

Population analyses of humpback dolphin (*Sousa plumbea*) in Richards Bay, KwaZulu-Natal, South Africa.

By

ALICE ELIZABETH JOHNSON

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DECLARATION

I, declare that the
thesis/dissertation, which I hereby submit for the degree
..... 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.

SIGNATURE:

DATE:

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Population Analyses of Humpback Dolphins (*Sousa plumbea*) in Richards Bay, KwaZulu-Natal, South Africa

ABSTRACT

Humpback dolphins (*Sousa plumbea*) inhabit the near shore waters of the Indian Ocean off the African continent. Inshore species of cetaceans are highly vulnerable to habitat alteration and destruction of these environments. This study focussed on the humpback dolphin, *Sousa plumbea*, in Richards Bay, KwaZulu-Natal, South Africa. In addition to habitat alteration and destruction, the humpback dolphins in Richards Bay are exposed to shark nets (gill nets) which are in place to reduce the risk to bathers from shark attacks. This study investigated the population biology of the Richards Bay humpback dolphin population from 1998 to 2006. Geographical Information Systems technology and home range estimates were used to assess the distribution of the humpback dolphins within the bay as well as to map their behaviour patterns to determine areas of behavioural importance for the population in the area. There was a clear definition of different behaviours being displayed in different areas within the study area with feeding being highly concentrated around the harbour mouth and shark net area. There was highly localised feeding activity with a 2.1km^2 50% Kernel Density Estimate (KDE). Resting, socialising and travelling presented 50% KDE areas greater than 3km^2 with travelling at 5.3km^2 . More specifically 72.36% of the 50% KDE area for feeding points was clustered around the harbour mouth area where the harbour walls and shark nets act as artificial reefs. The resting 50% KDE was clustered further south of the harbour where there is an area more favourable for resting, and socialising behaviour was scattered throughout and between both of these areas. Furthermore, using photo-identification and mark-recapture techniques implemented in Program MARK, population estimates were calculated. A Jolly-Seber open-population model was used to determine the population size of the Richards Bay humpback dolphins. This open model was chosen due to the length of the study as well as the steadily increasing discovery curve which indicated constant new identification of individuals. From 225 successful dolphin encounters an estimate of 203 (CL: 185 – 221) individuals was derived. With the proposed development and enlargement of the Richards Bay harbour this small population size and highly localised use of the shark net area by the dolphins to feed needs to be considered in future conservation management plans.

CHAPTER 1: INTRODUCTION

1.1. THE SPECIES: SUMMARY OF THE CURRENT KNOWLEDGE OF HUMPBACK DOLPHINS, *SOUSA PLUMBEA* IN SOUTHERN AFRICA

1.1.1. Introduction

Humpback dolphins, genus *Sousa*, inhabit coastal waters of tropical and subtropical West Africa, Indian Ocean, and western Pacific Ocean (Figure 1.1). Their taxonomy remains unresolved, with between one and five nominal species proposed (Ross *et al.* 1994; Rice 1998). Currently most researchers recognise either two (Jefferson & Karczmarski 2001) or three species of *Sousa* (Rice 1998). When the two species taxonomy is considered, *S. chinensis* form and *S. plumbea* form are recognised as one species *S. chinensis*. *S. chinensis* are found in the Indian Ocean and western Pacific Ocean with the second species being *S. teuzii* (Reeves *et al.* 2008). Where three species are recognised, they are; *S. teuzii* off West Africa, *S. plumbea* in the western Indian Ocean, and *S. chinensis* off Southeast Asia and western Pacific Ocean. In this study, the three-species taxonomy of Rice (1998) will be followed, and the subject of the study is *S. plumbea* (hereafter the ‘humpback dolphin’).

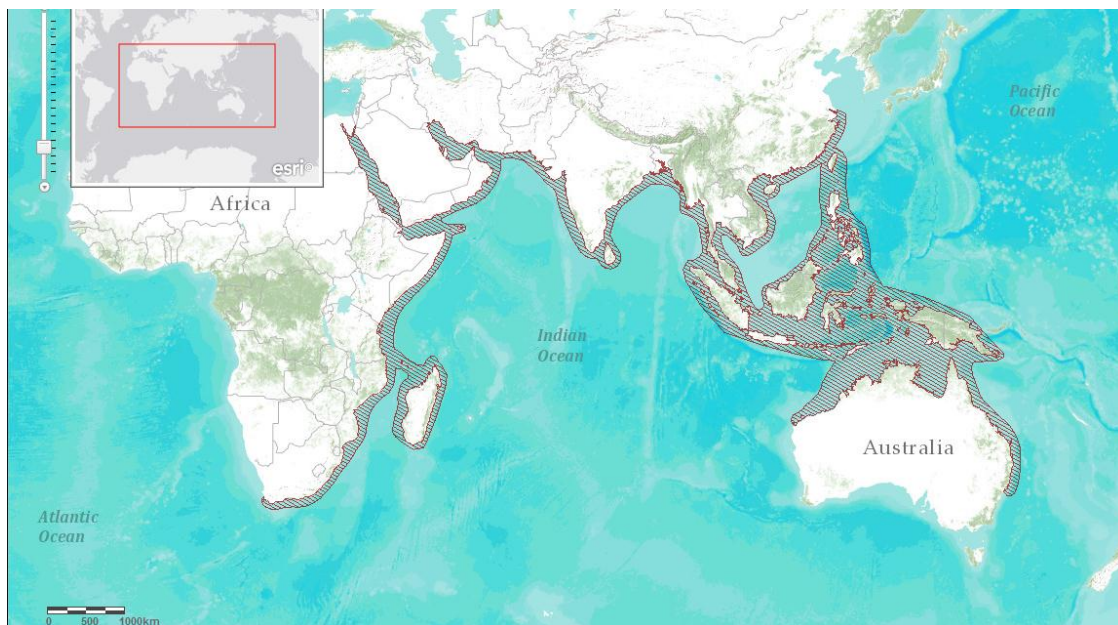


Figure 1.1. Representation of *Sousa chinensis/plumbea* global distribution range with the patterned area indicating their near shore distribution. (Source: IUCN (International Union for Conservation of Nature) 2008)

1.1.2. Morphology and Natural History

Humpback dolphins have a robust body with a distinguishable wide dorsal ridge, often referred to as a hump; hence the common name of the species. They have a long slender beak and variable colour patterns. The South African humpback dolphins are dark grey fading to off-white on the ventral surface when adults, and lighter in colour as calves (Ross *et al.* 1994; Jefferson & Karczmarski 2001). Males are substantially larger and more robust than females, with a maximum length of 226cm and 216cm recorded for males and females respectively (Ross *et al.* 1994; Jefferson & Karczmarski 2001). A new born calf is approximately 100cm in length (Ross 1984; Cockcroft 1989; Jefferson 2000).

Information on the natural history and reproductive biology of *Sousa* is still scarce. The gestation period is approximately 10-12 months (Cockcroft 1989) and in the southern African region there is an apparent calving peak in spring and summer (Saayman & Taylor 1979; Cockcroft 1989; Karczmarski 1999). The calving interval has been estimated to be three years and the lactation period approximately two years (Ross *et al.* 1994; Jefferson & Karczmarski 2001). The female-calf association is particularly strong for the first two years of the calf's life, and gradually weakens as the calf enters the third year of its life (Karczmarski 1999). South African humpback dolphins are thought to reach sexual maturity at 10 years for females and approximately 12 – 13 years for males (Cockcroft 1989).

