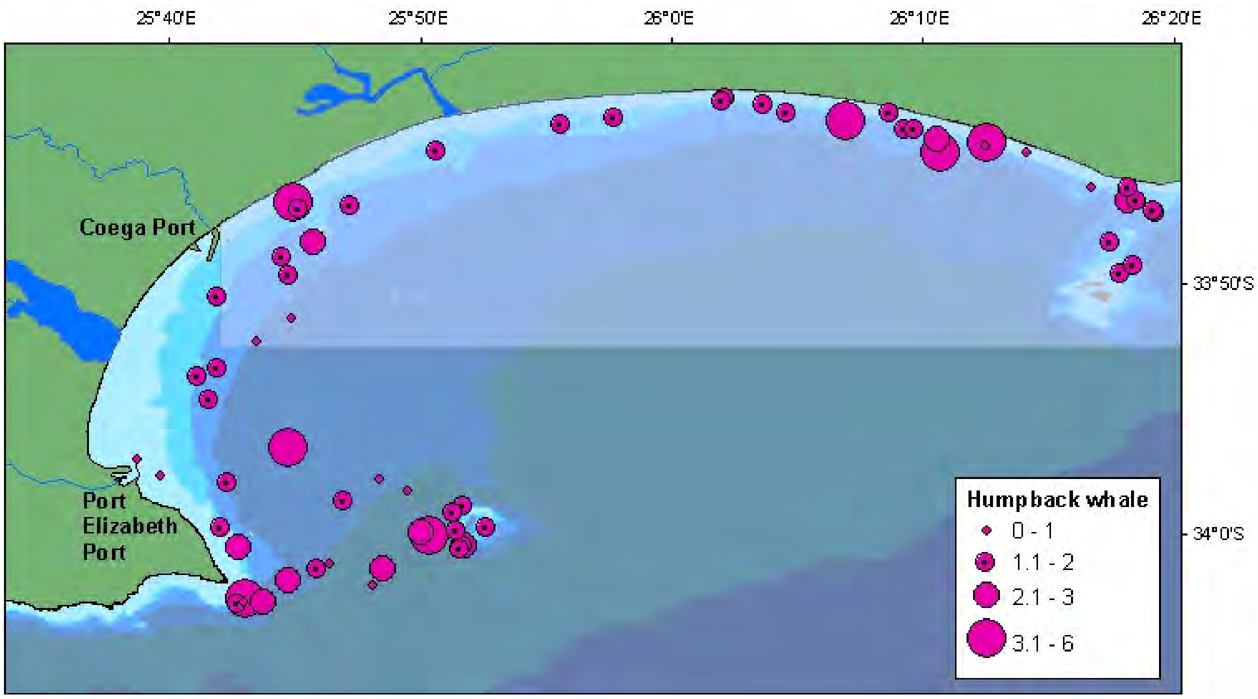

Figure A3.2. The spatial distribution of humpback whales with the size of the points representing the different group sizes.

