Developing methods to use static acoustic click detectors for long term monitoring of coastal delphinids along the Cape south coast, South Africa

By

Monica Elizabeth Betts

Submitted in partial fulfilment of the requirements for the degree of
Master of Science (Zoology)

In the Faculty of Natural and Agricultural Sciences
Department of Zoology and Entomology
University of Pretoria
Pretoria

September 2015

DECLARATION

I, **Monica Elizabeth Betts,** declare that the dissertation, which I hereby submit for the degree **MSc (Zoology)** at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

MBetts

Signature

11 September 2015

Date

Developing methods to use static acoustic click detectors for long term monitoring of coastal delphinids along the Cape south coast, South Africa

By

Monica Elizabeth Betts

Supervisors: Dr. S.H. Elwen
Mammal Research Institute,
Department of Zoology and Entomology,
University of Pretoria
Pretoria
0002
C/o Sea Search Africa
4 Bath Road,
Muizenberg,
Cape Town,
7945
South Africa
E-mail: s.elwen@gmail.com

Prof. M.N. Bester
Mammal Research Institute,
Department of Zoology and Entomology,
University of Pretoria,
Pretoria,

0002

South Africa

Email: mnbester@zoology.up.ac.za

Dr. E. Gennari

Oceans Research & South African Institute for Aquatic Biodiversity (SAIAB)

5 Klipheuwel Road,

Hartenbos,

Mossel Bay,

6520

South Africa

Email: egennari@oceans-research.com

Bottlenose dolphin, 2014, Monica Betts

“In the end, we will only conserve only what we love, we will love only what we understand, and we will understand only what we are taught.”

Baba Dioum

Humpback dolphins, 2014, Monica Betts

ACKNOWLEDGEMENTS

I would like to start off by thanking my supervisors, Dr. Simon Elwen for taking me on as a student even though I had limited knowledge of cetaceans at the time and willingly working through many drafts of my thesis. Prof. Marthán Bester for providing logistic support in the form of funding and reviewing different drafts of my thesis and to Dr. Enrico Gennari for providing a place for me to conduct my research and for all the valuable comments and tips that made my thesis so much better. A special thanks to the Oceans Research for funding my research and for covering food and accommodation and to Prof. Robert Millar for providing a NRF bursary which covered fees and other living expenses.

Then to all the staff and interns at Oceans Research a huge thank you for the assisting me with work both in and out the field. To the field specialists (Lauren Peel, Danielle Goodreau, Dorien Schröder, Blair Bentley, Curtis Young, Olivia Seeger and Dave van Beuningen), that helped with skippering, opening the C-POD, the odd land based surveys and dealing with me when I freaked out thanks so much this would not have been possible without any of you.

Thanks to everyone at Sea Search Africa for making the last few month of my write up possible. A special thanks to Bridget James for all the help she provided in showing me the ropes at Oceans Research and helping me with some of the analyses, to Dr. Theoni Photopoulou for her help with running models in R studio, to Dr. Tess Gridley for her comments and valuable tips on dolphin acoustics and to Mairi-ann Bonnet for editing my thesis.

A very special thank you to my CRC family, Ps Juan and Sarina Labuschagne, Caroleen Claasen, Linda Israel and everyone else at CRC George and CRC Cape Town, your friendship, prayers and support has meant the whole world to me. I also want to thank my parents, Arthur and Jackie and my sister, Carol- Anne whose support was never ending. Thanks for putting up with all my freak out sessions, long phone calls and many tears. And finally thanks goes to God who opened many doors and carried me through this incredible journey.

DISCLAIMER

This thesis consists of a series of chapters that have been prepared as stand-alone manuscripts for subsequent submission for publication purposes. However to avoid repetition between chapters methodology covering all the chapters will only be mentioned once in the general introduction.

GENERAL ABSTRACT

This thesis investigated the use of a static acoustic data logger known as a **C**etacean and **Po**rpoise **D**etection (**C-POD**) device for monitoring two species of dolphins that occur in Mossel Bay, South Africa: the Indo-Pacific bottlenose dolphin, *Tursiops aduncus*, and the Indian Ocean humpback dolphin, *Sousa plumbea.* These two species have a near shore distribution which brings them into frequent contact with human activities such as boating, fishing, desalination plants and the onshore component of gas extraction facilities which can potentially affect their behaviour and populations dynamics. Although both species are relatively well studied within South Africa in terms of biology and abundance, this has been limited to the KwaZulu-Natal coast and Algoa Bay with little information available for areas west of Algoa Bay, and almost no information available locally on their acoustic behaviour.

This study aimed to: 1) calculate the detection range and effective detection radius (EDR) of C-PODs for *T. aduncus* and *S. plumbea* taking into account environmental and group parameters that may affect these and 2) distinguish *T. aduncus* from *S. plumbea* based on temporal variation in specific echolocation click parameters. Field work took place in Mossel Bay from a land-based platform during the period May 2013 to August 2014. A surveyor's theodolite was used to collect positional data on dolphins and behavioural information was collected through visual observations. A C-POD was deployed near the land based site and serviced and downloaded on a monthly basis for the same survey period. Visual detections were matched to acoustic detections (echolocation clicks) made within a 60 sec and 30 sec time window. Data were analysed using the software programme R. General Estimating Equations (GEE) were used to 1) model the detection probability and EDR of a C-POD for both species during both time windows; 2) model differences between the two species for seven click parameters produced by the C-POD. The impact of background noise on C-POD detections was also assessed.

As cetaceans are not the only form of sound in a marine environment distinguishing dolphin clicks from all other noise sources can be a challenge. Sources of background noise include clicking shrimp, movement of sediment, boat traffic and chorusing by reef fish and crustaceans during reproductive or territorial displays and storms which can either mask the clicks produced by dolphins or fill up the memory card. Data collected from two different deployment locations at different depths were subsequently compared after significant interference from other noise source was detected at the first deployment location. Mean number of detected dolphin clicks after filtering increased from 6463.33 to 97820 clicks per deployment and mean number of minutes in which detections were recorded increased from 0.23 min to 2.79 min per deployment.

Average detection probability for bottlenose dolphins was 0.357 (95% CI: 0.352 - 0.363) for the 60 sec window and 0.257 (95% CI: 0.253 - 0.262) for the 30 second window. For humpback dolphins the average detection probability was 0.084 (95% CI: 0.082 - 0.087) for the 60 sec window, and 0.043 (95% CI: 0.042 - 0.044) for the 30 sec window. EDR for bottlenose dolphins was 1161.38 mm (95% CI: 1150.14m – 1172.62 m) for the 60 sec window and 1035.761 m (95% CI: 1024.89 m – 1046. 64 m) for the 30 sec window. EDR for humpback dolphins was 765.25m (95% CI: 755.64 m – 774.85 m) for the 60 sec window and 751.00 m (95% CI: 741. 40 m – 760. 60 m) for the 30 sec window. Detection probability and EDR were higher for bottlenose dolphins than humpback dolphins over both time windows. For both species, during both windows, detection probability was significantly influenced by group size ($p < 0.05$). Four out of the seven parameters produced by the C-POD yielded significant pairwise differences ($p < 0.05$) between the species. Average inter-click interval was the only co-variable that was significant in the GEE model. The average ICI for bottlenose dolphins was 55.91 ms (95% CI: 51.23 – 60.60) whilst the average ICI for humpback dolphins was longer at 119.76 ms (95% CI: 119.76 – 174.00). The interaction between average ICI and modal frequency was also significant ($p < 0.05$) indicating that a combination of co-variables might be required in order to differentiate between the two species. Despite the small sample size and the challenges associated with acoustic studies in a noisy marine environment this study provided valuable information regarding the use of static acoustic data loggers such as C-POD in South Africa. As newer versions of C-POD are frequently introduced many of the challenges encountered in this study will be minimized.

Keywords: C-POD, detections, differentiation, Mossel Bay, noise, *Sousa plumbea*, theodolite, *Tursiops aduncus.*

TABLE OF CONTENTS

LIST OF FIGURES

Chapter 1:

Chapter 2:

Chapter 3:

Chapter 4

LIST OF TABLES

Chapter 1:

Chapter 2:

Chapter 3:

Chapter 4:

Chapter 5:

Chapter 1

1.1. GENERAL INTRODUCTION

This chapter provides a detailed introduction to the two study species and study site as well as providing background and motivation for the study. It also includes the research aims for each chapter and the methodology used to collect data.

The rapid use of Earth's limited resources and the ever increasing human population places several constraints on wildlife populations (Marques *et al.* 2012). To effectively protect and manage these populations, knowledge of their population size and demographic structure is critical (Marques *et al.* 2012). However, for many populations throughout the world this information is very difficult to obtain due to cost and limitations of time and accessibility (Elwen *et al.* 2011; Marques *et al.* 2012).

In general, our knowledge of cetaceans in the southern African sub-region is fragmented and for many species we lack basic information such as habitat use and population size (Elwen *et al.* 2011). However, technological advancements in cetacean research in recent years have rapidly increased the suite of tools available to biologists to study and manage populations of wild animals (Marques *et al.* 2012). One such tool is Passive Acoustic Monitoring (PAM), which uses the sounds that animals naturally make to study their presence and behaviour.

This study trialled the use of a **C**etacean and **Po**rpoise **D**etection (**C-POD**) device, an echolocation detecting, autonomous data logging hydrophone system to acoustically detect Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) and Indian Ocean humpback dolphins (*Sousa plumbea*). This study served as a precursor to using C-PODs for longer term and broader scale monitoring projects. Simultaneous shore observations of the study species around the C-POD were used to confirm species identity, behaviour and movements patterns. This information was then used to investigate the effect of underwater noise on the ability of the C-POD to detect clicks, detection probabilities of the C-POD for each species and the acoustic differentiation of species using the C-POD data outputs. The study was conducted in Mossel Bay, South Africa, a protected bay area which houses a small commercial harbour and moderate levels of tourism.

1.1.1. Overview of Sound Production in Animals/ Cetaceans/ Delphinids

The first animals found to use echolocation to orientate itself and find food were bats. In the early 1770's, bats were observed with the ability to avoid obstacles even when they were unable to see (Au 1993). Echolocation in bats and their ability to hear ultrasonic sounds was only formally proven over 100 years later (Pierce and Griffin 1938; Galambos 1942; Griffin 1944; Au 1993). Using this information, scientists were able to discover echolocation in dolphins (McBride 1956; Norris *et al.* 1961; Au 1993).

Common bottlenose dolphins (*Tursiops truncatus)* were first thought to use echolocation in 1947 when they were observed navigating the muddy night waters of the Florida coastline successfully avoiding mesh nets and cork lines (McBride 1956; Au 1993). A series of experiments were conducted and by 1960 the first conclusive proof of echolocation in common bottlenose dolphins was published (Norris *et al.* 1961; Au 1993). In this experiment, a trained common bottlenose dolphin had its vision obscured using plastic suction cups and was placed within a maze of pipes (Norris *et al.* 1961). The individual was successfully able to navigate the maze and locate fish thrown into the tank (Norris *et al.* 1961). This experiment was repeated on an untrained recently caught common bottlenose dolphin and produced the same results (Wood and Evans 1980). Today, echolocation has been described in all odontocete species including porpoises but is not known to occur in mysticetes.

Dolphins evolved flexible sonar systems that can adjust to the continuously changing marine landscape (Au 1993). Information is encoded in specific signals and then decoded by the brain. Currently it is believed that dolphins possess two identical sound producing structures consisting of fatty dorsal bursae located with two phonic lips in both nasal passages (Bradley and Sterm 2008; Cranford *et al.* 2011). These phonic lips along with the bursae enable the recirculation of air in the body which is used to produce sounds by changing the air pressure and frequency as it moves through the lips (Bradley and Sterm 2008).

Vocalisations can be grouped broadly into one of these three categories: 1) Whistles are tonal sounds with frequencies of around 800 Hz (Schulz and Corkeron 1994) to 28.5 kHz (May-Callado and Wartzok 2008) and can last from 100 ms to 4 sec (Buckstaff 2004); 2) Clicks are broadband short signals with frequency ranges around 100 kHz in most species (Richardson *et al.* 1995), although species within the family Kogiidae, Phocoenidae and the genus *Cephalorhynchus* are known to produce narrow band clicks at frequencies above 100 kHz instead (Madsen *et al.* 2005a; Morisaka and Connor 2007); 3) Burst pulses are a succession of rapid click trains that include brays, moans and rasps (Caldwell and Caldwell 1967; Janik 2000a; Janik 2009). Whistles and burst pulses are generally used during social interactions (Cook *et al.* 2004; Simard *et al.* 2011) whilst clicks are used in echolocation (Janik 2009). Dolphins have a hearing range of 50 Hz to 150 kHz depending on the species (Richardson *et al.* 1995). Hearing range tends to closely match production ranges in order for individuals of the same species to communicate effectively with each other (Janik 2009).

Most studies of vocalization in dolphins focused on the two species of bottlenose dolphins, common bottlenose dolphin (*Tursiops truncatus*) and Indo–Pacific bottlenose dolphin (*Tursiops aduncus*) (Janik 2009). Their echolocation beam is highly directional and the frequency spectrum for clicks produced at angle to the hydrophone beam (referred to as off-axis clicks) is highly variable (Morisaka *et al.* 2005b). Each individual bottlenose dolphin also has the ability to produce its own distinct whistle referred to as a ‘signature whistle’ which is used primarily when conspecific individuals become separated from the rest of the group (Caldwell and Caldwell 1965; Janik 2009). Signature whistle use has recently been confirmed in wild common bottlenose dolphins from southern Africa (Kriesell *et al.* 2014) and in Indo-Pacific bottlenose dolphins (Gridley 2010, Gridley *et al.* 2012). Clicks are used primarily during foraging and decrease during travelling and socialising (Janik 2009; Simard *et al.* 2011).

1.1.2. Visual Monitoring using theodolites

Theodolites have been used to study cetaceans since the 1970s when Roger Payne first used a theodolite to track right whales (*Eubalaena australis*) in Argentina (Payne 1986). Not long after Würsig and Würsig (1979) followed with a shore-based study of bottlenose dolphins (*Tursiops truncatus*) also in Argentina. Theodolites have a distinct advantage over boat-based studies in some contexts as they enable undisturbed observations of the target animals whilst providing precise information on location and movement (Würsig *et al.* 1991; Gailey and Ortega-Ortiz 2000; Denardo *et al.* 2001).

A theodolite is a surveying device that precisely measures the vertical and horizontal angles of an object (such as a whale, dolphin or boat) relative to the observer’s location (Harzen 2002; Bailey and Lusseau 2004). If the base (site location), exact height above sea level and the variations caused by tide and the curvature of the earth are known, it is possible to use trigonometric calculations to convert these angles to coordinates of longitude and latitude therefore providing the exact location of the target object (Harzen 2002; Bailey and Lusseau 2004). The major disadvantages of using a theodolite are that surveys are limited to shore areas that have high vantage points close to the ocean and to cetacean species that occur within view of the shore (Denardo *et al.* 2001; Harzen 2002; Bailey and Lusseau 2004).

Theodolites have been used to study a range of topics including; 1) interactions between boats and cetaceans (Acevedo 1991); 2) the effect of gillnets and acoustic alarms on the behaviour of cetaceans (Todd *et al.* 1992; Goodson and Mayo 1995) and 3) provide information on breathing rates, swimming speeds, direction and sonar activities (Würsig *et al.* 1991; Goodson and Mayo 1995; Gailey and Ortega-Ortiz 2000; Harzen 2002; Barendse *et al.* 2010; Findlay *et al.* 2011).

1.1.3. Acoustic Monitoring

Passive Acoustic Monitoring (PAM) is an increasingly used form of monitoring animals in remote locations and refers to the process of detecting wildlife through passive listening (rather than active sonar such as used in fisheries surveys). The technique is particularly suitable to cetaceans as they are often acoustically very active. PAM data can be used to detect simple presence as well as behaviour if specific vocalisations are associated with specific behaviours.

There are two main types of passive acoustic equipment used for monitoring cetaceans, namely cabled hydrophones and autonomous recorders (Mellinger *et al.* 2007). Cabled hydrophones are highly diverse, can be deployed on a semi-permanent or permanent basis and provide continuous near-real time data if deployed from a stable platform or shore (Mellinger *et al.* 2007). However, cabled hydrophones linking to shore have high purchase, transport and deployment costs and recordings take up large volumes of data storage space (Mellinger *et al.* 2007).

Autonomous recorders consist of a hydrophone and battery-powered recording or data-logging system (Mellinger *et al.* 2007). Autonomous recorders can record data continuously or at set intervals and deployments can last for up to 2 years (Mellinger *et al.* 2007). The major advantage of autonomous recorders is that they are relatively inexpensive given the continuous, long-term nature of their recording (Mellinger *et al.* 2007). Autonomous recorders, however, store data internally and need to be retrieved before data can be downloaded (Mellinger *et al.* 2007).

PAM recorders are highly dependent on hydrophone sensitivity, ambient noise levels, transmission losses, behaviour of the animal and orientation of the animal relative to the recorder. It is therefore important to consider these factors when designing a PAM study (Holt *et al.* 2012). Factors that can influence detections are as follows; 1) Frequency – sounds below 1 kHz travel further than sounds above 10 kHz as there is less interference by sea water at lower frequencies (François and Garrison 1982); 2) Vocal behaviour – some species are more vocal than others making them easier to detect and vocalisations can also change with animal behaviour (e.g. feeding, mating) (Mellinger *et al.* 2007); 3) Source level – larger species can produce vocalisations that can be detected many kilometres away (Clark 1995; Barlow and Taylor 2005); 4) Directionality – high-frequency clicks tend to be directional whilst low-frequency clicks tend to be omnidirectional making them more difficult for the hydrophone to detect (Au 1993; Møhl *et al.* 2000).

Static acoustic monitoring (SAM) refers to PAM systems that are moored in place and can be used to study patterns in relative abundance and behaviour of target animals in a particular area (Tougaard *et al.* 2006; Philpott *et al.* 2007; Marques *et al.* 2012). SAM has many of the benefits associated with PAM, including continuous monitoring in any type of weather and a reduction in observer bias due to environmental condition (Mellinger *et al.* 2007; Leeney *et al.* 2011). In addition, SAM equipment produces a detailed dataset of animal presence and trends in occurrence (diurnal and nocturnal) at very little cost and effort (Mellinger *et al.* 2007; Leeney *et al.* 2011).

C-PODs and their predecessors T-PODs were first produced to study behaviour of harbour porpoise (*Phocoena phocoena*) around nets and to assess the effect of pingers on reducing accidental capture in fishing nets (Cox *et al.* 2001; Carlström *et al.* 2009). Porpoises echolocate continuously, producing echolocation clicks at ultrasonic levels (around 130 kHz) as they navigate through their environment (Villadsgaard *et al.* 2007). These narrow-band high frequency (NBHF) echolocation clicks differ to the broad-band clicks produced by a wide variety of marine organisms (Bailey *et al.* 2009; Tregenza 2012). The T-POD was calibrated to detect NBHF echolocation clicks by only recording clicks that occurred within a pre-determined frequency range (Cox *et al.* 2001; Leeney and Tregenza 2006; Tregenza 2012).

PODs have a few disadvantages that include: 1) a limit on the maximum number of clicks recorded per minute (4096); 2) these are data-loggers so echolocation clicks are just logged and playback of recorded clicks is not possible and 3) some PODs are over-sensitive which can be a potential problem if results are to be comparable across studies (Dahne *et al.* 2013). The C-POD is an improved and enhanced version of a T-POD and therefore many of the challenges faced with T-PODs should be minimized (Tregenza 2012; Dahne *et al.* 2013). For instance, previous studies testing the sensitivity of different T-PODs revealed that differences in detection rates between different T-PODs were high leading to a large variation in parameters analysed (Tougaard *et al.* 2006; Kyhn *et al.* 2008; Dahne *et al.* 2013). However, this is much reduced in C-PODs. A recent calibration experiment within a tank revealed that C-PODs have little variation in detection thresholds at higher frequencies (around 130 kHz) but sensitivity decreased dramatically below 80 kHz which could influence studies on cetacean species with wide frequency range (Dahne *et al.* 2013).

The T-POD is now well established as a monitoring tool for porpoise and dolphins in the genus *Cephalorhynchus* such as Heaviside's dolphins, *C. heavisidii* (Leeney *et al.* 2011) and Hector's dolphins, *C. hectori* (Rayment *et al.* 2011). Improved versions of the T-POD and the later introduction of the C-POD made acoustic monitoring of broad-band clicking species possible. Since then C-PODs and T-PODs (collectively referred to as PODs) have been used to study common bottlenose dolphin, *Tursiops truncatus*, (Philpott *et al.* 2007; Bailey *et al.* 2009; Nuuttila *et al.* 2013b) and beluga whales, *Delphinapterus leucas*, (Castellote *et al.* 2012). In addition, research expanded to include habitat use patterns (Simon *et al.* 2010), population abundances (Kyhn *et al.* 2012) and the impact of anthropogenic factors such as wind, wave and tidal power stations on porpoises and other dolphin species (Jefferson *et al.* 2009).

1.1.4. Visual & Acoustic Monitoring Combined

Static acoustic monitoring studies have increasingly been combined with visual surveys as together they can produce more accurate information regarding cetacean presence/absence, behaviour and movement patterns (Bailey *et al.* 2009; Nuuttila *et al.* 2013a). In addition, SAM has also been used to estimate absolute densities and quantify differences in habitat use and abundance (Tougaard *et al.* 2006; Philpott *et al.* 2007; Rayment *et al.* 2009; Kyhn *et al.* 2012; Nuuttila *et al.* 2013b).

To use SAM devices to estimate absolute densities, abundance or quantify differences in habitat use it is necessary to know how the ability of the SAM device to detect cetaceans varies with the range of the animal from the device (Akamatsu *et al.* 2001; Tougaard *et al.* 2006; Bailey *et al.* 2009; Rayment *et al.* 2009; Nuuttila *et al.* 2013b). The ability of receivers to detect cetaceans is referred to as detection probability and the region covered by a receiver in which all animals are detected is referred to as the effective detection radius (EDR) (Tougaard *et al.* 2006; Rayment *et al.* 2009; Kyhn *et al.* 2012). It is also necessary to assess the influence of environmental and biological factors on the detection probability and EDR (Tougaard *et al.* 2006; Rayment *et al.* 2009; Kyhn *et al.* 2012).

1.1.5. Species Background

1.1.5.1. Tursiops spp.

The relatively recent (in evolutionary time) radiation of the family Delphinidae left little time for diagnostic characteristics to develop which can be used to classify different species taxonomically (Pichler *et al.* 2001; Möller *et al.* 2008). Recently, through improved access to morphological and osteological data, some of the confusion has been eliminated (Hale *et al.* 2000; Möller and Beheregaray 2001). As a result, there are now three recognized species within the genus *Tursiops* (Wang *et al.* 1999; Möller *et al.* 2008). *Tursiops truncatus* (Montagu 1821), *T. aduncus* (Ehrenberg 1833) and *T. australis* (Charlton-Robb *et al.* 2011) which are characterised by distinct genetic and morphological differences (Charlton *et al.* 2006; Möller *et al.* 2008; Charlton-Robb *et al.* 2011).

T. truncatus are found throughout the temperate and tropical waters of the Atlantic and Indian Oceans whilst *T. aduncus* individuals are found throughout the Indian Ocean in coastal and shallow offshore waters (Best 2007). The recently described *T. australis* is found in coastal waters exclusively around south-eastern and southern Australia (Charlton-Robb *et al.* 2011)

In South Africa, *T. aduncus* (hereafter bottlenose dolphins) are distributed along the east coast of southern Africa as far west as False Bay (34° 06' S, 18° 48' E) (Findlay *et al.* 1992; Best 2007). Individuals show a distinct preference for near shore areas within the 50 m isobath and are not known to occur in waters more than 100 m deep (Findlay *et al.* 1992; Best 2007). A recent shore-based theodolite study in Mossel Bay showed that individuals are found in waters up to 40 m deep with a preference for reef-associated habitat near river mouths (James 2014).

Sightings of *T. truncatus* along the east coast of southern Africa are generally limited to offshore sightings in waters 500 to 1000 m deep with only a few inshore sightings around St Helena Bay (32° 45’ S, 18° 01’ E) (Findlay *et al.* 1992; Best 2007). As the study area (Mossel Bay) was located in the Indian Ocean and extremely close to shore (< 20 m depth) it is highly unlikely that *Tursiops* spp. encountered are *T. truncatus* and therefore all bottlenose dolphin sightings during the study were assumed to be *T. aduncus.*

Indo-Pacific bottlenose dolphins tend to be smaller with a relatively longer rostrum and more triangular dorsal fin than other species within their genus (Ross 1977a; Wang *et al.* 2000; Charlton-Robb *et al.* 2011). Indo-Pacific bottlenose dolphins are generally uniform in colour and in some areas are known to have dark spots over the lower half of the body (Möller and Beheregaray 2001). The diet of bottlenose dolphins consists of mainly reef and benthic dwelling fish though they are known to feed on cephalopods and even some pelagic species of fish (Ross 1977b; Ross 1984; Cockcroft and Ross 1990).

Population size of bottlenose dolphins along the Cape south coast of South Africa was estimated to be between 16,220 and 40,744 individuals during a photo-identification mark-recapture study on data collected from 1991 to 1994 (Reisinger and Karczmarski 2010). Group size along the South African coast generally ranges from 1 to 500 individuals with a mean of 76.2 (SD ± 84.98) even though larger groups of up to 1000 individuals can occur (Saayman and Tayler 1973; Ross 1984; Findlay *et al.* 1992). Along the coast bottlenose dolphins are known to exhibit a combination of long-range seasonal movements and periods of higher residency (Peddemors 1999).

Globally bottlenose dolphins (*T. aduncus*) is currently rated as data deficient (DD) according to IUCN’s Red List of threatened species (Hammond *et al.* 2008). This is due to the overall lack of information regarding population distributions and abundances (Hammond *et al.* 2008). In addition, little is known regarding the impact of pollution, habitat degradation and climate change on the different populations (Hammond *et al.* 2008). Within South Africa they are listed as of ‘Least Concern’ during a National Red List Assessment (June 2014), due mostly to the large estimated population size and no evidence of major direct conservation concerns such as directed or accidental catches (beyond that in the shark nets of the KwaZulu-Natal Sharks Board (Meyer *et al.* 2011)) (Atkins *et al.* in press).

1.1.5.2. Sousa spp.

The genus *Sousa* has also been subject to widespread debate regarding the number of species therein (Ross *et al.* 1994; Mendez *et al.* 2013; Jefferson and Rosenbaum 2014). However recent studies on genetic and morphological samples throughout their known global range led to the classification of four species (Mendez *et al.* 2013; Jefferson and Rosenbaum 2014). These are the Atlantic humpback dolphin, *Sousa teuszi* (Kukenthal 1892), the Pacific humpback dolphin, *S. chinensis* (Osbeck 1765), the Indian Ocean humpback dolphin, *S. plumbea* (Cuvier 1829*)* and the recently described Australian humpback dolphin, *S. sahulenis* (Mendez *et al.* 2013; Jefferson and Rosenbaum 2014).

S. teuszi is found in shallow coastal and estuarine habitats throughout the temperate and tropical waters of the Atlantic Ocean and *S. chinensis* is found in the temperate and tropical waters of the Indian Ocean along the coast India extending towards Indonesia (Mendez *et al.* 2013; Jefferson and Rosenbaum 2014). *S. plumbea* is found exclusively in the temperate waters of the Indian Ocean along the east coast of Southern Africa and the recently described *S. sahulensis* is found in the tropical and subtropical waters around Australia towards Papua New Guinea (Mendez *et al.* 2013; Jefferson and Rosenbaum 2014).

The distribution of *S. plumbea* (hereafter humpback dolphins) in South Africa extends all the way along the east coast of South Africa and as far west as False Bay (34° 06' S, 18° 48' E) (Findlay *et al.* 1992; Best 2007). Individuals show a distinct preference for shallow coastal waters, bays and estuaries that are often less than 50 m deep (Findlay *et al.* 1992; Best 2007). In Mossel Bay during a shore-based theodolite study individuals were found to prefer shallow waters less than 20 m deep, near shore reef systems and river mouths in the sheltered portions of the bay (James 2014).

Indian Ocean humpback dolphins, have a much more prominent dorsal hump with a smaller, more pointed dorsal fin than the other species within the genus (Ross 1984; Best 2007). They tend to be uniform brownish grey in colour with a lighter belly with spotting or scaring on the tail (Best 2007). Humpback dolphins in South Africa feed on a variety of fish species although a distinct preference is evident for species within the families Sciaenidae and Sparidae (Cockcroft 1999; Barros *et al.* 2004). Population size of humpback dolphins from Mossel Bay was estimated to be between 61 to 260 individuals (James *et al.* 2015). Group size estimates for Mossel Bay varied from 1 to 15 individuals with a mean of 4.91 animals (SD ± 3.48) (James 2014; James *et al.* 2015). Humpback dolphins exhibit seasonal variations in movement patterns and abundance levels (Durham 1994; Karczmarski 1999a; Karczmarski 1999b; Guissamulo 2008; James 2014; James *et al.* 2015).

Humpback dolphins (*S. plumbea*) are currently listed as Vulnerable on the IUCN Red List for threatened species due to a fragmented distribution, extensive habitat loss and incidental captures which have resulted in a dramatic decline in already small populations (Reeves *et al.* 2011). Within South Africa, the species was recently up-listed from Vulnerable to Endangered during the South African National Red List Assessment (June 2014) due to its limited range, possibly shrinking population size and high level of threats in their coastal habitats (Plön *et al.* 2015; Atkins *et al.* in press).

1.1.6. Study Area

Mossel Bay (34 ˚11' S, 22˚ 09' E) located along the southern coast of South Africa served as the location for this study (Figure 1.1). It is a semi-enclosed bay protected from extreme weather conditions by a peninsula located on the western side (Figure 1.1). The bay itself is shallow with the 20 m depth contour ranging between 1,230 m and 2,760 m from shore (Johnson *et al*. 2009; James 2014). The topography of the ocean floor is a combination of sand or exposed reef (Jackson and Lipschitz 1984). In addition, three major rivers empty out into the bay, namely Hartenbos, Klein Brak and Groot Brak rivers (Heydorn and Tinley 1980). The sheltered nature of the bay as well as the warmer waters of the Agulhas Current results in a mild climate (Clark *et al.* 2010). Wind direction is primarily east during the spring and summer and west during autumn and winter (Hanekom *et al.* 2009; Clark *et al.* 2010). Swell generally comes from the south east making the western section of the bay fairly sheltered (Clark *et al.* 2010).

Figure 1.1: The location of the study area (Mossel Bay) within its country (South Africa), and continent (Africa). Inset: Map of the study area (Mossel Bay) including the 3 major rivers that empty into the bay (Hartenbos river, Klein Brak river and Groot Brak river). The 5, 10, 20, 30 and 50 m isobaths are also indicated.

Due to its sheltered nature, warm waters and a number of estuarine habitats Mossel Bay supports a large diversity of aquatic animals throughout the year such as Cape fur seals *(Arctocephalus pusillus pusillus*), great white sharks (*Carcharodon carcharias*) and three species of dolphins namely, Indo-Pacific bottlenose dolphins (*T. aduncus*), Indian Ocean humpback dolphins (*S. .plumbea*) and long beaked common dolphins (*Delphinus capensis*) (Best 2007; James 2014). During the winter months two whale species, the southern right whale (*Eubalaena australis*) and humpback whale (*Megaptera novaeangliae*) frequent this area for breeding, feeding or to rest as they migrate further up the coast (Best 2007). In addition, Bryde's whales (*Balaenoptera edeni*) can sometimes be seen during the summer months.

1.1.7. Human impact on cetaceans

The marine environment of Mossel Bay is subject to a number of anthropogenic activities that have the potential to negatively impact the cetacean species that frequent the area. Potential factors include; a) boat activities (including a commercial harbour, marine tourism activities and recreational boats); b) PetroSA's gas-to-liquid refinery operations; and c) a desalination plant.

a) Boat activities

The potential impact of sea going vessels on cetaceans is one of the most well studied anthropogenic impacts. Studies have illustrated that vessel size, noise, speed, approach angle, and even just presence have the potential to influence the behaviour of a range of cetacean species (Bejder *et al.* 2006; Wright *et al.* 2007; Rolland *et al.* 2012). Studies have also shown that these responses vary between species, populations, ages and individual experience (Ribeiro *et al.* 2005; Wright *et al.* 2007; Rolland *et al.* 2012).

Bottlenose dolphins respond differently to boat presence depending on experience, behaviour and age. Groups habituated to the presence of boats or groups actively engaged in foraging showed no alternation in behaviour (Janik and Thompson 1996; Constantine 2001; Nowacek *et al.* 2001; Lusseau 2003). However distinct changes in behaviour and surfacing patterns were observed when boats approached socialising, resting, or mother/calf groups (Janik and Thompson 1996; Constantine 2001; Nowacek *et al.* 2001; Lusseau 2003).

Humpback dolphins have been observed in numerous locations fleeing or increasing their dive times as soon as boats appeared at high speeds (Karczmarski *et al.* 1997; Ng and Leung 2003). However no behavioural changes were observed when boats approached at slower speeds (Karczmarski *et al.* 1997; Ng and Leung 2003). In Algoa Bay, South Africa humpback dolphins displayed negative responses to the presence of high speed vessels, watercrafts, surf skis, and to some extent swimmers and surfers (Koper *et al.* in press). These negative responses included a change in swimming direction, increased dive times and group splits as well as distinct changes in behaviour (Koper *et al.* in press). The changes in behaviour included an increase in travelling and milling behaviour, and a decrease in foraging behaviour (Koper *et al.* in press).

Both species were found to alter their vocalisation pattern in relation to the presence or absence of boats (Van Parijs and Corkeron 2001c; Buckstaff 2004). Individuals whistled more often and at higher rates when boats were approaching (Van Parijs and Corkeron 2001c; Buckstaff 2004). It was suggested that these changes occur so that individuals, especially mother/calf pairs, remain in contact with each other thereby allowing communication to continue despite the noisy environment (Van Parijs and Corkeron 2001c; Buckstaff 2004).

b) Desalination plant

The process of using desalination to produce freshwater is becoming increasingly popular as the world faces an increasing demand for freshwater (Clark *et al.* 2010; Ahmed and Anwar. 2012). Desalination involves removing all the salts and other solids from seawater making it suitable for human use (Haurwitz *et al.* 2008; Clark *et al.* 2010; Roberts *et al.* 2010).

While studies highlighted the potential impact on marine flora and micro fauna few evaluated the effect of desalination on larger marine organisms such as cetaceans. Several cetacean species are found close to the shore where they feed and breed bringing them into frequent contact with the desalination plant. The discharge of the desalination process known as brine has a known negative impact on the growth and survival of many marine organisms (Clark *et al.* 2010; Roberts *et al.* 2010). Brine, when discharged in large quantities, forms a hypersaline layer that increases the salinity of the water (Clark *et al.* 2010). Although marine organisms are adapted to changes in salinity, the rapid increase in salinity levels (from 33-36 parts per thousand to 66 parts per thousand) can affect the development and growth rate of many marine species particularly in the larval stage (Neuparth *et al.* 2002; Clark *et al.* 2010) .