As an inshore species, humpback dolphins feed on inshore, demersal, reef and estuarine associated fishes. Ross (1984), and Barros & Cockcroft (1991) found that in Durban and Port Elizabeth in South Africa, prey species include *Mugil cephalus*, *Pomadasys olivaceum*, *Pachymetopon anuem* and some unidentified seabreams. This data is based on a very small sample size (N = 2). In a study conducted in Australia with a sample size of six, teleost species were found to be the most prominent food source (Parra & Jedensjö 2009)

1.1.3. Distribution, Ecology and Behaviour

On the southern and east coast of Africa, *Sousa plumbea* is distributed as far south as Cape Town, South Africa, and extends along the shore northwards to India, also occurring on the Comoro Islands (Jefferson & Karczmarski 2001). They are generally found in waters less than 50m deep (Findlay *et al.* 1992), although in Algoa Bay, on the Eastern Cape coast of South Africa, the dolphins are seen primarily in waters of less than 15m deep (Karczmarski *et al.* 2000a). In general they are restricted to close proximity of the shore, however in some areas they can be seen further offshore if the water remains shallow (Corkeron 1990; Karczmarski *et al.* 2000a; Atkins *et al.* 2004).

The inshore habitats frequented by humpback dolphins vary with geographic location. In Plettenberg Bay and Algoa Bay rocky reefs or sandy gullies are the predominant habitats (Saayman & Taylor 1979; Karczmarski *et al.* 2000a), whereas off the KwaZulu-Natal coast they are seen primarily in large estuarine systems (Durham 1994; Atkins *et al.* 2004). Further north, in Maputo Bay, Mozambique, they frequent coral reef areas, seagrass beds, tidal channels, and sheltered shallow inshore areas (Karczmarski 2000; Guissamulo 2008). Although no specific patterns in seasonal migrations have been documented to date, groups in the Algoa Bay region are considerably larger in summer and late winter, which corresponds with an increased number of sightings (Karczmarski *et al.* 1999a) and seasonal immigration and emigration of individuals (Karczmarski *et al.* 1999b). Similar seasonality of sightings was also reported in Maputo Bay (Guissamulo 2008), suggesting that seasonal dynamics might be considerable in at least some parts of the species range.

In Algoa Bay, humpback dolphins are mainly seen in the morning and less frequently later on during the day (Karczmarski *et al.* 2000b), either solitary or in small groups (Karczmarski *et al.* 1999a). Although groups can be as large as 25 animals, they rarely have more than 10 members (Karczmarski 1999). Group membership is not consistent; their social system has been described as highly dynamic, with only casual and short lasting affiliations (Karczmarski 1999). The animals in Algoa Bay show different degrees of site fidelity with some members of the population being resident and others ranging

over considerable distances in a narrow band of coastal waters (Karczmarski 1999). This pattern seemed evident in other populations along the coast line, particularly the Richards Bay population (Durham 1994; Keith *et al.* 2002)

1.1.4. Population Status and Conservation Issues

Throughout the species range there is little information on the status of local populations. Abundance and population estimates are available only for a limited few locations and the numbers are generally low; less than 500 humpback dolphins are thought to inhabit the Algoa Bay region in the Eastern Cape (Karczmarski *et al.* 1999b), and estimates ranging from 60 to 244 were suggested for the Kwazulu-Natal coast, South Africa (Durham 1994; Atkins & Atkins 2002; Keith *et al.* 2002). Guissamulo & Cockcroft (2004) estimated a population of 105 individuals for Maputo Bay, Mozambique, and Stensland *et al.* (2006) estimated the population off the southwest coast of Zanzibar to be between 58 and 65 individuals.

There is a general consensus that the low population estimates in the southern African region warrant serious conservation attention. In 2004, the regional Red List for South Africa listed humpbacks as Vulnerable (VU B1 ab(ii iii)) (Friedman & Daly 2004). The global IUCN assessment of humpback dolphins listed the species as near threatened (NT) in 2010 (Reeves *et al.* 2010). Furthermore, throughout the region humpback dolphins are exposed to threats such as habitat loss, depletion of food resources, boat traffic, pollution, and either incidental capture or deliberate kills for human consumption (Karczmarski 2000; Reeves *et al.* 2010). In some areas, a developing threat is tourism, taking on the form of aggressive ‘swim-with-dolphins’ operations (Parra *et al.* 2004; Stensland *et al.* 2006).

Furthermore, most of the southern African region represents areas of high human population growth. Their near shore distribution makes humpback dolphins particularly susceptible to the adverse effects of human activities, which includes the impacts on the inshore resources upon which the dolphins rely on (Karczmarski 2000; Reeves *et al.* 2008).

In South Africa, the major threat that affects humpback dolphins is mortality in shark-nets (Cockcroft 1990). These are gill nets set off the KwaZulu-Natal coast in order to keep the bathers safe from sharks (Cockcroft 1990). These gill nets are a cause of mortality that at some point was suggested to be higher than the population growth rate (Cockcroft 1990). Although in recent years the captures in shark nets decreased, they remain a major cause of conservation concern. In earlier work, Cockcroft (1990) suggested that mortality in shark nets off KwaZulu-Natal might be close to or even exceed the likely replacement rate of humpback dolphins. In Richards Bay alone the mortalities are high; between 1980 and 1998 there were 132 dolphins caught in shark nets along the KwaZulu-Natal coast and 78 of them were caught in Richards Bay (Cockcroft 1990; Atkins & Atkins 2002; Natal Sharks Board unpublished data). Since then (1999 – 2008) a further 67 humpback dolphins have been caught in the shark nets along the KwaZulu-Natal coast with 43 of those being caught in Richards Bay (Natal Sharks Board unpublished data).

1.2. HUMPBACK DOLPHINS IN RICHARDS BAY, KWAZULU-NATAL COAST, SOUTH AFRICA

1.2.1. The Richards Bay Study Area

Richards Bay (28°48'S 32°06'E) is situated on the Tugela bank in KwaZulu-Natal, South Africa. There are two river systems in the study area, the Mzingazi River that flows into the harbour, and the Mhlatuzi River which flows into the Mhlatuzi estuary. The harbour was constructed by dredging the existing estuary to an approximate depth of 20m. The study area stretches for 13km from the Mhlatuzi River mouth to the Richards Bay lighthouse (Figure 1.2). The area was divided into zones which encompassed the six shark nets and the harbour. It is the northern most installation in KwaZulu-Natal with six permanent gill nets, which are set offshore in an attempt to keep sharks away from the bathing area.