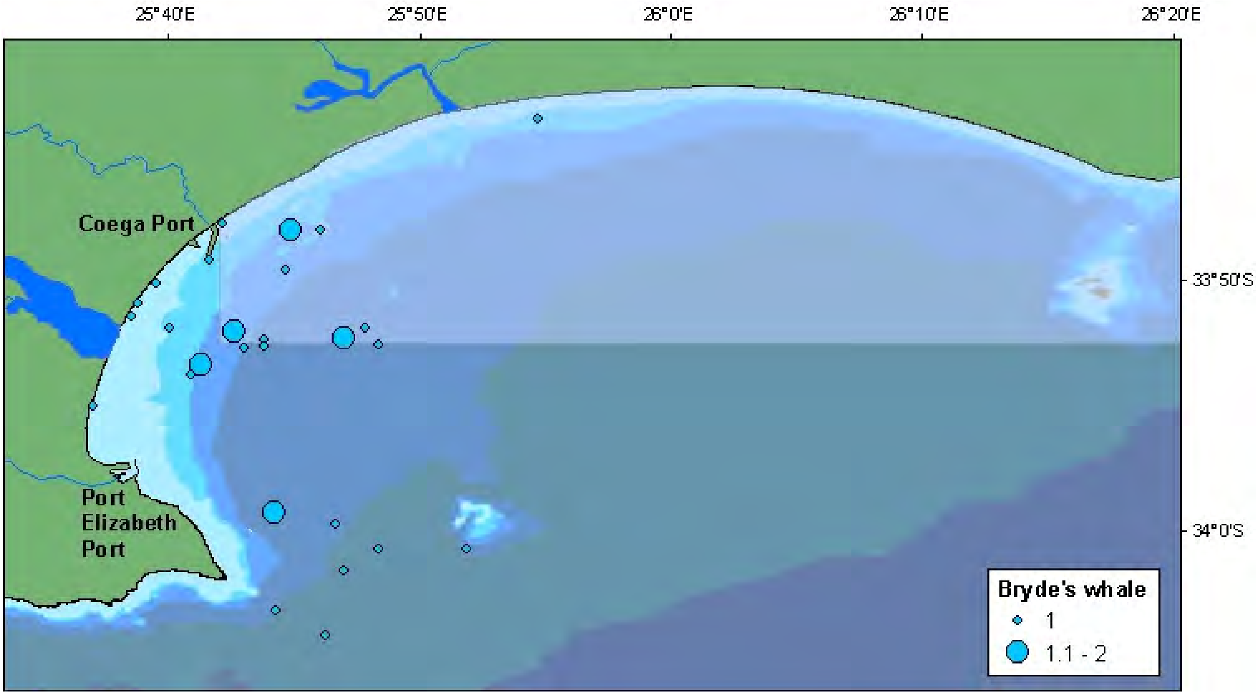

Figure A3.3. The spatial distribution of Bryde's whales with the size of the points representing the different group sizes.

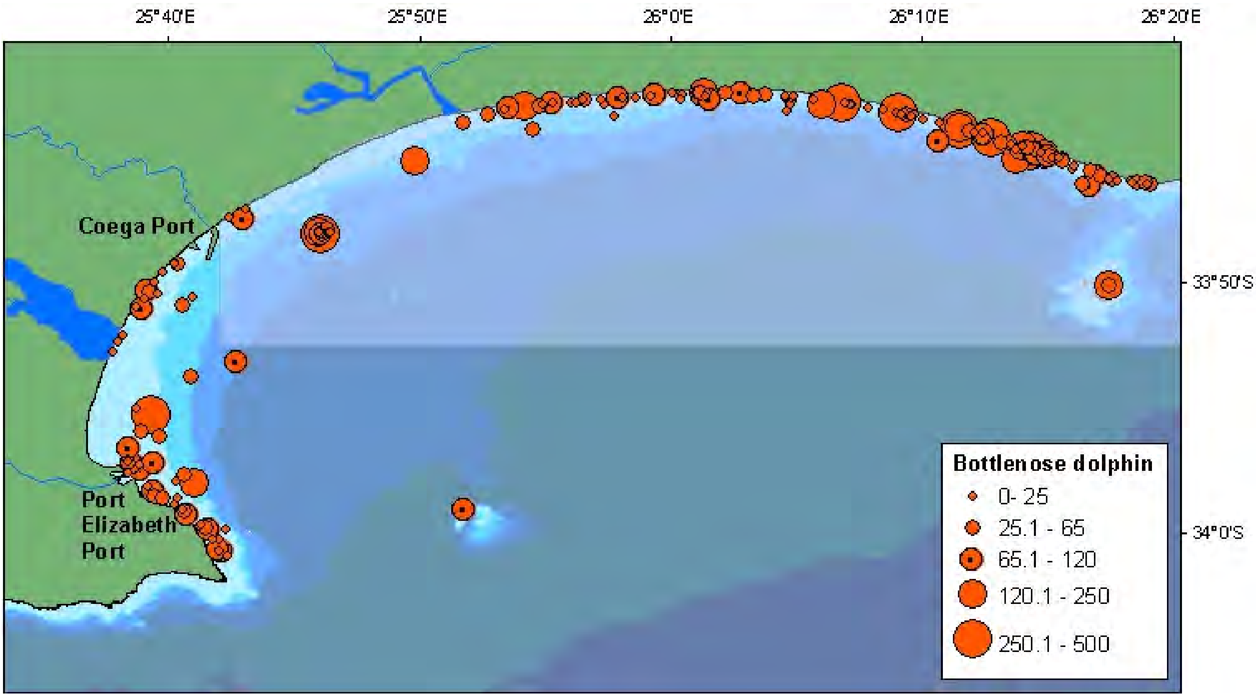

Figure A3.4. The spatial distribution of bottlenose dolphins with the size of the points representing the different group sizes.