In addition the small concentrations of anti-fouling compounds, toxic chemicals, heavy metals and hydrocarbons released can also affect marine life (Clark *et al.* 2010; Roberts *et al.* 2010).

c) Gas to liquid factory

Finally, a gas to liquid processing plant was built in 1992 on the western side of Mossel Bay The facility provides a way to extract gas from remote locations, produce clean useful hydrocarbons (including fuels, such as unleaded petrol and diesel and chemicals such as methanol and kerosene) which therefore helps decrease environmental pollution (Keshav and Basu 2006; Verhoef 2008). The most likely impact from this factory on the marine environment includes the initial offshore drilling and placing of pipes and the subsequent maintenance of the pipes along the sea floor (de Mestral 1979; Rolland *et al.* 2012). The increased presence of maintenance ships may also influence the behaviour and population dynamics of different cetacean species (Rolland *et al.*, 2012).

1.2. AIMS AND KEY QUESTIONS

The aim of this study was to assess the feasibility of using a static acoustic data logger (C-POD) as a monitoring tool to study *Tursiops aduncus* and *Sousa plumbea* in Mossel Bay, South Africa.

This study was divided into three data chapters which addressed the following key questions.

Chapter two aimed to address the potential challenges associated with using a C-POD in a noisy marine environment to study cetaceans specifically:

1) What are the impacts of background noise on C-POD detections?

Chapter three aimed to estimate detection ranges of a C-POD for *T. aduncus* and *S. plumbea* in a noisy marine environment specifically:

2) What is the overall probability of acoustically detecting groups of *T. aduncus* and *S. plumbea*?
3) What is the effective detection radius (m) for acoustically detecting groups of *T. aduncus* and *S. plumbea*?

In both analyses the influence of intrinsic parameters (group size, overall group behaviour and swimming direction relative to the hydrophone) and extrinsic factors (environmental conditions such as wind and sea state) on detection probability and detection radius were investigated.

Chapter four aimed to investigate species-specific patterns in echolocation clicks using the output from the C-POD in order to differentiate *T. aduncus* and *S. plumbea* specifically:

4) Are there any species specific differences in visual or acoustic encounter duration for *T. aduncus* and *S. plumbea*?
5) Are there any species-specific differences in click rate, average inter-click interval, train duration, frequency range, modal frequency, average click cycle or rising inter-click interval for *T. aduncus* and *S. plumbea?*

1.3. RESEARCH DESIGN AND METHODS

This study used three methods for the collection of cetacean data which forms part of a long-term data collection project: 1) Land-based tracking of cetaceans using a surveyor's theodolite to obtain visual confirmation of species and to calculate their location (started 2010). 2) boat-based surveys to collect photo-ID and distribution data (started 2011). And 3) boat- based deployment/retrieval of a C – POD (started in 2013).

1.1.1. Visual Methods

This study formed part of a long-term monitoring project that commenced in 2010. A total of 6 sites (labelled site 1 – 6) located around Mossel Bay (Figure 1.2) were surveyed on a regular basis until March 2013. From 1st April 2013 when this study commenced until 31 January 2014 only 5 sites were surveyed; site 3 was removed from the study due to low sighting rate (Figure 1.3). Surveys were conducted at sites 1, 2, 5 and 6 twice a week and lasted two hours as done in previous years. Sampling effort at site 4 was increased to three times a week with 4 hour long surveys, as this site overlooked the deployment location of the C-POD. Historically, site 4 had the highest mean sighting frequency for humpback dolphins and a good sighting frequency for bottlenose dolphins (Figure 1.3). In addition to land-based surveys boat-based surveys were also conducted on a weekly basis for the entire study period. Cetaceans encountered were followed and photographs were obtained for photo-identification studies. Sighting and tracking data collected from site 1, 2, 5, and 6 was not used for this study but forms part of a long-term study. These data are currently under analysis and will be presented at a later stage. Photo–identification data of humpback dolphins was used in an existing study recently published in the African Journal of Marine Science (James *et al.* 2015). During this study priority was given to the two study species, but the presence of other cetacean species was always recorded and when possible, they were tracked with the theodolite.

From 1 February 2014 to 31 August 2014 sites 2, 5 and 6 were not surveyed in order to increase the survey effort at site 4 and site 1. Surveys at site 4 took place three times a week and lasted 6 hours whilst surveys at site 1 were conducted 2 to 3 times a week and lasted 3 hours (* Refer to chapter 2 for an explanation of change in methodology).

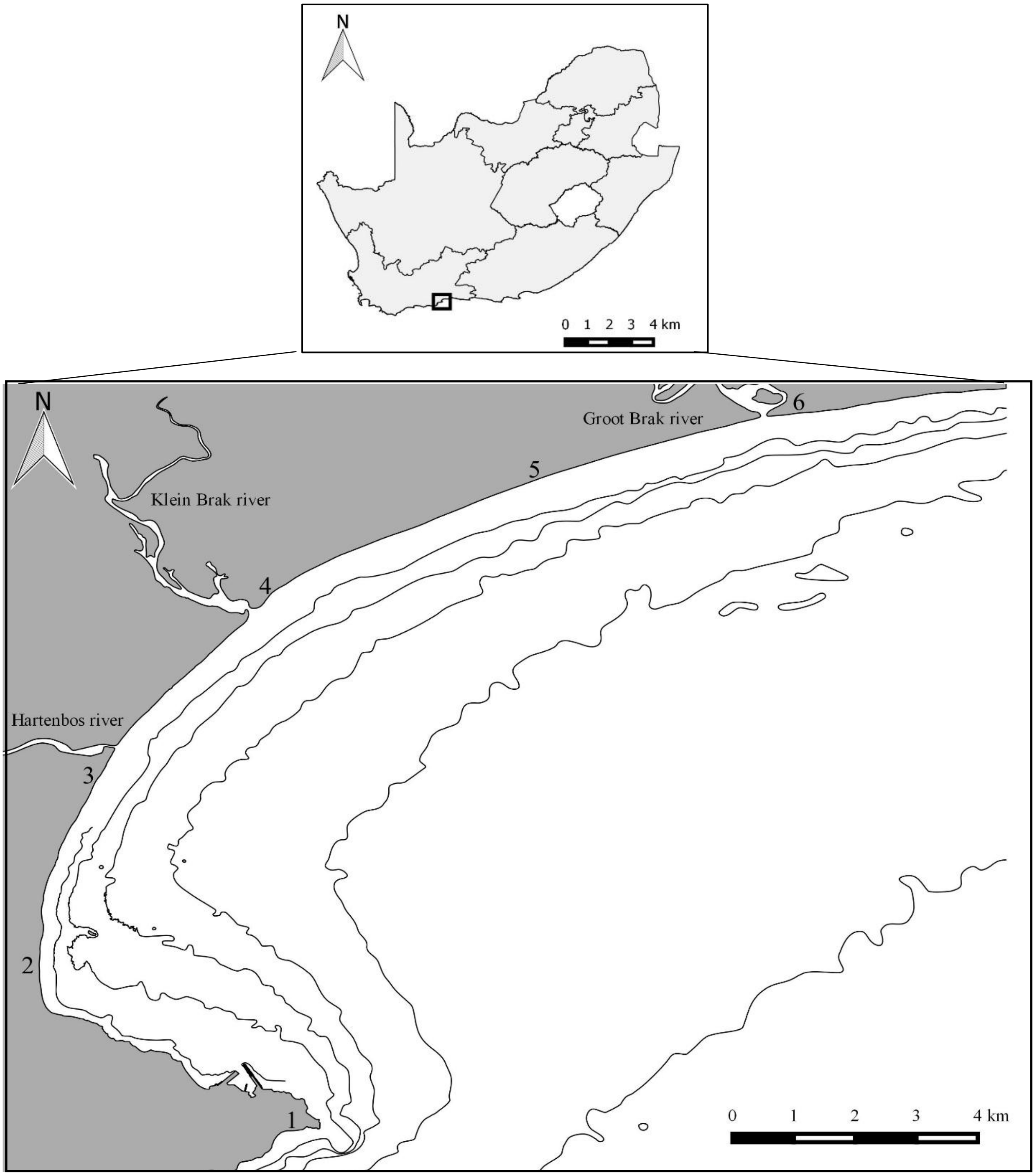

Figure 1.2: Map of Mossel Bay showing the six survey sites (1 - 6). The three rivers (Hartenbos, Klein Brak and Groot Brak rivers) found in Mossel Bay are indicated on the map. The 5, 10, 15, 20, 30 and 50 m isobaths are also indicted. Inset: Location of Mossel Bay (marked by a box) in South Africa.

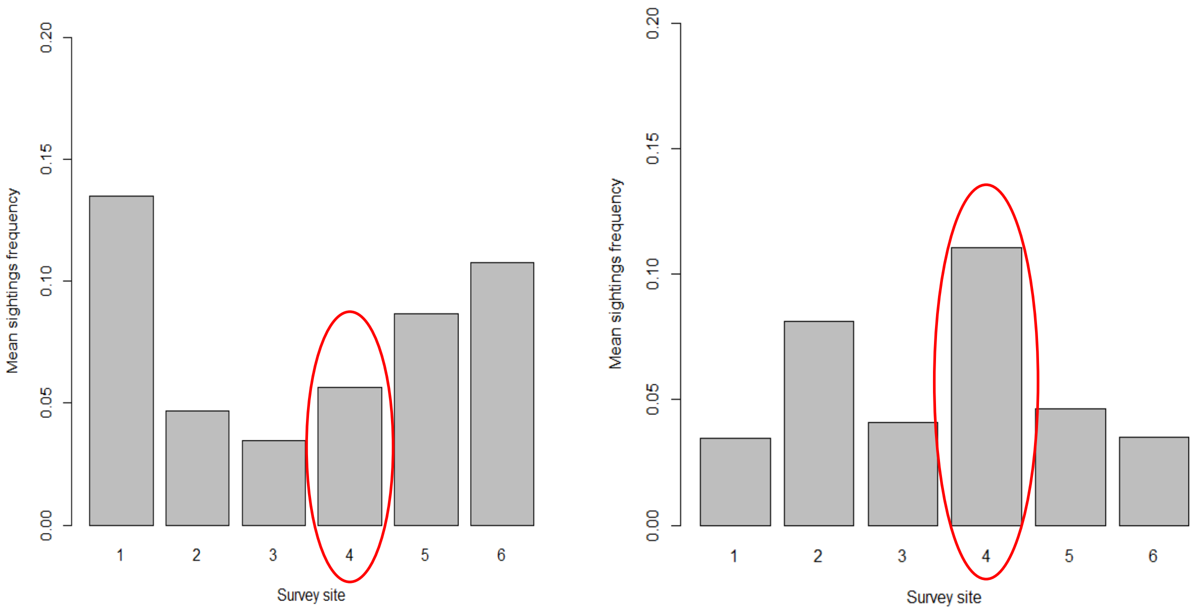

Figure 1.3: Mean sighting frequency of *T. aduncus* (left) and *S. plumbea* (right) individuals at each of the 6 survey sites in Mossel Bay. Based on data collected between April 2011 and March 2013, Ms Bridget James (unpublished data).

Following the method described by Bailey *et al.* (2009) scans were made every 30 min for a 5 min period. At least two observers scanned the bay using binoculars (1 Minolta (10 X 50) and 1 Tasco (10 X 50)) and the naked eye. Observers started at opposite ends of the bay focusing on the area close to shore before searching further out to sea. All cetaceans spotted during 5 min scans were recorded and if possible tracked using a theodolite. The two observers were responsible for aiding the tracker and keeping a watch for new groups. Between scans, the observers continued to keep watch for cetaceans. Sightings of cetaceans during this period were recorded as off-effort and tracked using the theodolite. Species identification generally took place using the theodolite telescope (30 X magnification) and was based on distinct morphological differences between each species (colouration, presence/absence of dorsal fins and humps, surfacing behaviour and group size).

Data on the different environmental parameters were collected during each scan. These included wind speed, wind direction, cloud cover, swell, sightability, sea state and visibility at the mid - line. Wind speed was determined using a handheld anemometer (Major Tech 947) and wind direction was related to magnetic north. Cloud cover was determined on a scale of 1 to 8 (1 being sky contains no clouds and 8 being sky is covered with clouds). Swell height was estimated at half metre intervals and sightability was determined using a scale of 1 to 5 (1 indicating poor visibility and 5 indicating excellent visibility). Sea state was determined using the Beaufort Scale (from 0 - calm and flat to 12 - hurricane conditions). Visibility at the mid-line was calculated as the maximum distance perpendicular to shore at which wavelets can be distinguished through the theodolite (Barendse *et al.* 2010). This provides a constant index for the observer's ability to sight cetaceans based on the prevailing weather conditions (Hastie *et al.* 2004; Photopoulou *et al.* 2011). Surveys were only abandoned in cases of poor weather, defined as: sea state > 4, wind speeds averaging 25 knots as measured on land, poor visibility or rain. This minimized the effect of poor weather conditions on the ability to see animals (Hastie *et al.* 2004; Photopoulou *et al.* 2011). Poor weather conditions can lead to incorrect assumptions regarding behaviour and movement patterns if species are either not sighted or they are incorrectly identified (Constantine *et al.* 2004).

For this study a Sokkisha Set 2B electronic theodolite was used to track cetaceans. A location fix was taken every minute until the group was lost. A group was defined as a collection of dolphins within approximately five body lengths of each other which are closely associated and engaging in similar activities. Groups were assigned specific track codes: yy/mm/dd_## (## being a sequential daily number for each group tracked). If multiple groups or species were present during tracking then positions were attained for all groups as far as possible as long as the groups remained distinguishable with preference for the two study species. In the event the groups merged, tracking would continue for the 'merged group' with a new track code. Minimum, maximum and best estimates were made for group size. Location fixes were taken from the front of each tracked group except when a group was highly dispersed, and then a fix was taken at both the front and back of the group. For each fix, time, group number, group size, activity, direction of dolphin group relative to the C-POD and dispersion (bunched, sub-grouped, dispersed) were also recorded. Direction of dolphin relative to the C-POD was defined as towards (facing the C-POD), away (moving away from the C-POD) and unknown (unable to accurately determine direction of dolphin). Following Shane (1990) activity was defined as travelling (continuous and directional movement); socializing (jumping, somersaults, tail slaps and physical contact between individuals); foraging (chasing prey, bursts of high speed, lunging and splashing often with sea birds present); milling (slow swimming at the surface with no apparent direction often in circles) for the dolphin group closest to C-POD. Tracking ended when the dolphin group was not visually detected for more than 10 min.

1.1.2. Acoustic Methods

C-POD number 1803 (Chelonia Limited ©) was deployed effectively continuously over a 16 month period from 17 May 2013 to 2 September 2014 and serviced monthly. These devices consist of a basic hydrophone encased in a hard cylindrical polypropylene shell with a single mooring line attached at the centre by a metal ring. The C-POD was set up following the instructions in the C-POD User Guide (Tregenza 2009). Exact time and date of recording was noted as the C-POD has an accurate timer but no knowledge of date or time (Tregenza 2009). Once deployed the hydrophone floated vertically and logging commences automatically (Würsig *et al.* 1991; Gailey and Ortega-Ortiz 2000).

The C-POD was deployed off the research vessel at approximately 2 m above the sea floor in 12 m – 15 m of water. The C-POD was anchored to the ocean floor using a temporary U-shaped mooring consisting of 3 bottom weights made of large chains weighing approximately 30kg each linked by rope longer than the water depth (Figure 1.4). The two outer weights each contained a surface line marked with a surface buoy whilst the C-POD was attached to the middle weight with a subsurface buoy to assist in keeping the C-POD at a consistent depth (Figure 1.4). Date, time, and GPS coordinates of the mooring point were recorded at each deployment.

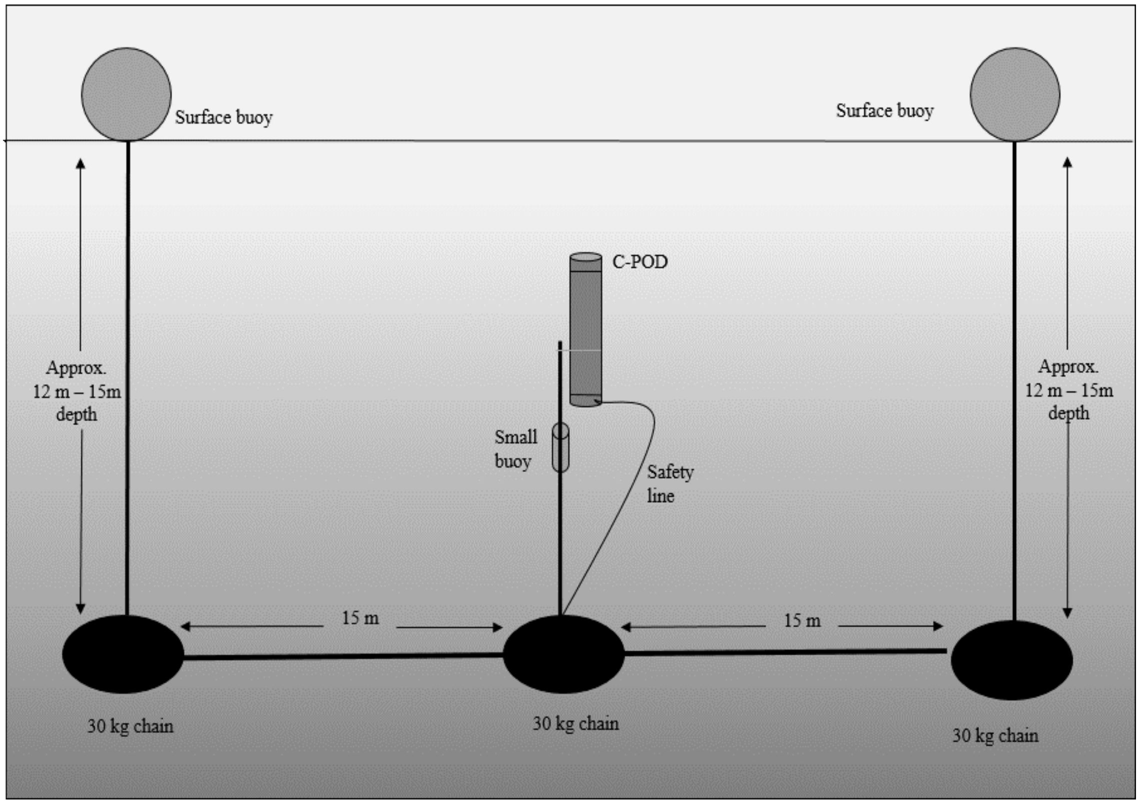

Figure 1.4: Schematic of the C-POD mooring at the deployment site (Site 4) in Mossel Bay.

At the end of each deployment the C-POD was removed from the water, cleaned and data downloaded on board the vessel. Data were downloaded onto the computer for later analysis using the programme C-POD.exe (Version 2.044). Batteries were checked and replaced if needed after which the C-POD was redeployed.

1.4. DATA PROCESSING

1.4.1. Visual Data

Tracking data were entered into a Microsoft Access database. In order to improve theodolite accuracy hourly tide height, site height above sea level (m), location (GPS) and observer eye height (1.57 m) were also included in order to obtain more accurate estimates of positions (Table 1.1) (Gailey and Ortega-Ortiz 2000). The software programme Pythagoras© (Tregenza 2012; Tregenza 2009) was used to convert angles, elevation and height measurements of each track point along with a correction factor (for the curvature of the earth) to produce a table of longitudes and latitudes for each track point. Hourly predicted tide heights (m) were obtained from the South African Naval Hydrographer's Office for the study period (2013-2014).

Table 1.1: The GPS location (Deg, min, sec) and height (m) above sea level of the five land based used to survey cetaceans in Mossel Bay. The site information used in this particular study is indicated in bold.

Site	Site height (m)	Latitude (S)	Longitude (E)
1	59	34° 11' 9.99"	22° 9' 23.00"
2	51.5	34° 9' 30.97"	22° 6' 34.85"
4	**20**	**34° 5' 17.31''**	**22° 9' 5.08''**
6	44.7	34° 3' 16.99"	22° 14' 40.99"

1.4.2. Acoustic Data

The raw data file (.CP1format) was imported into the software programme CPOD.exe (Version 2.044) and run through a specific train detection algorithm known as a KERNO classifier which searched for specific patterns in groups of clicks and assigned a probability value of it arising by chance from a non-train producing source. The KERNO classifier assesses rate of click arrival, size of time interval between clicks, regularity of trains, number of clicks in a train, amplitude, duration and frequency of clicks (Tregenza 2012). Groups of trains are assigned into one of four probability classes depending on their suspected source (Tregenza 2012). These classes are NBHF (Narrow Band High Frequency cetaceans), other cet (cetaceans), sonar (boats) and unclassed (unknown sources). The classifier then assigns one of four detection filters to each individual train which indicates the confidence of that particular click train arising from a cetacean source (Tregenza 2012). The filters are ‘Hi’ (high), ‘Mod’ (moderate), ‘Lo’ (low) and ‘Doubtful’ or ‘?’. The processed CP1 file is referred to as a CP3 file and contains only clicks that have been identified by the KERNO classifier as being a part of a train (Tregenza 2012). After being run through the KERNO classifier the trains are then automatically run through an encounter classifier known as GENENC which improves the discrimination of NBHF species from other cetacean species and helps distinguish cetacean sound from noise (Tregenza 2012).

1.5. SUMMARY

This study aimed to assess the effectiveness of using a C-POD to monitor two species of dolphins namely bottlenose and humpback dolphins in Mossel Bay. Land-based surveys from one vantage point overlooking the location of the CPOD were conducted over a 16 month period to verify species identity, estimate behaviour and group size of each dolphin group and to determine the distance of each species from the C-POD. Acoustic data obtained from the monthly deployments of the C-POD were then cross checked with visual data to confirm species identity. Once cross-checked the detection probability of each species was estimated. Lastly the potential of the C-POD to differentiate the two species based soley on their acoustic was also investigated.

1.6. REFERENCES

ACEVEDO, A. 1991. Behaviour and Movements of bottlenose dolphins, *Tursiops truncatus*, in the entrance to Ensenada De La Paz, Mexico. *Aquatic Mammals.* **17**: 137-147.

AHMED, M. & ANWAR. 2012. An Assessment of the environmental impact of brine disposal in marine environment. *International Journal of Modern Engineering Research.* **2**: 2756-2760.

AKAMATSU, T., WANG, D., WANG, K. & WEI, Z. 2001. Comparison between visual and passive acoustic detection of finless porpoises in the Yangtze River, China. *Journal of the Acoustical Society of America.* **109**: 1723–1727.

ATKINS, S. A., S., P., CONRY, D., PISTORIUS, P. A., COCKCROFT, V. G. & ELWEN, S. H. in press. A conservation assessment of *Sousa plumbea*, In: M.F. CHILD, D. LINH, E. SAN, D. RAIMONDO & H. DAVIES-MOSTERT (eds), *The national red list of mammals of South Africa, Swaziland and Lesotho*. Pretoria, South Africa: South African National Biodiversity Institute.

AU, W.W. 1993. Characteristics of Dolphin Sonar Signals. In: *The Sonar of Dolphins.* Berlin, Heidelberg, Springer-Verlag.

BAILEY, H., CLAY, G., COATES, E. A., LUSSEAU, D., SENIOR, B. & THOMPSON, P. 2009. Using T-PODs to assess variations in the occurrence of coastal bottlenose dolphins and harbour porpoises. *Aquatic Conservation: Marine and Freshwater Ecosystems.* **20**: 150-158.

BAILEY, H. & LUSSEAU, D. 2004. Increasing the precision of theodolite tracking: modified technique to calculate the altitude of land-based observation sites *Marine Mammal Science.* **20**: 880–885.

BARENDSE, J., BEST, P.B., THORNTON, M., POMILLA, C., CARVALHO, I. & ROSENBAUM, H.C. 2010. Migration redefined? Seasonality, movements and group composition of humpback whales *Megaptera novaeangliae* off the west coast of South Africa. *African Journal of Marine Science.* **32**: 1-22.

BARLOW, J. & TAYLOR, B.L. 2005. Estimates of sperm whale abundance in the northeastern temperate Pacific from a combined visual and acoustic survey. *Marine Mammal Science*. **21**: 429-445.

BARROS, N.B., JEFFERSON, T.A. & PARSONS, E.C. 2004. Feeding Habits of Indo-Pacific Humpback Dolphins (*Sousa chinensis*) Stranded in Hong Kong. *Aquatic Mammals*. **30**: 179-188.

BEJDER, L., SAMUELS, A., WHITEHEAD, H., GALES, N., MANN, J., CONNOR, R., HEITHAUS, M., WATSON-CAPPS, J., FLAHERTY, C. & KRUTZEN, M. 2006. Decline in relative abundance of bottlenose dolphins exposed to long-term disturbance. *Conservation Biology*. **20**: 1791-1800.

BEST, P.B. 2007. *Whales and Dolphins of the Southern African subregion* Cape Town, Cambridge Univeristy Press.

BRADLEY, D.L. & STERM, R. 2008. Underwater sound and the marine mammal acoustic environment. Maryland. United States of America: U. S. Marine Mammal Commission.

BUCKSTAFF, K. 2004. Effects of watercraft noise on the acoustic behaviour of bottlenose dolphins *Tursiops truncatus*, in Sarasota Bay, Florida *Marine Mammal Science*. **20**: 709-725.

CALDWELL, M.C. & CALDWELL, D.K. 1965. Individualized whistle contours in bottlenosed dolphins *(Tursiops truncatus)*. *Nature*. **207**: 434-435.

CALDWELL, M.C. & CALDWELL, D.K. 1967. Intraspecific transfer of information via the pulsed sound in captive odontocete cetaceans. In: R.G. BULLOCK, (ed.), *Animal sonar systems - biology and bionics*. France, Laboratoire Physiologie Acoustique. Jouy-en-Josas.

CARLSTRÖM, J., BERGGREN, P. & TREGENZA, N. 2009. Spatial and temporal impact of pingers on porpoises. *Canadian Journal of Fisheries and Aquatic Sciences*. **66**: 72-82.

CASTELLOTE, M., LEENEY, R.H., O'CORRY-CROWE, G., LAUHAKANGAS, R., KOVACS, K. M., LUCEY, W., KRASNOVA, V., LYDERSEN, C., STAFFORD, K.M. & BELIKOV, R. 2012. Monitoring white whales (*Delphinapterus leucas*) with echolocation loggers. *Polar Biology*. **36**: 493-509.

CHARLTON-ROBB, K., GERSHWIN, L.A., THOMPSON, R., AUSTIN, J., OWEN, K. & MCKECHNIE, S. 2011. A new dolphin species, the Burrunan Dolphin *Tursiops australis* sp. nov., endemic to southern Australian coastal waters. *PLoS One.* **6**: e24047.

CHARLTON, K., TAYLOR, A.C. & MCKECHNIE, S. 2006. A note on divergent mtDNA lineages of bottlenose dolphins from coastal waters of southern Australia. *Journal of Cetacean Resource Management*. **8**: 173–179.

CLARK, B., TURPIE, J., HUTCHINGS, K. & LAIRD, M. 2010. *Marine Specialist Impact Assesment for a Proposed Reverse Osmosis Desalination Plant at Mossel Bay* [Online]. Available: https://www.google.co.za/url?sa=t&rct=j&q=&esrc=s&source=web&cd=7&cad=rja&uact=8&ved=0CEUQFjAG&url=http%3A%2F%2Fwww.ibrarian.net%2Fnavon%2Fpaper%2FMARINE_SPECIALIST_IMPACT_ASSESSMENT_FOR_A_PROPOSE.pdf%3Fpaperid%3D21604899&ei=5PZPVJunIIn3apjngOgB&usg=AFQjCNFNQRu9VAuiwURty3R1NQrtD7bwng&sig2=vJcqPoB7QCNtRxsc5xRNHA.

CLARK, C.W. 1995. Application of U.S. Navy underwater hydrophone arrays for scientific research on whales. International Whaling Commission.

COCKCROFT, V.G. 1999. Organochlorine levels in cetaceans from South Africa: a review. *Journal of Cetacean Research and Management.* 169-176.

COCKCROFT, V.G. & ROSS, G.J.B. 1990. Food and feeding of the Indian Ocean Bottlenose Dolphin off Southern Natal, South Africa. In: *The bottlenose dolphin.* Academic Press Incorporated.

CONSTANTINE, R. 2001. Increased avoidance of swimmers by wild bottlenose dolphins (*Tursiops truncatus*) due to long-term exposure to swim-with-dolphin tourism. *Marine Mammal Science*. **17**: 689–702.

CONSTANTINE, R., BRUNTON, D.H. & DENNIS, T. 2004. Dolphin-watching tour boats change bottlenose dolphin (*Tursiops truncatus*) behaviour. *Biology Conservation.* **117**: 299-307.

COOK, M.L., SAYIGH, L.S., BLUM, J.E. & WELLS, R.S. 2004. Signature-whistle production in undisturbed free-ranging bottlenose dolphins (*Tursiops truncatus*). *Proceedings of the Royal Society of London B: Biological Sciences.* **271**: 1043-1049.

COX, T.M., READ, A.J., SOLOW, A. & TREGENZA, N. 2001. Will harbour porpoises (*Phocoena phocoena*) habituate to pingers? *Journal of Cetacean Resource Management.* **31**: 81–86.

CRANFORD, T.W., MADSEN, P.T., WISNIEWSKA, D. & BEEDHOLM, K. 2011. Biosonar sources in odontocetes: considering structure and function and response. *Journal of Experimental Biology.* 1403-1405.

DAHNE, M., KATHARINA VERFUSS, U., BRANDECKER, A., SIEBERT, U. & BENKE, H. 2013. Methodology and results of calibration of tonal click detectors for small odontocetes (C-PODs). *Journal of the Acoustical Society of America.* **134**: 2514-2522.

DE MESTRAL, A.L. C. 1979. The prevention of pollution of the marine environment arising from offshore mining and drilling. *Heinonline.* **20**: 469-480.

DENARDO, C., DOUGHERTY, M., HASTIE, G.D., LEAPER, R., WILSON, B. & THOMPSON, M.A. 2001. A new technique to measure spatial relationships within groups of free-ranging coastal cetaceans. *Journal of Applied Ecology.* **38**: 888 - 895.

DURHAM, B.D. 1994. *The Distribution and Abundance of the Humpback Dolphin (Sousa chinensis) along the Natal Coast, South Africa.* Msc, University of Kwa-Zulu Natal.

ELWEN, S.H., FINDLAY, K.P., KISZKA, J. & WEIR, C.R. 2011. Cetacean research in the southern African subregion: a review of previous studies and current knowledge. *African Journal of Marine Science.* **33**: 469–493.

FINDLAY, K.P., BEST, P.B., ROSS, D. & COCKCROFT, V.G. 1992. The Distribution of small odontocetes off the coasts of South Africa and Namibia. *South African Journal of Marine Science.* **12**: 237-270.

FRANÇOIS, R.E. & GARRISON, G.R. 1982. Sound absorption based on ocean measurements: Part II: Boric acid contribution and equation for total absorption. *Journal of the Acoustical Society of America.* **72**: 1879-1890.

GAILEY, G. & ORTEGA-ORTIZ, J.G. 2000. *User's manual: 'Pythagoras'. (Version:1.2.15). Theodolite cetacean tracking* [Online]. Texas A & M University, Galveston, USA. Available: [Available at: http://www.tamug.tamu.edu/mmrp/pythagoras].

GALAMBOS, R. 1942. Cochler potentials elicited from bats by supersonic sound. *Journal of the Acoustical Society of America.* **14**: 41-49.

GOODSON, D. & MAYO, R. 1995. Interactions between free-ranging dolphins (*Tursiops truncatus*) and passive acoustic gill-net deterrent devices. In: R.A. KASTELEIN, P.E. NACHTIGALL (eds.), *Sensory Systems of Aquatic Mammals.* Woerden, De Spil.

GRIDLEY, T., BERGGREN, P., COCKCROFT, V.G. & JANIK, V.M. 2012. Whistle vocalizations of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) inhabiting the south-west Indian Ocean. *Journal of the Acoustical Society of America.* **132(6):** 4032–4040.

GRIFFIN, D.R. 1944. Echolocation in blind men, bats and radar. *Science.* **100**: 589-590.

HALE, P.T., BARRETO, A.S. & ROSS, G.J.B. 2000. Comparative morphology and distribution of the *aduncus* and *truncatus* forms of bottlenose dolphin *Tursiops* in the Indian and Western Pacific Oceans. *Aquatic Mammals.* **26**: 101–110.

HAMMOND, P.S., BEARZI, G., BJØRGE, A., FORNEY, K., KARCZMARSKI, L., KASUVA, T., PERRIN, W.F., SCOTT, M.D., WANG, J.Y., WELLS, R.S. & WILSON, B. 2008. *Tursiops aduncus* [Online]. Available: http://www.iucnredlist.org/details/full/41714/0 [Accessed Downloaded on 08 October 2014.

HANEKOM, N., RANDALL, R.M., BOWER, D., RILEY, A. & KRUGER, N. 2009. *Garden Route National Park: The Tsitsikamma Area – State of Knowledge. South African National Parks.* [Online]. Available: http://www.sanparks.org/conservation/scientific/coastal/docs/Tsitsikamma/TNP_SOK_Mar2009.pdf [Accessed 1 November 2014].

HARZEN, S.E. 2002. Use of an electronic theodolite in the study of movements of the bottlenose dolphin (*Tursiops truncatus*) in the Sado Estuary, Portugal. *Aquatic Mammals*. **28**: 251-260.

HASTIE, G.D., WILSON, B., PARSONS, E.C. & THOMPSON, P.M. 2004. Functional mechanisms underlying cetacean distribution patterns: hotspots for bottlenose dolphins are linked to foraging. *Marine Biology*. **144**: 397–403.

HAURWITZ, R., BROAD, T., COLLINS, J., CARMAN, N., ARROYO, J., KRISHNA, H., MANNCHEN, B., MCFADDEN, J. & STACHOWITZ, A. 2008. Desalination: Is It Worth its Salt? A Primer on Brackish and Seawater Desalination. Texas: Lone Star Chapter of the Sierra Club.

HEYDORN, A.E.F. & TINLEY, K.L. 1980. Estuaries of the Cape. Council for Scientific and Industrial Research- National Research Institute for Oceanology.

HOLT, M.M., NOREN, D.P. & EMMONS, C.K. 2012. An investigation of sound use and behavior in a killer whale (*Orcinus orca*) population to inform passive acoustic monitoring studies. *Marine Mammal Science*. 1-10.