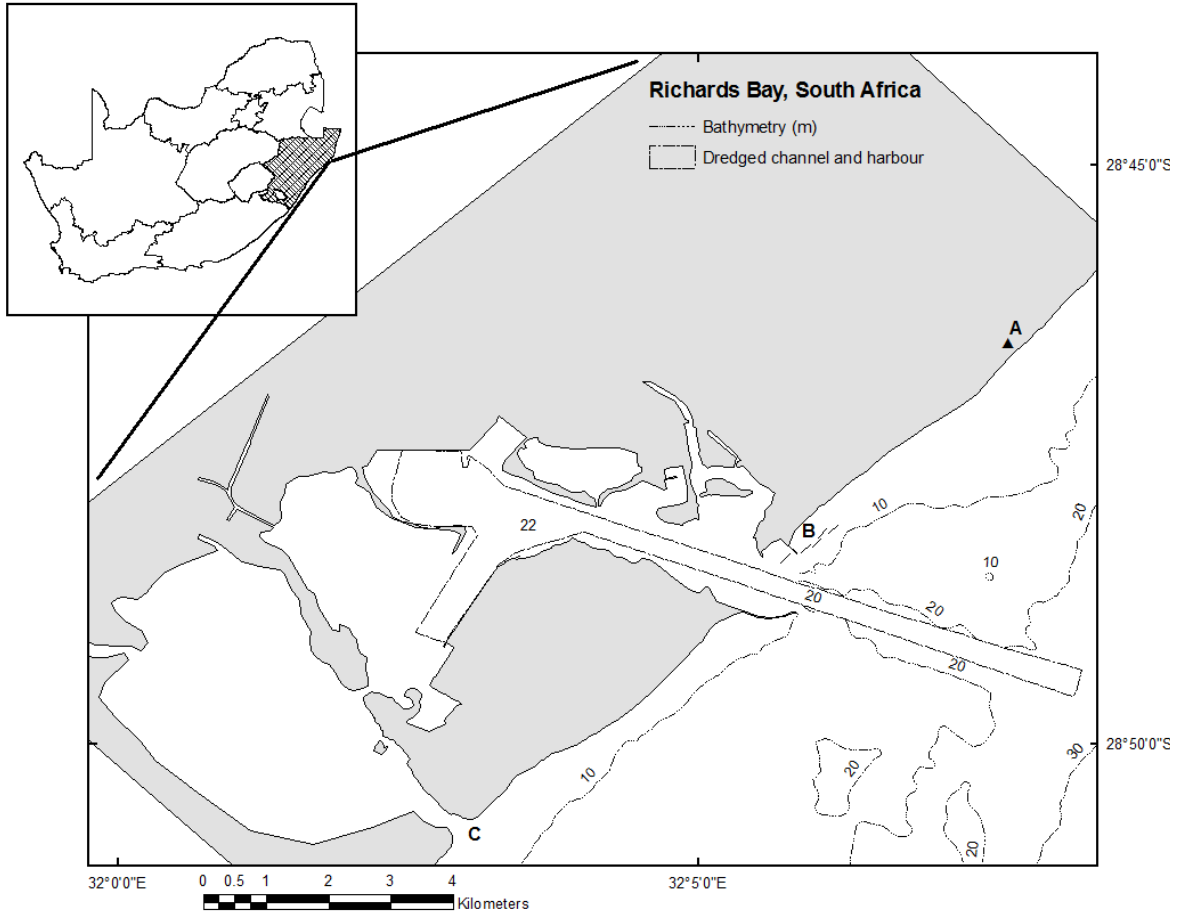


Figure 1.2. Richards Bay study area, including the Richards Bay harbour, with the bathymetry indicated in metres. A: Richards Bay Lighthouse, B: Shark nets, C: Mhlatuzi estuary.

1.2.2. Humpback Dolphins in Richards Bay

Three studies have been conducted on the humpback dolphins in Richards Bay. These three studies were conducted by Durham (1994), Atkins & Atkins (2002) and Keith *et al.* (2002). They used mark-recapture and photo identification techniques to produce information on the Richards Bay and KwaZulu-Natal humpback dolphin population (for more detail on these techniques see chapter three). One of the aspects which these studies investigated was estimating the size of the humpback dolphin population in Richards Bay, population estimates. Early population estimates, in Table 1.1 from Durham (1994), Atkins & Atkins (2002) and Keith *et al.* (2002), estimate the KZN (166 (134-299)) and Richards Bay (74 (60-88), 170 (112-230), 244 (217-287)) populations (Table 1.1).

Table 1.1. Early population studies on Humpback dolphins in Richards Bay including the mark recapture methods used, the length of the study and the population estimate for each study.

| | Model | Length of Study | Estimate | Confidence limit |
|----------------------------|----------------|------------------------|-----------------|-------------------------|
| Durham (1994) | Jolly - Seber | 2 years | 166 | 134-229 |
| Atkins & Atkins (2002) | Mh (Chao 1989) | 3 years | 244 | 217-287 |
| | Jolly-Seber | 3 years | 170 | 112-230 |
| Keith <i>et al.</i> (2002) | Jolly-Seber | 1 year | 74 | 60-88 |

The studies described in the Table 1.1 are Durham (1994), Atkins & Atkins (2002) and Keith *et al.* (2002). These three studies all estimated the population size of the Richards Bay humpback dolphins, but all used slightly different approaches to analyse the data. The study by Durham (1994) was conducted on the entire KwaZulu-Natal coast, but an estimate of the Richards Bay population was done separately using the Jolly-Seber open population model. Atkins & Atkins (2002) and Keith *et al.* (2002) also used the Jolly-Seber method. This method was used because; by looking at the discovery curves, which indicates the cumulative number of dolphins identified over time, for these studies, the population seemed to be an open population which requires the use of an open population model for analysis such as the Jolly-Seber model. Atkins & Atkins (2002) also got an estimate using the Mh (Chao 1989) method. This estimate is based on a closed population model. It was used because there was heterogeneity of capture displayed in the data and this method allows for that. The Jolly-Seber method assumes homogeneity of capture and according to Atkins & Atkins (2002) because of the nature of the population, using this method then may have resulted in an underestimated population size.

All three studies assume that the Richards Bay population is an open population. As aforementioned, this assumption was made by looking at the discovery curves. Because of the short duration of these studies, these discovery curves may not be an exact representation of the population. For example, Keith *et al.* (2002) is only a one year in

length and therefore all or most of the dolphins in the population may not have been photographed and new dolphins were still being discovered after one year.

Atkins & Atkins (2002) data included the one year of data used by Keith *et al.* (2002), with the resulting estimates differing as there were differences in their criteria for the dolphin identification. Atkins & Atkins (2002) used a much more strict quality and distinctiveness control when identifying the dolphins compared to the method used by Keith *et al.* (2002). In total, Keith *et al.* (2002) identified 181 individuals for the 1998 period, but this was an estimate for the resident population only. However, with the high number of individuals seen only once, the sample used was restricted to individuals photographed two or more times. Whereas Atkins & Atkins (2002), with strict identification techniques, identified only 59 individuals using a larger set of photographs which did include the photographs used in Keith *et al.* (2002) and estimated the entire Richards Bay population.

Atkins *et al.* (2004) also conducted studies on the behaviour of the humpback dolphins in Richards Bay. By defining and identifying different behaviours and identifying these behaviours and recording where the dolphins displayed the different behaviours, Atkins *et al.* (2004) was able to understand which areas were important to the dolphins for different reasons. For example, Atkins *et al.* (2004) found that the Harbour Mouth, which is defined by two breakwaters, is an important feeding area for the dolphins (Atkins *et al.* 2004).