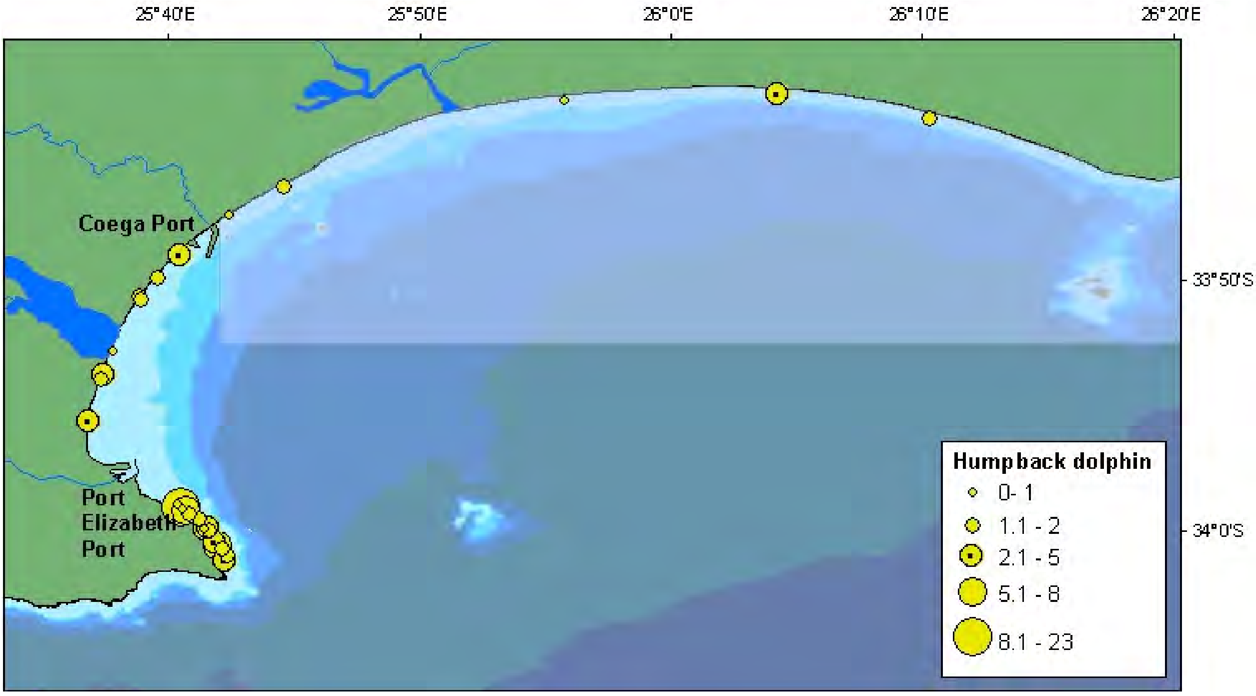

Figure A3.5. The spatial distribution of humpback dolphins with the size of the points representing the different group sizes.

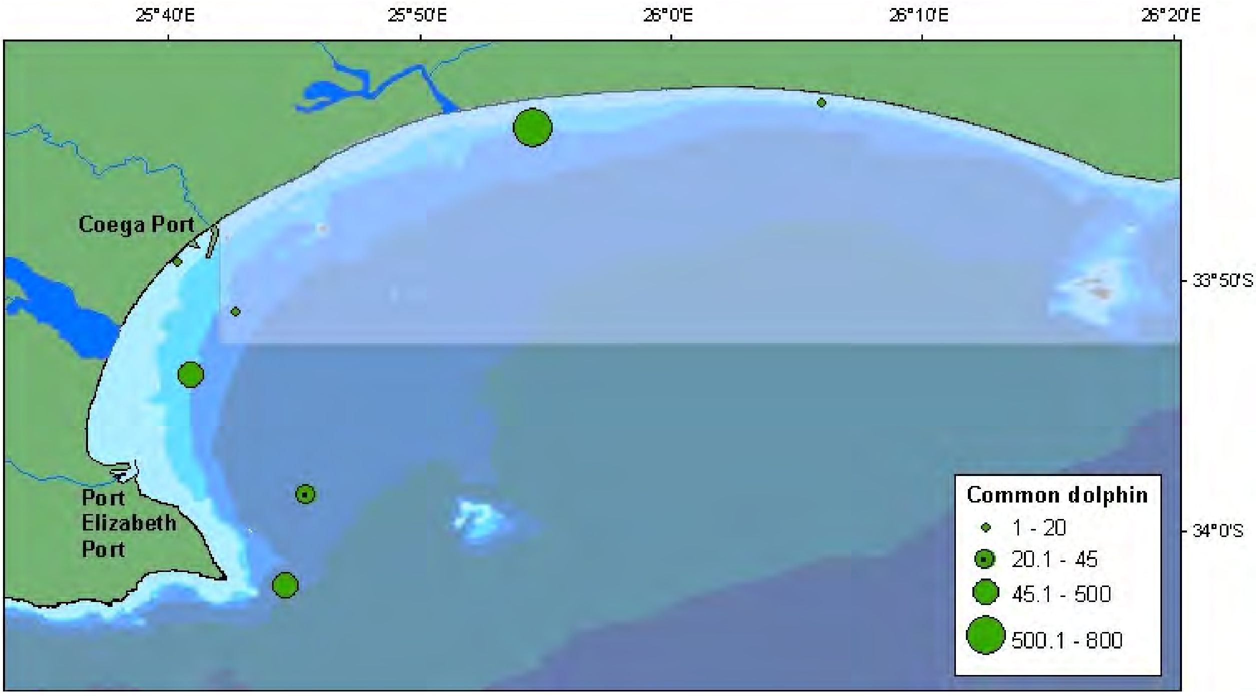

Figure A3.6. The spatial distribution of common dolphins with the size of the points representing the different group sizes.