JACKSON, L.F. & LIPSCHITZ, S. 1984. *Coastal sensitivity atlas of southern Africa,* Pretoria, Department of Transport.

JAMES, B.S. 2014. *Natural and human impacts on habitat use of coastal delphinids in the Mossel Bay area, Western Cape, South Africa.* MSc: Zoology, University of Pretoria.

JAMES, B.S., BESTER, M.N., PENRY, G.G., GENNARI, E. & ELWEN, S.H. 2015. Abundance and degree of residency of humpback dolphins Sousa plumbea in Mossel Bay, South Africa. *African Journal of Marine Science*. **37**: 383-394.

JANIK, D.V.M. & THOMPSON, P.T. 1996. Changes in surfacing patterns of bottlenose dolphins in response to boat traffic. *Marine Mammal Science.* **12**: 597-602.

JANIK, V.M. 2000a. Food-related bray calls in wild bottlenose dolphins (*Tursiops truncatus*). *Proceedings of the Royal Society of London B: Biological Sciences.* **267**: 923-927.

JANIK, V.M. 2009. Acoustic Communication in Delphinids. *Advances in the Study of Behavior.* **40**: 1-34.

JEFFERSON, T.A., HUNG, S.K. & WÜRSIG, B. 2009. Protecting small cetaceans from coastal development: Impact assessment and mitigation experience in Hong Kong. *Marine Policy.* **33**: 305-311.

JEFFERSON, T.A. & ROSENBAUM, H.C. 2014. Taxonomic revision of the humpback dolphins (*Sousa* spp.), and description of a new species from Australia. *Marine Mammal Science.* **30**: 1494-1541.

JOHNSON, R., BESTER, M.N., DUDLEY, S.F.J., OOSTHUIZEN, W.H., MEŸER, M., HANCKE, L. & GENNARI, E. 2009. Coastal swimming patterns of white sharks (*Carcharodon carcharias)* at Mossel Bay, South Africa. *Environmental Biology of Fishes.* **85**: 189–200.

KARCZMARSKI, L. 1999a. Group dynamics of humpback dolphins (*Sousa chinensis)* in the Algoa Bay region, South Africa. *Journal of Zoology London.* **249**: 283-293.

KARCZMARSKI, L. 1999b. Population analyses of Indo- Pacific humpback dolphins *Sousa chinensis* in Algoa Bay, Eastern Cape, South Africa. *Marine Mammal Science.* **15**: 1115-1123.

KARCZMARSKI, L., THORNTON, M. & COCKCROFT, V.G. 1997. Description of selected behaviours of humpback dolphins *Sousa chinensis*. *Aquatic Mammals.* **23**: 127-133.

KESHAV, T.R. & BASU, S. 2006. Gas-to-liquid technologies: India's perspective. *Fuel Processing Technology.* **2**: 493-500.

KOPER, R.P., KARCZMARSKI, L., DU PREEZ, D., PLÖN, S. In press. Sixteen years later: occurrence, group size, and habitat use of humpback dolphins (*Sousa plumbea*) in Algoa Bay, South Africa. *Marine Mammal Science.*

KRIESELL, H.J., ELWEN, S.H., NASTASI, A. & GRIDLEY, T. 2014. Identification and characteristics of signature whistles in wild bottlenose dolphins (Tursiops truncatus) from Namibia. *PLoS One.* **9**: e106317.

KYHN, L.A., TOUGAARD, J., TEILMANN, J., WAHLBERG, M., JØRGENSEN, P.B. & BECH, N.I. 2008. Harbour porpoise (*Phocoena phocoena*) static acoustic monitoring: Laboratory detection thresholds of T-PODs are reflected in field sensitivity. *Journal of the Marine Biological Association of the UK.* **88**: 1085 -1091.

KYHN, L.A., TOUGAARD, J., THOMAS, L., DUVE, L.R., STENBACK, J., AMUNDIN, M., DESPORTES, G. & TEILMANN, J. 2012. From echolocation clicks to animal density--acoustic sampling of harbor porpoises with static dataloggers. *Journal of the Acoustical Society of America.* **131**: 550-560.

LEENEY, R.H., CARSLAKE, D. & ELWEN, S.H. 2011. Using Static Acoustic Monitoring to Describe Echolocation Behaviour of Heaviside's Dolphins (*Cephalorhynchus heavisidii*) in Namibia. *Aquatic Mammals.* **37**: 152-159.

LEENEY, R.H. & TREGENZA, N. 2006. Static Acoustic Monitoring of Cetaceans *Proceedings of the European Cetacean Society, 2006* Gdynia, Poland. 7-14.

LUSSEAU, D. 2003. Male and female bottlenose dolphins *Tursiops spp*. have different strategies to avoid interactions with tour boats in Doubtful Sound, New Zealand. *Marine Ecology Progress Series.* **257**: 267–274.

MADSEN, P.T., CARDER, D.A., BEDHOLM, K. & RIDGWAY, S.H. 2005a. Porpoise clicks from a sperm whale nose–Convergent evolution of 130 kHz pulses in toothed whale sonars? *Bioacoustics.* **15**: 195–206.

MARQUES, T.A., THOMAS, L., MARTIN, S.W., MELLINGER, D.K., WARD, J.A., MORETTI, D.J., HARRIS, D. & TYACK, P.L. 2012. Estimating animal population density using passive acoustics. *Biological Reviews of the Cambridge Philosophical Society.* **88**: 287-309.

MAY-CALLADO, L.J. & WARTZOK, D. 2008. A comparison of bottlenose dolphin whistles in the Atlantic ocean factors promoting whistle variation. *Journal of Mammalogy*. **89**: 1229–1240.

MCBRIDE, A.F. 1956. Evidence for echolocation in cetaceans. *Deep-Sea Research.* **3**: 153-154.

MELLINGER, D.K., STAFFORD, K.M., MOORE, S.E., DZIAK, R.B. & MATSUMOTO, H. 2007. An Overview of Fixed Passive Acoustic Observation Methods for Cetaceans. *Oceanography*. **20**: 36-45.

MENDEZ, M., JEFFERSON, T.A., KOLOKOTRONIS, S.O., KRUTZEN, M., PARRA, G.J., COLLINS, T., MINTON, G., BALDWIN, R., BERGGREN, P., SARNBLAD, A., AMIR, O.A., PEDDEMORS, V.M., KARCZMARSKI, L., GUISSAMULO, A., SMITH, B., SUTARIA, D., AMATO, G. & ROSENBAUM, H. C. 2013. Integrating multiple lines of evidence to better understand the evolutionary divergence of humpback dolphins along their entire distribution range: a new dolphin species in Australian waters? *Molecular Ecology.* **22**: 5936-5948.

MEYER, M., BEST, P.B., ANDERSON-READE, M.D., CLIFF, G., DUDLEY, S.F.G. & KIRKMAN, S.P. 2011. Trends and interventions in large whale entanglement along the South African coast. *African Journal of Marine Science.* **33**: 429–439.

MØHL, B., WAHLBERG, M., MADSEN, P.T., MILLER, L.A. & SURLYKKE, A. 2000. Sperm whale clicks: Directionality and source level revisited. *Journal of the Acoustical Society of America.* **107**: 638–648.

MÖLLER, L.M. & BEHEREGARAY, L.B. 2001. Coastal bottlenose dolphins from southeasten Australia are *tursiops aduncus* according to sequences of the mitochondrial DNA control region. *Marine Mammal Science.* **17**: 249-263.

MÖLLER, L.M., BILGMANN, K., CHARLTON-ROBB, K. & BEHEREGARAY, L. 2008. Multi-gene evidence for a new bottlenose dolphin species in southern Australia. *Moleccular Phylogenetics and Evolution.* **49**: 674-681.

MORISAKA, T. & CONNOR, R.C. 2007. Predation by killer whales (Orcinus orca) and the evolution of whistle loss and narrow-band high frequency clicks in odontocetes. *Journal of Evolutionary Biology*. **20**: 1439-1458.

MORISAKA, T., SHINOHARA, M., NAKAHARA, F. & AKAMATSU, T. 2005b. Geographic variations in the whistles among three Indo-Pacific bottlenose dolphin *Tursiops aduncus* populations in Japan. *Fisheries Science*. **71**: 568–576.

NEUPARTH, F., COSTA, O. & COSTA, M.H. 2002. Effects of temperature and salinity on life history of the marine Amphipod, *Gammarus locusta*. Implications for ecological testing. *Ecotoxicology*. 61-73

NG, S.L. & LEUNG, S. 2003. Behavioral response of Indo-Pacific humpback dolphin (*Sousa chinensis*) to vessel traffic. *Marine Environmental Research*. **56**: 555–567.

NORRIS, K.S., PRESCOTT, J.H., ASA-DORIAN, P.V. & PERKINS, P. 1961. An experimental demonstration of echolocation behavior in the porpoise, *Tursiops trucatus* (Montagu). *Biology Bulletin*. **120**: 163-176.

NOWACEK, S.M., WELLS, R.S. & SOLOW, A.R. 2001. Short-term effects of boat traffic on bottlenose dolphins *Tursiops truncatus*, in Sarasota Bay, Florida. *Marine Mammal Science*. **17**: 673-688.

NUUTTILA, H.K., MEIER, R., EVANS, P.G., TURNER, J.R., BENNELL, J.D. & HIDDINK, J.G. 2013a. Identifying Foraging Behaviour of Wild Bottlenose Dolphins (*Tursiops truncatus*) and Harbour Porpoises (*Phocoena phocoena*) with Static Acoustic Dataloggers. *Aquatic Mammals*. **39**: 147-161.

NUUTTILA, H.K., THOMAS, L., HIDDINK, J.G., MEIER, R., TURNER, J.R., BENNELL, J.D., TREGENZA, N.J. & EVANS, P.G. 2013b. Acoustic detection probability of bottlenose dolphins, *Tursiops truncatus*, with static acoustic dataloggers in Cardigan Bay, Wales. *Journal of the Acoustical Society of America*. **134**: 2596-2609.

PAYNE, R. 1986. Long term behavioral studies of the southern right whale (*Eubalaena australis*). *Report of the International Whaling Commission (special issue).*

PEDDEMORS, V.M. 1999. Delphinids of South Africa - A review of their status, distribution life history *Journal of Cetacean Resource Management*. **1**: 157-165.

PHILPOTT, E., ENGLUND, A., INGRAM, S. & ROGAN, E. 2007. Using T-PODs to investigate the echolocation of coastal bottlenose dolphins. *Journal of the Marine Biological Association of the United Kingdom.* **87**: 11–17.

PHOTOPOULOU, T., BEST, P.B., HAMMOND, P.S. & FINDLAY, K.P. 2011. Movement patterns of coastal bottlenose dolphins in the presence of a fast-flowing, prevailing current: shore-based observations at Cape Vidal, South Africa. *African Journal of Marine Science.* **33**: 393–401.

PICHLER, F.B., ROBINEAU, D., GOODALL, R.N.P., MEЎER, M.A., OLIVARRIA, C. & BAKER, C.S. 2001. Origin and radiation of Southern Hemisphere coastal dolphins (genus *Cephalorhynchus*). *Molecular Ecology.* **10**: 2215–2223.

PIERCE, G.W. & GRIFFIN, D.R. 1938. Experimental determination of supersonic notes emitted by bats. *Journal of Mammalogy.* **19**: 454-455.

PLÖN, S., COCKCROFT, V.G., PISTORIUS, P., CONRY, D., ATKINS, S., 2015. A conservation assessment of *Sousa plumbea*. In: M.F. CHILD, D. RAIMONDO, (Eds.), *The Red List of Mammals of South Africa, Swaziland and Lesotho*. South African National Biodiversity Institute, Pretoria.

RAYMENT, W., DAWSON, S., SCALI, S. & SLOOTEN, L. 2011. Listening for a needle in a haystack: passive acoustic detection of dolphins at very low densities. *Endangered Species Research.* **14**: 149-156.

RAYMENT, W.J., DAWSON, S. & SLOOTEN, L. 2009. Trialling an automated passive acoustic detector (T-POD) with Hector's dolphins (Cephalorhynchus hectori). *Journal of the Marine Biological Association of the United Kingdom.* **89**: 1015–1022.

REEVES, R.R., DALEBOUT, M.L., JEFFERSON, T.A., KARCZMARSKI, L., LAIDRE, K., O'CORRY-CROWE, G., ROJAS-BRACHO, L., SECCHI, E.R., SLOOTEN, E., SMITH, B.D., WANG, J.Y. & ZHOU, K. 2011. *Sousa chinensis* [Online]. Available: www.iucnredlist.org. [Accessed 22 October 2014.

REISINGER, R.R. & KARCZMARSKI, L. 2010. Population size estimate of Indo-Pacific bottlenose dolphins in the Algoa Bay region, South Africa. *Marine Mammal Science*. **26**: 86-97.

RIBEIRO, S., VIDDI, F.A. & FREITAS, T.R. O. 2005. Behavioural Responses of Chilean Dolphins (*Cephalorhynchus eutropi*a) to Boats in Yaldad Bay, Southern Chile. *Aquatic Mammals*. **31**: 234-242.

RICHARDSON, W.J., GREENE JR, C.R., MALME, C.I. & THOMSON, D.H. 1995. *Marine mammals and noise,* San Diego., Academic Press.

ROBERTS, D.A., JOHNSTON, E.L. & KNOTT, N.A. 2010. Impacts of desalination plant discharges on the marine environment: A critical review of published studies. *Water Research*. **44**: 5117-5128.

ROLLAND, R.M., PARKS, S.E., HUNT, K.E., CASTELLOTE, M., CORKERON, P.J., NOWACEK, D.P., WASSER, S.K. & KRAUS, S.D. 2012. Evidence that ship noise increases stress in right whales. *Proceedings of the Royal Society B: Biological Sciences*. **279**: 2363-2368.

ROSS, G.J.B. 1977a. The taxomony of bottlenosed dolphins *Tursiops* species in South African waters, with notes on their biology. *annuals of the Cape Provincial Museum of Natural History*. **11**: 135-194.

ROSS, G.J.B. 1977b. The taxonomy of Bottlenosed dolphins *Tursiops* species in South African waters, with notes on their biology. *annuals of the Cape Provincial Museum of Natural History*. **11**: 135-185.

ROSS, G.J.B. 1984. The smaller cetaceans of the south east coast of southern Africa. *Annuals of the Cape Provincial Museum of Natural History*. **11**: 259-327.

ROSS, G.J.B., HEINSOHN, G.E. & COCKCROFT, V.G. 1994. Humpback Dolphins *Sousa chinensis* (Osbeck, 1765), *Sousa plumbea* (G. Cuvier, 1829) and *Sousa teuzii* (Kukenthal, 1892). In: S.H. RIDGWAY & R. HARRISON (eds.), *Handbook of Marine Mammals*. New York, Academic Press.

SAAYMAN, G.S. & TAYLER, C.K. 1973. Social Organisation of Inshore Dolphins (*Tursiops aduncus* and *Sousa*) in the Indian Ocean. *Journal of Mammalogy*. **54**: 993-996.

SCHULZ, K.W. & CORKERON, P.J. 1994. Interspecific Signature whistles of free-ranging bottlenose dolphins *Tursiops truncatus*: stability and mother-offspring comparisons. differences produced by inshore dolphins in Moreton Bay, Queensland. *Journal of Zoology*. **72**: 1061-1068.

SHANE, S.H. 1990. Behaviour and ecology of the bottlenose dolphin at Sanibel Island, Florida. In: S. LEATHERWOOD & R.R. REEVES (eds.), *The Bottlenose Dolphin.* New York, Academic Press Inc.

SIMARD, P., LACE, N., GOWANS, S., QUINTANA-RIZZO, E., KUCZAJ, S. A., WELLS, R.S. & MANN, D.A. 2011. Low frequency narrow-band calls in bottlenose dolphins (Tursiops truncatus): signal properties, function, and conservation implications. *Journal of the Acoustical Society of America.* **130**: 3068-3076.

SIMON, M., NUUTTILA, H.K., REYES-ZAMUDIO, M., UGARTE, F., VERFUB, U. & EVANS, P.G. 2010. Passive acoustic monitoring of bottlenose dolphin and harbour porpoise, in Cardigan Bay, Wales, with implications for habitat use and partitioning. *Journal of the Marine Biological Association of the United Kingdom.* **90**: 1539–1545.

TODD, S., LIEN, J. & VERHULST, A. 1992. Orientation of humpback whales (*Megaptera novaengliae*) and minke whales (*Balaenoptera acutorostrata*) to acoustic alarm devices designed to reduce entrapment in fishing gear. In: J. THOMSON (ed.), *Marine Mammal Sensory System.* New York, Plenum Press.

TOUGAARD, J., POULSEN, L.R., AMUNDIN, M., F., L., RYE, J. & TEILMANN, J. 2006. Detection function of T-PODs and estimation of porpoise densities. In: R.H. LEENEY & N. TREGENZA (eds.), *Static Acoustic Monitoring of Cetaceans. Proceedings of the European Cetacean Society, 2006.* Gdynia, Poland. 7-14.

TREGENZA, N. 2009. C-POD User Guide.

TREGENZA, N. 2012. CPOD.exe : a guide for users. 1-56.

VAN PARIJS, S.M. & CORKERON, P.J. 2001a. Vocalizations and behaviour of Pacific Humpback dolphins *Sousa chinensis*. *Ethology*. **107**: 701-716.

VAN PARIJS, S.M. & CORKERON, P.J. 2001b. Evidence for signature whistle production by a Pacific humpback dolphin, *Sousa chinensis. Marine Mammal Science.* **17(4):** 944-949.

VAN PARIJS, S.M. & CORKERON, P.J. 2001c. Boat traffic affects the acoustic behaviour of Pacific humpback dolphins *Journal of the Marine Biology Association of the United Kingdom.* **81**: 533-538.

VERHOEF, G. 2008. Environmental and Economic considerations In Gas-To-Liquid Industry: the role of SASOL in gasification, 1970 – 2006. In: *APBEH Conference,* 2008, Melbourne. 1-25.

VILLADSGAARD, A., WAHLBERG, M. & TOUGAARD, J. 2007. Echolocation signals of wild harbour porpoises, *Phocoena phocoena. Journal of Experimental Biology*. **210**: 56-64.

WANG, C., CHOU, L.S. & WHITE, B.N. 1999. Mitochondrial DNA analysis of sympatric morphotypes of bottlenose dolphins (genus: *Tursiops*) in Chinese waters. *Molecular Ecology*. **8**: 1603–1612.

WANG, J. Y., CHOU, L.S. & WHITE, B.N. 2000. Osteological differences between two sympatric forms of bottlenose dolphins (genus *Tursiops*) in Chinese waters. *Journal of Zoology London.* **252**: 147-162.

WOOD, F.G. & EVANS, W.E. 1980. Adaptiveness and ecology of echolocation in toothed whales. In: R.G. BUSNEL & J.F. FISH (eds.), *Animal Sonar Systems.* New York, Plenum Press.

WRIGHT, A.J., SOTO, N.A., BALDWIN, A.L., BATESON, M., BEALE, C.M., CLARK, C., DEAK, T., EDWARDS, E.F., HUTCH, L.T., KAKUSCHKE, A., LUSSEAU, D., MARTINEAU, D., ROMERO, M., WEILGART, L.S., WINTLE, B.A. & MARTIN, V. 2007. Do marine mammals experience stress related to anthropogenic noise? *International Journal of Comparative Psychology*. **20**: 274-316.

WÜRSIG, B. & WÜRSIG, M. 1979. Behavior and ecology of bottlenose dolphin, *Tursiops truncatus*, in the South Atlantic. *Fisheries Bulletin*. **77**: 399–412.

WÜRSIG, B., CIPRIANO, F. & WÜRSIG, M. 1991. Dolphin movement patterns: information from radio and theodolite tracking studies. In: K. PRYOR. & K.S. NORRIS (eds.), *Dolphin Societies: Discoveries and Puzzles*. Los Angeles, University of California Press.

Chapter 2

Challenges of detecting dolphins using a static acoustic data logger (C-POD) in a noisy marine environment.

ABSTRACT

Cetaceans are not the only animals that produce sound underwater and interference from a number of other underwater sources is a challenge that scientists have to deal with in all forms of acoustic monitoring. Data collected from two different deployment locations (referred to as 'Before' and 'After') in Mossel Bay, South Africa were compared after considerable interference from other noise sources was detected at the first site. Mean recording time lost for all deployments decreased significantly from 26.37 minutes per hour during the 'Before' period (95% CI: 25.66 - 27.08) to 0.69 minutes (95% CI: 0.57 – 0.81) per hour during the 'After' period. Mean number of cetacean clicks detected before moving increased from only 6463.33 (95% CI: 6133.31 - 6793.36) per deployment to 97820 (95% CI: 61829.58 - 133809.8) per deployment after moving. Mean detection positive minutes also increased from 0.23 minutes per hour per day per deployment (95% CI: 0.06 - 0.53) to 2.79 minutes (95% CI: 1.54 – 4.04) per hour per day per deployment. These results illustrated the considerable effect that marine background noise (both biological and anthropogenic) can have on the ability of the C-POD to detect cetaceans. The location of a C-POD deployment needs to be selected carefully in order to minimize the effect of background noise ensuring the C-POD functions optimally. Moving the C-POD into deeper waters reduced the amount of background noise that often occurs in shallow waters however this is not always possible when studying near-shore species.

KEYWORDS: Bottlenose dolphin, humpback dolphin, Mossel Bay, noise levels, snapping shrimp, sediment transport noise.

2.1. INTRODUCTION

Ambient underwater noise was first highlighted early in the discovery of sonar and the creation of sonar systems. Ambient noise is defined as "the noise associated with the back-ground din emanating from a myriad of unidentified sources." (in Dahl *et al.*2007 from the National Research Council's 2003 report, Ocean Noise and Marine Mammals). These sounds can sometimes resemble the 'sonar signal (i.e. sounds dolphin produce)' in some way and is often referred to as interference. Each of these sounds has the potential to impact the detection of true signals by passive acoustic monitoring equipment such as **C**etacean and **Po**rpoise **D**etection devices (**C-PODs)** (Dahl *et al.* 2007). Some of the more common sounds found in the marine environment include; 1) Snapping shrimps; 2) chorusing or group noises; 3) movement of sediment with tides; 4) boat sonars; 5) unidentified clicks from storms and weak unknown train sources; 5) wind and wave action and 6) cetaceans (Mellan 1952; Wenz 1962; Dyer 1973; Ross 1976; Thorne 1986; Thorne 1990; Dahl *et al.* 2007). These sounds are not consistent and change constantly with time of day, seasons, ocean floor topography and habitat type (Dahl *et al.* 2007; Radford *et al.* 2008).

2.1.1. Snapping shrimps

Reefs are often associated with a high diversity of marine life including the reef-associated snapping shrimp (Family: Alpheidae) (Everest *et al.* 1948; Knudsen *et al.* 1948; Au and Banks 1998). Snapping shrimp are known to be a major source of noise in shallow waters (less than 60 m deep) at latitudes less than 40° The snapping sound is continuous and is produced by the rapid closing of their front claws causing the ends to snap together creating the loud click sound (Au and Banks 1998). Snapping shrimp tend to be found in large numbers and the combined clicking referred to as chorusing can actually interfere with transmission and reception of sounds produced by cetaceans (Au *et al.* 1974; Au *et al.* 1982 Radford *et al.* 2008). Au *et. al.* (1982) found snapping shrimp to have a frequency range extending up to 200 kHz which overlaps almost entirely with the frequency range of the C-POD. In large enough numbers snapping shrimp can fill up the PODs memory with clicks and also interfere with the ability to identify cetacean click trains (N. Tregenza, Chelonia, pers. comm.).

2.1.2. Chorusing or group noises

Chorusing (group noises) occurs during reproductive, territorial or feeding displays in various fish and crustacean species spanning a wide range of frequencies including the frequency range of the PODs (Radford *et al.* 2008). Apart from snapping shrimp and an area specific sea urchin species this phenomenon and its effect on PODs has been poorly studied (Radford *et al.* 2008).

2.1.3. Sediment transport noise

Shallow sandy sea-beds are constantly shifting as particles of sand are circulated by currents, tides, storms, waves or salinity/temperature differences (Mellan 1952; Thorne 1990). The constant movement of sand produces a distinct sound as particles continuously collide with each other which can dominate the immediate marine environment (Mellan 1952; Thorne 1990). The sounds produced can be in the same range as those of cetaceans (Thorne 1986; Thorne 1990) and may therefore be logged by the PODs as a potential dolphin click. In cases where sand is shifted in large quantities the sound produced can form a continuous noise (Thorne 1986; Thorne 1990) that quickly fills up the memory of the PODs. This continuous noise can also affect the cetaceans' ability to detect clicks which may cause them to change sound types (whistle instead) or decrease frequency of clicks produced (Au and Banks 1998; Radford *et al.* 2008).

2.1.4. Boat sonars

Boat sonars (often in the form of depth sounders and fish finders) can produce trains that are similar to cetacean clicks and in areas of high boat traffic it can be the main source of interference (Dyer 1973). Boat sonars produce highly coherent trains spanning a wide range of frequencies that are readily logged by PODs (Tregenza 2012). The trains produced by boat sonar can mask echolocation click trains produced by cetaceans, increasing the potential for false negatives (no echolocation click trains are logged even though cetaceans are present around the POD) which lead to incorrect conclusions regarding cetacean presence/absence within the area (Tregenza 2012; Roberts and Read 2015).

2.1.5. Storms, boat sounds and WUTS

Storms, boat sounds and weak unknown train sources (WUTS) are poorly studied underwater sounds (Radford *et al.* 2008); therefore the exact impact of these sounds on the detection ability of PODs is unknown (Tregenza 2012). Storms are known to produce irregular noises at varying frequencies (Wenz 1962) and depending on their source could be loud enough to interfere with PODs (N. Tregenza, Chelonia, pers. comm.). Boat sounds generally consist of engine and propeller noise as the boat moves through the water which may mask sounds produced by cetaceans (Roberts and Read 2015). WUTS are thought to be caused by small crustaceans that settle on the C-POD housing (Dahl *et al.* 2007). Sound production from small crustaceans has been poorly studied so the exact impact on C-POD detections is unknown.

2.1.6. Wind and wave noise

Background noise levels caused by wind action is largely related to the resulting wave action and spray (Simmonds *et al.* 2004). Wind generated background noise is largely influenced by wind speed and duration, water depth, sea floor topography and proximity to coastline (Simmonds *et al.* 2004). Wind generated noise tends to fall within ~0.1 kHz and 30 kHz while wave generated noise tends to fall within the infrasonic range of 1 to 20 Hz (Simmonds *et al.* 2004). As wind generated noise falls within the range of PODs it increases the likelihood of this noise being logged as a potential click (Tregenza 2012). To minimize the effect of wind – and wave generated noises; it is recommended that the C-POD be deployed at least 5 m below the surface (Tregenza 2009).

2.1.6. Cetaceans

C-PODs are highly useful in long-term monitoring of cetaceans especially those which use high-frequency narrow-band echolocation clicks such as porpoises, kogiids and dolphins of the genus, *Cephalorhynchus*. C-POD's are easy to use and require minimal managing once deployed, can be used in all types of weather and produce highly compressed data files (Tregenza 2009). However, C-PODs detect all possible forms of clicks and; only 4096 clicks are stored per minute. If this limit is reached before a minute (60 sec) ends, the C-POD will stop recording clicks until the minute ends (even if echolocating individuals are present) resulting in the loss of recording time (Tregenza 2009). Although this limit can be increased, it is not recommended as it may cause memory over- load. The C-POD is a data logger, not a recorder, so sound cannot be played back and clicks do not travel as far as whistles so detection ranges are reduced (Tregenza 2009).

During the first few months of the current study, background noise was a major problem at the initial mooring location with a large amount of recording time lost due to excessive background clicks (noise). Optimal mooring location for a hydrophone to detect the two study species in this environment is a trade-off between proximity to the surf zone where the animals are frequently encountered, and needing to be deep enough to reduce bottom noise caused by the continuous movement of sediment, surface noise from breaking waves, as well as potential wave damage in shallower waters. In addition, reefs are known to be a source of biological noise; therefore placement in relation to these reefs is also important. Some C-PODs are prone to be more sensitive to background noises. Following initial results, and discussion with the manufacturer (Nick Tregenza, Chelonia Ltd) on available options, the optimal strategy, given the timelines of the project, was to find a more suitable mooring site with less noise. Several short experimental deployments were conducted and a secondary mooring site selected.

2.2. AIMS AND KEY QUESTIONS

This chapter aimed to address some potential challenges associated with using a C-POD in a noisy marine environment to study cetaceans.

This chapter focused on one key question:

1) What are the impacts of background noise on C-POD detections in a noisy environment?

2.3. METHODS

Details of the study area, species, theodolite tracking, and C-POD set up and deployment strategy, including initial deployments are available in Chapter 1.

2.3.1. Initial deployments

The C-POD was initially deployed on 7 occasions (for approximately 28 -31 days per deployment) from 17 May 2013 to 27 December 2013. Six of these deployments accumulated recorded data in the form of CP1 files. The single failed deployment was due to an unknown fault with the extra SD card which prevented the C-POD from logging any detection during the deployment period.

2.3.2. Sensitivity tests

Subsequent to initial deployments of the C-POD at sea which detected substantial background noise, a series of in-air tests were conducted on land to determine if the C-POD was too sensitive and recording any form of noise as potential echolocation clicks, and whether internal noise generation was the culprit. The C-POD was exposed to three different types of background noise and left to record for 15 min. The three types of noise tested were absolute silence, moderate noise and continuous noise generated by tapping on the hydrophone housing (Table 2.1). After each test the SD card was checked for potential detections.

2.3.3. Site, depth and topography tests

After the sensitivity tests, the C-POD a series of short deployments were conducted at sea to the east and west of the original site to investigate levels of background noise in these locations. The C-POD was deployed at a series of locations 500 m apart and within range of the theodolite, for 15 min each (Table 2.1). Four locations were tested at similar depths (8 - 10 m), and three at a greater depth (15 m). For each deployment the depth and GPS location were recorded and after each deployment the SD card was removed and downloaded and the instrument re-setup. The topography for each test deployment was also recorded.

Seafloor topography was obtained from a previous study conducted on cetacean habitat use in Mossel Bay (James 2014). As there is no accurate description of the seafloor topography for

Mossel Bay, sea floor type within 1.2 km from the shore was estimated using predetermined shore type which are known to extend some distance out to sea (Elwen & Best, 2004a, James 2014). Shore types were obtained from the Coastal Sensitivity Atlas’s (Jackson & Lipschitz, 1984) and bathymetric data including depth counters and soundings and the coastline contours were obtained from South African Navy Hydrographer’s office (SANHO).

2.3.4. Final deployments

A further 7 deployments (including the 14-day deployment) were conducted from the 6th February 2014 to 2nd September 2014. Six of these deployments recorded data in the form of CP1 files. The exact cause of the single failed deployment remains unknown. There were instances where fishermen were observed trying to lift the mooring and/or anchoring to it which may have shifted the battery pack causing the C-POD to lose power.

Table 2.1: Location and results of each deployment test on the C-POD. The C-POD was subject to a series of land - based sensitivity (1-3), sea - based location (4-7) and sea-based depth tests (4-10) with each test lasting 15 min. The location selected for the remaining deployments is indicated in bold.

Test	Date	Location	Longitude (S)	Latitude (E)	Depth (m)	Duration (min)	Type of deployment	Habitat type	Results
1	02-Jan-14	land – office	34°09'51.51"	22°03'31.74"	Na	15	no noise	N/A	no detections
2	02-Jan-14	land – office	34°09'51.51"	22°03'31.74"	Na	15	no noise	N/A	no detections
3	02-Jan-14	land – office	34°09'51.51"	22°03'31.74"	Na	15	Continuous taps	N/A	detections matched taping
4	02-Jan-14	sea – 500 m west	34° 06' 21.5"	22° 08' 21.11	9.05	15	Normal	Wave cut rocky platforms	Background noise detected.
5	02-Jan-14	sea – 500 m east	34° 05' 28.5"	22° 09' 33.84	9.05	15	Normal	Estuarine & fine grained sandy beaches	Background noise detected.
6	02-Jan-14	sea – 1 km east	34° 05' 00.3"	22° 10' 37.55	10.1	15	Normal	Wave cut rocky platforms	Background noise detected.
7	02-Jan-14	sea - main site	34° 05'58.5"	22° 08' 40.2	8.4	15	Normal	Wave cut rocky platforms	Background noise detected.
8	21-Jan-14	sea – 500 m east	34° 04' 53.4"	22° 11' 13.92	14.45	15	Normal	Wave cut rocky platforms	Background noise detected.
9	**21-Jan-14**	**sea - main site**	**34° 05' 47.8''**	**22° 09' 31.67**	**14.9**	**15**	**Normal**	**Outside estuarine environment**	**Little / no background noise**
10	21-Jan-14	sea – 500 m west	34° 07' 20.0"	22° 08' 08.51	17.45	15	Normal	Unknown	Some background noise detected.