Atkins *et al.* (2004) continued to collect data and ended up with an eight year dataset which has not been analysed in its entirety. The continuation of the humpback dolphin research in Richards Bay until 2006, allows an opportunity to assess the population using a larger data set and so gain a more robust population estimate as well as learn more about the dolphins' use of the area. This study is focussed on the analysis of this dataset as the data has already been collected prior to the commencement of this study.

1.3. THE IMPORTANCE OF RESEARCH AND CONSERVATION MANAGEMENT IMPLICATIONS

This project will contribute to the advancement of the knowledge of the species. It is based on a long term study which will provide a very good and reliable estimate of the humpback dolphins in Richards Bay and give a clear indication of the habitat use of the population. For conservation and management, these results will define the management strategies, and show the range and level of impact this area has on the population. In order to accurately inform management strategies, population size estimates are required as well as specific information on population characteristics. This study will use mark recapture methods to investigate if this population is open or closed. If the population is found to be open, the impact of shark net captures will not be as severe, but it will mean that Richards Bay is a transition area and these captures will be having an unknown effect on immigrating individuals from the larger populations. If the population is found to be a closed population, the high rate of captures in the shark nets will most likely be detrimental to the population.

In addition, this study will use geographic information systems (GIS) to spatially map the different behaviours within the Richards Bay study area. Understanding differentiation in areas between behaviours will elucidate on habitat preference and associated threats with habitat use.

Overall this study asks the following key questions for the time period of 1998 to 2004:

- 1) Which areas of the study site are important to the humpback dolphins of Richards Bay? (Chapter two)
- 2) What is the size of the Richards Bay humpback dolphin population? (Chapter three)
- 3) Does this population have limited entry from other populations or is it part of a larger population along the KwaZulu-Natal coastline? (Chapter three)

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CHAPTER 2: SPATIAL AND TEMPORAL DISTRIBUTION PATTERNS OF THE BEHAVIOUR OF HUMPBAC DOLPHINS (*SOUSA PLUMBEA*) IN RICHARDS BAY, KWAZULU-NATAL, SOUTH AFRICA.

2.1. INTRODUCTION

Inshore species of cetaceans are highly vulnerable to habitat alteration and destruction of inshore environments (Karczmarski 2000). Several dolphin species exhibit a preference for particular sites where specific behaviours are concentrated (Saayman & Taylor 1979; Karczmarski *et al.* 2000; Parra *et al.* 2006; Guissamulo 2008), making these populations prone to human impact. These sites correspond with areas which provide a good food source, are an ideal habitat for prey capture, offer a hospitable environment for mate selection, and are an ideal safe resting or nursery area (Saayman & Taylor 1979; Karczmarski *et al.* 2000; Parra *et al.* 2006; Guissamulo 2008).

Of particular concern for this study is the humpback dolphin, *Sousa plumbea*. Humpback dolphins occur in a variety of coastal marine environments, with the 25m isobaths being reported to represent the critical depth in certain regions (Jefferson & Karczmarski 2001). They are found from Cape Town, South Africa, along the east coast of Africa through to India and the Comoros Islands (Jefferson & Karczmarski 2001). This species is threatened by the loss of suitable habitat, siltation of rivers and estuaries, loss of suitable nursery areas for prey fish species, and fishing pressure (Jefferson & Karczmarski 2001). In 2004, the regional Red List for South Africa listed humpbacks as Vulnerable (VU B1 ab (ii iii)) (Friedman & Daly 2004). The global IUCN assessment of humpback dolphins listed the species as near threatened (NT) in 2010 (Reeves *et al.* 2010). Population reductions have been inferred by Reeves *et al.* (2010) over much of the species' range, due to consistent and increasing incidental mortality in fishing/gill nets, and habitat loss in coastal and estuarine areas. *Sousa plumbea* is known for local discrete, discontinuous and separated populations throughout the species' range (Jefferson & Karczmarski 2001; Reeves *et al.* 2010).

This study specifically focuses on the Richards Bay population of humpback dolphins, as this population is under severe threat. Situated on the east coast of South Africa, Richards Bay and the surrounding areas are characterised by a diversity of different habitats ranging from sandy

beaches, enclosed bays, estuaries, mangrove swamps and a harbour. The Richards Bay harbour is known for large volumes of boat traffic, dredging and pollution, all activities which are listed as threats to the Richard Bay humpback dolphin population (Cockcroft 1990; Karczmarski 2000; Reeves *et al.* 2010). In addition to these listed threats, Richards Bay also employs shark nets to reduce the risk of bather-shark incidences. These nets are situated within and just north of the harbour mouth (Atkins *et al.* 2004). The Richards Bay shark net installations are known for capturing the highest number of humpback dolphins in KwaZulu-Natal since their installation in the 1950s (Cockcroft 1990) and have captured 129 animals in 18 years with an estimated annual bycatch of 5% of the Richards Bay population (Atkins *et al.* 2004). Humpback dolphins are slow breeders, only breeding every few years; and therefore the population cannot sustain a high number of mortalities such as those occurring from the shark nets (Cockcroft 1990).

Earlier work by Durham (1994), Keith *et al.* (2002), Atkins and Atkins (2002) and Atkins *et al.* (2004), indicates that the Richards Bay area is preferred by humpback dolphins, with feeding predominantly occurring close to shore. To gain a greater insight into the population ecology of humpback dolphins at Richards Bay, it is important to understand their area use in an environment where several potential threats are concentrated within a spatially limited area, especially with a focus on the area around the shark nets. If it is found that this area is a biologically important area for the dolphins, this will guide strategic management and conservation actions for this species (Karczmarski *et al.* 2000). This data, along with current knowledge of this species in the area, will in turn enable the identification of key biologically and socially important areas to ensure the survival of the species in Richards Bay.

2.2. MATERIALS & METHODS

Dolphin Data

The data for the Richards Bay Humpback Dolphin Project was collected from 1998 to 2006, by Shannan and Bret Atkins. During this period, on each sampling occasion a boat was launched from within the harbour, and a search for dolphins commenced as the harbour mouth was reached. Long-shore searches were conducted, and once a dolphin group was encountered, their position was recorded using a Garmin II-Plus Global Positioning System (GPS) with point

localities recorded every five minutes from thereafter during the follow. The behaviour of the group was noted on five minute intervals. The behaviour of at least 50% of the group was noted as the group's behaviour. Follows were stopped when the focal group of dolphins was not seen for more than 10 minutes, or the group was lost. The behaviours identified were:

Feeding:

- Irregular diving and direction with short swimming distances covered between dives.
- Displays of steep diving and somersaulting out of the water.
- Sometimes fish were seen at the surface or in the dolphin's mouth.

Resting:

- Associated with a low level of activity, with regular long dives covering a short distance, either in one direction or in a localised circular pattern.

Socialising:

- Dive duration and distance was irregular with obvious interaction between individuals and displays of jumping, somersaults, lobtailing and spyhopping.

Travelling:

- Regular surfacing patterns over large distances in one direction with long dive durations.

These categories represent behavioural states (i.e. behaviour patterns of relatively long duration) and are consistent with similar studies of humpback dolphins elsewhere (Karczmarski & Cockcroft 1999; Karczmarski *et al.* 2000) and earlier work by Atkins *et al.* (2004).