APPENDIX 4: MAPS OF INDIVIDUALS PER UNIT EFFORT (IPUE)

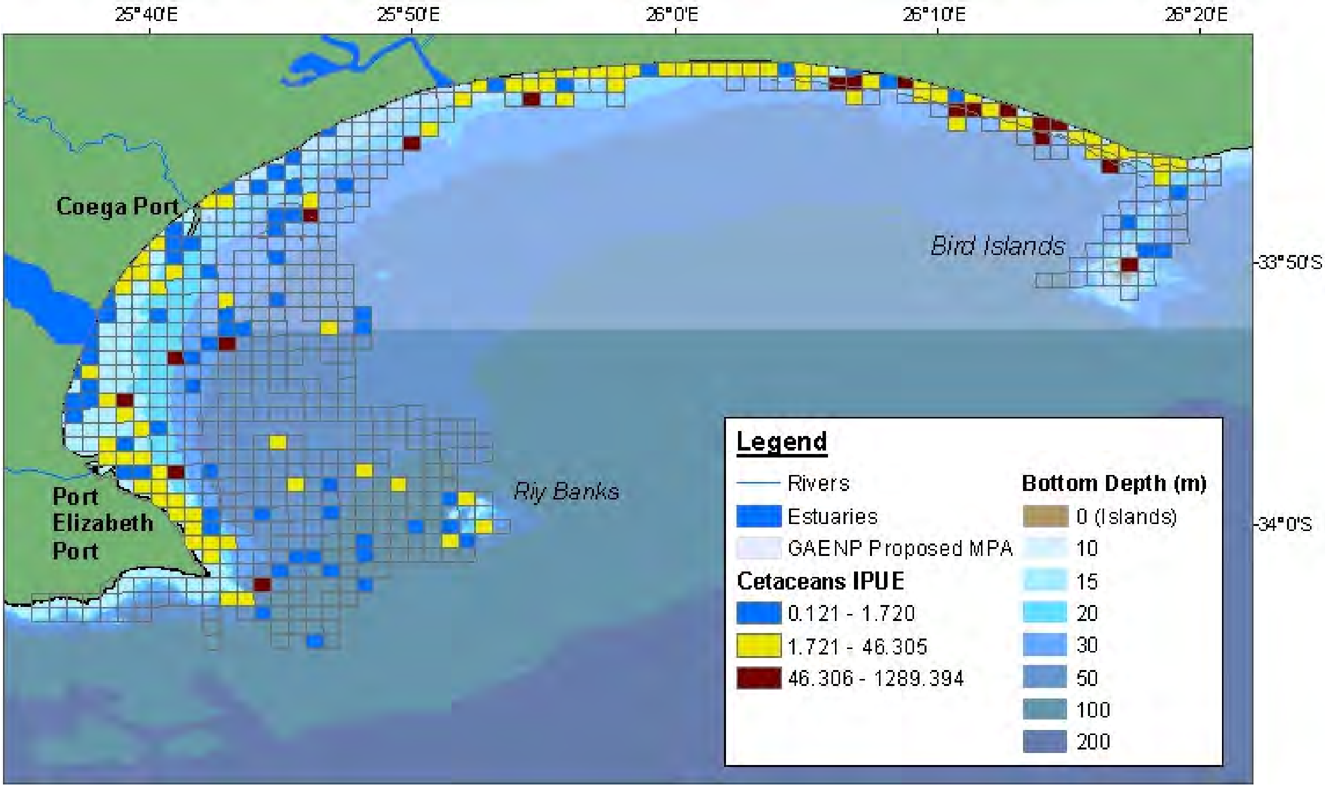

Figure A4.1. Spatial distribution of cetacean IPUE. Cells represent low, medium and high IPUE.