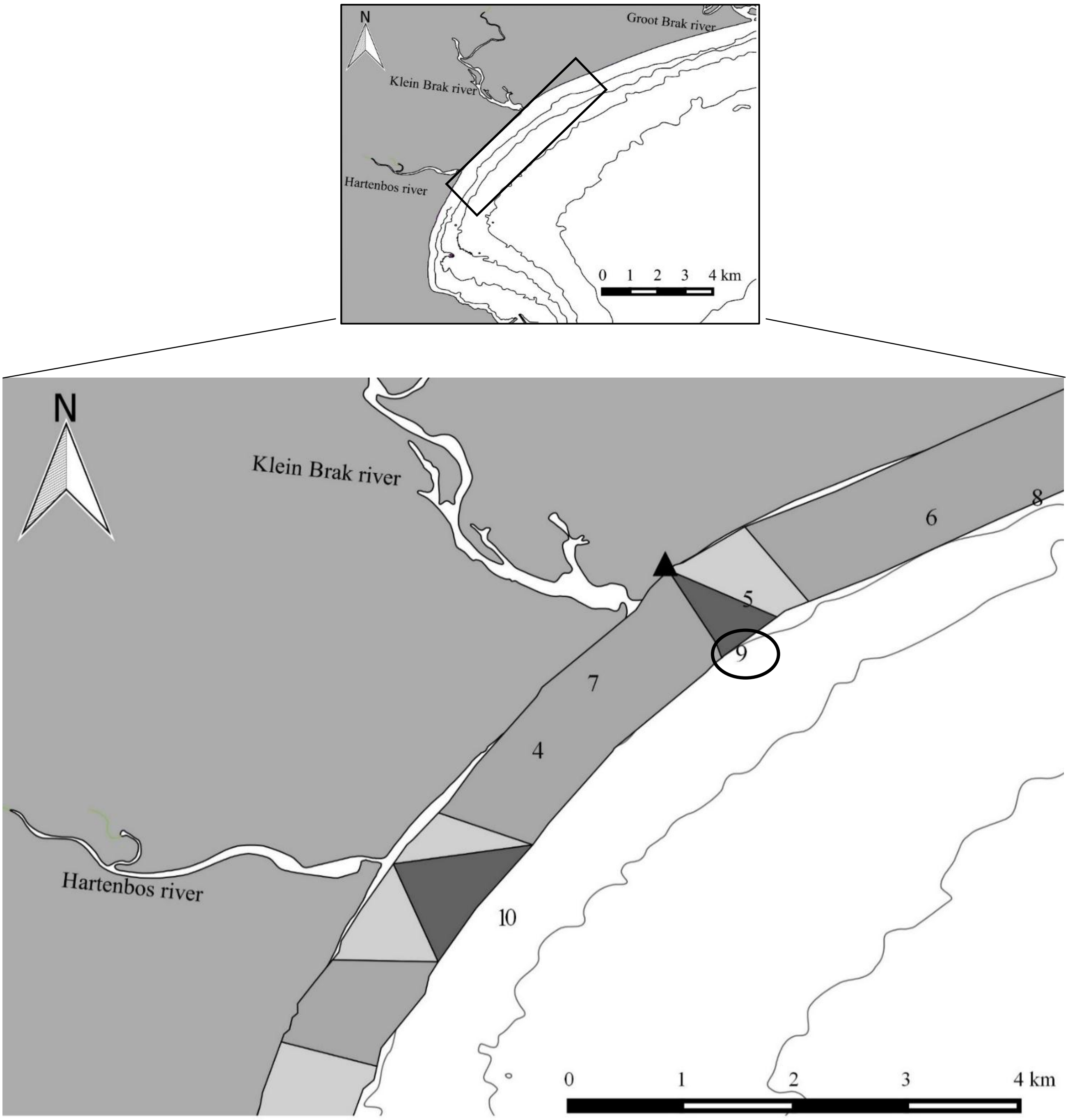

Figure 2.1: Locations of the different test deployments (4-10) in relation to the theodolite. Tests conducted on land are excluded from the figure (1-3). The location selected for the remaining deployments is circled. Habitat types are indicated; Estuarine environments – dark grey, wave cut rocky platforms – medium grey and fine grained sandy beaches – light grey. Two of the three rivers (Hartenbos, Klein Brak) found in Mossel Bay are also indicated on the map as well as the 10, 15 and 20 m isobaths. Inset: Map of Mossel Bay. The location where the test deployments were conducted are indicated by a box.

2.4. DATA PROCESSING

Data were exported from the C-POD using the detection and environment function within the programme C-POD.exe (Version 2.044). The detection and environment function provides an overview of how the data looks as it can indicate a potential problem with the site, such as too much background noise (Tregenza 2009). A number of parameters available from the C-POD detection and environment function were used to compare the effect of noise before and after the C-POD was moved (Table2.2).

Table 2.2: The selected parameters exported from the programme C-POD.exe using the detection and environment function as described in the user manual (Tregenza 2012) entitled C-POD.exe: a guide for users.

Parameter	**Definition**
Time lost (%)	Proportion of time C-POD reached logging limit (4096 clicks) before the end of a minute.
Continuous noise (kHz)	Measures the frequency of non – cetacean noises.
N. total clicks	Total number of clicks in the CP-1 file before filtering.
N. dolphin clicks	Total number of clicks in the CP-3 file that passed through the filter.
Sonar risk	Measures the presence of boat sonar which may interfere with detections and assigns the value 0 (no risk of boat noise) to 1 (some risk of boat noise).
Detection Positive Minutes (DPM)	Periods (1, 10 or 60 min) in which at least one echolocation click train has passed through the KERNO classifier.

2.5. DATA ANALYSIS

Detection Positive Minutes (DPM) for all deployments were exported as min. hour^{-1}.day^{-1}and percent time lost per minute was converted to actual time lost.

Deployments were separated into two periods; before and after changing the mooring site location, referred as ‘Before’ and ‘After’ respectively. ‘Before’ consisted of all the deployments between 17 May 2013 and 27 December 2013, whilst ‘After’ consisted of all the deployments between 05 February 2014 and 31 August 2014. Due to the non-parametric nature of the data, a Mann-Whitney U-test for dependent data was used to test for significant differences between the two deployment intervals (B = before and A = after) for the following parameters: time lost, continuous noise, recorded clicks, dolphin clicks, boat sonar and DPM before and after mooring.

2.6. RESULTS

2.6.1. Sensitivity tests

There were no click detections in the first (silence) and second (moderate) test whilst the third test (tapping) recorded constant detections (Table 2.1). Based on these results it was evident that the C-POD was not over-sensitive, and functioned correctly.

2.6.2. Site, depth and topography tests

Test 4, 6, 7 and 8 had high levels of background noise and were situated in wave cut rocky platform habitats. Test 5 conducted at the main site had high levels of background noise and was situated at the edge of two habitat types namely estuarine environments and fine grained sandy beaches. Test 9 had little to no levels of background noise and was located just outside the estuarine environment and test 10 had some background noise and took place in an unknown habitat type.

Test site 9 was selected as the most suitable deployment location for subsequent deployments. It was close to the original deployment site but in deeper water (originally from 8 m, then at 15 m). A short 14-day deployment of the C-POD at the location selected during the site, depth and topography tests (Table 2.1 & Figure 2.1) showed that the detections at the new location resulted in much lower levels of background noise. The proportion of time lost had dropped and the number of possible cetacean detections had increased.

2.6.3. General results

All deployments during the ‘Before’ period (n = 6) had a substantial amount of data eliminated during processing (truncation) from a CP1 file to a CP3 file. On average 79% (SE = 0.25) of the recording minutes on the CP1 file were truncated and on one occasion the SD card memory was full after only 16 days. All deployments during the ‘After’ period (n = 6) had very little data eliminated and on average only 2% (SE = 0.04) of recording minutes on the CP1 file were truncated. Time lost (Figure 2.2), continuous noise (Figure 2.3) and number of recorded clicks (Figure 2.4) were consistently higher during the ‘Before’ period (Table 2.3), while the number of dolphin clicks (Figure 2.5) and detection positive minutes were higher during the ‘After’ period (Table 2.3). Mean sonar risk was similar during both periods (Table 2.3). There were significant differences between time lost, continuous noise, recorded clicks, dolphin clicks, boat sonar and DPM ‘Before’ and ‘After’ moving the C-POD mooring (Table 2.3).

Table 2.3: Mean values of each parameter per deployment during the 'Before' and 'After' period. Mann – Whitney U test (U) test was performed on each parameter and values were tested for significance at the 5% level. The 95% confidence intervals for each parameter are indicated in brackets.

Parameters	**Before**	**After**	**U**	**P (<|U|)**
Time lost (min)	26.37 (25.66 - 27.075)	0.69 (0.57 – 0.81)	8647508	< 2.2e-16
Continuous noise (kHz)	3.55 (3.49 - 4.1)	0.42 (0.07 - 0.18)	4900880	< 2.2e-16
Number of recorded clicks	98599679.33 (98007552 - 99191807)	20651745 (0– 42156584)	36	0.00125
Number of dolphin clicks	6463.33 (6133.31 - 6793.36)	97820 (61829.58 - 133809.8)	0	0.00217
Boat sonar	0.016 (-0.01 - 0.02)	0.02 (0.01 – 0.03)	4179720	0.0002
DPM (min)	0.13 (0.09 - 0.17)	0.84 (0.69 – 0.99)	3944913	4.63e-14

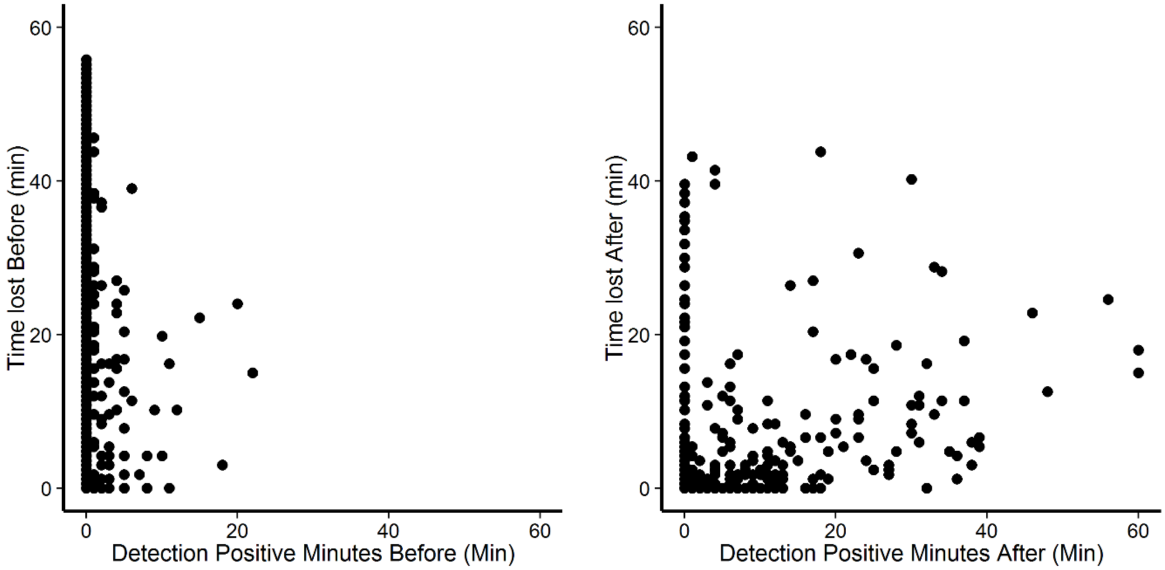

Figure 2.2: Influence of time lost (min) on Detection Positive Minutes (min. hour^{-1}.day^{-1}) 'Before' moving the C-POD and 'After' moving the C-POD.

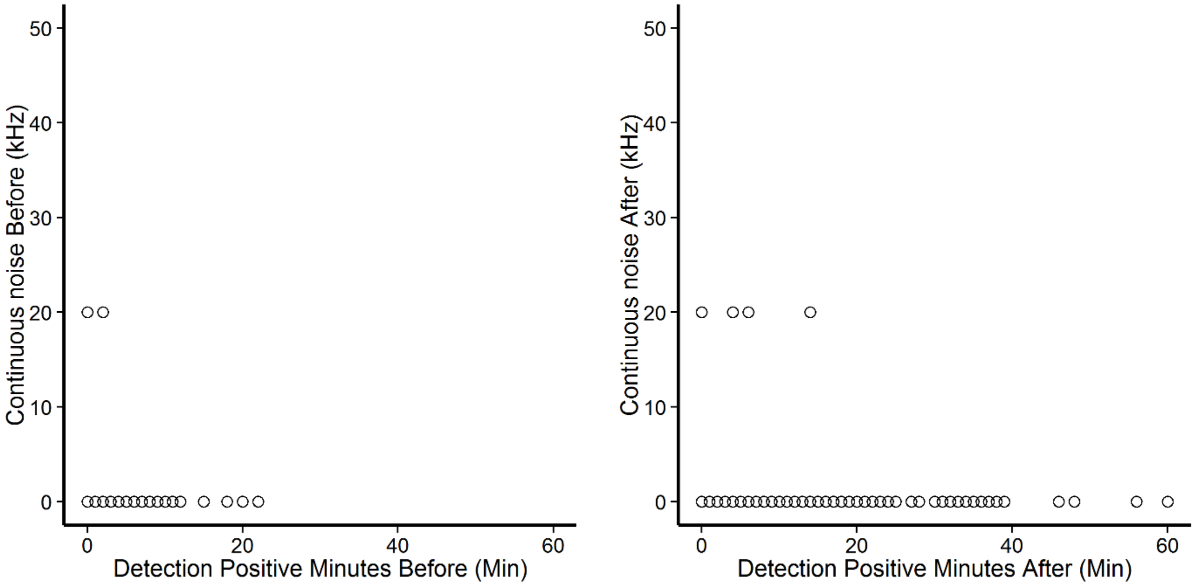

Figure 2.3: Influence of sediment transport noise represented as continuous noise (kHz) on Detection Positive Minutes (min. hour^{-1}.day^{-1}) 'Before' moving the C-POD and 'After' moving the C-POD.

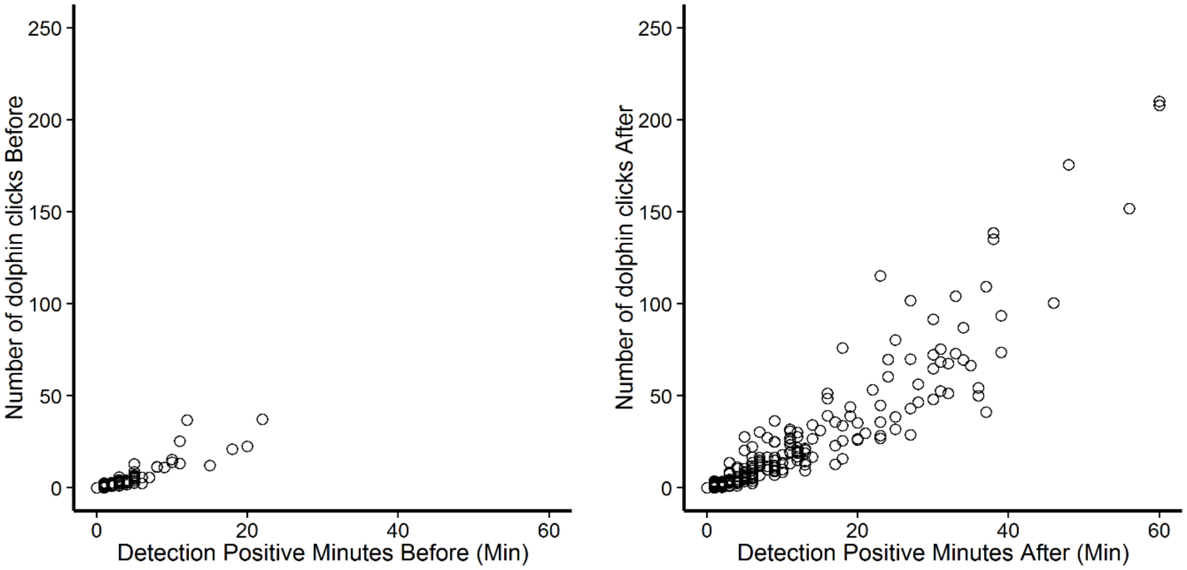

Figure 2.4: Number of detected clicks ‘Before’ and ‘After’ moving the C-POD as a function of Detection Positive Minutes (min. hour^{-1}.day^{-1}). This represents the raw data before any processing has taken place. Maximum number of clicks logged per minute is 4096.

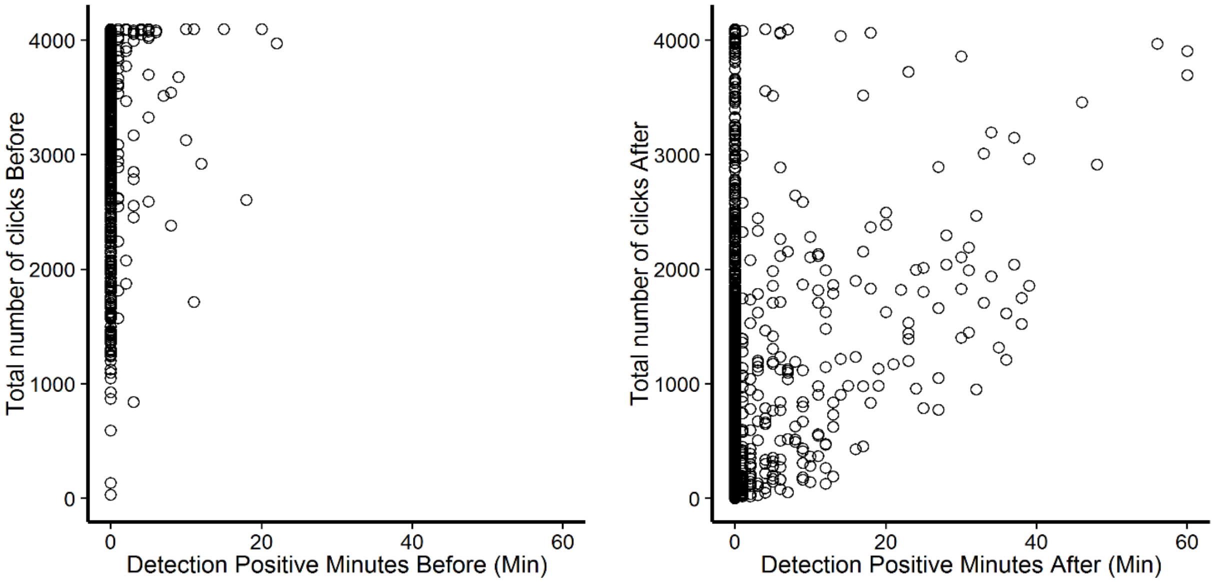

Figure 2.5: Number of identified dolphin clicks before and after moving the C-POD as a function of Detection Positive Minutes (min. hour^{-1}.day^{-1}). Data presented here have been run through the train detection algorithm and assigned probability of being from a dolphin (‘Hi’,

2.7. DISCUSSION

Throughout this study it became clear that a thorough understanding of the topography and acoustic background of the study area is critical. It is not only the presence of study species that should be considered when deploying C-PODs but also the surrounding sea conditions. The ‘noise levels’ of a study area need to be evaluated before commencing a study in order to assess the potential impact the noise may have on detection ability. If a study area is noisy then the following different options need to be considered; 1) moving the C-POD to a different area if possible (deeper waters) 2) manually adjusting the click thresholds on the C-POD or 3) if neither option is possible then a complete change in equipment might be necessary.

The distinct and substantial increase in the number of dolphin clicks and DPM followed by an equivalent decrease in time lost and continuous noise recorded is a clear indication that the C-POD was being affected by external non-cetacean sounds. Further evaluation of the topography of the area revealed a substantial reef system close to shore (Jackson and Lipschitz 1984). Snapping shrimps are known to be a major source of noise in shallow waters associated with reefs (Knudsen *et al.* 1948; Everest *et al.* 1948; Au and Banks 1998) and although no studies on snapping shrimp have been conducted in Mossel Bay, it is possible that snapping shrimp contributed to the large amount of possible clicks the C-POD was picking up. This is further supported by the dramatic improvement in possible dolphin detections after moving the C-POD away from the reef, where snapping shrimp are thought to occur.

In addition, to snapping shrimp, a reef will also be home to a variety of different fish and sea urchin species that contribute to environmental noise. Along the east coast of New Zealand snapping shrimp and sea urchins were the dominant source of biological noise around shallow reefs (Castle 1974; Radford *et al.* 2008; Radford *et al.* 2010). These sounds, if produced in large enough quantities and tonal enough, could easily be logged by the PODs as potential cetacean clicks and rapidly deplete the memory. Chorusing has not been studied in reefs around South Africa, although it was documented in reef fish associated with rocky cave environments around South Africa (Hastings and Širović 2015). The influence of chorusing on POD detections, however, has been poorly documented and therefore little is known regarding the extent of this influence.

Chorusing, boat noise and sediment in high enough quantities could potentially mask the echolocation clicks produced by cetaceans (Radford *et al.* 2008; Radford *et al.* 2010) which are subsequently not identified by the classification algorithms of CPOD.exe as coming from a dolphin source (Roberts and Read 2015). These sounds effectively mask the echolocation clicks which may dramatically decrease the detection range of a C-POD. False negatives, however, are difficult to quantify based solely on visual detections as; 1) individual(s) may not be echolocating when passing by the C-POD; 2) individual(s) may not be close enough to the C-POD for a detection; 3) individual(s) are not facing the C-POD it is possible that some of the clicks are not picked up by the C-POD (Leeney and Tregenza 2006; Radford *et al.* 2008; Radford *et al.* 2010; Roberts and Read 2015); there is therefore the possibility that the C-POD was not picking up echolocation clicks due to masking caused by chorusing, boat sounds and sediment noise resulting in the low number of dolphin click trains and DPM during the first deployment (this study). The increase in the number of dolphin click trains and DPM after the C-POD was moved further supports this notion.

The significant decline in sediment transport noise (kHz continuous) ‘Before’ and ‘After’ moving the C-POD must be related to the positioning of the instrument. The initial deployment site (Before) was very close to the mouth of an estuary which is subject to high levels of turbidity as waters of different densities are continuously mixed (van Rijn 1993; McAnally and Mehta 2002). In addition during the site, depth and topography tests it was evident that the initial deployment location was near or within a fine grained sandy habitat. Combined with current and wave action, this would have resulted in a substantial amount of sediment being shifted about producing high levels of noise that may have been logged by the C-POD as a potential click source or masked actual clicks produced by cetaceans (Tregenza 2012; Roberts and Read 2015). In deeper waters, further away from the estuary mouth, waves and fine grained sandy habitat, the movement of sediment will likely be less; thus minimizing its effect on the C-POD.

The significant decline in boat sonar detections ‘Before’ and ‘After’ the C-POD was moved is most likely due to the types of boats observed around the study area which largely consisted of recreational fishers, holiday makers and research vessels. These boats often employ fish finders which use sonar to detect the presence of fish, measure depth and navigate around the bay. In addition, a research vessel from Oceans Research frequented the area conducting research on white sharks, cetaceans and other marine organisms (James 2014). On closer inspection of the data it was evident that boat sonar detections often occurred just after the C-POD was deployed and just before the C-POD was retrieved when the fish finder on the deployment vessel was directly overhead and used to record the depth of deployment.

WUTS are difficult to quantify; in C-POD.exe, high levels of WUTS are identified by the classification algorithm by their falling click rate and short weak tones (Tregenza 2012). In high enough quantities CPOD.exe produces a warning and requires visual validation in order to determine if the clicks are from a dolphin source. In this study, none of the deployments produced a warning for high levels of WUTS and it is therefore unlikely that WUTS contributed to the high levels of background noise.

In addition to masking the sound or filling up the POD with background noise levels either one of the noise sources mentioned above could also be classed as coming from a cetacean resulting in a false positive (Philpott *et al.* 2007; Nuuttila *et al.* 2013b). False positives can result in the incorrect assumption that dolphins are around the C-POD when there are actually none present leading to inaccurate conclusions regarding the presence/absence and distribution of dolphins around the POD (Kyhn *et al.* 2012; Nuuttila *et al.* 2013b). A more in depth analysis of false positives is conducted in chapter 3.

2.8. CONCLUSION

In this study, based solely on the issues caused by background noise levels, the C-POD was not the ideal PAM tool to use in the Mossel Bay area, or along the Cape south coast in general, where reef-associated and sediment transport noise may be a very common source of noise. However, many of the challenges faced will be the same for any static acoustic monitoring system. Both bottlenose and humpback dolphins found in the area have a very near shore distribution. Therefore hydrophone placement location needs to balance the needs of proximity to the main habitat used by dolphins with the safety of the instrument in surf zones and the increased noise associated with these areas. It is recommended that a clear understanding of the composition of the bay (presence/absence of reefs, tidal movements and even wind as well as the biological components) is achieved in order to ensure the best possible placement of the C-POD within the study area. The final placement of the C-POD in this study was further from shore than was ideal to detect the very coastal species under study, which has had knock on effects to some of the other analyses attempted in the remainder on this dissertation.

2.9. REFERENCES

AU, W.W. & BANKS, K. 1998. The acoustics of the snapping shrimp *Synalpheus parneomeris* in Kaneohe Bay. *Journal of the Acoustical Society of America.* **103**(1): 41-47.

AU, W.W., FLOYD, R.W., PENNER, R.H. & MURCHISON, A.E. 1974. Measurement of echolocation signals of the Atlantic bottlenose dolphin, Tursiops truncatus Montagu, in open waters. *Journal of the Acoustical Society of America.* **56**: 1280-1290.

AU, W.W., PENNER, R.H. & KADANE, J. 1982. Acoustic behaviour of echolocating Atlantic bottlenose dolphins. *Journal of the Acoustical Society of America.* **71**: 1269-1275.

CASTLE, M.J. 1974. *A study of ambient sea noise*, Auckland, University of Auckland.

DAHL, P.H., MILLER, J.H., CATO, D.H. & ANDREW, R.K. 2007. Underwater ambient noise. *Acoustics Today.* **3**: 23-33.

DYER, I. 1973. Statistics of distant shipping noise. *Journal of the Acoustical Society of America.* **53**: 564-570.

ELWEN, S.H. & BEST, P.B. 2004a. Environmental factors influencing the distribution of southern right whales (*Eubalaena australis*) on the south coast of South Africa I: Broad scale patterns. *Marine Mammal Science* **20(3)**: 567-582.

EVEREST, F.A., YOUNG, R.W. & JOHNSON, M.W. 1948. Acoustical characteristics of noise produced by snapping shrimp. *Journal of Acoutical Society of America.* **20**: 137–142.

HASTINGS, P.A. & ŠIROVIĆ, A. 2015. Soundscapes offer unique opportunities for studies of fish communities. *Proceedings of the National Academy of Sciences.* **112**: 5866-5867.

HOELZEL, A.R., HEY, J., DAHLHEIM, M.E., NICHOLSON, C., BURKANOV, V. & BLACK, N. 2007. Evolution of population structure in a highly social top predator, the killer whale. *Molecular Biology and Evolution.* **24**: 1407-15.

JACKSON, L.F. & LIPSCHITZ, S. 1984. *Coastal sensitivity atlas of southern Africa.* Pretoria, Department of Transport.

JAMES, B.S. 2014. *Natural and human impacts on habitat use of coastal delphinids in the Mossel Bay area, Western Cape, South Africa.* MSc: Zoology, University of Pretoria.

KNUDSEN, V.O., ALFORD, R.S. & EMLING, J.W. 1948. Underwater ambient noise. *Journal of Marine Research.* **7**: 410-429.

KYHN, L. A., TOUGAARD, J., THOMAS, L., DUVE, L. R., STENBACK, J., AMUNDIN, M., DESPORTES, G. & TEILMANN, J. 2012. From echolocation clicks to animal density--acoustic sampling of harbor porpoises with static dataloggers. *Journal of the Acoustical Society of America.* **131**: 550-560.

LEENEY, R.H. & TREGENZA, N. 2006. Static Acoustic Monitoring of Cetaceans. *Proceedings of the European Cetacean Society 2006,* Gdynia, Poland. 7-14.

MCANALLY, W.H. & MEHTA, A.J. 2002. Significance of Aggregation of Fine Sediment Particles in Their Deposition. *Estuarine, Coastal and Shelf Science.* **54**: 643-653.

MELLAN, R. H. 1952. The thermal-noise limit in the detection of underwater acoustic signals. *Journal of the Acoustical Society of America.* **24**: 478-480.

NUUTTILA, H.K., THOMAS, L., HIDDINK, J.G., MEIER, R., TURNER, J.R., BENNELL, J. D., TREGENZA, N.J. & EVANS, P.G. 2013b. Acoustic detection probability of bottlenose dolphins, *Tursiops truncatus*, with static acoustic dataloggers in Cardigan Bay, Wales. *Journal of the Acoustical Society of America.* **134**: 2596-2609.

PHILPOTT, E., ENGLUND, A., INGRAM, S. & ROGAN, E. 2007. Using T-PODs to investigate the echolocation of coastal bottlenose dolphins. *Journal of the Marine Biological Association of the United Kingdom.* **87**: 11–17.

RADFORD, C.A., JEFFS, A.G., TINDLE, C.T. & MONTGOMERY, J.C. 2008. Temporal patterns in ambient noise of biological origin from a shallow water temperate reef. *Oecologia.* **156**: 921-9.

RADFORD, C.A., STANLEY, J.A., TINDLE, C.T., MONTGOMERY, J.C. & JEFFS, A.G. 2010. Localised coastal habitats have distinct underwater sound signatures. *Marine Ecology Progress Series.* **401**: 21-29.

ROBERTS, B.L. & READ, A. J. 2015. Field assessment of C-POD performance in detecting echolocation click trains of bottlenose dolphins (*Tursiops truncatus*). *Marine Mammal Science.* **31**: 169-190.

ROSS, D. 1976. *Mechanics of Underwater Noise*, New York, Pergamon.

SIMMONDS, M. P., DOLMAN, S. & WEILGART, L. S. 2004. *Oceans of Noise 2004*. United Kingdom,Whale and Dolphin Conservation Society.

THORNE, P.D. 1986. Laboratory and marine measurements on the acoustic detection of sediment transport *Journal of the Acoustical Society of America.* **80**: 900-910.

THORNE, P.D. 1990. Seabed generation of ambient noise. *Journal of the Acoustical Society of America.* **87**: 149-153.

TREGENZA, N. 2009. C-POD User Guide.

TREGENZA, N. 2012. CPOD.exe : a guide for users. 1-56.

VAN RIJN, L.C. 1993. *Principles of sediment transport in rivers, estuaries and coastal seas*, Netherlands, Aqua Publishers.

WENZ, G.M. 1962. Acoustic Ambient Noise in the Ocean: Spectra and Sources. *Journal of the Acoustical Society of America.* **34**: 1936-1956.

Chapter 3

Detection ranges of Indo-Pacific bottlenose dolphins, *Tursiops aduncus,* and Indian Ocean humpback dolphins, *Sousa plumbea,* using a static acoustic data logger (C-POD).

ABSTRACT

Cetacean and **Po**rpoise **D**etection (**C-PODs**) devices are useful tools to monitor cetaceans however the exact detection capabilities of these devices in each particular area require investigation. Generalized estimating equations (GEE) were used to model the effect of distance, group size, behaviour, sea state and direction of dolphin on the detection probabilities of Indo-Pacific bottlenose dolphins (*Tursiops aduncus)* and Indian Ocean humpback dolphins (*Sousa plumbea).* Detection probabilities were estimated using acoustic detections that occurred within a 60 sec or 30 sec window of a visual detection for each species. Average detection probability for bottlenose dolphins was 0.357 (95% CI: 0.352 - 0.363) for the 60 sec window and 0.257 (95% CI: 0.253 - 0.262) for the 30 sec window. For humpback dolphins the average detection probability was 0.084 (95% CI: 0.082 - 0.087) for the 60 sec window, and 0.043 (95% CI: 0.042 - 0.044) for the 30 sec window. Effective detection radius (EDR) for bottlenose dolphins was 1161.38 mm (95% CI: 1150.14m – 1172.62 m) for the 60 sec window and 1035.761 m (95% CI: 1024.89 m – 1046. 64 m) for the 30 sec window. EDR for humpback dolphins was 765.25m (95% CI: 755.64 m – 774.85 m) for the 60 sec window and 751.00m (95% CI: 741. 40 m – 760. 60 m) for the 30 sec window. In both species during both windows detection probability was influenced by group size. A noisy marine environment and a small sample size for both species likely affected results though there are indications that C-PODs might be more useful in monitoring bottlenose dolphins than humpback dolphins.

KEYWORDS: Bottlenose dolphins, C-POD, detection distance, detection probability, effective Detection Radius, EDR, group size, humpback dolphins.

3.1. INTRODUCTION

Static acoustic data loggers such as T-PODs and C-PODs have rarely been used to measure abundance and estimate density in porpoises and dolphins (Kyhn *et al.* 2012). As with visual detections, acoustic detections decrease with increased distance from the receiver, to the point where animals are not detected. Acoustic survey are also limited as cetaceans do not constantly echolocate or vocalise, therefore individuals may pass right next to a receiver without being detected, thus leading to an underestimation of the variable of interest. To be able to accurately determine absolute animal density it is necessary to analytically account for these two problems (Kyhn *et al.* 2012). This can be achieved by first determining the detection function which can then be used to determine effective detection radius from which an index of abundance can be calculated (Marques *et al.* 2009; Kyhn *et al.* 2012).

The **E**ffective **D**etection **R**adius (**EDR**) is the distance from the recorder where as many detections are detected within as those missed at greater distances whilst the effective detection area is the circular area where as many dolphins are missed inside the area as are detected outside the area (Buckland 2001, Kyhn *et al.* 2012, Nuuttila *et al.* 2013b) The EDR and subsequently the effective detection area is determined based on the derived detection function g(x) which is the probability of acoustically detecting individuals as a function of distance (r) from the acoustic data logger (Buckland *et al.* 2001; Marques *et al.* 2009; Kyhn *et al.* 2012). Estimates of g(r) can be determined by modifying a standard point transect survey sampling method (Buckland *et al.* 2001; Marques *et al.* 2009; Kyhn *et al.* 2012). Standard methods assume that 1) all animals are detected at zero distance and 2) all detection distances are accurate. Cetaceans, however, often violate one or both of these assumptions which makes accurate determination of the distance of a vocalizing group of cetaceans from a hydrophone challenging. An alternative method commonly used for cetaceans, is to determine the position and exact time of a group surfacing, usually using a theodolite, and link this location to acoustic detections within a specified time period ranging from 15 to 60 sec (Philpott *et al.* 2007; Bailey *et al.* 2009; Rayment *et al.* 2009; Kyhn *et al.* 2012; Nuuttila *et al.* 2013b). These values can then be used within a distance sampling framework to calculate the variation in detection probability with distance to the hydrophone as well as the influence of other parameters such as behaviour, group size or species (Philpott *et al.* 2007; Bailey *et al.* 2009; Rayment *et al.* 2009; Simon *et al.* 2010;

Kyhn *et al.* 2012; Nuuttila *et al.* 2013b). Using the calculated detection probability (or detection function) the effective detection radius can then be calculated and used to estimate the effective detection area (Kyhn *et al.* 2012; Nuuttila *et al.* 2013b).

To date only a few studies directly investigated the detection capabilities of T-PODs and C-PODs (Tougaard *et al.* 2006; Philpott *et al.* 2007; Bailey *et al.* 2009; Rayment *et al.* 2009; Kyhn *et al.* 2012; Nuuttila *et al.* 2013b). Each study combined the use of a theodolite to visually track cetaceans and matched it to acoustic detections by the PODs. The process of matching acoustic detections to each visual detection and then estimating detection probability varied slightly between the studies. Currently, detection probability has been estimated for harbour porpoises (*Phocoena phocoena*) (Tougaard *et al.* 2006; Kyhn *et al.* 2012), Hector's dolphins (*Cephalorhynchus hectori*) (Rayment *et al.* 2009) and common bottlenose dolphins (*Tursiops truncatus*) (Philpott *et al.* 2007; Bailey *et al.* 2009; Nuuttila *et al.* 2013b) in different locations around the world.

Tougaard *et al*. (2006) and Kyhn *et al.* (2012) used a similar mark-recapture approach to estimate the detection function of T-PODs for harbour porpoises where a 'mark' counted as a visual sighting and a simultaneous acoustic detection was a 'recapture'. Detection function was modelled using binary generalized linear models (GLMs), effective detection radius (EDR) and overall animal density was calculated for each T-POD.