Data analysis

Geographic coordinates (GPS positions) recorded during the behavioural data collection were used to investigate spatial patterns within the data. In order to estimate the area (km²) for the duration of the study period, two methods were used: the Minimum Convex Polygon (MCP) and Kernel Density Estimate (KDE). Analyses were undertaken to investigate each behaviour. Using Hawth's Tools extension for ArcMap 9.2, MCPs were calculated for each behaviour. Adaptive KDEs (95% KDE with 50% core areas) were also calculated, using a least-squares cross-validation in ArcMap 9.2 and the Home Range Estimate extension tool (Rodgers *et al.* 2005). Area calculations were based on a projection of WGS 84 UTM 36S and were done in XTools 7

Trial version for ArcGis (<http://www.xtoolspro.com/>). The MCP and 95% KDE were used for the overall occurrence estimations and the 50% KDE was used for the core area of occurrence estimation. MCPs are often criticised for not being the most accurate tool, but are used to estimate the range size, which is done by calculating the smallest polygon in which the external angles exceed 180° and incorporates all point localities (Rodgers & Carr 2002; Burgman & Fox 2003; Laver & Kelly 2008). MCPs even though not highly accurate, are used frequently and therefore provide a good comparison between other studies (Rodgers & Carr 2002; Laver & Kelly 2008). KDEs, on the other hand, allow for estimating core activity areas. Using the two methods together, estimate of home range size (MCP) and estimate of home range shape (KDE), allows for an estimation of the core area (Rodgers & Carr 2002).

The adaptive kernel method with least-squares cross-validation techniques (LSCV) to estimate the smoothing parameter, h , was used to create a core 50% kernel and 95% kernel utilisation distribution (UD) (Rodgers & Carr 1998). The smoothing parameter controls the amount of variation in each component of the UD estimate. Small h values reveal the fine details of the data while large h values obscure all but the most prominent features (Worton 1989). The h values were compared to the “known standard distribution (h_{ref})” (Rodgers & Carr 1998), in order to assess whether the smoothing factor used to derive the kernels was within acceptable standards ($h \approx 40\%$ of h_{ref}) (Rodgers & Carr 1998; Seaman *et al.* 1998). The frequently asserted requirement for independence of observations (high autocorrelation: Swihart and Slade index > 0.6) was relaxed to maximise sample size and hence the precision and accuracy of the utilisation distributions for our fine scale analysis (de Solla *et al.* 1999).

Statistical data analysis

The behavioural data collected were tested for normal distribution using the Shapiro Wilks test in Statistica version 8.0. Once normal distribution was confirmed, Statistica version 8.0 was used to do a single sample t-test to identify if there was a difference in area usage over the study period (1998 – 2006) for each behaviour. Temporal analysis for areas used during the two distinct seasons (summer: September to February, and winter: March to August) from 1998 – 2006 were compared using a one-way ANOVA on Statistica version 8.0. No temperature data was collected

during the study so the seasons were determined based on the average temperatures for Richards Bay collected from the South African Weather Service (2003) (Table 2.1).

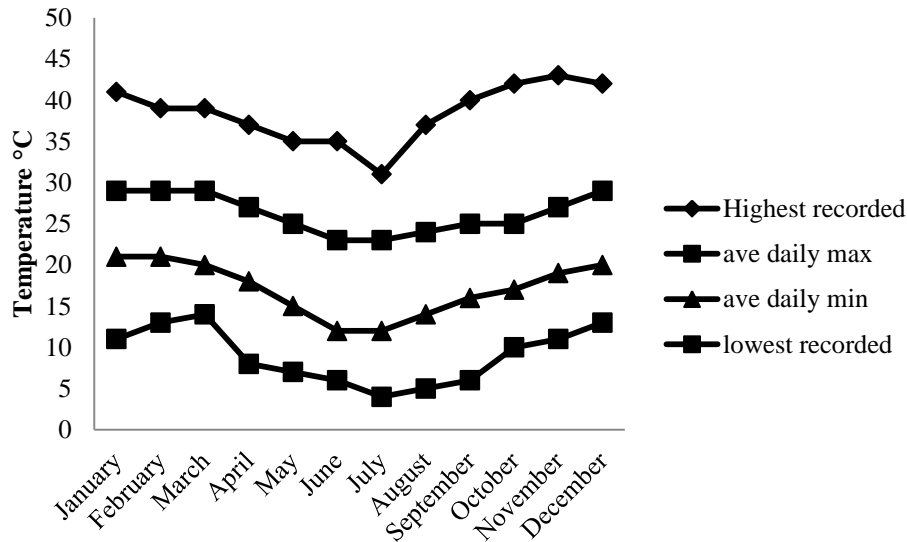


Figure 2.1. Annual weather temperatures for Richards Bay showing highest recorded temperatures, average daily maximum, average daily minimum and lowest recorded temperatures for each month. Temperatures displayed in °C. (Source: South African Weather Service 2003).

General linear modelling

In order to understand the variables that might influence behaviour, feeding and other behaviours (resting, socialising and travelling) were treated as binomial response variables (feeding =1, and all other behaviours clumped = 0). Analysis was conducted of the explanatory variables and the response variable (behaviour) suitable for logistic regression analysis where a generalised linear model is fitted using maximum likelihood techniques (McCullagh & Nelder 1989). Mixed generalized linear models (GLMM) were applied using restricted maximum likelihood techniques (family = binomial, logit link function, lmer() in R Ver. 2.10; R Development Core Team 2009), to partially account for temporal pseudo replication.

Initially the probability of dolphins feeding (F.A) was modelled by including the following continuous explanatory variables into a global model: latitude (Y), longitude (X), depth, year, month, hour, and group size (MGroup). To test whether latitude, longitude and depth affected the

probability of dolphins feeding, the interaction terms between the three variables were also included in the global model (latitude:longitude:depth). To account for the dependency of behaviours within a dolphin encounter, (1|ENC) was included as a random factor. A set of ecologically relevant alternative simplifications of the global model were then composed (Burnham & Anderson 2002).

Model selection by use of the Akaike's Information Criteria (AIC)

To compare alternative nested models, the principle of Akaike's Information Criteria was applied (AIC, Akaike 1973; Burnham & Anderson 1998). In particular, the AIC-weight criteria (w) was applied, which reflects the relative performance of models and can be interpreted as the probability that a given model is the best model, i.e. the model that minimises the Kullback-Leibler discrepancy (Burnham & Anderson 2002; Wagenmakers & Farrell 2004). In the evaluation of alternative models, the evidence ratio expressed as a normalised probability as $w_m(AIC)/w_n(AIC)$ was made use of, where model m is the best fitting model compared to model n (see Wagenmakers & Farrell 2004). As all models had the same structure and sample size, their respective AIC values were comparable (Burnham & Anderson 1998).

Correlation among explanative variables

In order to account for the problem of multicollinearity among explanatory variables, the intercorrelation among the explanative variables was investigated by performing Spearman correlation tests (r_s).

2.3. RESULTS

Over 1300 hours of boat based surveys were collected over the nine years of data collection. Of the total surveys done 275 were successful meaning that of the total surveys conducted dolphins were encountered in 275 of them. For the spatial analysis, 4481 GPS records were recorded, where the 1998 period had 1396 GPS records and every other year had less than 1000 GPS records. 29% of the points ($n = 1308$) were regarded as travelling behaviour and the remaining 71% ($n = 3173$) comprised feeding, resting and socialising behaviour (Table 2.1).