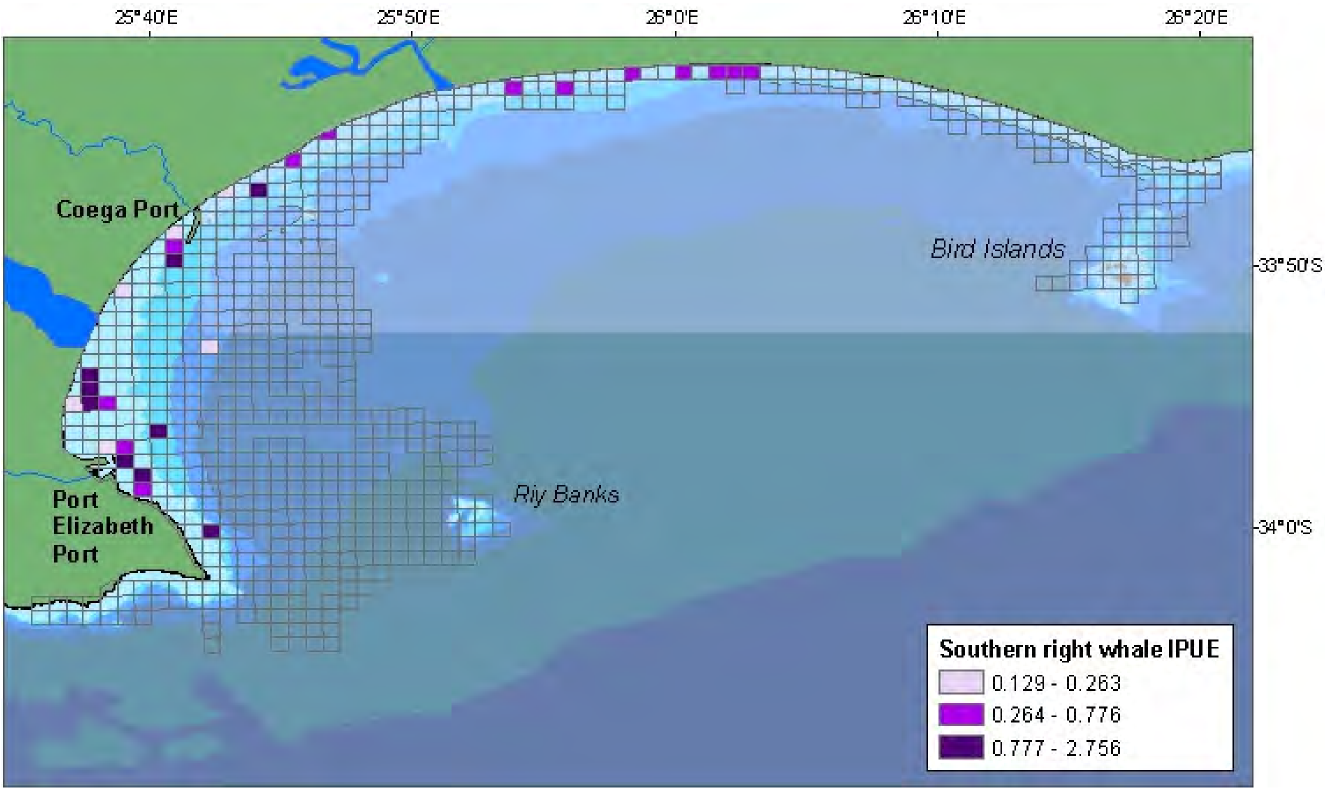

Figure A4.2. Spatial distribution of southern right whale IPUE.

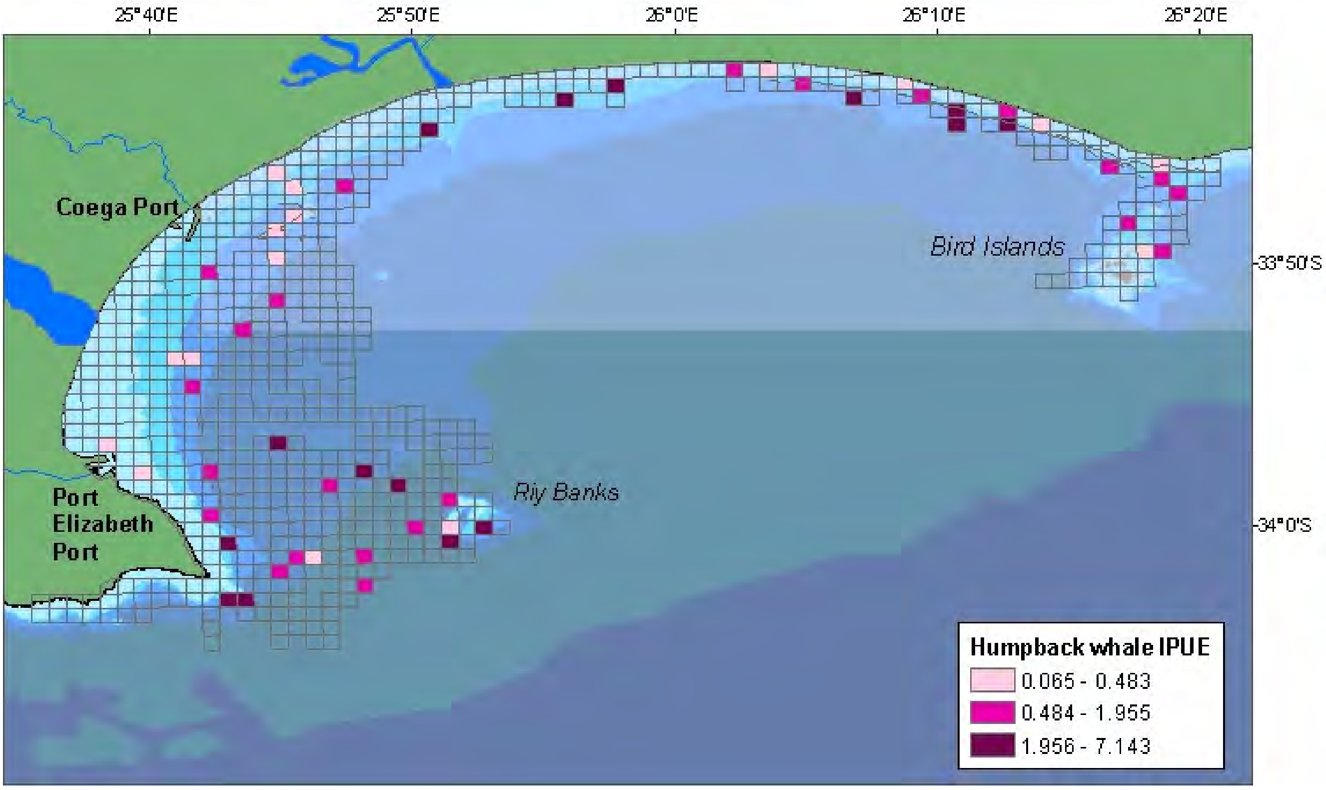

Figure A4.3. Spatial distribution of humpback whale IPUE.