Rayment *et al.* (2009) used a slightly different method to estimate detection probabilities of T-PODs for Hector's dolphins. Visual detections were first matched to acoustic detections (within a 60 sec window straddling the moment of visual detection/fixing) which were then assigned to binned distance categories. Detection probability was estimated for each bin as the proportion of time spent in a particular bin with acoustic detections divided by the total time spent within the particular bin (Rayment *et al.* 2009). Effective detection radius was estimated and the influence of biological and environmental factors was modelled using linear regression models (Rayment *et al.* 2009).

Philpott *et al.* (2007), Bailey *et al.* (2009) and Nuuttila *et al.* (2013b) estimated the detection probabilities of T-PODs and C-PODs for common bottlenose dolphins. Detection probability was estimated as the proportion of matching acoustic detections against the total number of visual detections. Nuuttila *et al.* (2013b) also modelled the influence of distance, group size and behaviour on the detection probability using generalised additive mixed models (GAMMs). EDR was calculated following the formula presented by Kyhn *et al.* (2012).

3.2. AIMS AND KEY QUESTIONS

This study aimed to determine the detection probability and effective detection radius of *T. aduncus* and *S. plumbea* individuals by a C-POD. This was achieved by combining acoustically collected data logged by the C-POD with visual observations of the dolphin species, group size, behaviour and distance from the C-POD. In addition the impact of environmental factors on the detection probability of the C-POD was assessed.

This chapter focused on the following key questions:

1) What is the probability of a C-POD acoustically detecting groups of *T. aduncus* and *S. plumbea* as detection distance increases?

2) What is the influence of group size, group behaviour and direction of dolphin (relative to the C-POD) on detection distances and probability of detection for each species?

3) What is the influence of environmental factors such as sea state and wind speed on detection distances and probability of detection for each species?

4) What is the effective detection radius of the C-POD for *T. aduncus* and *S. plumbea*?

3.3. METHODS

3.3.1. Visual data

In order to avoid repetition, aspects of the methodology covered in chapter 1 will be summarized here and only new techniques applying to this section will be covered in detail.

Visual data were collected from 17 May 2013 to 31 August 2014 at a predetermined site (34° 5' 17.31" S and 22° 9' 5.08" E) in Mossel Bay, South Africa using a surveyor’s theodolite.

Surveys lasted 4 - 6 hours and were conducted 3 - 4 times a week (weather dependent). Active scans of the area using binoculars were conducted every 30 min and lasted for 5 min. During each scan environmental and sighting conditions were also recorded. Once dolphins were sighted, the species were identified, and individuals were tracked. Their behaviours, dispersion, group size and the direction of dolphins in relation to the C-POD were also recorded during the tracking.

3.3.2. Acoustic data

The C-POD was initially deployed from 17 May 2013 to 27 December in water averaging 9.15 m deep. Due to a substantial amount of background noise the C-POD was moved to deeper waters (See Chapter 2 for more information) for the remaining deployments which took place from 6 February 2014 – 2 September 2014 in water averaging 16.31 m deep. The C-POD was deployed in view of the theodolite and serviced and downloaded monthly. The coordinates, depth and time of each deployment were also recorded.

3.4. DATA PROCESSING

3.4.1. Visual data

Tracking data were imported into the software programme, Pythagoras (Gailey and Ortega-Ortiz 2000) which converted the angles recorded during tracking into a table of longitudes and latitudes for each track point.

3.4.2. Distance of dolphin from C-POD

The coordinates obtained for the dolphin group's location from Pythagoras along with the GPS coordinates of the C-POD location were used to calculate the distance between the dolphin group and the C-POD. Distances were calculated in MS Excel using the formula created by Pearson (2013) as follows (Equation 3.1)

Equation 3.1

$$d = cos^{-1}[\cos(\cos(radians(90 - lat_1)) * \cos(radians(90 - lat_2)) + \sin(radians(90 - lat_1)) * \sin(radians(90 - lat_2)] * \cos(radians(long_1 - long_2))) * R$$

where lat_1 $long_1$ are the coordinates for the dolphin group and lat_2 $long_2$ are the coordinates for the C-POD and, R is the mean radius of earth (6371km) (Pearson 2013). This formula along with an explanation can be found online at http://www.cpearson.com/excel/LatLong.aspx (Pearson 2013). This formula was also used by Nuuttila *et al.* (2013b).

3.4.3. Acoustic data

The raw data file (.CP1 format) obtained from the SD card was imported into the program, CPOD.exe (Version 2.044) and run through a specific train detection algorithm named as a KERNO classifier which produced a CP3 file containing potential click trains (Tregenza 2012). The classifier assigned the click trains into one of four probability classes (NBHF, Other cet, Sonar, Unclassed) which were then assigned one of four detection filters (‘Hi’, ‘Mod’, ‘Lo’ ‘Doubtful’).

3.4.4. False positive test

In this study; ‘Hi’, ‘Mod’ and ‘Lo’ quality trains were used, ‘Doubtful’ trains were excluded. The inclusion of ‘Lo’ quality trains can be problematic as it increases the possibility of including false positives. False positives are when acoustic detections occur even though no dolphins are present (Philpott *et al.* 2007). Earlier studies on common bottlenose dolphins using T-POD’s have either followed a conservative approach and only used ‘High’ and ‘Mod’ trains (Bailey *et al.* 2009) or have successfully included ‘Lo’ trains after recording a low number of false positives (Philpott *et al.* 2007) . Kyhn *et al.* (2012) measured the false positives rate in T-PODs as the number of acoustic detections when the target species was not visually sighted divided by the total observation time. This method was also used by Nuuttila *et al.* (2013b) to measure the false positive rates in C-POD’s. As the C-POD’s train detection ability is better than that of the T-POD, the proportion of false positive should be relatively small (Roberts and Read 2015). Nuuttila *et al.* (2013b) calculated a false positive rate of just 0.0018 for common bottlenose dolphins across the whole dataset and thus ‘Lo’ quality trains were included in their analysis. The same method was used to determine the rate of false positives in the present study.

Acoustic detections of dolphins (trains) in processed CP3 files were cross referenced with 5 min visual scans. If an acoustic detection occurred with no corresponding visual detection then it was assumed to be a false positive and the quality of the train was recorded. The proportion of false positive was found to be very low with only 11 acoustic detections occurring in the absence of recorded dolphins out of 1229 visual scans (0.00895). Of these detections two were classed as ‘Lo’; two were ‘Hi’ and seven were ‘Mod’. As the false positive rate was very small ‘Lo’ trains were included in the analysis.

3.4.5. Comparison of visual and acoustic data

To visually assess the spatial distribution of acoustic detections on the C-POD they were linked to visual detections (i.e. a single visual track point with associated time and location from theodolite tracking data). Following Kyhn *et al.* (2012) acoustic detections were defined as positive if they occurred within either a 60 sec or a 30 sec window of each visual detection. The visual detection served as the midpoint for each widow. A binary code was used to indicate a match (1) or a miss (0). Detection probability was calculated as a proportion of the total number of acoustic detections to the total number of visual detections. This was done for each species separately (Figure 3.1 & 3.2).

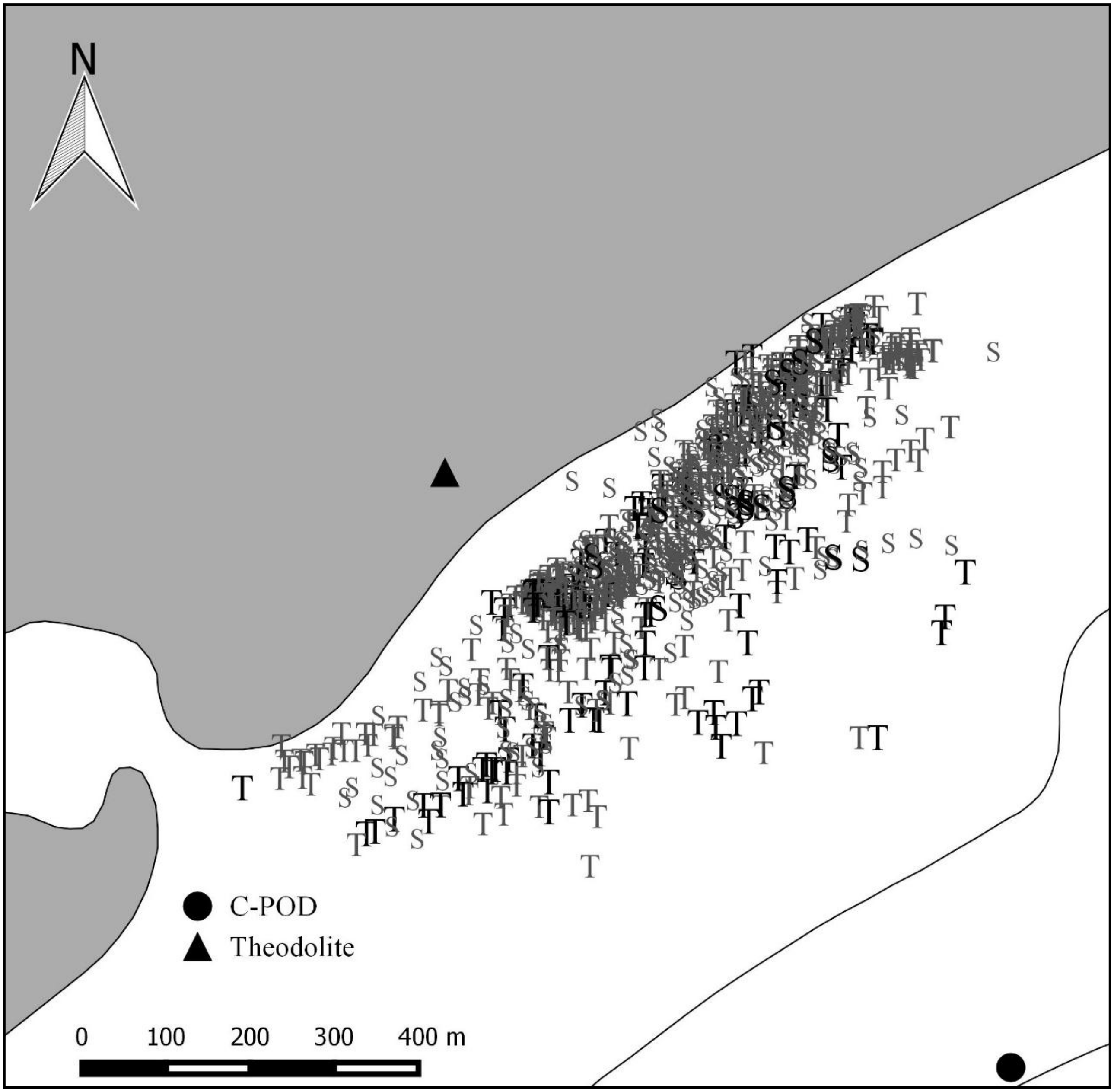

Figure 3.1: Location of theodolite and average C-POD deployment location in relation to bottlenose (T) and humpback (S) dolphin tracks for the 60 sec window. Matched/No matched detections are indicated in colour (black = match and grey= no match).

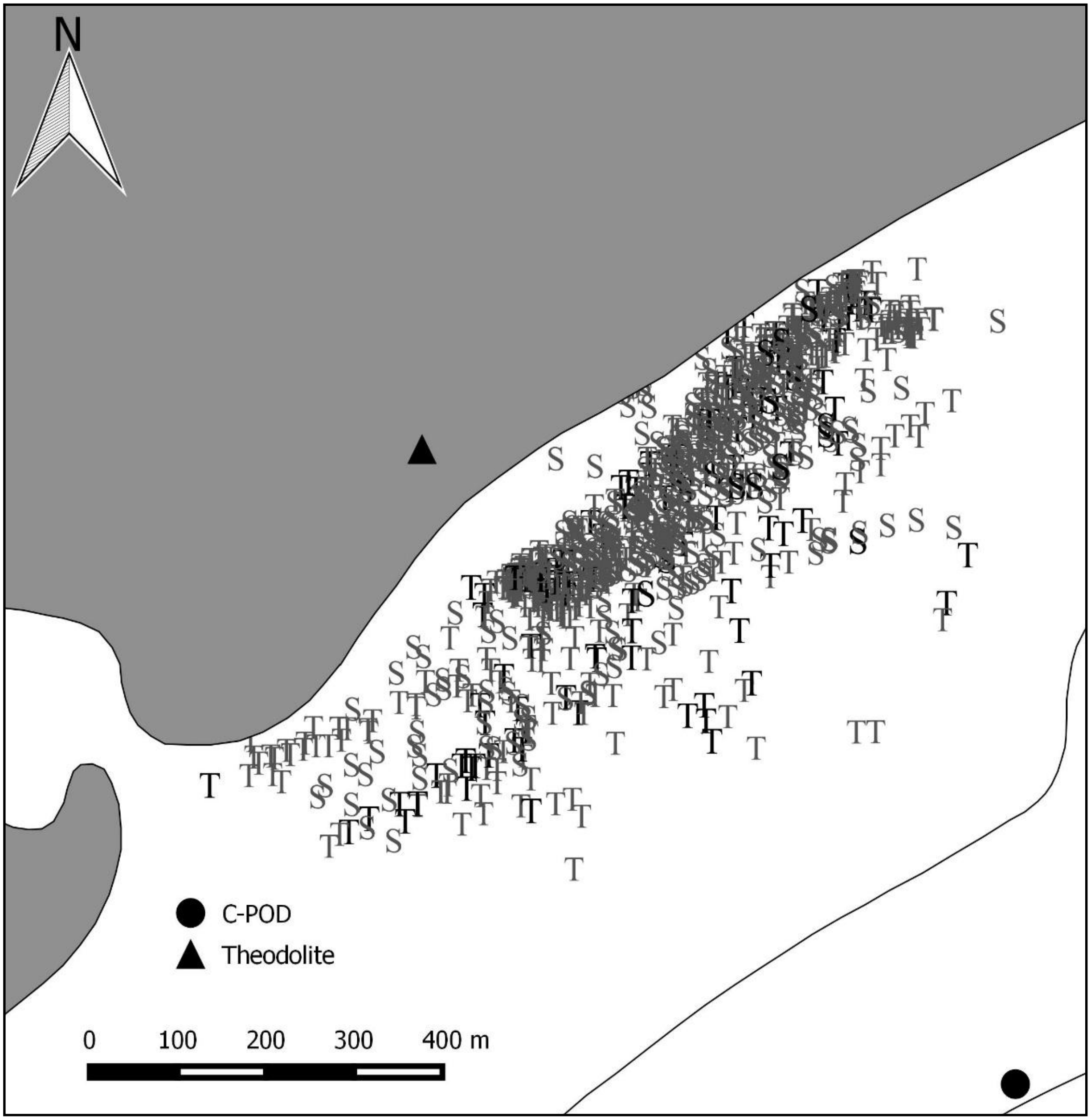

Figure 3.2: Location of theodolite and average C-POD deployment location in relation to bottlenose (T) and humpback (S) dolphin tracks for the 30 sec window. Matched/No matched detections are indicated in colour (black = match and grey = no match).

3.5. DATA ANALYSIS

3.5.1. Detection probability

All modelling and analyses were conducted in the software program R (Version 3. 01) using the R-Studio interface (Version 0.98.978) and packages geepack (Yan and Højsgaard 2005) for the models, MuMln (Burham and Anderson 2002) for model selection, and ggplot2 (Wickham and Chang 2009) for the graphs. Due to the change in location of the C-POD and its impact on detection probability due to truncation of recording minutes (see Chapter 2), results from the initial set of deployments were not included in the detection models presented here. Generalized estimating equations (GEEs) were used to model detection probability of each species for each window period while taking into account auto-correlation of parameters within encounters. GEEs are useful when modelling auto-correlated data from longitudinal/ repeated measure studies as they are not likelihood based and different possible correlation structures can be modelled to produce consistent normal estimates (Pan 2001; Yan and Højsgaard 2005; Zuur *et al.* 2009). GEE's are represented in R by the general formula (Equation 3.2):

Equation 3.2

$$geeglm\begin{pmatrix} response\ variable \sim explanatory\ variable + covariable\ 1 + covariable\ 2 \ldots , \\ family = \ distribution\ , data = imported\ data\ , corstr = correlations \end{pmatrix}$$

The response variable for this study was a binary value for acoustic detections within either the 60 sec or 30 sec window either side from each visual detection. The two dolphin species were analysed separately. In this study, detection probability was modelled as a function of distance from the C-POD, group size (best estimate), behaviour, and direction of dolphin group in relation to the C-POD (Table 3.1). Potential interactions between the co-variable distance, group size and behaviour were also included in the model. Because of the nature of the response variable, a binomial family with a logit – link function was chosen. Different correlation (association) structures were tested. In GEE models the association between observations is unknown and therefore needs to be specified. There are four possible associations that need to be tested: 1) ‘Independent’ - correlated responses function as independent groups; 2) ‘Exchangeable’ - all measurements of the same group are equally correlated; 3) ‘Auto-regressive-1’ - correlation occurs within-subject observation can be modelled directly as a function of distance (m) between observations; and 4) 'Unstructured correlation' - all correlations between within-subject observations are estimated independently (Zuur *et al.* 2009). The fourth correlation structure was not used as the large number of parameters required in this study will likely prevent the model from converging (Zuur *et al.* 2009). Model selection for the correlation matrix took place using the **Q**uasi-likelihood under the **I**ndependence model information **C**riterion (**QIC**) which is based on the **A**kaike **I**nformation **C**riterion (**AIC**) used to compare models(Pan 2001; Hardin and Hilbe 2003; Zuur *et al.* 2009; Hocking 2012). AIC is based on estimates of maximum likelihood, GEE however, does not define maximum likelihood, therefore AIC cannot be used (Pan 2001). QIC replaces the maximum likelihood with a quasi-likelihood that was generated from the estimating equations (Wedderburn 1974). The model with lowest QIC value is the one that best represents the data. Once a particular correlation structure was selected a modified version of the QIC known as QICu was used to compare models with the same correlation structure but differing combination of variables and interactions (Hardin and Hilbe 2003).

In addition to producing the models, the package geepack also includes a Wald test of significance for variables with multiple levels. This provides an indication of the amount of influence each co-variable and interaction has within each GEE model and helped with model selection (Zuur *et al.* 2009). The significance of each variable was estimated at the 5%, 1% or 0.01% levels. A Mann-Whitney-U test for dependent data was used to test for significant differences between the detection distances of each species during the two time intervals (60 sec and 30 sec).

Table 3.1: The variables used in the GEE models including the response variable (*) and the codes used in the model to distinguish each one.

Variable	Code
Detection – 60 sec *	60SEC
Detection – 30 sec *	30SEC
Distance	DIS
Best Group Size	BGS
Behaviour	BEH
Direction	DIR
Sea State	SS

3.5.2. Effective detection radius.

The **E**ffective **D**etection **R**adius (**EDR**) was calculated following Kyhn *et al.* (2012). To calculate the EDR, the average probability ($\hat{P}$) of the C-POD detecting a dolphin at distance X was calculated using Equation 3. 3 & Equation 3.4, where g(x) is the predicted value produced by the GEE models, d(x) is the distance of the dolphin from the C-POD and w is the truncated distance beyond which detection probability is assumed to be zero.

$$\hat{P} = \int_0^w \frac{2\pi g(x)dx}{\pi w^2} \qquad \text{Equation 3.3}$$

$$= \frac{2}{w^2} \int_{x=0}^{w} x\hat{g}\,(x)dx. \qquad \text{Equation 3.4}$$

The EDR was calculated as the square root of the average detection probability ($\hat{P}$) multiplied by the truncation distance of 1200 m (Equation 3.5). Truncation distance was determined using the detection distances calculated from the theodolite tracks. The effective detection area was then calculated using the formula for the area of a circle (Equation 3.6).

$$\hat{p} = \sqrt{\hat{P}w^2}. \qquad \text{Equation 3.5}$$

$$area\ (km^2) = \pi r^2. \qquad \text{Equation 3.6}$$

3.6. RESULTS

Visual surveys were conducted over 90 days averaging 5 to 6 hours a day. Total visual hours for all sites combined were 837 hrs and 36 min. Total visual effort at site 4 (the main study site) was 643 hrs and 36 min. The C-POD was in the water for a total of 162 days, 3 hrs and 30 min. A total of 13 encounters for bottlenose dolphins and 17 for humpback dolphins were used in the analysis. Out of the 13 bottlenose dolphin encounters there were 562 visual detections with 148 matched events for the 60 sec window and 115 matched events for the 30 sec window. For humpback dolphins the visual fixes were slightly fewer at 244 with 19 matches during the 60 sec window and 11 matches during the 30 sec window.

The maximum detection distances calculated from the theodolite fixes was the same for the 60 sec and 30 sec window for both species: 1177.90 m for bottlenose dolphins and 1148.67 m for humpback dolphins. Mean detection distance for bottlenose dolphins was 748.79 m (95% CI: 728.41 m – 769.17 m) for the 60 sec window and 749.57 m (95% CI: 728.33 m – 770.80 m) for the 30 sec window (Figure 3.3). For humpback dolphins, mean detection distances were slightly further at 936.52 m (95% CI: 903.56 m – 969.48 m) for the 60 sec window, and 926.26 m (95% CI: 867.48 m – 985.04 m) for the 30 sec window (Figure 3.3). For bottlenose dolphins, the average detection probability was 0.357 (95% CI: 0.352 - 0.363) for the 60 sec window and 0.257 (95% CI: 0.253 - 0.262) for the 30 sec window. For humpback dolphins, the average detection probability was lower at 0.084 (95% CI: 0.082 - 0.087) for the 60 sec window, and 0.043 (95% CI: 0.042 - 0.044) for the 30 sec window. There were no significant differences in detection distances of bottlenose dolphins between the 60 sec and 30 sec window ($U = 3197$, $p =$

0.82). For humpback dolphins, there were no significant differences in detection distances between the 60 sec and 30 sec window (U = 23, p = 0.70).

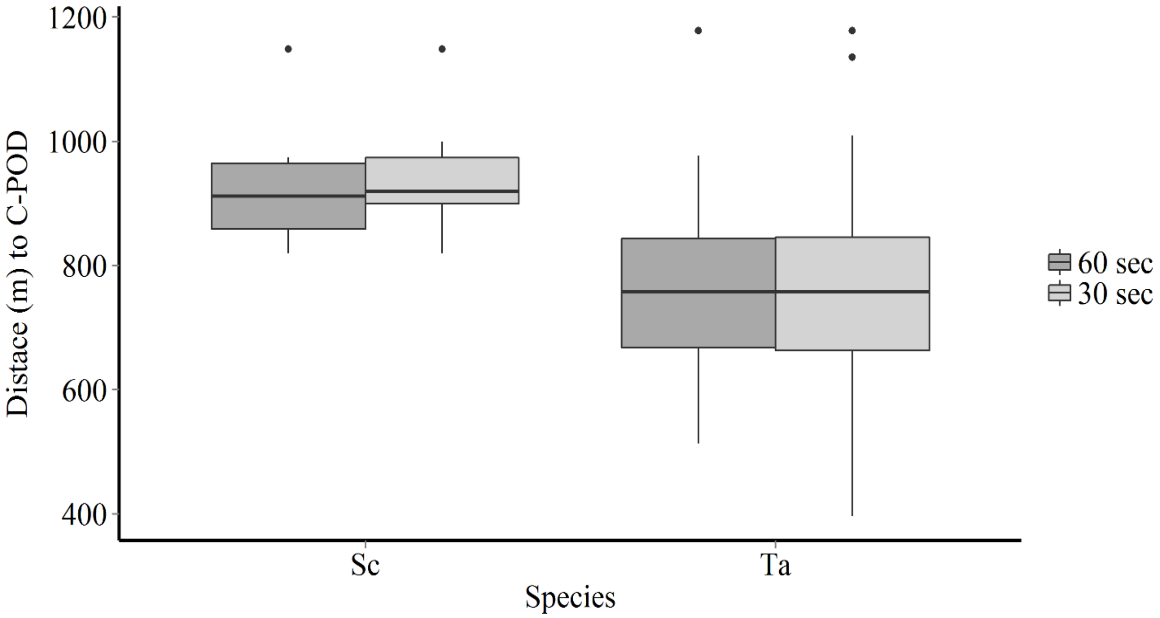

Figure 3.3: Mean distances (m) of humpback dolphins (Sc) and bottlenose dolphins (Ta) to C-POD when acoustic detections were made within a 60 sec and 30 sec window of a theodolite fix.

3.6.1. Modelling of acoustic detection probability

For bottlenose dolphin during both windows the co-variables distance, best group size, behaviours and directions were included in all the models (Table 3.1; Table 3.2). Sea state however was not included in either window as it caused a model convergence error. For humpback dolphins during both windows all possible co-variables and interactions were included in the models (Table 3.1; Table 3.2). For both species during both windows the correlation structure with the lowest QIC value was the model with independent correlation structure and this was therefore selected for all subsequent models (Table 3.2).

Table 3.2: The QIC values obtained from the different correlation structures used in the initial general estimating equation models (GEE) for each species during the 60 sec and 30 sec window respectively. The variables and interactions remained constant whilst the correlation structure was varied between 'Independent', 'Exchangeable' and 'Auto-regressive – 1'. The correlation structures with the lowest QIC (in bold) was selected for subsequent models.

	Model	**QIC - Independent**	**QIC- Exchangeable**	**QIC- Auto- regressive-1**
Bottlenose dolphins – 60 sec	60SEC ~ DIST * BEH + DIST * BGS + DIST * DIR	**618.5**	628.99	628.99
Bottlenose dolphins – 30 sec	30SEC ~ DIST * BEH + DIST * BGS + DIST * DIR	**547.3**	545.93	545.93
Humpback dolphins - 60 sec	60SEC ~ DIST * BGS + DIST * SS + DIST * BEH + DIR	**104**	1566	1566
Humpback dolphins - 30 sec	30SEC ~ DIST * BGS + DIST * SS + DIST * BEH + DIR	**61.6**	1022.71	1022.71

For bottlenose dolphins, using the 60 sec window, GEE models were run using the family 'binomial' and the correlation structure 'Independent'. Interactions between co-variables and then the co-variables were subsequently removed from each model run (Table 3.3). The QICu value for each model was calculated. The model with the lowest QICu was selected as the model that best described the data (Table 3.3). This process was repeated for the 30 second window using the same family, correlation structure, co-variables and interactions. Co-variables and interactions were also removed from each model run (Table 3.4) and the model with the lowest QICu value was selected (Table 3.4).

Table 3.3: Generalized estimating equation models (GEEs) of the variables that influence detection probability of a C-POD for bottlenose dolphins during the 60 sec window. The model with the smallest QICu is indicated in bold.

Models	**QICu**
60SEC ~ DIST * BGS + DIST * BEH + DIST * DIR	610.0
60SEC ~ DIST * BGS + DIST * BEH + DIR	608.8
60SEC ~ DIST * BGS + DIST * BEH	608.1
60SEC ~ DIST * BGS + BEH	606.6
60SEC ~ DIST * BGS	**604.7**
60SEC ~ DIST + BGS	614.3
60SEC ~ DIST	639.4

Table 3.4: Generalized estimating equation models (GEEs) of the variables that influence detection probability of a C-POD for bottlenose dolphins during the 30 sec window. The model with the smallest QICu is indicated in bold.

Models	QICu
30SEC ~ DIST * BGS + DIST * BEH + DIST * DIR	537.37
30SEC ~ DIST * BGS + DIST * BEH + DIR	535.98
30SEC ~ DIST * BGS + DIST * BEH	535.05
30SEC ~ DIST * BGS + BEH	536.3
30SEC ~ DIST * BGS	**534.52**
30SEC ~ DIST + BGS	537.4
30SEC ~ DIST	564.9

The best fitting model for bottlenose dolphins using the 60 sec window included the co-variable group size and the interaction between distance and group size (Table 3.5). The co-variable group size was significant (Wald test, $P < 0.05$, Table 3.5) as well as the interaction between distance and group size (Wald test, $P < 0.05$, Table 3.5). Detection probability using the 30 sec detection window was best described by the same model (Table 3.6); the co-variable group size was again significant (Wald test, $P < 0.05$, Table 3.6) but the interaction between distance and group size was not significant (Wald test, $P > 0.05$, Table 3. 6).

Table 3.5: Model parameter estimates and their significance from a generalized estimating equation model (GEE) of detection probability for bottlenose dolphins using the 60 sec window. Selected model was 60SEC ~ DIST * BGS, family = binomial, correlation structure = independent, with distance (DIST) and best group size (BGS) as co-variables and distance and best group size (DIST * BGS) as an interaction.

Coefficients	**Estimate**	**Standard error**	**Wald**	**P(>|W|)**
Intercept	-2.80e+00	2.42e+00	1.34	0.247
DIST	-1.31e-03	2.92e-03	0.20	0.653
BGS	5.56e-02	2.19e-02	6.45	0.011 *
DIST * BGS	-5.99e-05	2.66e-05	5.06	0.024 *

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘‘1

Table 3.6: Model parameter estimates and their significance from a generalized estimating equation model (GEE) of detection probability for bottlenose dolphins using the 30 sec window. Final model was 30SEC ~ DIST * BGS, family = binomial, correlation structure = independent, with distance (DIST), best group size (BGS) as co-variables and distance and best group size (DIST * BGS) as an interaction.

Coefficients	**Estimate**	**Standard error**	**Wald**	**P(>|W|)**
Intercept	-2.66e+00	2.04e+00	1.70	0.192
DIST	-5.30e-04	2.50e-03	0.04	0.832
BGS	4.21e-02	1.78e-02	5.58	0.018 *
DIST * BGS	-4.05e-05	2.38e-05	2.89	0.089 .

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ‘1

For humpback dolphins, during the 60 sec window, GEE models were run using the family ‘binomial’ and the correlation structure ‘Independent’. Interactions between co-variables and then the co-variables were subsequently removed from each model run (Table 3.7). The QICu value for each model was calculated. The model with the lowest QICu was selected as the model that best described the data (Table 3.7). This process was repeated for the 30 second window using the same family, correlation structure, co-variables and interactions. Co-variables and interactions were also removed from each model run (Table 3.8) and the model with the lowest QICu value was selected (Table 3.8).

Table 3.7: Generalized estimating equation models (GEEs) of the variables that influence detection probability of a C-POD for humpback dolphins using the 60 sec window. The model with the smallest QICu is indicated in bold.

Models	**QICu**
60SEC ~ DIST * BGS + DIST * SS + DIST * BEH + DIR	132.00
60SEC ~ DIST * BGS + DIST * SS + DIST * BEH	128.00
60SEC ~ DIST * BGS + DIST * SS + BEH	125.00
60SEC ~ DIST * BGS + DIST * SS	124.44
60SEC ~ DIST * BGS + SS	123.32
60SEC ~ DIST * BGS	121.90
60SEC ~ DIST + BGS	**120.59**
60SEC ~ DIST	134.38
60SEC ~ DIST * SS	132.94
60SEC ~ DIST + SS	131.35

Table 3.8: Generalized estimating equation models (GEEs) of the variables that influence detection probability of a C-POD for humpback dolphins during the 30 sec window. The model with the smallest QICu is indicated in bold.

Models	QICu
30SEC ~ DIST * BGS + DIST * SS + DIST * BEH + DIR	87.9
30SEC ~ DIST * BGS + DIST * SS + DIST * BEH	84.8
30SEC ~ DIST * BGS + DIST * SS + BEH	81.0
30SEC ~ DIST * BGS + DIST * SS	75.26
30SEC ~ DIST * BGS + SS	76.80
30SEC ~ DIST * BGS	74.83
30SEC ~ DIST + BGS	**72.87**
30SEC ~ DIST * SS + BGS	74.19
30SEC ~ DIST * SS	82.38
30SEC ~ DIST + SS	82.1
30SEC ~ DIST	80.18

The best fitting model for humpback dolphins using the 60 sec window included the co-variable group size with no interactions. Group size was significant in the model (Wald test, P < .01, Table 3.9). Detection probability using the 30 sec detection window was best described by the same model (Table 3.10); the co-variable group size was again significant (Wald test, P < 0.05, Table 3.10).

Table 3.9: Model parameter estimates and their significance from a generalized estimating equation model (GEE) of detection probability for humpback dolphins using the 60 sec window. Best fitting model was 60SEC ~ DIST + BGS, family = binomial, correlation structure = independent, with distance (DIST) and best group size (BGS) as the co-variables.

Coefficients	Estimate	Standard error	Wald	Pr(>|W|)
Intercept	-1.29246	1.91519	0.46	0.49977
DIST	0.00047	0.00206	0.05	0.81964
BGS	-0.4128	0.12196	11.44	0.00072 **

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ‘ 1

Table 3.10: Model parameter estimates and their significance from a generalized estimating equation model (GEE) of detection probability for humpback dolphins during the 30 sec window. Final model was 30SEC ~ DIST + BGS, family = binomial, correlation structure = independent, with distance (DIST) and group size (BGS) as the co-variables.

Coefficients	Estimate	Standard error	Wald	Pr(>|W|)
Intercept	0.30904	2.48094	0.02	0.9009
DIST	-0.00152	0.00285	0.29	0.5930
BGS	-0.59274	0.19118	9.61	0.0019 **

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ‘ 1

Detection probability for bottlenose dolphins during the 60 sec and 30 sec windows initially increased as distance from the C-POD increased but around 750 m from the hydrophone detection probability began to decrease as the distance from C-POD continued to increase (Figure 3.4). For group size, detection probability initially increased with increasing group size before decreasing (Figure 3.5). Detection probability for humpback dolphins using the 60 sec and 30 sec windows initially increased as distance from the C-POD increased but around 900 m detection probability began to decrease as the distance from C-POD continued to increase (Figure 3.6). For group size, detection probability decreased with increasing group size (Figure 3.7). Sea state and direction of dolphin were not included in the best fitting models for either species during both window periods and therefore had no influence on detection probability.