Table 2.1. Number of GPS points recorded, for all behaviours during each year (1998 to 2006). Totalled columns include the total number of points used for each year (Total (y)) and the total number of points for each categorised behaviour (Total (b)).

| | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | Total (b) |
|--------------------|-------------|------------|------------|------------|-----------|------------|------------|------------|-----------|-------------|
| Feeding | 733 | 209 | 268 | 94 | 40 | 105 | 81 | 60 | 13 | 1603 |
| Resting | 111 | 91 | 96 | 43 | 3 | 28 | 14 | 13 | | 399 |
| Socialising | 323 | 281 | 168 | 89 | 27 | 85 | 86 | 91 | 21 | 1171 |
| Travel | 229 | 174 | 385 | 198 | 23 | 88 | 106 | 97 | 8 | 1308 |
| Total (y) | 1396 | 755 | 917 | 424 | 93 | 306 | 287 | 261 | 42 | 4481 |

Spatial Analysis: KDE and MCP results

The Minimum Convex Polygon approach (MCP) estimated considerably large areas of the dolphin use for different behaviours (32.5 - 102.3 km², Table 2.2). Using the more conservative Kernel Density Estimates (KDE), utilization distributions resulted in estimates for different space use for the different behaviours. Feeding behaviour presented an outer 95% KDE of 22.3km², with 95% KDE for resting at 17.5km² and socialising at 16.8km² (Table 2.2). There was a clear concentration (core 50% KDE) of feeding in the harbour mouth area, yielding a kernel of 2.1km² (Figure 2.2a). This core feeding area was smaller than the socialising and resting areas of 3.2km² and 3.0km² respectively (Table 2.2). The highest concentration of feeding points yielded the largest core KDE making up 72.36% of the 50% KDE area, resulting in a core area of 1.53 km². The KDE derived for feeding was based on the automated LSCV derived h value (h = 0.03) which yielded a relatively small value (h/href = 0.13), producing a conservative KDE.

Table 2.2. Calculated areas (km²) for Minimum Convex Polygon (MCP), Kernel Density Estimate at 95% KDE and 50% KDE for classified behaviours for the 1998-2006 study period for humpback dolphins in Richards bay (see methods for behaviour description). The smoothing factor (*h* value), reference *h* (href) and number of points used in KDE estimation for each behaviour. The Swihart and Slade index value > 0.6 indicate significant spatial and temporal autocorrelation (HRE tool, Rodgers *et al.* 2005).

| | MCP | KDE 95% UD | KDE 50% UD | h | href | No. points | Swihart & Slade Index |
|--------------------|-------|---------------|---------------|-------|------|------------|--------------------------|
| Feeding | 102.3 | 22.3 | 2.1 | 0.03 | 0.29 | 1603 | 2.49 |
| Resting | 32.5 | 17.5 | 3 | 0.067 | 0.37 | 399 | 3.01 |
| Socialising | 60.5 | 16.8 | 3.2 | 0.046 | 0.31 | 1171 | 3.31 |
| Travelling | 92.6 | 38.1 | 5.3 | 0.061 | 0.30 | 1308 | 2.99 |

Resting behaviour was also recorded along the coastline, but never in the harbour (95% KDE: 17.5km; Figure 2.2b), extending the kernel further offshore than the other behaviours, with the 50% KDE core areas restricted (3.0 km²) with many patches in the 10m-20m depth range and occasionally even deeper. Resting KDE was produced with considerably smaller number of points (n = 399), resulting in h value ($h = 0.067$) and href (href = 0.37).

Socialising behaviour was recorded (95% KDE: 16.8 km²) along the coastline, though rarely inside the harbour (Figure 2.2c). The 50% KDE (3.2km²) were found predominantly to the south of the harbour, generally in water less than 15m in depth, though not uncommon in the 20m depth range. The h value derived ($h = 0.046$) was ~ 15% of href value (href = 0.31).

Travel behaviour occurred throughout the study area, including much of the harbour (Figure 2.2d), with 50% KDE estimated to be 5.3 km². The 50% KDE occurred predominantly within the 15m-isobath and, unlike resting and socialising, extended into the harbour.

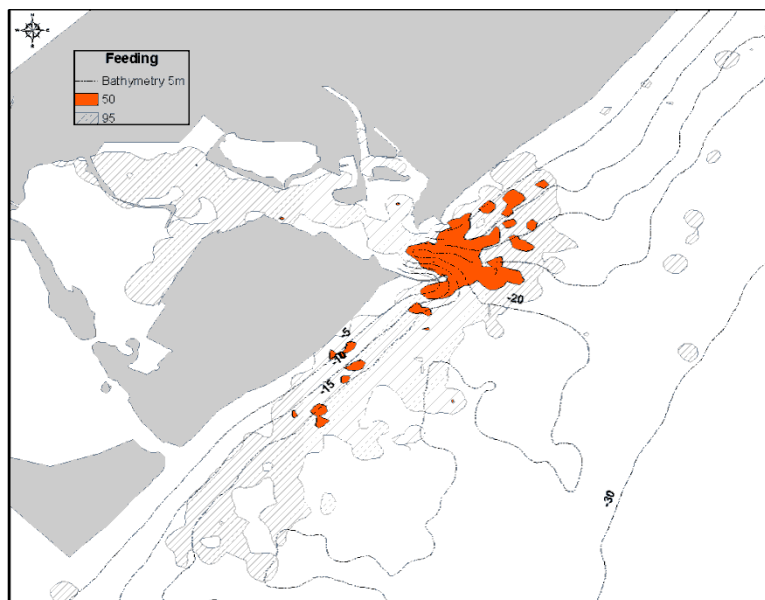


Figure 2.2a. Feeding Kernel Density Estimate (KDE) of humpback dolphins in the Richards Bay Harbour area for the period 1998 to 2006 (KDE h value: 0.03, 1603 points). Solid red area represents the 50% KDE and the patterned area represents the 95% KDE.

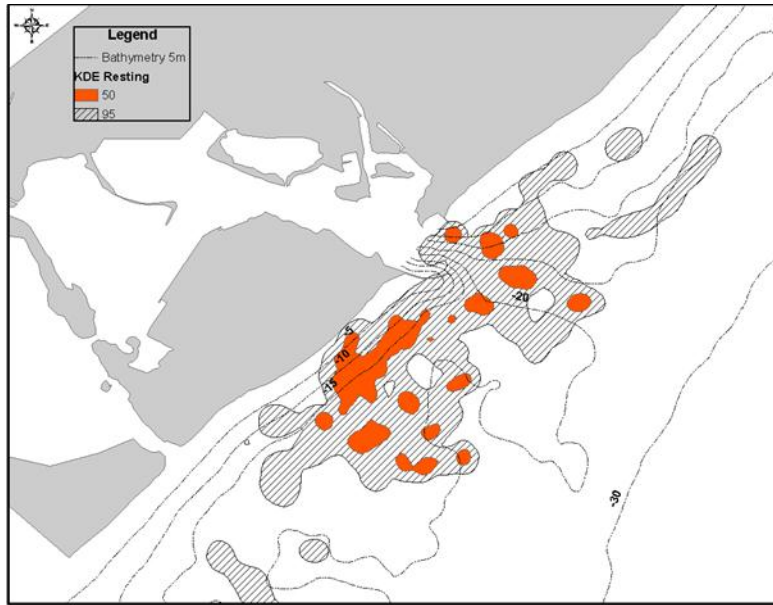


Figure 2.2b. Resting Kernel Density Estimate (KDE) of humpback dolphins in the Richards Bay Harbour areas for the period 1998 to 2006 (KDE h-value: 0.067, 399 points). Solid red area represents the 50% KDE and the patterned area represents the 95% KDE.