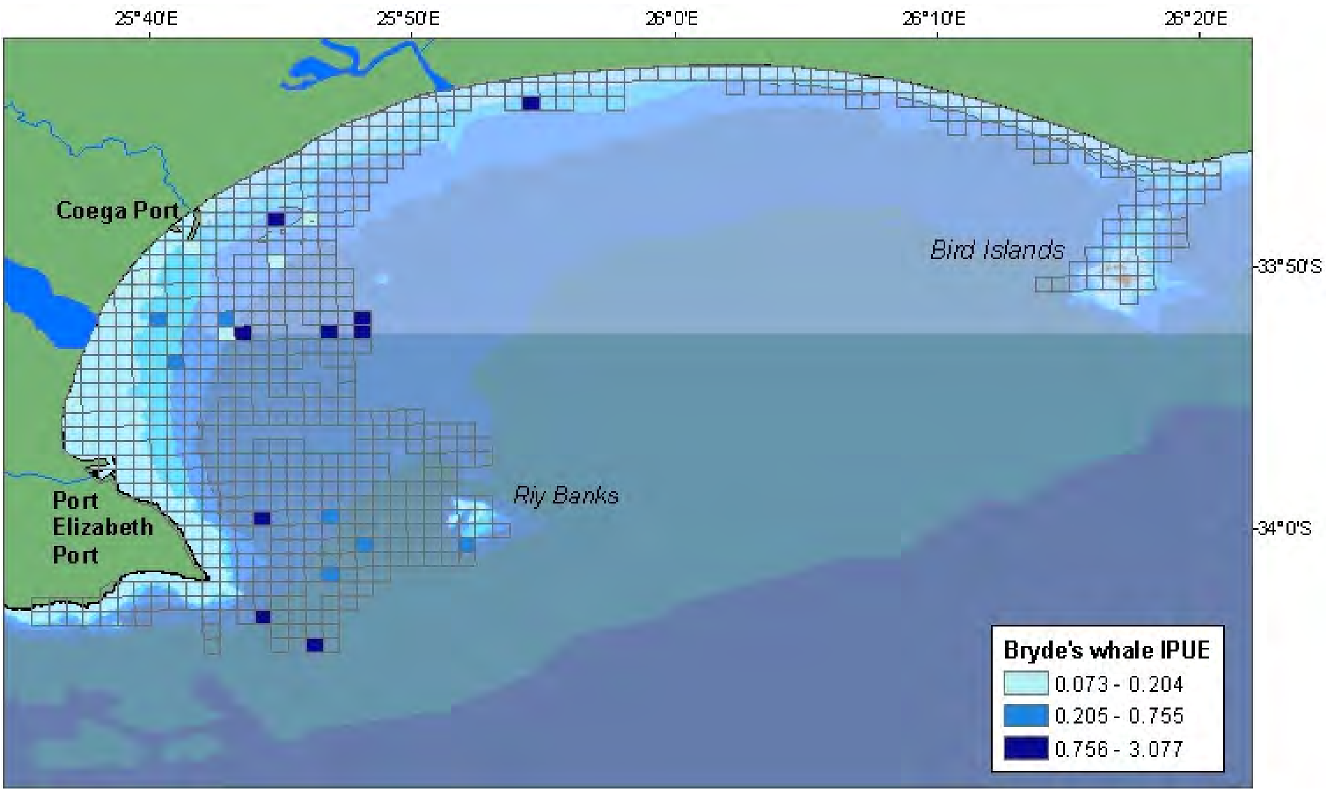

Figure A4.4. Spatial distribution of Bryde's whale IPUE.