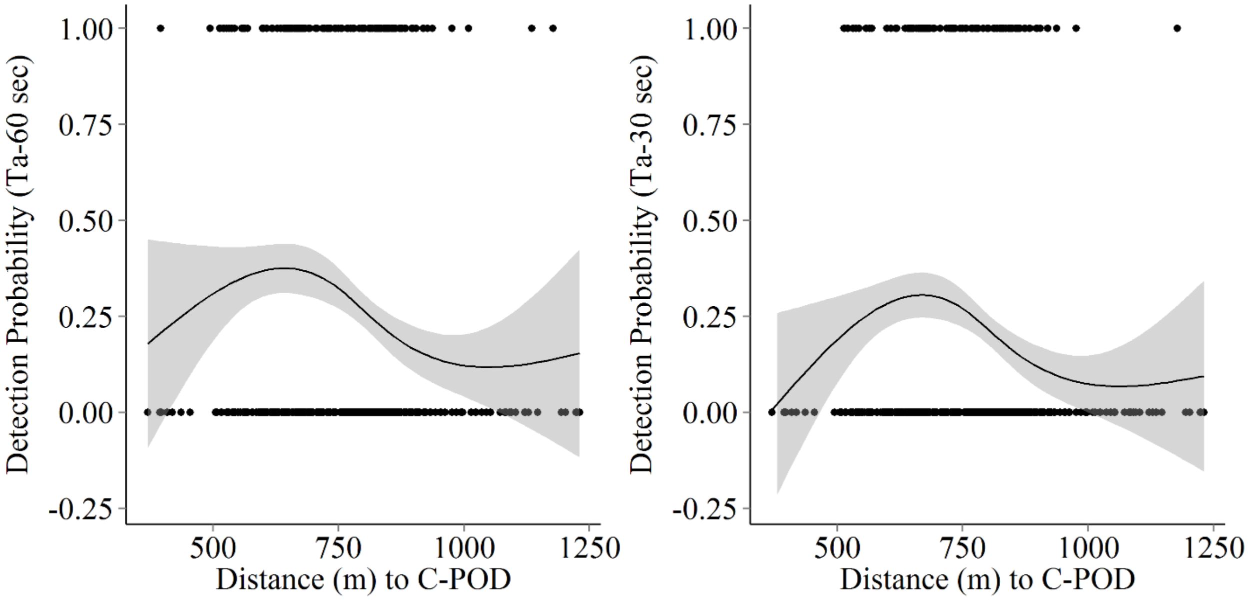

Figure 3.4: Detection probability of bottlenose dolphins for each window (60 sec and 30 sec) as a function of distance from the C-POD. Solid line is the estimated probability of detection produced by the GEE and the shaded region represents the 95% confidence interval. Dots represent the observed data where 0 was for no match between visual and acoustic detections and 1 for a match between visual and acoustic detections.

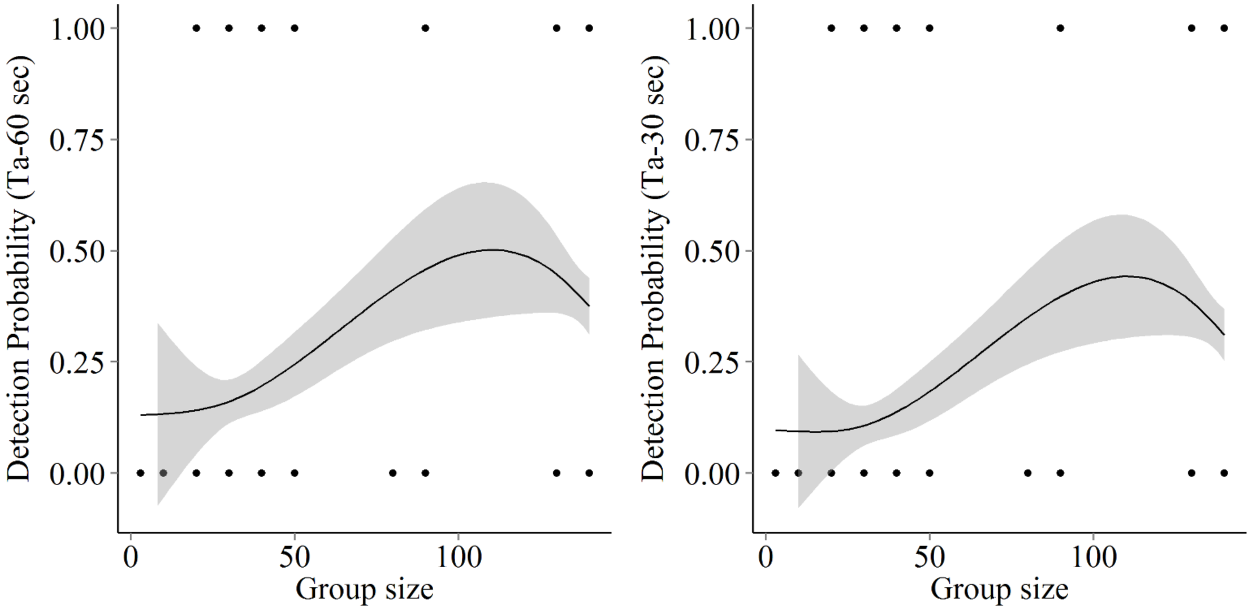

Figure 3.5: Detection probability of bottlenose dolphin for each window (60 sec and 30 sec) as a function of group size. Solid line is the estimated probability of detection produced by the GEE and the shaded region represents the 95% confidence intervals. Dots represent the observed data where 0 was for no match between visual and acoustic detections and 1 for a match between visual and acoustic detections.

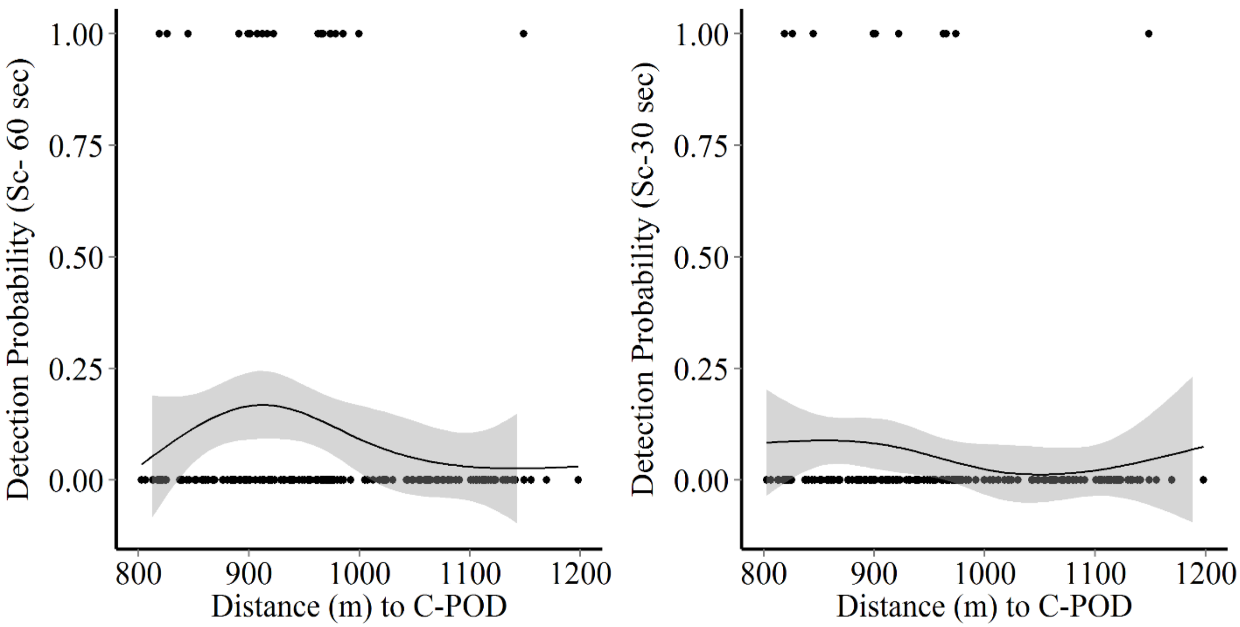

Figure 3.6: Detection probability of humpback dolphins for each window (60 sec and 30 sec) as a function of distance from the C-POD. Solid line is the estimated probability of detection produced by the GEE and the shaded region represents the 95% confidence interval. Dots represent the observed data where 0 was for no match between visual and acoustic detections and 1 for a match between visual and acoustic detections.

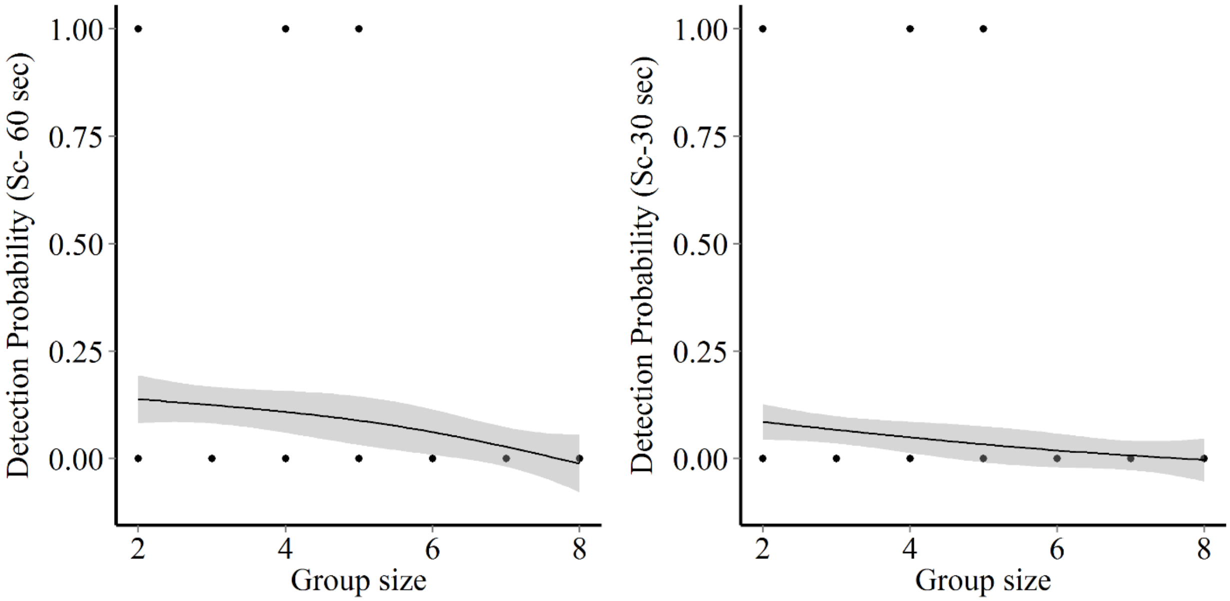

Figure 3.7: Detection probability of humpback dolphins for each window (60 sec and 30 sec) as a function of group size. Solid line is the estimated probability of detection produced by the GEE and the shaded region represents the 95% confidence interval. Dots represent the observed data where 0 was for no match between visual and acoustic detections and 1 for a match between visual and acoustic detections.

Total observed behaviour for bottlenose dolphins consisted of milling (25.44 %) and travelling (74.56 %) whilst total observed behaviour for humpback dolphins consisted of surface feeding (0.75 %), socialising (2.76 %), milling (27.39 %) and travelling (69.10 %). For bottlenose dolphins, using the 60 sec window, 24.44 % of matched acoustic detections occurred during milling and 75.68 % occurred during travelling (Figure 3.8). Using the 30 sec window, 5.56 % of matched acoustic detections occurred during milling, 11.11 % occurred during socialising and 83.33 % occurred during travelling (Figure 3. 8). For humpback dolphins, using the 60 sec window, 26.09 % of matched acoustic trains occurred during milling and 73.91 % during travelling (Figure 3. 8). Using the 30 sec window, 11.11 % of matched trains occurred during milling and 88.89 % occurred during travelling (Figure 3. 8). In the models, behaviour had no influence on detection probability for either species in both windows.

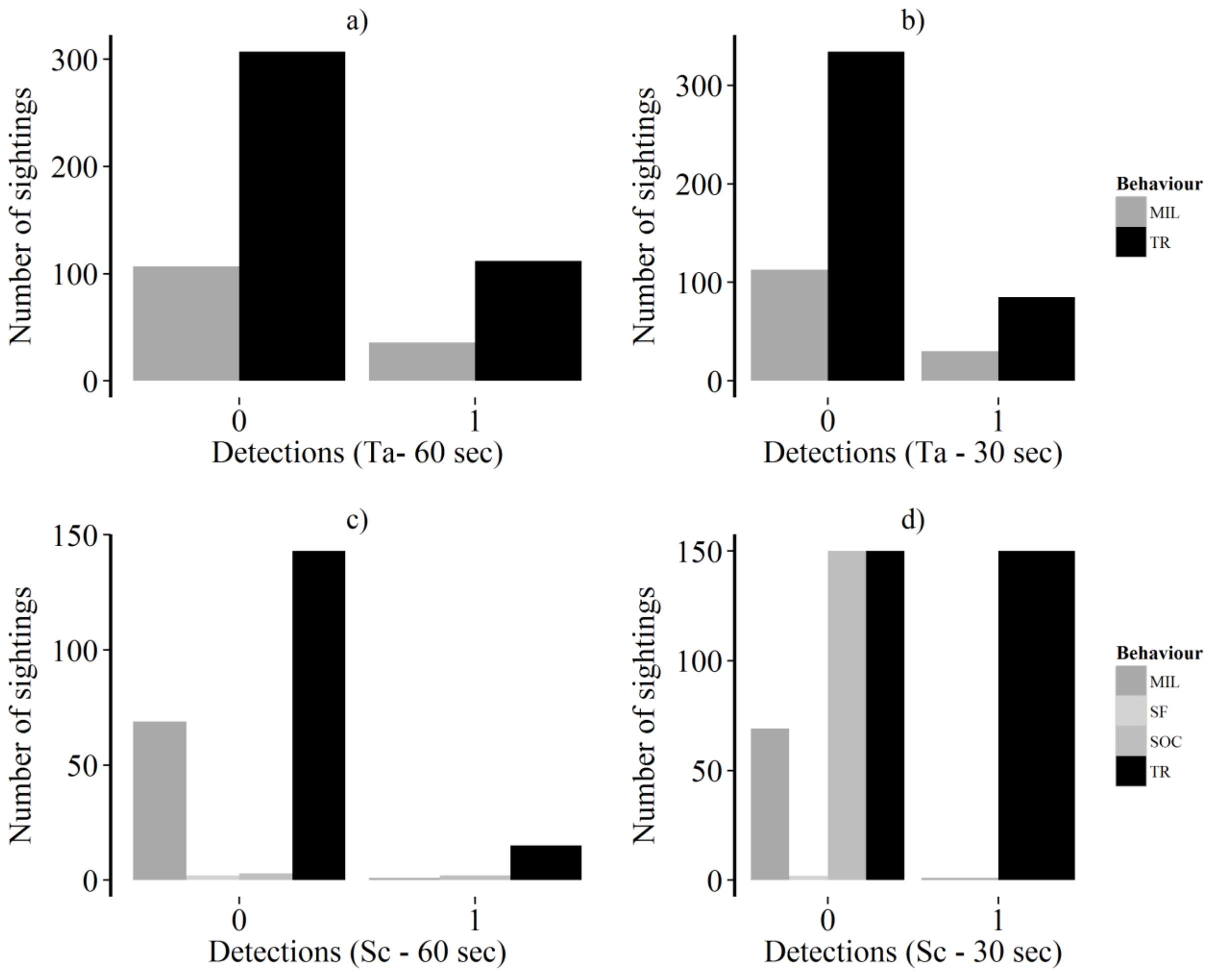

Figure 3.8: The total number of unmatched visual detections (0) and matched acoustic detections (1) for bottlenose dolphins (a-b) and humpback dolphins (c-d) during the 60 sec and 30 sec window in relation to the different behaviour classes; MILL– milling (dark grey), SF - surface feeding (light grey), SOC – socialising (grey) and TR - travelling (black).

3.6.2. Effective Detection Radius

The mean EDR for bottlenose dolphins was 1161.38 mm (95% CI: 1150.14m – 1172.62 m) using the 60 sec window and 1035.761 m (95% CI: 1024.89 m – 1046. 64 m) using the 30 sec window. The mean EDR for humpback dolphins was 765.25m (95% CI: 755.64 m – 774.85 m) using the 60 sec window and 751.00m (95% CI: 741. 40 m – 760. 60 m) using the 30 sec window. Effective detection area for bottlenose dolphins was 4.24 km^2 using the 60 sec window and 3.37 km^2 using the 30 sec window. Effective detection area for humpback dolphins was slightly less at 3.37 km^2 for the 60 sec window and 1.77 km^2 for the 30 sec window.

3.7. DISCUSSION

This is the first study to our knowledge that has attempted to estimate the detection probabilities of a C-POD for Indo-Pacific bottlenose dolphins and Indian Ocean humpback dolphins. Therefore this study provided key information on the potential advantages and disadvantages of using C-PODs to study these two species.

3.1.1. Detection Probability

In both species there was an initial increase in detection probability with distance from the C-POD. This is largely due to the fact that the majority of individuals passed well inshore of the C-POD and therefore the overall estimates of detection distances were much larger. The shortest distance between a bottlenose dolphin and the C-POD in which a match occurred was 396.18 m for the 60 sec window and 513.20 m for the 30 sec window whilst for humpback dolphins the shortest distance was 819 m and 899 m for the 60 sec and 30 sec windows respectively. Both species are known to have a distinct preference for near-shore habitats either within the breakers or sea-facing side of the breakers (Saayman & Taylor 1973, Findlay *et al.* 1992, Best 2007). Earlier work in Mossel Bay found that all bottlenose dolphins were present on average 304.16 m (SD ± 381.88) from the shore at depths of less than 40 m and humpback dolphins on average 179.39 m (SD ± 131.5) from shore at depths of less than 20 m (James 2014). Although the manufacturer recommended a minimum deployment depth of 8 m, the C-POD was deployed in 16 m to 18 m around 970 m from the shore in order to minimize background noise levels (see chapter 2). Despite the initial challenges of noise, deployment location and fewer detections around the C-POD (i. e. at distance 0 m) the overall maximum detection range of 1178.0 m for bottlenose dolphins and 1148.7 m for humpback dolphins was very similar to maximum detection ranges previously reported for common bottlenose dolphins suggesting overall detection was good (Philpott *et al.* 2007; Elliott *et al.* 2011; Nuuttila *et al.* 2013b). The T-POD studies had maximum detection ranges of 1246 m (Philpott *et al.* 2007) and 1313 m (Elliot *et al.* 2011) whilst the C-POD study had a slightly higher maximum detection range of 1512 m (Nuuttila *et al.* 2013b). These results suggest that for any future studies, C-PODs can either be moored much closer to the breaker zone in quieter waters, possibly using a different type of mooring design or in very sheltered waters where swell is less of a safety issue.

The detection probability for bottlenose dolphins was higher than humpback dolphins most likely due to differences in group size, behaviour and vocalisation behaviour. In Mossel Bay both species spend an extensive amount of time near reef areas (James 2014). In addition, humpback dolphins were also consistently present in shallow waters less than 20 m deep, while bottlenose dolphins were found in waters up to 40 m deep (James 2014). The sea topography around the study site is dominated by an estuary and a large near shore reef system (Jackson and Lipschitz 1984; James 2014) which may have further influenced the movement of each species into the shallower waters closer to the shore and thus influenced the detection probability.

The detection probability of bottlenose dolphins for both window detection periods increased with group size as expected but dropped again for groups larger than 100 individuals. This latter pattern is largely driven by the low sample size of very large groups (there were only 189 theodolite fixes of two groups of 100 or more dolphins of which only 76 had simultaneous acoustic detections for the 60 sec window and 63 for the 30 sec window). However, the C-POD detection algorithm is set to search for regular spacing between clicks and the irregular spacing potentially caused by many simultaneous echolocation trains coming from many different directions can result in many click trains being missed (Nuuttila *et al.* 2013b). Counter to expectations, detection probability of humpback dolphins decreased almost linearly as group size increased. In larger groups, the vocalisation rate per individual tends to decrease to either minimise con-specific jamming (the so called cocktail party effect, Nachtigall *et al.* (2000)) or because animals are capable of ‘eavesdropping’ on each other’s echolocation clicks (Gregg *et al.*

2007). Using an array of C-PODs, Nuuttila *et al.* (2013b) showed that a single common bottlenose dolphin (*T. truncatus*) was more likely to be detected acoustically than larger groups. In addition, individuals more familiar with an area may be less likely to echolocate in order to navigate (Nuuttila *et al*. 2013b). Bottlenose dolphins and humpback dolphins (James 2014) in the study area are thought to be a part of a fairly resident population that moves up and down the south coast meaning they are likely familiar with the topography of the area. It is therefore possible that due to this familiarity they were 1) not echolocating much when navigating; 2) 'eavesdropping' on each other's clicks.

Behavioural states did not influence the detection probability of either species. Behavioural classification can be very subjective and prone to bias (Similä and Ugarte 1993) as factors such as; 1) experience of the observers; 2) encounter duration; 3) prevailing weather conditions' 4) group size and 5) time spent at surface can easily affect the final classification. This may lead to an over- or-under estimate of the influence of a particular behaviour on the various click parameters. Observed behaviour was recorded following the guidelines found in Shane *et al.* (1990). One of the most difficult behaviour types to classify is feeding as it can only be recorded when dolphins are visually observed chasing or mouthing fish (Shane 1990). Therefore, it is possible that some feeding events are miss-classified as travelling or socialising.

In common bottlenose dolphins in Wales, C-POD detections were highest during feeding and foraging and lowest during travelling (Nuuttila *et al.* 2013b), but behavioural state did not affect the overall detection probability of common bottlenose dolphins. In this study, detections were highest when the bottlenose dolphins were travelling and no matches were recorded when foraging was visually observed. When hunting, dolphins and porpoises change the rate at which they click, notably when closing in on prey, resulting in so-called feeding buzzes, a parameter that can be detected on C-PODs and T-PODs (Similä and Ugarte 1993). Feeding buzzes have been used as an indicator of foraging behaviour in several previous studies using PODs (Carlström 2005; Verfuss *et al.* 2009; Nuuttila *et al.* 2013a). Nuuttila *et al.* 2013 suggested that echolocation click trains with a minimum ICI of 10 ms or less could be indicative of a feeding buzz. For bottlenose dolphins, in this study, a total of 134 trains out of the 1508 trains (8.89%) had a minimum ICI below 10 ms, whilst for humpback dolphins only 4 out of 95 (4.2%) trains included possible feeding buzzes therefore it is possible that the dolphins were recorded as travelling when foraging was occurring below the surface. As the proportion of potential feeding buzzes in this study, contributed a small percentage of the overall sample size; it is therefore unlikely to significantly influence the detection probabilities of each species. However, it is also important to consider that the behavioural state most frequently recorded for bottlenose dolphins when no matches took place was also travelling. As travelling dominated both matched detections and no matched detection it becomes difficult to accurately determine the influence of behaviour on detection probabilities for bottlenose dolphins.

Australian humpback dolphins (*S. sahulenis*) rarely echolocate when travelling or milling with peaks in echolocations occurring during foraging and socialising (Van Parijs and Corkeron 2001a; Van Parijs *et al.* 2002; Jefferson and Rosenbaum 2014). As Indian Ocean humpback dolphins are suspected to have similar vocalisation patterns to their Australian counterparts it is likely that the same behavioural limitations occur here. These suspected similarities were not immediately evident as travelling accounted for the majority of the matched detections whilst socializing, feeding and milling accounted for only a small portion of the matched detections. The observed decrease in detection probability for humpback dolphins during travelling is most likely due to changes in their vocalisation types as they are known to whistles more in noisy marine environments which are often associated with shallow inshore waters (van Parijs and Corkeron 2001b). For humpback dolphins, due to the small sample, caution should be exercised when interpreting influence of behaviour on the detection probability.

3.7.2. Effective Detection Radius

The EDR serves as a useful indication of where to place multiple C-PODs in order to ensure total acoustic coverage of an area (Buckland 2001; Kyhn *et al*. 2012; Nuuttila *et al.* 2013b). The EDR for bottlenose dolphins in both time windows was around 1000 m with acoustic detections occurring at distances of up to 1177.9 m. For humpback dolphins the EDR was below 800 m in both time windows despite detections of up to 1148.7 m. The same pattern was evident in common bottlenose dolphins from Wales where the average EDR was at 400 m yet detections were made up to 1512 m (Nuuttila *et al.* 2013b). The variation in EDR between the study species was quite large and again reflects the habitat use and biological limitations of each species. It is more interesting to note the difference in results between time windows, especially for bottlenose dolphins where the EDR differed by more than 100 m despite there being no significant differences in the detection distances for each window. This could have serious implications when attempting to monitor dolphins using an array of C-PODs. If C-PODs are not placed at the correct distances from each other, large areas will be missed which will affect detection probability as individuals might be detected visually but not acoustically. The difference between the EDR for the two windows for humpback dolphins was around 14 m and as there were no significant differences ($P > 0.05$) in detection distances between each window there should be no impact on the detection probability. A disadvantage of using EDR is that it assumes uniform detection around the C-POD. In reality, this is often not the case as dolphins will favour certain area(s) based on their needs and requirements. Common bottlenose dolphins in Cardigan Bay, Wales, spent most of their time in a narrow band near the coastline (Nuuttila *et al.* 2013b); the same pattern was observed in this study for both species (Figure 3.1 & 3.2). The exact implications of this on calculating EDR is unknown and further study is necessary.

3.8. CONCLUSION

One of the challenges of working with wild dolphins is that it is rarely possible to conduct the controlled field trials required to fully understand the range and detection limits of the instruments used to study them in a range of settings. This study highlighted several of these challenges but also achieved some successes. Despite an extensive field season of over 16 months, sample size, especially for humpback dolphins was low. This was partly a result of the compromise induced by surveying multiple sites along the Mossel Bay coastline. Future studies would benefit from focussing full time on the C-POD location. Although the original site was selected based on several years of good sightings of humpback dolphins, it was not ideal due to the high surf and presence of a reef creating excessive background noise which impacted acoustic detections. Although partially solved by moving the C-POD into deeper water future studies and monitoring projects in general might benefit from choosing a site with lower wave energy or absence of reefs, even if at the cost of lower detections/sightings. Overall, the C-POD indicated some potential for use as a monitoring tool for bottlenose dolphins; however for humpback dolphins there are indications that acoustic monitoring may not be that suitable due to the low overall detection rates. Further assessment of humpback dolphin detection ranges and acoustic behaviour with a much larger sample size might provide a clearer answer.

3.9. REFERENCES

BAILEY, H., CLAY, G., COATES, E. A., LUSSEAU, D., SENIOR, B. & THOMPSON, P. 2009. Using T-PODs to assess variations in the occurrence of coastal bottlenose dolphins and harbour porpoises. *Aquatic Conservation: Marine and Freshwater Ecosystems.* **20**: 150-158.

BEST, P.B. 2007. *Whales and Dolphins of the Southern African subregion.* Cape Town, Cambridge Univeristy Press.

BUCKLAND, S.T. 2006. Point-Transect surveys for songbirds: Robust methodologies. *Auk.* **123**: 345–357.

BUCKLAND, S.T., ANDERSON, D.R., BURNHAM, K.P., LAAKE, J.L., BORCHERS, D.L. & THOMAS, L. 2001. Distance Sampling. In: *Introduction to Distance Sampling, Estimating Abundance of Biological Populations.* New York, Oxford University Press.

BURHAM, K. P. & ANDERSON, D.R. 2002. Model selection and multimodel inference; a pratical information - theoretic approach 2nd edition. New York, Springer- Verlag.

CARLSTRÖM, J. 2005. Diel Variation in Echolocation Behaviour of Wild Harbour Porpoises. *Marine Mammal Science.* **21**: 1-12.

ELLIOTT, R.G., DAWSON, S.M. & RAYMENT, W.J. 2011. Optimizing TPOD settings and testing range of detection for bottlenose dolphins in Doubtful Sound, New Zealand. *Journal of the Marine Biological Association of the United Kingdom.* 1-7.

FINDLAY, K.P., BEST, P.B., ROSS, D. & COCKCROFT, V.G. 1992. The Distribution of small odontocetes off the coasts of South Africa and Namibia. *South African Journal of Marine Science.* **12**: 237-270.

GAILEY, G. & ORTEGA-ORTIZ, J.G. 2000. *User's manual: 'Pythagoras'. (Version:1.2.15). Theodolite cetacean tracking* [Online]. Texas A & M University, Galveston, USA. Available: [Available at: http://www.tamug.tamu.edu/mmrp/pytha goras].

GREGG, J.D., DUDZINSKI, K.M. & SMITH, H.V. 2007. Do Dolphins Eavesdrop on the Echolocation Signals of Conspecifics? *International Journal of Comparative Psychology*. **20**: 65-88.

HARDIN, J.W. & HILBE, J.M. 2003. *Generalized Estimating Equations*. New York, Chapman and Hall.

HOCKING, D.J. 2012. *Model Selection for generalized estimating equations using QIC* [Online]. Available: http://github.com/djhocking/qicpack.

JACKSON, L.F. & LIPSCHITZ, S. 1984. *Coastal sensitivity atlas of southern Africa*. Pretoria, Department of Transport.

JAMES, B.S. 2014. *Natural and human impacts on habitat use of coastal delphinids in the Mossel Bay area, Western Cape, South Africa*. MSc: Zoology, University of Pretoria.

JEFFERSON, T.A. & ROSENBAUM, H.C. 2014. Taxonomic revision of the humpback dolphins (*Sousa* spp.), and description of a new species from Australia. *Marine Mammal Science*. **30**: 1494-1541.

KYHN, L.A., TOUGAARD, J., THOMAS, L., DUVE, L.R., STENBACK, J., AMUNDIN, M., DESPORTES, G. & TEILMANN, J. 2012. From echolocation clicks to animal density--acoustic sampling of harbor porpoises with static dataloggers. *Journal of the Acoustical Society of America*. **131**: 550-560.

MARQUES, T.A., THOMAS, L., WARD, J., DIMARZIO, N. & TYACK, P.L. 2009. Estimating cetacean population density using fixed passive acoustic sensors: an example with Blainville's beaked whales. *Journal of the Acoustic Society of America*. **125**: 1982-1994.

NACHTIGALL, P.E., LEMONDS, D.W. & ROITBLAT, H. L. 2000. Psychoacoustic studies of dolphin and whale hearing. In: W.W. AU, A.N. POPPER & R.F. FAY (eds.), *Hearing by whales and dolphins*. New York, Springer.

NUUTTILA, H.K., MEIER, R., EVANS, P.G., TURNER, J.R., BENNELL, J.D. & HIDDINK, J.G. 2013a. Identifying Foraging Behaviour of Wild Bottlenose Dolphins (*Tursiops* *truncatus*) and Harbour Porpoises (*Phocoena phocoena*) with Static Acoustic Dataloggers. *Aquatic Mammals*. **39**: 147-161.

NUUTTILA, H.K., THOMAS, L., HIDDINK, J.G., MEIER, R., TURNER, J.R., BENNELL, J.D., TREGENZA, N.J. & EVANS, P.G. 2013b. Acoustic detection probability of bottlenose dolphins, *Tursiops truncatus*, with static acoustic dataloggers in Cardigan Bay, Wales. *Journal of the Acoustical Society of America*. **134**: 2596-2609.

PAN, W. 2001. Akaike's Information Criterion in Generalized Estimating Equations. *Biometrics*. **57**: 120-125.

PEARSON, C. 2013. *Latitude, Longitude, And Great Circles* [Online]. Available: http://www.cpearson.com/excel/latlong.aspx [Accessed 1 October 2014 2013].

PHILPOTT, E., ENGLUND, A., INGRAM, S. & ROGAN, E. 2007. Using T-PODs to investigate the echolocation of coastal bottlenose dolphins. *Journal of the Marine Biological Association of the United Kingdom*. **87**: 11–17.

RAYMENT, W.J., DAWSON, S. & SLOOTEN, L. 2009. Trialling an automated passive acoustic detector (T-POD) with Hector's dolphins (Cephalorhynchus hectori). *Journal of the Marine Biological Association of the United Kingdom,*. **89**: 1015–1022.

ROBERTS, B.L. & READ, A. J. 2015. Field assessment of C-POD performance in detecting echolocation click trains of bottlenose dolphins (*Tursiops truncatus*). *Marine Mammal Science*. **31**: 169-190.

SAAYMAN, G.S. & TAYLER, C.K. 1973. Social Organisation of Inshore Dolphins (*Tursiops aduncus* and *Sousa*) in the Indian Ocean. *Journal of Mammalogy*. **54**: 993-996.

SHANE, S.H. 1990. Behaviour and ecology of the bottlenose dolphin at Sanibel Island, Florida. *In: The Bottlenose Dolphin*. LEATHERWOOD, S. & REEVES, R. R. (eds.). New York, Academic Press Inc.

SIMILÄ, T. & UGARTE, F. 1993. Surface and Underwater observations of cooperatively feeding killer whales in northern Norway. *Canadian Journal of Zoology*. **71**:1494-1499.

SIMON, M., NUUTTILA, H.K, REYES-ZAMUDIO, M., UGARTE, F., VERFUB, U. & EVANS, P.G. 2010. Passive acoustic monitoring of bottlenose dolphin and harbour porpoise, in Cardigan Bay, Wales, with implications for habitat use and partitioning. *Journal of the Marine Biological Association of the United Kingdom.* **90**: 1539–1545.

TOUGAARD, J., POULSEN, L.R., AMUNDIN, M., LARSEN, F., RYE, J. & TEILMANN, J. 2006. Detection function of T-PODs and estimation of porpoise densities. In: R.H. LEENEY, & N. TREGENZA (eds.), *Static Acoustic Monitoring of Cetaceans*. *Proceedings of the European Cetacean Society, 2006.* Gdynia, Poland. 7-14.

TREGENZA, N. 2012. CPOD.exe : a guide for users. 1-56.

VAN PARIJS, S.M. & CORKERON, P.J. 2001a. Vocalizations and behaviour of Pacific Humpback dolphins *Sousa chinensis*. *Ethology*. **107**: 701-716.

VAN PARIJS, S.M., SMITH, J. & CORKERON, P.J. 2002. Using calls to estimate the abundance of inshore dolphins: a case study with Pacific humpback dolphins *Sousa chinensis*. *Journal of Applied Ecology Letters.* **39**: 853–864.

VERFUSS, U.K., MILLER, L.A., PILZ, P.K. & SCHNITZLER, H.U. 2009. Echolocation by two foraging harbour porpoises (*Phocoena phocoena*). *Journal of Experimental Biology*. **212**: 823-834.

WEDDERBURN, R.W. M. 1974. Quasi-likelihood functions, generalized linear models, and the Gauss-Newton method. *Biometrika*. **61**: 439-447.

WICKHAM, H. & CHANG, W. 2009. *Elegant graphics for data analysis.*, New York, Springer.

YAN, J. & HØJSGAARD, S. 2005. The geepack Package.

ZUUR, A.F., SAVELIEV, A.A., IENO, E.N., WALKER, N.J. & SMITH, G.M. 2009. *Mixed Effect Models and Extensions in Ecology with R*, New York, Springer.

Chapter 4

Investigating species-specific patterns in echolocation clicks to differentiate Indian Ocean bottlenose dolphins (*Tursiops aduncus*) and Indo-Pacific humpback dolphins (*Sousa plumbea*) using a static acoustic data-logger (C-POD).