Figure 2.2c. Socialising Kernel Density Estimate (KDE) of humpback dolphins in the Richards Bay Harbour areas for the period 1998 to 2006 (KDE h-value: 0.046, 1171 points). Solid red area represents the 50% KDE and the patterned area represents the 95% KDE.

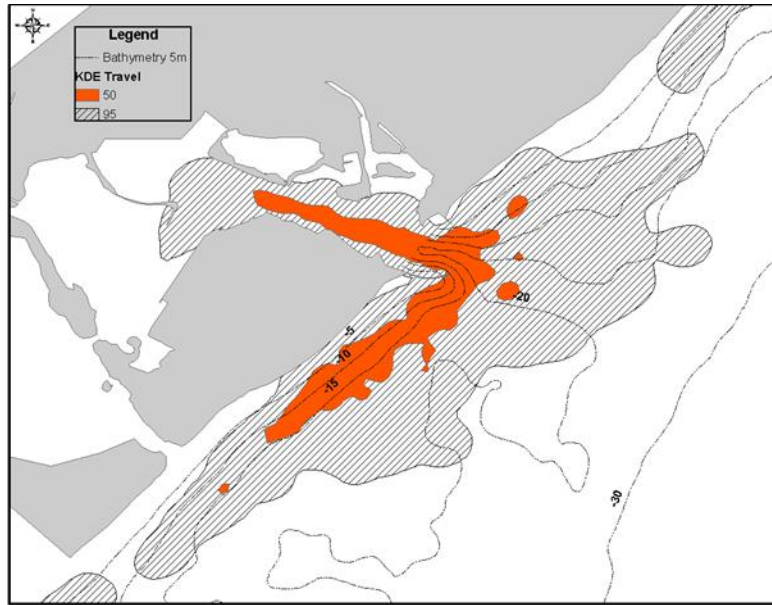


Figure 2.2d. Travelling Kernel Density Estimate (KDE) of humpback dolphins in the Richards Bay Harbour areas for the period 1998 to 2006 (KDE h -value: 0.061, 1308 points). Solid red area represents the 50% KDE and the patterned area represents the 95% KDE.

All KDE's were based on small smoothing factor values (h -values \sim 0.03-0.067; Table 2.2), which was based on ArcGIS extension HRE tools Least Square Cross Validation calculation. In context of the href value, all h values for KDE's were between 13-19.7% of the automatically calculated href value through the HRE tools.

There was a significant difference in the size of the 50% KDE area for all behaviours from 1998 – 2006, indicating a shift in the area used by the dolphins ($X = 2.41$ (SD = 1.01; t-test: df = 7; $p = 0.0003$). The same trend was seen for the travel behaviour from 1998 – 2006 mean area (3.85 (SD = 2.43) (t-test: df = 8; $p = 0.0014$) indicating a change in area over the years from 1998 – 2006. A change in the area size denotes a change in behaviour in different areas or a shift of the core area for that behaviour. These changes reveal that the core area for each behaviour is different in size as well as indicating a shift in behaviour area use over the nine year study period. There was no statistically significant difference in concentration of behaviour points between seasons (winter and summer) from 1998 – 2006 (ANOVA: $F_{6,9} = 0.17$, $p < 0.05$).

The relationships among the explanatory variables were weak (Table 2.3). Only longitude (X) and latitude (Y), and Min Depth and Max Depth, presented relatively strong correlations.

Table 2.3. Spearman R values for correlations between month (MONTH), year (YEAR), longitude (X), latitude (Y), minimum group size (MGROUP) and minimum depth (MIN DEPTH) and maximum depth (MAX DEPTH). Strong correlations ($R > 0.5$) are highlighted in bold.

| | MONTH | YEAR | X | Y | MGROUP | MIN DEPTH |
|-----------|--------|--------|--------------|--------|--------|--------------|
| MONTH | | | | | | |
| YEAR | -0.303 | | | | | |
| X | 0.056 | -0.093 | | | | |
| Y | -0.05 | 0.086 | 0.595 | | | |
| MGROUP | 0.148 | -0.226 | -0.054 | -0.193 | | |
| MIN DEPTH | 0.065 | -0.111 | 0.118 | -0.032 | 0.074 | |
| MAX DEPTH | 0.113 | -0.191 | 0.146 | -0.255 | 0.168 | 0.993 |

General Linear Modelling

The model best explaining the truest model with the lowest AIC output ($W_{AIC} = 0.58$, Table 2.4), was compiled from four of the seven explanatory variables (with the year (YEAR) of the encounter as a factor) (Table 2.4). In the majority of models (Table 2.4), the main predictive explanatory variables, latitude (Y), longitude (X), the average group size (GROUP) and year (YEAR), consistently emerged significant and yielded the lowest AIC output, as well as producing statistically significant interactions. The estimated latitude (Y), longitude (X), the average group size (MGROUP) and year (YEAR), all contributed a significant proportion of the variance found in the model (Table 2.5).

The probability to feed declined to the west (decrease in X) of the study site, whereas, the latitude (Y) increased, so did the probability to feed. This indicates that, in line with the observed behaviours and the Kernel Density Estimate, the dolphins were most likely to feed northeast of the study area (Harbour mouth Figure 2.2a). The inclusion of year (YEAR) as a factor in the GLMM indicated significant differences between years, despite small differences in terms of adjusting the 1998 (intercept) (Table 2.5).

Table 2.4. Statistical outputs of the ten best models (of 27) according to the lowest AIC, explaining variation in the probability feeding behaviour and other behaviour (Feeding All) in the Richards Bay area. Components featuring in model outputs are as follows: latitude (Y), longitude (X), depth of locality during the encounter (DEPTH), the month of the encounter (MONTH), the hour of the day when the encounter occurred (HOUR) and the average group size (MGROUP). The year during the encounter (YEAR) was included as a factor. The encounter (1|ENC) was included as a random factor in all models.

| Model | AIC | ΔAIC | W_{AIC} |
|--|------------|-------------------------------|-----------------------------|
| X + Y + MGROUP + YEAR | 4695 | 0 | 0.58 |
| X + Y + DEPTH + MGROUP + YEAR | 4696 | 1 | 0.35 |
| X + Y + DEPTH + MGROUP + YEAR + MONTH | 4700 | 5 | 0.05 |
| X + Y + YEAR | 4702 | 7 | 0.02 |
| X + Y + MGROUP | 4762 | 67 | 1.64E-15 |
| Y + YEAR | 4859 | 164 | 1.42E-36 |
| YEAR + MGROUP + MONTH + DEPTH | 4992 | 297 | 1.87E-65 |
| YEAR + MGROUP + MONTH | 4997 | 302 | 1.54E-66 |
| YEAR + MGROUP | 4998 | 303 | 9.31E-67 |