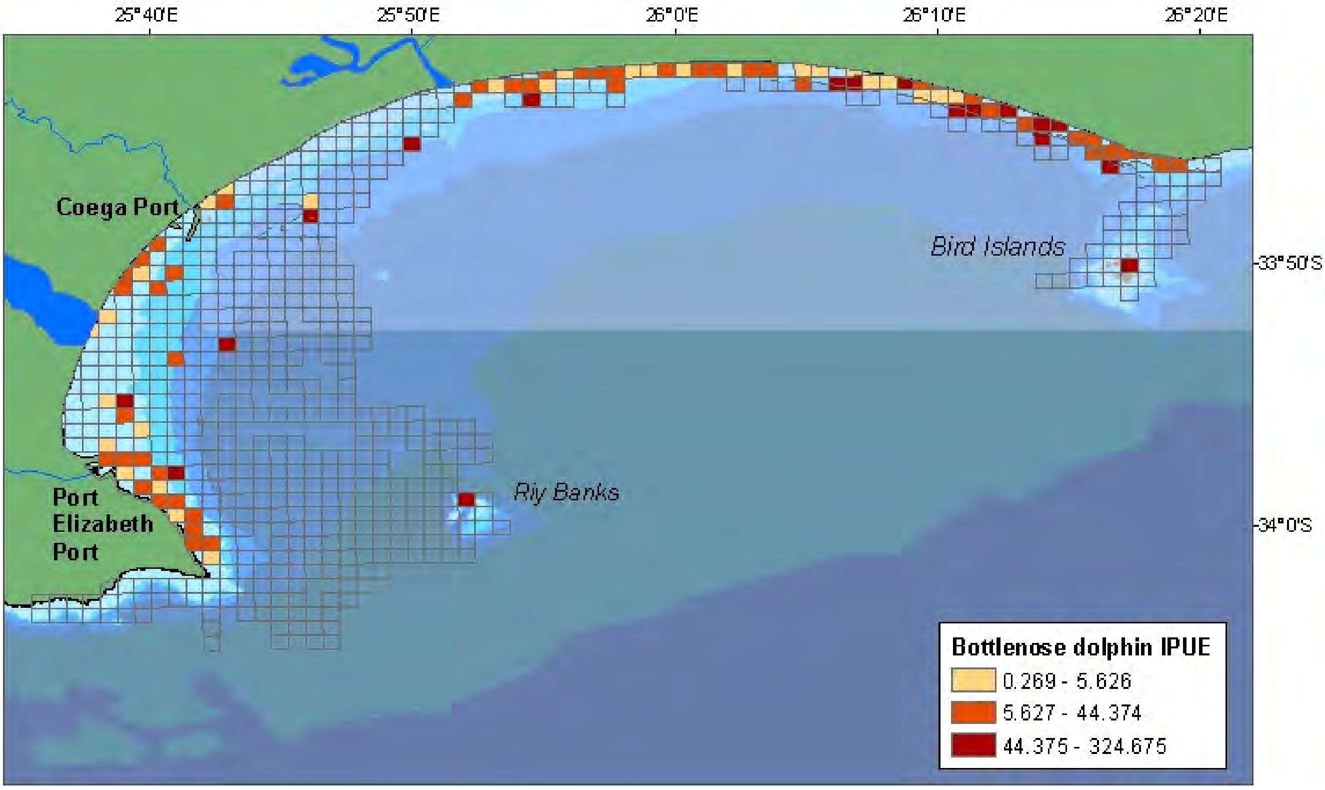

Figure A4.5. Spatial distribution of bottlenose dolphin IPUE.