ABSTRACT

The C-POD is a commercially available and well tested click-logging hydrophone system with custom software that allows for fast and simple production of many measures associated with the echolocation clicks of odontocetes. Combined with its ease of use, long battery life and robustness, it is an ideal choice for long-term monitoring of echolocating dolphins. As the majority of delphinids produce echolocation clicks with similar frequency ranges it is difficult for C-PODs to distinguish between species based only on the frequency ranges of their clicks. However differences in other aspects of their acoustic behaviour may offer alternate methods for species differentiation based on echolocation behaviour alone. This study investigated species-specific differences between Indo-Pacific bottlenose dolphins (*Tursiops aduncus)* and Indian Ocean humpback dolphins (*Sousa plumbea)* from field recordings of the animals. Seven variables obtained from the C-POD, namely, train duration, click rate, average inter-click interval (ICI), average number of clicks per click cycle, frequency range, modal frequency, and rising ICI were investigated. Generalized estimating equations were used to model these co-variables and interactions as an indicator of species differences. Four out of the seven parameters yielded significant pairwise differences ($p < 0.05$); of which only one was significant in the model. Average ICI as well as the interaction between average ICI and modal frequency had the biggest differences between species. Small sample size was an issue for humpback dolphins and further highlighted the difficulties associated with acoustic monitoring of this species.

KEYWORDS: Average number of cycles, click rate, frequency range, inter-click interval (ICI), modal (kHz), species differentiation, train duration.

4.1. INTRODUCTION

Toothed whales and bats evolved a highly complex echolocation system in order to navigate, communicate and hunt in their respective environments (Griffin 1944; Griffin *et al.* 1958; Norris *et al.* 1961; Wahlberg *et al.* 2011). Since the discovery of echolocation in these two very different taxa, intensive laboratory based experiments were conducted to determine capabilities and limitations of these animals (Griffin *et al.* 1958; Au 1993). Over time, more studies were conducted on free-ranging animals, making it possible to determine the exact use of echolocation in natural environments (Evans and Powell 1967; Au 1993; Janik 2009; Verfuss *et al.* 2009; Wahlberg *et al.* 2011).

All toothed whales rely on echolocation to find prey, and to orientate themselves in their environment (Au 1993). Clicks are the primary source of echolocation used during foraging (Au 1993). As they search for a target, dolphins emit bursts of echolocation clicks referred to as a click train (Au 1993). The number of clicks within a train and the time lapse between clicks varies depending on distance to the item of interest, difficulty in detecting the item of interest, presence or absence of the item, and the animal's desire to find the object of interest (Au 1993). Studies on the development of clicks through either learning or pre-birth development are limited (Janik 2009). Two anecdotal reports indicated the presence of either fully developed pre-birth clicks or learnt click production. Bottlenose dolphin calves used echolocation clicks straight after birth (Caldwell and Caldwell 1965, 1967) yet in killer whale calves no echolocation clicks were produced within the first 12 - 15 days, but were detected eight months later (Bowles *et al.* 1988). Echolocation clicks are often described using a series of source parameters which help to define the echolocation abilities of different species of cetaceans (Table 4. 1). Over the years, different characteristics of echolocation clicks have been reported for wild odontocetes, mostly using broadband recording systems.

Table 4.1: The different source parameters most commonly used to characterise the echolocation clicks of different cetacean species (Au 1993; Wahlberg *et al.* 2011).

Characteristic	**Definition**
Peak to peak source level (dB re 1µPa)	The maximum deviation in ambient pressure caused by an echolocation click. Measured as decibels (dB) relative to reference pressure (re) of 1 micropascal (µPa).
Click duration (µs)	Duration of a click in microseconds.
Peak frequency (kHz)	Maximum frequency of echolocation click produced.
Frequency range (kHz)	Range over which echolocation clicks can be produced.
rms bandwidth (kHz)	Effective bandwidth of echolocation click calculated using the root mean square (rms).
-3 dB or -10 dB beam width	Beam width measured at either 3 dB or 10 dB down from the maximum value.
Inter-click interval (ms)	Time between successive clicks measured in microseconds
Directionality index (dB)	Measures the quantity of echolocation clicks (sound) directed towards a particular area against the echolocation clicks (sound energy) being produced.

Echolocation clicks are difficult to describe for several reasons including: 1) they do not propagate as well as other vocalisations such as whistles over long distance (Oswald *et al.* 2007; Roch *et al.* 2011); 2) signal distortion and attenuation increases as distance from hydrophone or angle between hydrophone and dolphin increases (Au 1993; Zimmer *et al.* 2008; Roch *et al.* 2011); 3) the dolphin's ability to vary frequencies and duration of clicks in relation to their behaviour or environment (Au 1993; Madsen *et al.* 2005b). Recent improvements in hydrophone designs and post-recording analysis reduced/incorporated the influence of some of these challenges and increased the possibility of describing clicks to species level (Roch *et al.* 2011).

Some taxa are easy to identify due to the unique nature of their clicks. Porpoises, sperm whales and beaked whales' clicks differ from delphinid clicks in the duration of clicks, inter-click intervals and peak frequencies (Kamminga *et al.* 1996; Madsen *et al.* 2005a; Zimmer *et al.* 2005; Soldevilla *et al.* 2008). Some species of porpoises can be distinguished to a subfamily level based on duration and dominant click frequency (Kamminga *et al.* 1996; Soldevilla *et al.* 2008). Delphinid clicks are difficult to distinguish at a species level due to overlapping frequencies and similar durations (Nakamura and Akamatsu 2003; Soldevilla *et al.* 2008), although research in this field is quite active with many recent and on-going advances. For example, echolocation clicks of Risso's (*Grampus griseus*) and Pacific white-sided (*Lagenorhynchus obliquidens*) dolphins along the coast of southern California contained distinct and unique spectral peaks and notch structures in their click frequency diagram (referred to as a spectrogram) making it possible to identify them to species level (Soldevilla *et al.* 2008). However, the clicks of common bottlenose (*Tursiops truncatus)* and common (*Delphinus spp.)* dolphins from the same area did not have any clear differences in spectral peaks or notches (Soldevilla *et al.* 2008).

Recently studies have linked changes in inter-click intervals (ICI) to animal behaviour. The ICI fluctuates substantially during hunting and prey capture (Au 1993; Janik 2009; Verfuss *et al.* 2009). A ‘feeding buzz’ occurs when clicks produced during foraging are produced very quickly, as the animal approaches the target for either prey capture or investigation. Feeding buzzes are usually defined as having ICIs of less than 10 ms (Verfuss *et al.* 2009; Nuuttila *et al.* 2013a). Variations in the ICI, particularly the occurrence of feeding buzzes are frequently used to infer feeding behaviour and have been used in the study the acoustic behaviour of porpoises (Verfuss *et al.* 2009), beaked whales (Johnson *et al.* 2004), sperm whales (Miller *et al.* 2004), Heaviside’s dolphins (Leeney *et al.* 2011), beluga whales (Castellote *et al.* 2012) and bottlenose dolphins (Nuuttila *et al.* 2013a).

Bottlenose dolphin clicks have been extensively studied in both captive and free-ranging settings and descriptions of their clicks are relatively detailed (Table 4.2) (Wahlberg *et al.* 2012). Humpback dolphin clicks, however, have been poorly described both locally and internationally (Table 4.2) (Van Parijs *et al.* 2002; Elwen *et al.* 2011).

Table 4.2: Reported click characteristics for *T. aduncus* and *Sousa* spp. Due to the overall lack of information on *S. plumbea*, the click traits reported are for the genus in general (Au 1993; van Parijs and Corkeron 2001a; Goold and Jefferson 2004; Jensen *et al.* 2009; Wahlberg *et al.* 2011, Fang *et al.* 2015).

Click characteristics	***T. aduncus***	***Sousa spp.***
Mean peak to peak source level (dB re 1µPa)	177 – 219	177.1 – 207.3
Click duration (µs)	8 - 48	50 - 80 (1.5 - 3 periods)
Centroid frequency (kHz)	45–109	85.1 – 113.1
Frequency range (kHz)	33 – 109	12 - 200
rms bandwidths (kHz)	23 – 54	23.1 – 38.3
-3 dB Beam width	8º	5º - 11º
-10 dB Beam width	10º	13º - 30º
Inter-click interval (ms)	3–255	13.5 – 104.5
Transmission directionality index (dB)	29	Unknown

To effectively describe echolocation clicks based on the traditional source parameters requires a hydrophone system that is able to record at high frequencies and can distinguish on-axis clicks (those made directly toward the hydrophone) from off-axis clicks (Au 1993; Janik 2009; Wahlberg *et al.* 2011). Off-axis clicks are often distorted and therefore appear longer in duration leading to incorrect conclusion regarding the click duration (Au *et al.* 1978; Baumann-Pickering *et al.* 2010). Usually an array of hydrophones or visual confirmation is required to confirm the on-axis nature of echolocation clicks. C-PODs are single hydrophone instruments and were not designed to sample at the high frequencies required to describe echolocation clicks, (Nick Tregenza, pers. comm.). Nevertheless, the C-POD does produce a number of different click parameters that could potentially differentiation the echolocation clicks of species recorded. However the potential of these click parameters to distinguish species has been poorly studied.

4.2. AIMS AND KEY QUESTIONS

This chapter aimed to differentiate *T. aduncus* from *S. plumbea* based only on differences in click parameters using a single C-POD. This was achieved by combining acoustic recordings and visual species confirmation of species, and assessing the effect of group size and behaviour on the C-POD.

This chapter focused on the following questions:

1. Are there any species specific differences in visual or acoustic encounter duration for *T. aduncus* and *S. plumbea*?

2. Are there any species-specific differences in click rate, average inter-click interval, train duration, frequency range, modal frequency, average click cycle or rising inter-click interval for *T. aduncus* and *S. plumbea?*

4.3. METHODS

Many aspects of the methodology and analysis were similar to Chapters one and three, therefore, to avoid repetition a summary of the methods will be used here and only new techniques applying to this section will be covered in detail.

4.3.1. Visual data

Visual data were collected from shore from 17 May 2013 to 31 August 2014 at a single site in Mossel Bay, South Africa (34° 5' 17.31" S and 22° 9' 5.08" E) using binoculars and a surveyor's theodolite. Visual surveys were conducted 3-4 times a week and lasted for 4-6 hours (weather dependent). Active scans were conducted every 30 min and lasted 5 min during which environmental and sighting conditions were also recorded. Once dolphins were sighted they were identified to species level, counted and then tracked using the theodolite with behaviour recorded at each location fix of the theodolite.

4.3.2. Acoustic data

Acoustic data were collected from 17 May 2013 to 27 December 2013 using a single C-POD anchored in water 9.15 m deep. Due to a substantial amount of background noise the C-POD was moved to deeper waters (See Chapter 2 for more information) for the remaining deployments from 6 February 2014 to 2 September 2014 in water 16.31 m deep. The instrument was downloaded monthly and the time, location and depth of deployment were all recorded at each deployment. Upon retrieval, data on the SD were downloaded and prepared for analysis.

4.3.3. Defining Visual and Acoustic Encounters

A visual encounter was defined from the moment of first sighting until the last individual of that same group was no longer visible. An acoustic encounter was defined if an acoustic detection (single or multiple trains) was recorded within 10 min before or after a visual encounter. A new visual and/or acoustic encounter was defined if the group was not seen or detected for more than 10 min. Duration of each encounter was recorded for both visual and acoustic encounters.

4.4. DATA PROCESSING

4.4.1. Visual

Theodolite tracking data were imported into the software programme Pythagoras (Gailey and Ortega-Ortiz 2000) which converted each track into coordinates of longitudes and latitudes.

4.4.2. Acoustic

The raw data (.CP1 format) are imported into the software programme, CPOD.exe (Version 2.044) and run through a train detection algorithm known as a KERNO classifier, which produces a CP3 file containing click trains (Tregenza 2012). The classifier assigned the click trains into one of four filters (‘Hi’, ‘Mod’, ‘Lo’ ‘Doubtful’) based on the probability of it arising from a cetacean source (Tregenza 2012). Only trains within the species class ‘other cet’ (i.e. dolphins) and the train classes ‘High’, ‘Mod’ and ‘Lo’ were exported (See Chapter 1 & 3 for details). The “full train details” function allows for the export of all the parameters of echolocation trains recorded by the C-POD, which were used to investigate differences between the two species (Table 4.3).

Table 4.3: The selected variables exported from the programme C-POD.exe using the 'full train details' function as described in the user manual (Tregenza 2012).

Explanatory variable	**Description**
Train duration (µs)	Total duration of train in microseconds
Average click rate (Cl/s)	Average number of clicks produced in a second
Average inter-click interval (ms)	Average time between successive clicks (AICI)
Average number of click cycles	Average number of cycles produced by the clicks in the train
F-range	Max click frequency (kHz) - min click frequency (kHz)
Modal (kHz)	Modal frequency of train clicks in kHz
Inter-click interval rising	% of ICI that are longer than Previous ICI

4.5. DATA ANALYSIS

All modelling and analyses were conducted in the software program R (Version 3. 01) using the R-Studio interface (Version 0.98.1103), applying the software packages geepack (Yan and Højsgaard 2005) for the models, MuMln (Burnham and Anderson 2002) for model selection, and ggplots2 (Wickham 2009) for the graphs. Although the changes in C-POD location may have affected overall detection probability (Chapter 2), it is not likely to have affected the ability of the C-POD to describe parameters from individual clicks. Thus, data from both 'before' and 'after' the C-POD was moved were used. Due to the non-parametric nature of the data, a Mann-Whitney U-test for independent data (Logos 2009) was used to test for significant differences between the explanatory variables for each species.

Generalized estimating equations (GEEs) were used to model the likelihood of each acoustic parameter arising from either species. The response variable for this analysis was species, where bottlenose dolphin detections were assigned the number 1 and matched humpback dolphin detections were assigned the number 0. A binomial family was chosen. All the variables were modelled together as co-variables and all possible interactions were also included in the models (Table 4.4). In the initial models the variables and interactions remained constant whilst the correlation structure was varied between ‘Independent’, ‘Exchangeable’ and ‘Auto-Regressive – 1’ (Zuur *et al.* 2009). Model selection for the best fitting correlation structure was based on the model with the lowest QIC value (Pan 2001; Hocking 2012). Using the selected correlation structure subsequent models were run using different combinations of co-variables and interactions. Model selection for these models was based on the model with the lowest QICu value (Hardin and Hilbe 2003) (See Chapter 3 for more information).

Table 4.4: The click train variables used in the GEE model including the response variable (*) and the codes used in the model to distinguish each one.

Variable	Code
Species*	SPECIES
Train duration (µs)	TRD
Average click rate (Cl/s)	CLS
Average inter-click interval (ms)	AVICI
Average number of click cycles	ANCY
F-range	FR
Modal (kHz)	MOD
Inter-click interval rising	ICIR

4.6. RESULTS

4.6.1. Encounters

The total number of visual encounters was similar for both species however the number of matched trains was higher for bottlenose dolphins than humpback dolphins (Table 4.5). The mean number of trains per acoustic encounter, mean visual encounter duration and mean acoustic encounter duration were all higher for bottlenose dolphins than humpback dolphins (Table 4.5). The mean group size per encounter was larger for bottlenose dolphins than humpback dolphins (Table 4.5). The longest visual encounter and longest acoustic encounters were similar for both species (Table 4.5).

Table 4.5: Summary statistics showing the differences in visual and acoustic encounters for bottlenose dolphins (Ta) and humpback dolphins (Sc). The 95% confidence intervals are also indicated.

	Bottlenose dolphins (Ta)	**Humpback dolphins (Sc)**
Total number of visual encounters	27	32
Click trains matched to visual theodolite fixes in all encounters	1508	95
Mean number of trains per acoustic encounter	57.44 (95% CI: 17.72 - 97.17)	3.04 (95% CI: 0.66 - 5.49)
Mean visual encounter duration (min)	40.33 (95% CI: 24.32 - 56.35)	23.88 (95% CI: 14.43 min - 33.32 min)
Mean acoustic encounter duration (min)	18.52 (95% CI: 6.95 - 30.08)	11.63 (95% CI: 1.97 - 21.36)
Mean group size per encounter	72.25 (95% CI: 52.7 – 91.8)	4.88 (95% CI: 3.03 – 4.56)
Longest visual encounter (min)	128 (Group size = 110 Behaviour = Travelling)	120 (Group size = 2 Behaviour = Travelling)
Longest acoustic encounter (min)	107 (406 trains detected)	93 (20 trains detected)

4.6.2. Pairwise comparison of click and click-train features

Bottlenose dolphins had significantly higher click rates, shorter inter-click intervals and shorter train durations than humpback dolphins (Table 4.6 & Figure 4.1). Frequency range, modal frequency, average click cycles and rising inter-click interval were similar for both species (Table 4.6).

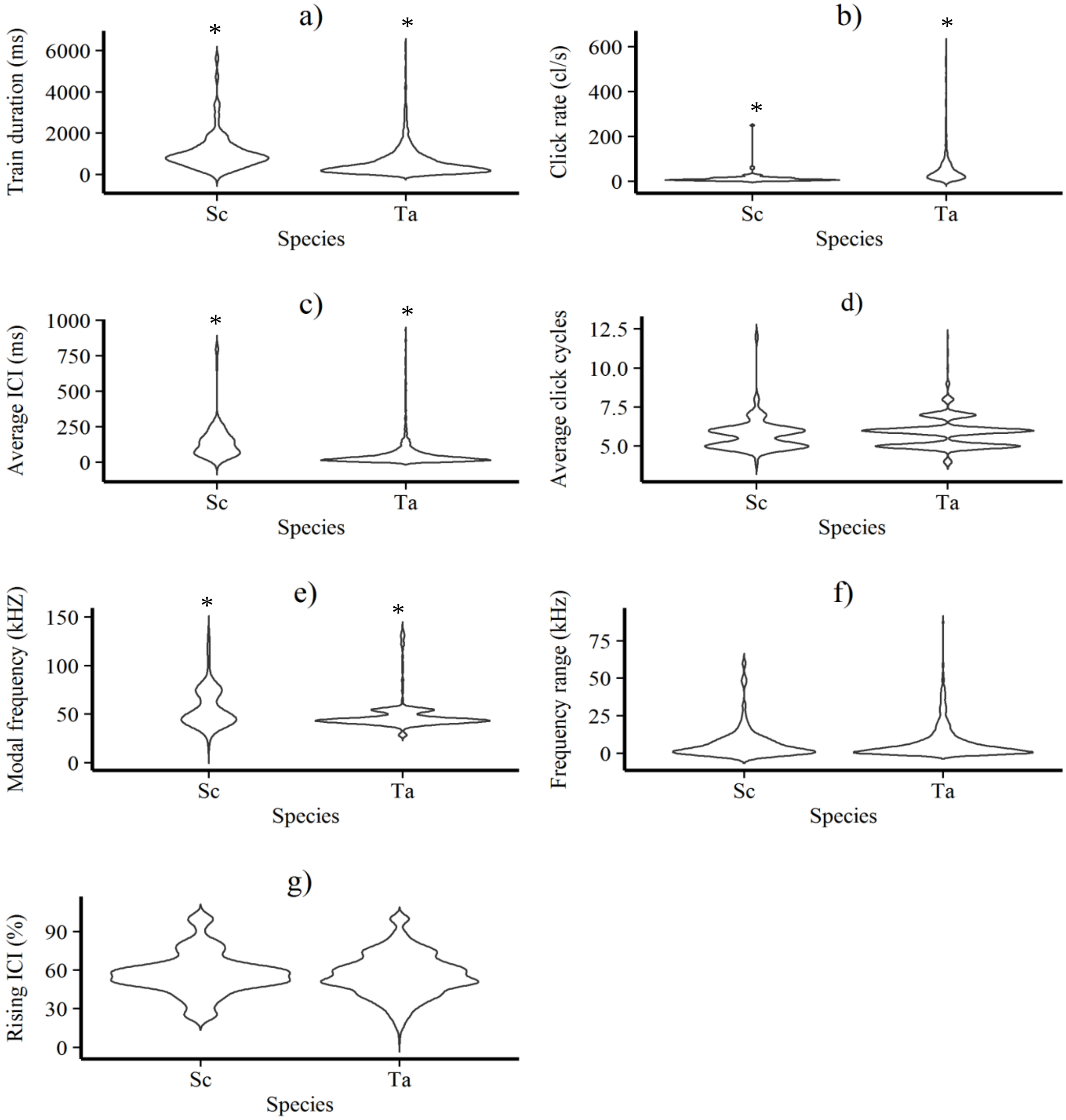

Figure 4.1: The differences between bottlenose (Ta) and humpback (Sc) dolphin click trains in relation to each explanatory variable (a-g). Significance at the 5% level is indicated by *. Overall number of trains for bottlenose dolphins was 1508 and 95 for humpback dolphins. Width of violin plots indicates distribution of the sample across the measured parameter.

Table 4.6: Mean values for each explanatory variable for *T. aduncus* and for *S. plumbea* individuals. A Mann-Whitney U-test (U) was performed on each parameter and values were tested for significance at the 5% level. The 95% confidence intervals for each parameter are indicated in brackets. Train duration and average inter-click interval are represented in milliseconds (ms).

	Species			
Explanatory variable	**T. aduncus (1)**	**S. plumbea (0)**	**U**	**P(U)**
Train duration (ms)	584.53 (550.18 – 618.88)	1080.73 (899.81 – 1261.65)	35501	<2.2e-16
Clicks rate (Cl/s)	57.02 (53.15 - 61.25)	14.02 (8.64 - 19.04)	121367	<2.2e-16
Average inter-click interval (ms)	55.91 (51.23 - 60.60)	146.88 (119.76 – 174.00)	21965	<2.2e-16
Average click cycles (Ncyc)	5.83 (5.79 - 5.88)	5.72 (5.51 - 5.92)	78535	0.09
Frequency range (kHz)	7.37 (6.83 - 7.91)	6.64 (4.52 - 8.76)	75524.5	0.37
Modal frequency (kHz)	48.83 (48.00 - 49.67)	56.72 (52.72 - 60.72)	52631.5	1.331e-05
Rising inter-click interval (%ICI)	0.62 (0.61 - 0.63)	0.62 (0.59 - 0.66)	69881.5	0.67

4.6.3. Model results

The initial GEE models included all the possible co-variables (SPECIES ~ TRD + CLS + AVICI + MOD + ANCY + FR + ICIR), with a binomial family structure and only the correlation structure varied between 'Independent', 'Exchangeable' and 'Auto-regressive -1'). The QIC value for each model was estimated and the model with the lowest QIC value was selected. The model with the 'Independent' correlation structure had the lowest QIC value (460), and was therefore used for all further models (models with 'Exchangeable' and 'Auto-Regressive -1' correlation structures had QIC values of 461.53 and 464 respectively). Subsequent models tested the ability of different combinations of C-POD.exe export variables and potential interactions to distinguish the two species, namely bottlenose and humpback dolphins. Each interaction and then co-variable was removed or added and the QICu value for each model combination was calculated (Table 4.7). The model with the lowest QICu was selected as the model that best described the data (Table 4.7).

Table 4.7: Generalized estimating equation models (GEEs) of different combination of variables and interactions used to model differences between bottlenose and humpback dolphins. The model with the smallest QICu is indicated in bold.

Models	**QICu**
Species ~ AVICI + MOD + CLS + TRD + ICIR + FR + ANCY	476
Species ~ AVICI + MOD + CLS + TRD + ICIR + FR	475
Species ~ AVICI + MOD + CLS + TRD + ICIR	481.60
Species ~ AVICI + MOD + CLS + TRD	480
Species ~ AVICI + MOD + CLS	479.51
Species ~ AVICI + MOD	538.7
Species ~ AVICI + TRD	554
Species ~ AVICI	552.45
Species ~ TRD + MOD	550.0
Species ~ AVICI + MOD + TRD	540.6
Species ~ AVICI * MOD + AVICI * CLS + AVICI * TRD + MOD * CLS + MOD * TRD + TRD * CLS	452.07
Species ~ AVICI * MOD + AVICI * CLS + AVICI * TRD + MOD * CLS + MOD * TRD	456.99
Species ~ AVICI * MOD + AVICI * CLS + AVICI * TRD + MOD * CLS + TRD * CLS	**451.1**
Species ~ AVICI * MOD + AVICI * CLS + AVICI * TRD + TRD * CLS	453.37
Species ~ AVICI * MOD + AVICI * CLS + TRD * CLS	460.40
Species ~ AVICI * MOD + TRD * CLS	458.75
Species ~ AVICI + MOD + TRD * CLS	472.38

The best fitting model included the co-variables average inter-click interval, modal frequency, clicks per second and train duration as well as interactions between a) average inter-click interval and modal frequency; b) average inter-click interval and clicks per second; c) modal frequency and clicks per second; d) clicks per second and train duration (Table 4.8). The co-variables frequency range, average number of cycles and rising ICI interval were not included in the final model. Of all the co-variables included in the model only average inter-click interval was significant (Wald Test, $P < 0.05$, Table 4.8) as well as the interaction between average inter-click interval and modal frequency (Wald Test, $P < 0.05$, Table 4.8).

Table 4.8: Model parameter estimates and their significance from generalized estimating equation model (GEE) on the differences in average inter-click interval (AICI), modal frequency (MOD), click per second (CLS) and train duration (TRD) between bottlenose (1) and humpback dolphins (0). Selected model was SPECIES ~ AICI * MOD + AICI * CLS + MOD * CLS + CLS * TRD, family = binomial, correlation structure = independent with average inter-click interval, modal frequency, clicks per second and train duration as co-variables as well as potential interactions between the co-variables.

Coefficients	**Estimate**	**Standard Error**	**Wald**	**P(>|W|)**
(Intercept)	-4.06e+00	3.21e+00	1.59	0.207
AICI	2.13e-02	1.11e-02	3.66	0.056 *
MOD	4.20e-02	3.14e-02	1.79	0.180
CLS	6.27e-02	7.39e-02	0.72	0.396
TRD	-8.96e-04	1.04e-03	0.74	0.390
AICI * MOD	-4.85e-04	1.91e-04	6.41	0.011 *
AICI * CLS	3.68e-03	2.05e-03	3.23	0.072 .
MOD * CLS	-5.99e-04	5.82e-04	1.06	0.303
CLS * TRD	1.28e-04	1.08e-04	1.41	0.235

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1.

4.7. DISCUSSION

C-PODs and their predecessors T-PODs were originally designed to monitor the presence and absence of porpoises and not for in-depth analyses of either dolphin or porpoise click characteristics (Tregenza *et al.* 2012). Their simplicity of use and long-deployment live-span make them attractive options for monitoring odontocete species. Some species and taxon differentiation is already possible between dolphins and porpoises and between some porpoise species (Bailey *et al.* 2009; Simon *et al.* 2010; Nuuttila *et al.* 2013a). This is the first study in South Africa that, to our knowledge, has attempted to distinguish these two closely related dolphin species based solely on parameters obtained from a C-POD.

Despite extensive field effort of over 12 months, the overall sightings of humpback dolphins were low and the final sample size remained quite small even after an increase in survey effort from 12 hours to 24 hours per week. A final sample size of 95 click trains matched to visual theodolite fixes for humpback dolphins compared to 1508 click trains for bottlenose dolphins made interpretation of the results more challenging. A disproportionally small sample size can result in the over- or-under estimation of the significance of a particular variable making it difficult to assess if actual differences do exist (Lipschitz *et al.* 1994).

In this study, visual and acoustic encounters were longer for bottlenose dolphins than for humpback dolphins and the number of trains per encounter and maximum number of trains recorded during an encounter were also higher for bottlenose dolphins. Based on the pairwise analysis, modal frequency, average inter-click interval, click rate and train duration had the greatest differences between the two species. However in the models; the only co-variable that was significant was average ICI whilst the only interaction that was significant was between average ICI and modal frequency. These results suggest that humpback dolphins click at a slightly lower modal frequency and that click trains are longer in duration but produced more slowly than those of bottlenose dolphins.

The differences in visual and acoustic encounter duration between each species is most likely due to differences in group dynamics from group size and behaviour to habitat use and may vary considerably between different deployment locations. In this study, the average group size for bottlenose dolphins was much larger than the average group size of humpback dolphins. A larger group size increases the likelihood of dolphins being both visually and acoustically detected. During the study large groups of widely distributed bottlenose dolphins were often observed travelling across the bay instead of following the coastline. As the C-POD was located in deeper waters (See Chapter 2) these larger groups of dolphins would be closer to the C-POD and therefore more likely to be detected. The opposite was apparent for humpback dolphins which had very small group sizes and were often observed travelling along the coastline in very shallow waters. As these shallow waters are often associated with high levels of background noise that may interfere with the ability of the C-POD to detect the clicks (Chapter 2) resulting in a lower detections.

The pairwise analysis for train duration indicated that humpback dolphins produce longer trains than bottlenose dolphins which was supported by the model although train duration itself was not significant. Studies of species-specific differences in train duration have not been reported to our knowledge as most available literature focusses on the characteristics of individual clicks rather than trains (van Parijs and Corkeron 2001a; Goold and Jefferson 2004; Soldevilla *et al.* 2008; Wahlberg *et al.* 2011). Therefore, there is the potential that this parameter may serve as a useful indicator of species-specific differences, and would benefit from further study.

The pairwise analysis of click rate showed bottlenose dolphins to have a click rate higher than that of humpback dolphins which was supported by the model. This seems to indicate that bottlenose dolphins produce more clicks per second than humpback dolphins. However, click rate itself was not significant (Wald Test, $P > 0.05$, Table 4.6) in the model which may be due to the fact that the variation observed is due to differences within the species and not actual species-specific differences. Behaviours such as the characteristic ‘feeding buzzes’ mentioned earlier (see Chapter 3) could explain the variations in click rates between bottlenose and humpback dolphins. However, as only 8.89 % of bottlenose dolphin trains and 4.2 % of humpback dolphin’s trains during this study had a minimum ICI below the 10 ms (Verfuss *et al.* 2009) characteristic of ‘feeding buzzes’; it is therefore unlikely that ‘feeding buzzes’ influenced the overall click rate significantly. None of the interactions involving click rate were significant ($P > 0.05$) which further highlights that the differences in click rates might be due to within species variations such as behaviour rather than differences between the species.

The similarity between frequency range of clicks and average click cycles per train between the two species is expected because the majority of delphinid species produce clicks in a similar broad frequency ranges (Au 1993; Soldevilla *et al.* 2008; Roch *et al.* 2011). The majority of delphinids can produce distinct broad-band clicks with frequencies that extend to well above 100 kHz (Au 1993; Janik 2009). The number of cycles within an echolocation click has been used to distinguish Narrow Band High Frequency (NBHF) species from broad-band species. NBHF species produce clicks with 5 cycles which have increasing amplitude before decreasing exponentially (Nakamura and Akamatsu 2003) whilst broad-band click species produce echolocation clicks with only one or two cycles with the first cycle reaching maximum amplitude (Morisaka and Connor 2007). Due to the fact that broad-band clicking species have overlapping frequency ranges and similar peaks in amplitude it is unlikely that species differentiation between two broad-band species is possible based on frequency range or number of click cycles.

Rising inter-click interval is also related to feeding buzzes and reflects the behaviour of each species especially when foraging (Tregenza 2012). As the number of clicks within a train increases, the percentage of ICI rising tends to decrease. As click rate increases during foraging it becomes more challenging to assess within species variation from differences between species (Tregenza 2012).

Distinct differences were evident in the pairwise comparison of modal frequencies which was supported by the model although modal frequency on its own was not significant (Wald Test, $P < 0.05$, Table 4.6). The differences in modal frequencies could potentially be due to differences in modal peaks of each species. Bottlenose dolphins (*T. aduncus* and *T. truncatus*) were found to produce on-axis echolocation clicks with unimodal (single) peaks in frequency (Wahlberg *et al.* 2011) whilst humpback dolphins in Australia (*S. sahulensis)* produced what appeared to be echolocation clicks with bimodal peaks (two peaks) in frequency (Goold and Jefferson 2004). However caution must be used when considering modal frequencies as the C-POD cannot distinguish off-axis and on–axis clicks which could affect the modal frequency. Bottlenose dolphins have been recorded with bimodal peaks in echolocation click frequencies when click trains were recorded as off-axis echolocation clicks (Wahlberg *et al.* 2011). In addition, modal frequencies produced by the CPOD are considered unstable when the number of clicks in a train is low as this leads to an under /over estimation of the modal frequencies peaks (Tregenza 2012).

The differences in average ICI for the pairwise comparison indicated that bottlenose dolphins have a shorter ICI than humpback dolphins which was supported by the model as average ICI was significant. A shorter average ICI for bottlenose dolphins could potentially be attributed to the higher click rate and a longer average ICI for humpback dolphins can attributed to the lower click rate. As bottlenose dolphins (in this study), echolocate at a rate of 57 clicks per second the time between clicks (ICI) was therefore much shorter, whilst humpback dolphin's echolocate at a much slower rate of 14 clicks per second and therefore the time between clicks became longer.

The only interaction that was significant was between average ICI and modal frequency which indicated that as average inter-click interval decreases modal frequency also decreases. As bottlenose dolphins produce unimodal clicks with a much shorter click duration at a higher click rate (Wahlberg *et al.* 2011) than humpback dolphins which have bimodal clicks (Goold and Jefferson 2004) with longer click durations (van Parijs and Corkeron 2001a); it is possible that bottlenose dolphins have shorter average ICI's than humpback dolphins. Although a recent study was able to differentiate between porpoises and bottlenose dolphins based on their ICI (Nuuttila *et al.* 2013a) it appears that no other studies (to our knowledge) have used ICI to differentiate two closely related species of dolphins. Therefore, it seems that average ICI along with its interactions may serve as a useful indicator of species-specific differences; this should therefore be studied in more detail.

4.8. CONCLUSION

The ability to distinguish dolphin species based solely on their clicks is considered to quite difficult as clicks are easily altered by their surrounding environment and by off-axis effects. The use of a C-POD to differentiate species has been limited to distinguishing NBHF species such as porpoises from broad band species such as bottlenose dolphin. Until very recently (Robbins *et al.* 2015), no other C-POD studies had focused on species-specific differences between closely related species. As a result this study serves as a baseline indicator of the potential of a C-POD to differentiate species. Average ICI was the only co-variable out of the seven co-variables that were analysed to have significant species specific differences indicating some potential for species specific differences. The interactions between average ICI, modal frequency and train duration highlighted even stronger differences between the species which supports the possibility that species differentiation might be possible using combination of co-variables. Although the small sample size for humpback dolphins in this study made it difficult to draw any definitive conclusions there are indications that the parameters produced by the C-POD might be useful in differentiating species. Future studies with a larger sample size and improved detection capabilities might provide more definitive information on the ability of the C-POD to differentiate two closely related species.

4.9. REFERENCES

AU, W.W. 1993. Characteristics of Dolphin Sonar Signals. *In: The Sonar of Dolphins.* Berlin, Heidelberg, Springer-Verlag.

AU, W.W., FLOYD, R.W. & HAUN, J.E. 1978. Propagation of atlantic bottlenose dolphin echolocation signals. *Journal of the Acoustical Society of America.* **64**: 411–422.

AU, W.W., FLOYD, R.W., PENNER, R.H. & MURCHISON, A.E. 1974. Measurement of echolocation signals of the Atlantic bottlenose dolphin, Tursiops truncatus Montagu, in open waters. *Journal of the Acoustical Society of America.* **56**: 1280-1290.