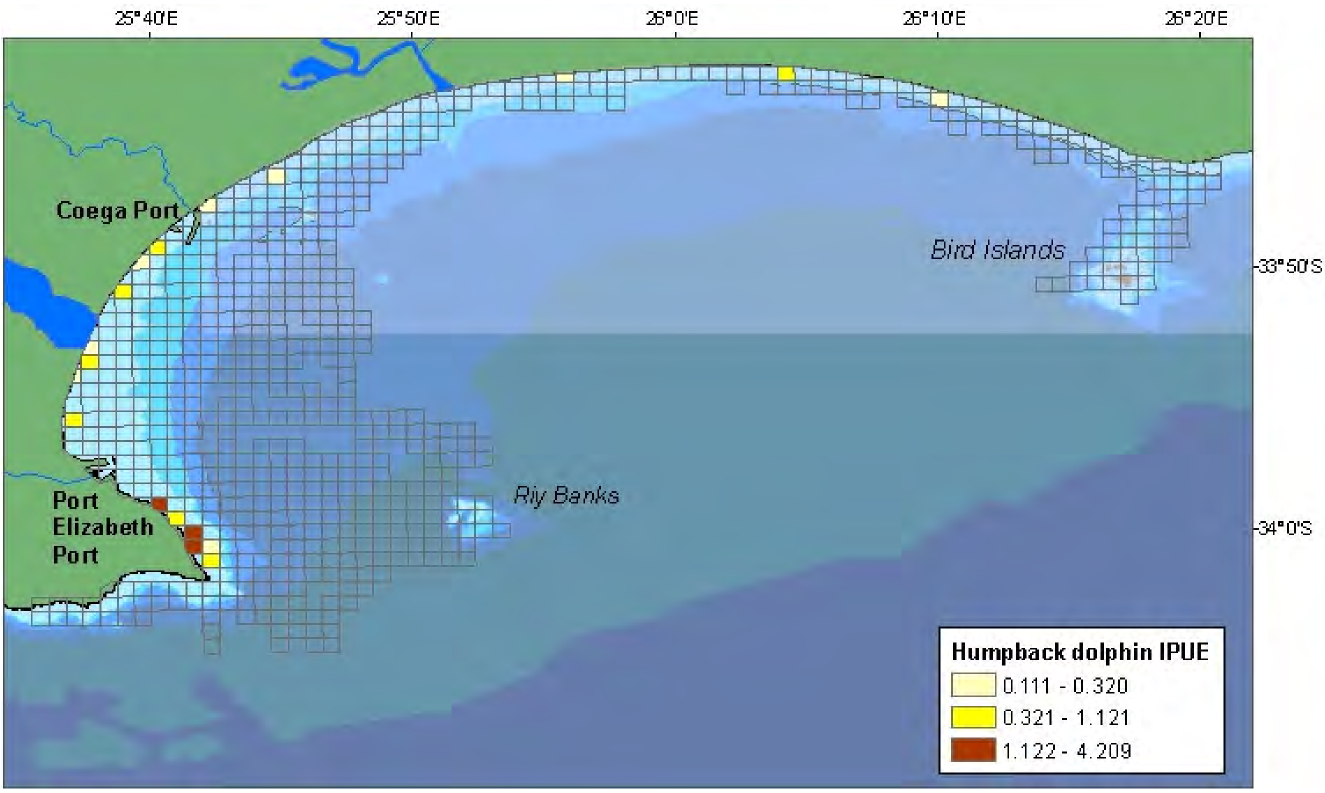

Figure A4.6. Spatial distribution of humpback dolphin IPUE.

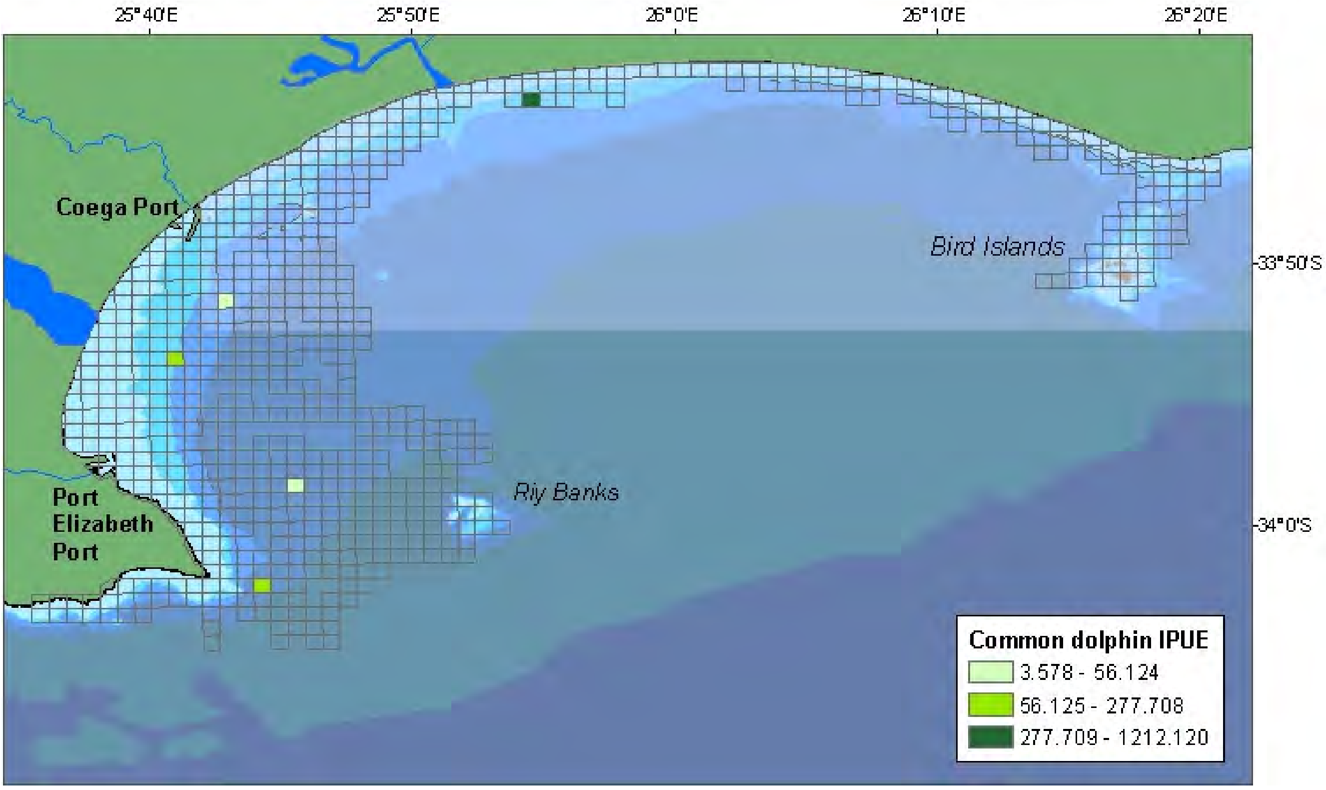

Figure A4.7. Spatial distribution of common dolphin IPUE.

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