AU, W.W., PENNER, R.H. & KADANE, J. 1982. Acoustic behaviour of echolocating Atlantic bottlenose dolphins. *Journal of the Acoustical Society of America.* **71**: 1269-1275.

BAUMANN-PICKERING, S., WIGGINS, S.M., HILDEBRAND, J.A., ROCH, M.A. & SCHNITZLER, H.U. 2010. Discriminating features of echolocation clicks of melon-headed whales (*Peponocephala electra*), bottlenose dolphins (T*ursiops truncatus*), and Gray's spinner dolphins (*Stenella longirostris longirostris*). *Journal of the Acoustical Society of America.* **128**: 2212-2224.

BURHAM, K.P. & ANDERSON, D.R. 2002. *Model selection and multimodel inference; a pratical information - theoretic approach 2nd edition*. New York, Springer- Verlag.

BOWLES, A.E., YOUNG, W.G. & ASPER, E.D. 1988. Ontogeny of stereotyped calling of a killer whale calf, *Orcinus orca*, during her first year. *Rit Fiskideildar*. **11**: 251–275.

CALDWELL, M.C. & CALDWELL, D.K. 1965. Individualized whistle contours in bottlenosed dolphins *(Tursiops truncatus)*. *Nature.* **207**: 434-435.

CALDWELL, M.C. & CALDWELL, D.K. 1967. Intraspecific transfer of information via the pulsed sound in captive odontocete cetaceans. In: R.G. BULLOCK (ed.), *Animal sonar systems - biology and bionics.* France, Laboratoire Physiologie Acoustique. Jouy-en-Josas.

CASTELLOTE, M., LEENEY, R.H., O'CORRY-CROWE, G., LAUHAKANGAS, R. KOVACS, K.M., LUCEY, W., KRASNOVA, V., LYDERSEN, C., STAFFORD, K.M. & BELIKOV, R. 2012. Monitoring white whales (*Delphinapterus leucas*) with echolocation loggers. *Polar Biology*. **36**: 493-509.

ELLIOTT, R.G., DAWSON, S.M. & RAYMENT, W.J. 2011. Optimizing TPOD settings and testing range of detection for bottlenose dolphins in Doubtful Sound, New Zealand. *Journal of the Marine Biological Association of the United Kingdom.* 1-7.

ELWEN, S.H., FINDLAY, K.P., KISZKA, J. & WEIR, C.R. 2011. Cetacean research in the southern African subregion: a review of previous studies and current knowledge. *African Journal of Marine Science.* **33**: 469–493.

EVANS, W.E. & POWELL, B.A. 1967. Discrimination of different metallic plates by an echolocating delphinid. In: R.G. BUSNEL (ed.), *Animal sonar systems, biology and bionics.* Laboratoire de Physiologie Acoustique.

FANG, L., Li, S., WANG, K., WANG, Z., SHI, W. & WANG, D. 2015. Echolocation signals of free-ranging Indo-Pacific humpback dolphins (*Sousa chinensis)* in Sanniang Bay, China. *Journal of the Acoustical Society of America.* **138**(3): 1346 -1352.

GAILEY, G. & ORTEGA-ORTIZ, J. G. 2000. *User's manual: 'Pythagoras'. (Version:1.2.15). Theodolite cetacean tracking* [Online]. Texas A & M University, Galveston, USA. Available: [Available at: http://www.tamug.tamu.edu/mmrp/pythagoras].

GOOLD, J.C. & JEFFERSON, T.A. 2004. A Note on Clicks Recorded from Free-Ranging Indo-Pacific Humpback Dolphins, *Sousa chinensis*. *Aquatic Mammals.* **30**: 175-178.

GREGG, J.D., DUDZINSKI, K.M. & SMITH, H.V. 2007. Do Dolphins Eavesdrop on the Echolocation Signals of Conspecifics? *International Journal of Comparative Psychology*. **20**: 65-88.

GRIFFIN, D.R. 1944. Echolocation in blind men, bats and radar. *Science.* **100**: 589-590.

GRIFFIN, D.R., NOVICK, A. & KORNFIELD, M. 1958. The Sensitivity of Echolocation in the fruit bat, *Rousettus*. *Biological Bulletin.* **115**: 107-113.

HARDIN, J.W. & HILBE, J.M. 2003. *Generalized Estimating Equations* New York, Chapman and Hall.

HOCKING, D.J. 2012. *Model Selection for generalized estimating equations using QIC* [Online]. Available: http://github.com/djhocking/qicpack.

HØJSGAARD, S., HALEKOH, U. & YAN, J. 2006. The R package geepack for generalized estimating equations. *Journal of Statistical Software.* **15**: 1-11.

JANIK, V.M. 2009. Acoustic Communication in Delphinids. *Advances in the Study of Behavior.* **40**: 1-34.

JENSEN, F.H., BEJDER, L., WAHLBERG, M. & MADSEN, P.T. 2009. Biosonar adjustments to target range of echolocating bottlenose dolphins (*Tursiops sp*.) in the wild. *Journal of Experimental Biology.* **212**: 1078-1086.

JOHNSON, M., MADSEN, P.T., ZIMMER, W.M., DE SOTO, N.A. & TYACK, P.L. 2004. Beaked whales echolocate on prey. *Proceedings of the Royal Society B: Biological Sciences.* **271 Suppl 6**: S383-386.

KAMMINGA, C., COHEN STUART, A. & SILBER, G.K. 1996. Investigations on cetacean sonar XI: Intrinsic comparison of the wave shapes of some members of the Phocoenidae family. *Aquatic Mammals.* **22**: 45-55.

LEENEY, R.H., CARSLAKE, D. & ELWEN, S.H. 2011. Using Static Acoustic Monitoring to Describe Echolocation Behaviour of Heaviside's Dolphins (*Cephalorhynchus heavisidii*) in Namibia. *Aquatic Mammals.* **37**: 152-159.

LIPSCHITZ, S.R., FITZMAURICE, G.M., ORAV, E.J. & LAIRD, N.M. 1994. Performance of generalized estimating equations in practical situations. *Biometrika.* **73**: 270-278.

LOGOS, T. 2009. *Wilcoxo-Mann-Whitney-rank sum test (or test U)* [Online]. Available: http://www.r-bloggers.com/wilcoxon-mann-whitney-rank-sum-test-or-test-u/ 2015].

MADSEN, P.T., CARDER, D.A., BEDHOLM, K. & RIDGWAY, S.H. 2005a. Porpoise clicks from a sperm whale nose–Convergent evolution of 130 kHz pulses in toothed whale sonars? *Bioacoustics*. **15**: 195–206.

MADSEN, P.T., JOHNSON, M., DE SOTO, N.A., ZIMMER, W.M. & TYACK, P. 2005b. Biosonar performance of foraging beaked whales (Mesoplodon densirostris). *Journal of Experimental Biology*. **208**: 181-194.

MILLER, P.J., JOHNSON, M.P. & TYACK, P.L. 2004. Sperm whale behavior indicates the use of echolocation click buzzes ‘creaks’ in prey capture. *Proceedings of the Royal Society B: Biological Sciences*. 2239–2247.

MORISAKA, T. & CONNOR, R.C. 2007. Predation by killer whales (Orcinus orca) and the evolution of whistle loss and narrow-band high frequency clicks in odontocetes. *Journal of Evolutionary Biology*. **20**: 1439-1458.

NAKAMURA, K. & AKAMATSU, T. 2003. Comparison of click characteristics among Odontocete species. In: J.A. THOMAS, C.F. MOSS & M. VATER (eds.), *Echolocation in Bats and Dolphins*. Chicago, University of Chicago Press.

NORRIS, K.S., PRESCOTT, J.H., ASA-DORIAN, P.V. & PERKINS, P. 1961. An experimental demonstration of echolocation behavior in the porpoise, *Tursiops trucatus* (Montagu). *Biology Bulletin*. **120**: 163-176.

NUUTTILA, H.K., MEIER, R., EVANS, P.G., TURNER, J.R., BENNELL, J.D. & HIDDINK, J.G. 2013a. Identifying Foraging Behaviour of Wild Bottlenose Dolphins (*Tursiops truncatus*) and Harbour Porpoises (*Phocoena phocoena*) with Static Acoustic Dataloggers. *Aquatic Mammals*. **39**: 147-161.

NUUTTILA, H.K., THOMAS, L., HIDDINK, J.G., MEIER, R., TURNER, J.R., BENNELL, J. D., TREGENZA, N.J. & EVANS, P.G. 2013b. Acoustic detection probability of bottlenose dolphins, *Tursiops truncatus*, with static acoustic dataloggers in Cardigan Bay, Wales. *Journal of the Acoustical Society of America*. **134**: 2596-2609.

OSWALD, J.N., RANKIN, S., BARLOW, J. & LAMMERS, M.O. 2007. A tool for real-time acoustic species identification of delphinid whistles. *Journal of the Acoustical Society of America*. **122**: 587-595.

PAN, W. 2001. Akaike's Information Criterion in Generalized Estimating Equations. *Biometrics*. **57**: 120-125.

PEARSON, C. 2013. *Latitude, Longitude, And Great Circles* [Online]. Available: http://www.cpearson.com/excel/latlong.aspx [Accessed 1 October 2014 2013].

ROBBINS, J.R., BRANDECKER, A., CRONIN, M., JESSOPP, M., MCALLEN, R. & CULLOCH, R. 2015: Handling dolphin detections from C-PODs, with the development of acoustic parameters for verification and the exploration of species identification possibilities. *Bioacoustics*. 1-12.

ROCH, M.A., KLINCK, H., BAUMANN-PICKERING, S., MELLINGER, D.K., QUI, S., SOLDEVILLA, M.S. & HILDEBRAND, J.A. 2011. Classification of echolocation clicks from odontocetes in the Southern California Bight. *Journal of the Acoustical Society of America*. **129**: 467-475.

SOLDEVILLA, M.S., HENDERSON, E.E., CAMPBELL, G.S., WIGGINS, S.M., HILDEBRAND, J.A. & ROCH, M.A. 2008. Classification of Risso's and Pacific white-sided dolphins using spectral properties of echolocation clicks. *Journal of the Acoustical Society of America*. **124**: 609-624.

TREGENZA, N. 2012. CPOD.exe : a guide for users. 1-56.

VAN PARIJS, S.M. & CORKERON, P.J. 2001a. Vocalizations and behaviour of Pacific Humpback dolphins *Sousa chinensis*. *Ethology*. **107**: 701-716.

VAN PARIJS, S.M., SMITH, J. & CORKERON, P.J. 2002. Using calls to estimate the abundance of inshore dolphins: a case study with Pacific humpback dolphins *Sousa chinensis*. *Journal of Applied Ecology Letters*. **39**: 853–864.

VERFUSS, U.K., MILLER, L.A., PILZ, P.K. & SCHNITZLER, H.U. 2009. Echolocation by two foraging harbour porpoises (*Phocoena phocoena*). *Journal of Experimental Biology*. **212**: 823-834.

WAHLBERG, M., JENSEN, F.H., SOTO, N.A., BEEDHOLM, K., BEJDER, L., OLIVEIRA, C., RASMUSSEN, M., SIMON, M., VILLADSGAARD, A. & MADSEN, P.T. 2011. Source parameters of echolocation clicks from wild bottlenose dolphins (*Tursiops aduncus* and *Tursiops truncatus*). *Journal of the Acoustical Society of America*. **130**: 2263-2274.

WICKHAM, H. 2009. *ggplot2: elegent graphics for data analysis* [Online]. New York: Springer. Available: http://had.co.nz?ggplot2/book.

ZIMMER, W.M., JOHNSON, M.P. & MADSEN, P.T. 2005. Three-dimensional beam pattern of regular sperm whale clicks confirms bent-horn hypothesis. *Journal of the Acoustical Society of America*. **117**: 1473-1485.

ZIMMER, W.M., HARWOOD, J., TYACK, P.L., JOHNSON, M.P. & MADSEN, P.T. 2008. Passive acoustic detection of deep-diving beaked whales. *Journal of the Acoustical Society of America*. **124**: 2823-2832.

ZUUR, A.F., SAVELIEV, A.A., IENO, E.N., WALKER, N.J. & SMITH, G.M. 2009. *Mixed Effect Models and Extensions in Ecology with R*, New York, Springer.

Chapter 5

5.1. GENERAL DISCUSSION

This study aimed to assess the suitability of using a static acoustic click detector (C-POD) to monitor delphinids, along the Cape south coast of South Africa. In Chapter 2 the impact of noise on C-PODs and the subsequent challenges associated with detecting dolphins were investigated. Chapter 3 investigated the detection parameters of a C-POD for two closely-related dolphin species namely the Indo-Pacific bottlenose dolphin (*Tursiops aduncus)* and the Indian Ocean humpback dolphin *(Sousa plumbea).* Lastly, Chapter 4 investigated the potential ability to distinguish between these two species based on differences in individual click parameters measured by the C-POD.

This study was the first (to our knowledge) that used a C-POD to study Indo-Pacific bottlenose dolphins and Indian Ocean humpback dolphins in Southern Africa. The overall goal of this study was to determine the fundamental parameters of detection probability, detection range and species differentiation. T-PODs (earlier versions of C-PODs) and C-PODs were initially designed to study cetacean species with Narrow Band High Frequency (NBHF) echolocation clicks such as harbour porpoises (*Phocoena phocoena*), and dolphins in the genus *Cephalorhynchus*, therefore its application to dolphin species which use broad-brand clicks is less versatile and accurate due to the more variable nature of broadband clicks (N. Tregenza, Chelonia, pers. comm.). Furthermore, as a data logger, the C-POD provides limited data for analysis compared to a recording hydrophone system. However, the bandwidth at which the C-POD records (20 - 160 kHz) and duration for which it can record at this bandwidth (up to 4 months) is currently unmatched by any autonomous recording system commercially available. These features counterbalance many of the drawbacks of the instrument making it an attractive option for studies where; 1) regular visual surveying is challenging (Castellote *et al.* 2012); 2) there is a mix of NBHF and broad-band species (Simon *et al.* 2010; Nuuttila *et al.* 2013a) or 3) to ensure minimal disturbance of the target species (in the case of boat-based studies) (Elliott *et al.* 2011; Roberts and Read 2015).

The detection ability of a C-POD is largely influenced by its environment, direction of echolocation beam, behaviour of dolphins and sensitivity of the particular unit (Au 1993; Nuuttila *et al.* 2013b; Roberts and Read 2015). In this study the detection ability of the C-POD was influenced by its environment and differences in group size and to some extent behaviour of each species. Continuous noise was the dominant source of disturbance and most likely caused by clicking shrimp or the movement of sediment in shallow waters.

Several papers also illustrated a behavioural change by dolphins in response to noisier marine environments (Richardson *et al.* 1995; Van Parijs and Corkeron 2001c; Buckstaff 2004; Morisaka *et al.* 2005a; Nowacek *et al.* 2007). Bottlenose (*T. aduncus*) and humpback dolphins (*S. chinensis*) whistled more in areas with higher levels of ambient noise caused by boat activity, sediment transport noise and/or snapping shrimp (Van Parijs and Corkeron 2001c). They also altered the frequency and duration of their whistles in relation to the external noise levels (Van Parijs and Corkeron 2001c; Morisaka *et al.* 2005a). Due to the likelihood of there being clicking shrimp around the reef and the significant change in detections after moving the C-POD; it is possible that both species were altering their sound production (whistling more or just going silent) in response to the increased noise levels of the reef-dominated shallow inshore zone where the C-POD was initially located. However, once the C-POD was relocated to a ‘quieter area’, C-POD detections of possible cetacean clicks increased significantly as the C-POD memory was no longer being filled by background noises. Nevertheless, a more detailed analysis of the ambient noise levels within Mossel Bay using more specialised equipment is recommended before any definitive conclusion can be made regarding the type of background noise present. In this study, boat traffic was relatively insignificant as the C-POD was placed in a region infrequently traversed by boats. Clicking shrimp and sediment transport noise were thought to be the major source of noise as detections improved as soon as the C-POD was relocated into deeper waters away from the reef.

Several recent studies evaluated detection probability parameters, such as the maximum distance of detection, the likelihood of detection and the radius of detection for PODs as this has implications for future surveys using an array of PODs (Philpott *et al.* 2007; Bailey *et al.* 2009; Kyhn *et al.* 2012; Nuuttila *et al.* 2013b). Despite the small sample sizes, especially for humpback dolphins, the maximum detection distances calculated for bottlenose dolphins at 1178.0 m and

1148.7 m for humpback dolphins were similar to previous estimates for other species using PODs (C-PODs and T-PODs). Maximum detection distance estimates for common bottlenose dolphins (*T. truncatus*) ranged from 1246 m and 1313 m using T-PODs (Philpott *et al.* 2007; Elliott *et al.* 2011) to 1512 m using C-PODs (Nuuttila *et al.* 2013b) The differences in maximum detection distances between T-PODs and C-PODs are most likely due to the fact that C-PODs are more sensitive and better able to detect clicks (Nuuttila *et al.* 2013b). However, it also possible that a number of different biological and environmental factors characterising the study areas also played a role (Tregenza 2012; Nuuttila *et al.* 2013b). Maximum detection distance estimates in this study were 1177.9 m for bottlenose dolphins and 1148.7 m for humpback dolphins. These distances were far less than the theoretical maximum detection range for wild dolphins producing an echolocation click at frequencies of 75, 100 and 135 kHz based on the reported minimum and maximum source levels of 177 and 228 dB re 1 Pa at 1 m (Wahlberg *et al.* 2011) and the minimum received level of 120 dB re 1Pa for the C-POD assuming no background noise (See J. Loveridge, Chelonia, pers. comm. in Nuuttila *et al.* 2013b; Table 5.1). These theoretical estimates apply directly to bottlenose dolphins (*T. aduncus* and *T. truncatus*) and it is therefore with caution that humpback dolphins are also included. As humpback dolphins have similar click frequency ranges to bottlenose dolphins it is likely that they will have similar minimum and maximum source levels and therefore similar theoretical maximum detection ranges. In this case, the lower maximum detection ranges are most likely due to the increased background noise levels which reduce the ability of the C-POD to distinguish potential dolphin clicks.

Table 5.1: Theoretical C-POD detection distances for an echolocation click produced at 75, 100, and 135 kHz using the reported minimum (177 dB re 1 Pa) and maximum (228 dB re 1Pa) wild dolphin source levels (SL) at the minimum received level of 120 dB re 1 Pa (Extracted from Table IV in Nuuttila *et al.* 2013b)

	Detection	**distances (m)**
kHz	**SL ¼ 177 dB re 1 Pa**	**SL ¼ 228 dB re 1Pa**
135	238	1167
100	275	1486
75	331	2082

Although moving the C-POD into deeper waters, resulted in an increase in dolphin detection and a decrease in background noise levels it also lead to disproportionally large minimum detection distances for both species. Bottlenose dolphins had minimum detection distances of 396.18 m and 513.20 m for the 60 sec and 30 sec windows respectively while humpback dolphins had minimum detection distances of 819 m and 899 m for the 60 sec and 30 sec windows respectively. The large values for minimum detection distances are indicative of both species distinct preference for near shore environments (James 2014). Both species spent the majority of their time in a narrow-band inshore of the C-POD close to or within the breakers and not distributed uniformly around it. The disproportion in distribution was also highlighted as a potential issue when calculating the EDR as it assumes uniform distribution around the C-POD. Nuuttila *et al.* (2013b) found a similar pattern in common bottlenose dolphins which also spent the majority of their time in a narrow band close to shore and not distributed equally around the C-POD. The exact implications of the large minimum detection distances and the lack of uniform distribution on the EDR are unknown and require further validation.

In addition to the challenges of distance and background noise, the probability of detecting echolocating dolphins acoustically is strongly influenced by the behaviour of the animals through two main mechanisms (Philpott *et al.* 2007; Nuuttila *et al.* 2013a). Firstly, the click rate changes in different behavioural states, for example, being lower during resting than when foraging, or there may be a shift to other sound types such as whistling which is more commonly observed during socialising (Au 1993; Madsen *et al.* 2005b; Simard *et al.* 2011; Nuuttila *et al.* 2013a). Secondly, the direction of animals relative to the hydrophone may also differ with behavioural state with travelling animals more likely to be moving in a set direction than when milling or foraging (Nuuttila *et al.* 2013b). As echolocation clicks are highly directional in nature (Au 1993; Roberts and Read 2015), these differences in direction relative to the hydrophone may influence both overall detection as well as species classification.

The size of dolphin groups significantly affected the detection probability and encounter durations. In this study, detection probability initially increased with group size before decreasing for bottlenose dolphins, yet decreased almost immediately for humpback dolphins. These observations seem to match observation made by Nuuttila *et al.* (2013b) which also recorded a decrease in detection probability with increasing group size for common bottlenose dolphins. As mentioned earlier, larger group sizes can cause an increase in the overlapping of click trains, changes in behaviour or even a complete change in sound type (changing to whistling instead) all of which can reduce the detection ability of the C-POD.

The ability to identify a dolphin species based solely on their echolocation clicks is inherently difficult. This is due to the fact that echolocation clicks become increasingly modified as they travel through their environment resulting in distinct differences in click parameters such as peak frequencies, modal frequencies and click duration (Soldevilla *et al.* 2008). Several studies have indicated significant differences between off-axis and on-axis clicks produced by the same species (Au *et al.* 1978; Au 1993; Soldevilla *et al.* 2008; Wahlberg *et al.* 2011). C-PODs and other PAM equipment cannot distinguish on-axis and off-axis clicks (Soldevilla *et al.* 2008). Therefore it is essential that the whole click range for both off-axis and on-axis clicks be defined for both species to ensure that potential differences in click parameters are due to differences between species and not differences within a species (Soldevilla *et al.* 2008).

The differences in modal frequencies could be due to the fact that bottlenose dolphins produce on-axis unimodal click frequencies (Wahlberg *et al.* 2011) whilst humpback dolphins in Australia (*S. sahulensis)* produced what appeared to be echolocation clicks with bimodal peaks in (two peaks) frequency (Goold and Jefferson 2004). This was unexpected due to the fact that delphinid species in general have overlapping frequency ranges, similar peak frequencies and generally produce one or two cycles within a click (Au 1993; Morisaka and Connor 2007; Soldevilla *et al.* 2008; Janik 2009; Roch *et al.* 2011). In addition, bottlenose dolphin clicks can appear bimodal if received off-axis (Wahlberg *et al.* 2011). Due to these uncertainties it is unlikely that modal frequency by itself can serve as accurate identifier of species differences.

Average ICI was the only co-variable that had significant differences ($P < 0.05$) in the pairwise comparisons and the GEE model whilst train duration, click rate and modal frequency were significant in the pairwise comparison only. In addition, the only interaction that was significant in the model was between average ICI and modal frequency. Bottlenose dolphins had a much shorter inter-click interval which coincided with the higher click rate and shorter train duration whilst humpback dolphins produced echolocation clicks with longer ICI and lower click rate and longer train duration. However, differences in click rate, train duration and ICI can be driven be differences in behaviour and group size (Deruiter *et al.* 2009; Jensen *et al.* 2009; Verfuss *et al.* 2009; Nuuttila *et al.* 2013a). Bottlenose dolphins are known to decrease their ICIs and increase their click rate the closer they get to a prey species producing the distinct ‘feeding buzzes’ (Jensen *et al.* 2009) Therefore if bottlenose dolphin in this study were actively searching or foraging the click rate would automatically be higher than non-foraging humpback dolphin. Although ICI’s have been poorly studied in humpback dolphins based on overall similarities in echolocation clicks it is likely that their click rate also increase when foraging (Van Parijs and Corkeron 2001a). The significant influence of the interaction in the models also need to be considered as it indicates the potential for differentiating species based on clicks might only be possible using a combination of co-variables.

The paucity of information on the sound production of humpback dolphins limited our ability to fully understand the reasons for the small number of detections. It also did not allow for a good understanding of basic click parameters which would potentially enable species differentiation using C-POD data. Indian Ocean humpback dolphins (*S. plumbea*) require extensive research in order to understand their behaviour, group dynamics, movement patterns and habitat preference all of which can influence the detection ability of a C-POD.

A very recent study by Robbins *et al.* (2015) also attempted to distinguish closely related species of dolphins, namely, common bottlenose dolphins (*Tursiops truncatus),* common dolphins *(Delphinus delphis)* and Risso's dolphins *(Grampus griseus)* all found off western Ireland with similarly mixed results based solely on output of the C-POD. In their study they considered the parameters frequency, inter-click interval and train duration and found that overlapping of click train parameters made species identification a challenge. Nevertheless when frequency, ICI and train duration were combined they found that species identification based solely on the clicks closely matched visual confirmations of species identities. However there was a high rate of false positives (68%) which affected the accuracy of the results. The results of their study are similar to the results of this study in that ICI and train duration showed potential for species differentiation; however, there were also several differences in parameters tested, methods of analysis and final results. Future studies should therefore consider both studies and take into consideration the site specific natures of each studies findings.

5.2. CONCLUSION

This study served as a baseline for C-POD monitoring of bottlenose and humpback dolphins along the Cape south coast. Despite the challenges of monitoring in a noisy marine environment and the small sample sizes, these results provide valuable information for future studies. The C-POD has definite potential for use as a monitoring tool for bottlenose dolphins. However, for humpback dolphins, monitoring using a C-POD, or any other passive acoustic monitoring system, may not be suitable as interference from high levels of background noise is likely to be a constant problem due to their preference for noisy inshore waters.

The need for more information on humpback dolphin acoustic behaviour is highlighted. The indication currently is that the C-POD cannot predictably distinguish between these two related species based solely on a single acoustic parameter provided by the C-POD software. However there is the potential that by combining the different parameters provided by the C-POD species-specific patterns may appear. Therefore it is recommended that future studies assess different combinations of these parameters for any species-specific differences. Based on the results of this study, future acoustic detection ability studies will have to be conducted in tandem with visual observations to confirm species identity.

Overall it is recommended that this study be conducted again in a less noisy area with a much larger sample size and an array of C-PODs in order to effectively determine the suitability of the C-POD as a monitoring tool for delphinids in southern Africa.

5.3. REFERENCES

AU, W.W. 1993. Characteristics of Dolphin Sonar Signals. In*: The Sonar of Dolphins.* Berlin, Heidelberg, Springer-Verlag.

AU, W.W., FLOYD, R.W. & HAUN, J.E. 1978. Propagation of atlantic bottlenose dolphin echolocation signals. *Journal of the Acoustical Society of America.* **64**: 411–422.

BAILEY, H., CLAY, G., COATES, E.A., LUSSEAU, D., SENIOR, B. & THOMPSON, P. 2009. Using T-PODs to assess variations in the occurrence of coastal bottlenose dolphins and harbour porpoises. *Aquatic Conservation: Marine and Freshwater Ecosystems.* **20**: 150-158.

BUCKSTAFF, K. 2004. Effects of watercraft noise on the acoustic behaviour of bottlenose dolphins *Tursiops truncatus,* in Sarasota Bay, Florida *Marine Mammal Science.* **20**: 709-725.

CASTELLOTE, M., LEENEY, R.H., O'CORRY-CROWE, G., LAUHAKANGAS, R., KOVACS, K.M., LUCEY, W., KRASNOVA, V., LYDERSEN, C., STAFFORD, K.M. & BELIKOV, R.A. 2012. Monitoring white whales (*Delphinapterus leucas*) with echolocation loggers. *Polar Biology*. **36**: 493-509.

DERUITER, S.L., BAHR, A., BLANCHET, M.A., HANSEN, S.F., KRISTENSEN, J.H., MADSEN, P.T., TYACK, P.L. & WAHLBERG, M. 2009. Acoustic behaviour of echolocating porpoises during prey capture. *Journal of Experimental Biology*. **212**: 3100-7.

ELLIOTT, R.G., DAWSON, S.M. & RAYMENT, W.J. 2011. Optimizing TPOD settings and testing range of detection for bottlenose dolphins in Doubtful Sound, New Zealand. *Journal of the Marine Biological Association of the United Kingdom.* **92**: 1901–1907.

GOOLD, J.C. & JEFFERSON, T.A. 2004. A Note on Clicks Recorded from Free-Ranging Indo-Pacific Humpback Dolphins, *Sousa chinensis*. *Aquatic Mammals.* **30**: 175-178.

JAMES, B.S. 2014. *Natural and human impacts on habitat use of coastal delphinids in the Mossel Bay area, Western Cape, South Africa*. MSc: Zoology, University of Pretoria.

JANIK, V.M. 2009. Acoustic Communication in Delphinids. *Advances in the Study of Behavior*. **40**: 1-34.

JENSEN, F.H., BEJDER, L., WAHLBERG, M. & MADSEN, P.T. 2009. Biosonar adjustments to target range of echolocating bottlenose dolphins (*Tursiops sp*.) in the wild. *Journal of Experimental Biology*. **212**: 1078-1086.

KYHN, L.A., TOUGAARD, J., THOMAS, L., DUVE, L.R., STENBACK, J., AMUNDIN, M., DESPORTES, G. & TEILMANN, J. 2012. From echolocation clicks to animal density--acoustic sampling of harbor porpoises with static dataloggers. *Journal of the Acoustical Society of America*. **131**: 550-560.

MADSEN, P.T., JOHNSON, M., DE SOTO, N.A., ZIMMER, W.M. & TYACK, P. 2005b. Biosonar performance of foraging beaked whales (Mesoplodon densirostris). *Journal of Experimenetal Biology*. **208**: 181-194.

MORISAKA, T. & CONNOR, R.C. 2007. Predation by killer whales (Orcinus orca) and the evolution of whistle loss and narrow-band high frequency clicks in odontocetes. *Journal of Experimental Biology*. **20**: 1439-1458.

MORISAKA, T., SHINOHARA, M., NAKAHARA, F. & AKAMATSU, T. 2005a. Effects of ambient noise on the whistles of Indo-Pacific bottlenose dolphin populations. *Journal of Mammalogy*. **86**: 541–546.

NOWACEK, D.P., THORNE, L.H., JOHNSTON, D.W. & TYACK, P. 2007. Responses of cetaceans to anthropogic noise. *Mammal Reviews*. **37**: 81-115.

NUUTTILA, H.K., MEIER, R., EVANS, P.G., TURNER, J.R., BENNELL, J.D. & HIDDINK, J.G. 2013a. Identifying Foraging Behaviour of Wild Bottlenose Dolphins (*Tursiops truncatus*) and Harbour Porpoises (*Phocoena phocoena*) with Static Acoustic Dataloggers. *Aquatic Mammals*. **39**: 147-161.

NUUTTILA, H.K., THOMAS, L., HIDDINK, J.G., MEIER, R., TURNER, J.R., BENNELL, J. D., TREGENZA, N.J. & EVANS, P.G. 2013b. Acoustic detection probability of bottlenose dolphins, *Tursiops truncatus*, with static acoustic dataloggers in Cardigan Bay, Wales. *Journal of the Acoustical Society of America*. **134**: 2596-2609.

PHILPOTT, E., ENGLUND, A., INGRAM, S. & ROGAN, E. 2007. Using T-PODs to investigate the echolocation of coastal bottlenose dolphins. *Journal of the Marine Biological Association of the United Kingdom*. **87**: 11–17.

RICHARDSON, W.J., GREENE JR, C.R., MALME, C.I. & THOMSON, D.H. 1995. *Marine Mammals and Noise*, San Diego, Academic Press.

ROBERTS, B.L. & READ, A.J. 2015. Field assessment of C-POD performance in detecting echolocation click trains of bottlenose dolphins (*Tursiops truncatus*). *Marine Mammal Science*. **31**: 169-190.

ROBBINS, J.R., BRANDECKER, A., CRONIN, M., JESSOPP, M., MCALLEN, R. & CULLOCH, R. 2015: Handling dolphin detections from C-PODs, with the development of acoustic parameters for verification and the exploration of species identification possibilities. *Bioacoustics*. 1-12.

ROCH, M.A., KLINCK, H., BAUMANN-PICKERING, S., MELLINGER, D.K., QUI, S., SOLDEVILLA, M.S. & HILDEBRAND, J.A. 2011. Classification of echolocation clicks from odontocetes in the Southern California Bight. *Journal of the Acoustical Society of America*. **129**: 467-475.

SAAYMAN, G.S. & TAYLER, C.K. 1973. Social Organisation of Inshore Dolphins (*Tursiops aduncus* and *Sousa*) in the Indian Ocean. *Journal of Mammalogy*. **54**: 993-996.

SIMARD, P., LACE, N., GOWANS, S., QUINTANA-RIZZO, E., KUCZAJ, S.A., WELLS, R. S. & MANN, D.A. 2011. Low frequency narrow-band calls in bottlenose dolphins (*Tursiops truncatus*): signal properties, function, and conservation implications. *Journal of the Acoustical Society of America*. **130**: 3068-3076.

SIMON, M., NUUTTILA, H.K., REYES-ZAMUDIO, M., UGARTE, F., VERFUSS, U. & EVANS, P.G. 2010. Passive acoustic monitoring of bottlenose dolphin and harbour porpoise, in Cardigan Bay, Wales, with implications for habitat use and partitioning. *Journal of the Marine Biological Association of the United Kingdom.* **90**: 1539–1545.

SOLDEVILLA, M.S., HENDERSON, E.E., CAMPBELL, G.S., WIGGINS, S.M., HILDEBRAND, J.A. & ROCH, M.A. 2008. Classification of Risso's and Pacific white-sided dolphins using spectral properties of echolocation clicks. *Journal of the Acoustical Society of America.* **124**: 609-624.

TREGENZA, N. 2012. CPOD.exe : a guide for users. 1-56.

VAN PARIJS, S.M. & CORKERON, P.J. 2001a. Vocalizations and behaviour of Pacific Humpback dolphins *Sousa chinensis*. *Ethology*. **107**: 701-716.

VAN PARIJS, S.M. & CORKERON, P.J. 2001c. Boat traffic affects the acoustic behaviour of Pacific humpback dolphins *Journal of the Marine Biology Association of the United Kingdom.* **81**: 533-538.

VAN PARIJS, S.M., SMITH, J. & CORKERON, P.J. 2002. Using calls to estimate the abundance of inshore dolphins: a case study with Pacific humpback dolphins *Sousa chinensis*. *Journal of Applied Ecology Letters.* **39**: 853–864.

VERFUSS, U.K., MILLER, L. A., PILZ, P.K. & SCHNITZLER, H.U. 2009. Echolocation by two foraging harbour porpoises (*Phocoena phocoena*). *Journal of Experimental Biology.* **212**: 823-834.

WAHLBERG, M., JENSEN, F.H., SOTO, N.A., BEEDHOLM, K., BEJDER, L., OLIVEIRA, C., RASMUSSEN, M., SIMON, M., VILLADSGAARD, A. & MADSEN, P.T. 2011. Source parameters of echolocation clicks from wild bottlenose dolphins (*Tursiops aduncus* and *Tursiops truncatus*). *Journal of the Acoustical Society of America.* **130**: 2263-2274.