Table 2.5. Linear mixed effects model output for the truest fit model for analysis on feeding (1) and other behaviour (0). Model variables are as follows: latitude (Y), longitude (X), mean group size (MGROUP) and year (YEAR) as a factor variable. We included the encounter (1|ENC) as a random factor in the model. Number of observations: 5251 and number of groups (ENC) = 259. Statistical significance: * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$; ns = not statistically significant.

$$F.A \sim X + Y + MGROUP + YEAR + (1 | ENC)$$

| AIC | BIC | logLik | deviance |
|------|------|--------|----------|
| 4695 | 4781 | -2335 | 4669 |

Fixed effects:

| | Estimate | Std. Error | Z value | Pr(> z) | |
|-------------|----------|------------|---------|------------|-----|
| (Intercept) | 4040.59 | 263.73 | 15.32 | < 2.00E-16 | *** |
| X | -50.37 | 4.41 | -11.42 | < 2.00E-16 | *** |
| Y | 84.1 | 5.39 | 15.6 | < 2.00E-16 | *** |
| MGROUP | -0.04 | 0.01 | -2.98 | 0.00 | ** |
| YEAR1999 | -1.52 | 0.49 | -3.14 | 0.00 | ** |
| YEAR2000 | -2.45 | 0.43 | -5.66 | 0.00 | *** |
| YEAR2001 | -3.65 | 0.51 | -7.2 | 0.00 | *** |
| YEAR2002 | -2.85 | 0.69 | -4.11 | 0.00 | *** |
| YEAR2003 | -2.94 | 0.52 | -5.67 | 0.00 | *** |
| YEAR2004 | -3.51 | 0.6 | -5.85 | 0.00 | *** |
| YEAR2005 | -3.32 | 0.61 | -5.48 | 0.00 | *** |
| YEAR2006 | -2.76 | 1.19 | -2.32 | 0.02 | * |

2.4. DISCUSSION

In terms of utilisation distributions, as might be expected, the more localised behaviours, i.e. feeding, resting and socialising, tend to occur over smaller areas and have smaller core distributions than travelling. Feeding was recorded most frequently and, compared to the other two localised behaviours (socialising and resting), occurred over a large area, yet had a small core area. The small bandwidth (h) suggests that the smoothing of the utilisation distribution was conservative and fits tightly around the points for feeding (Worton 1989). In spite of a difference in the frequency of social and rest behaviours being recorded (Table 2.1), they occurred over similar-sized areas; even the core areas are similar. The bandwidth (h) for resting is slightly

larger (possibly due to a fewer number of points) and therefore some fine detail of utilisation may be obscured. Having said this, in general, all the h values are quite small ($h < 0.40$ of href (Seaman *et al.* 1998)) and the fine detail of the data reflected quite accurately and fit well around the points. The area over which travelling occurs and where it occurs most focused, is the largest, which is intuitive since part of the definition of travel is the distance it covers. It is recognised that autocorrelation (high autocorrelation: Swihart and Slade index > 0.6 ; Table 2.2) within the data would have contributed to the concentrated utilisation distributions derived. However, attaining a fine scale pattern of utilization distributions was the objective for this study (de Solla *et al.* 1999), especially for the more limited behaviours such as resting.

The Richards Bay humpback dolphin population has displayed clear area preferences, through utilization distribution analysis, showing core areas for feeding in particular. These findings conform to other studies throughout the species' range (Saayman & Taylor 1979; Durham 1994; Karczmarski *et al.* 1999; Parra *et al.* 2006; Guissamulo 2008) as well as studies within other odontocete species ranges such as bottlenose dolphins, killer whales and spinner dolphins (Norris & Dohl 1980; Heimlich-Boran 1987; Ballance 1992; Wilson *et al.* 1997). These studies all show how these species use different habitats for different behaviours. Similarly, *Sousa plumbea* generally feed closer to estuaries or around rocky reefs, whereas resting and socialising often occur in shallower, sheltered areas (Parra *et al.* 2006; Guissamulo 2008). Karczmarski *et al.* (2000) explains how the area use of the humpback dolphins in Algoa Bay is often determined by prey availability and a feeding area will be defined by the abundance of prey. Many marine and terrestrial species will often move quickly over areas with little prey and spend more time in areas abundant in prey, with these prey abundant areas then determining these species' distribution (Karczmarski *et al.* 2002).

Conditions for prey capture determine preferred feeding areas. The two major deciding factors are the quantity of prey available, and how conducive a habitat is to capture prey. Richards Bay has two breakwaters at the entrance to the harbour that act as artificial reefs, with some habitat conforming to estuary definition, “a partially enclosed coastal body of water which is either permanently or periodically open to the sea and within which there is a measurable variation of salinity due to the mixture of seawater with freshwater derived from land drainage” (Day 1980),

found within the harbour. Durham (1994) found humpback dolphins to display a high affinity to estuaries in KwaZulu-Natal, whereas Karczmarski (2000) and Karczmarski *et al.* (2000) reported that rocky inshore reefs are key habitat areas for humpback dolphins in Algoa Bay. Karczmarski *et al.* (2000) does explain though that that is probably due to the fact that the Eastern Cape Estuaries are smaller than the KwaZulu-Natal estuaries, and therefore the abundance of prey is not as prolific.

Humpback dolphins feed predominantly on reef associated estuarine and demersal fishes (Barros & Cockcroft 1991; Ross *et al.* 1994). Therefore it is not surprising that in addition to the core feeding areas off the harbour mouth and shark net installation, feeding was also reported to occur to a lesser extent at the mouth of the Mhlathuzi Estuary, where they are most likely feed on estuarine fish (Atkins *et al.* 2004). This high concentration of dolphins in one area is not unique to the humpback dolphin population of Richards Bay. Bottlenose dolphins in the Gulf of California (Ballance 1992) as well as bottlenose dolphins in the Moray Firth in Scotland (Wilson *et al.* 1997) are found in high concentrations in the estuary mouth and deep narrows respectively. It is suggested that these dolphins are sighted in these areas more often because this is where they will find higher numbers of prey, and thus feeding will occur in these areas. It is also suggested that other displays of behaviour, such as resting, are then displayed elsewhere in the more sheltered areas (Ballance 1992; Wilson *et al.* 1997). This is clearly present in the current study, with resting mainly in the south of the southern breakwater.

Resting behaviour was seen irregularly during the course of the study ($n = 399$), producing a utilization distribution primarily to the south of the Richards Bay harbour area in a more scattered pattern (Figure 2.2b). Atkins *et al.* (2004) reported that the incidence of feeding decreased with distance offshore, whereas incidence for resting increased further offshore. Guissamulo's (2008) research in Maputo Bay, Mozambique, reported humpback dolphins to rest in deeper water and at low tide, following active feeding sessions. In Maputo Bay, feeding occurs frequently in shallow water during the rising and high tide, when the dolphins can come closer to the shore and then move offshore again during low tide. In Richards Bay, although there are records of resting in the northern area around the harbour mouth, and more offshore

(further offshore than the feeding behaviour), the area most favoured for resting appears to be in the southern reaches of the study site (Figure 2.2b).

Socialising is seen throughout both the main feeding and main resting areas (Figure 2.2c), with scattering seen from the south of the study area stretching to slightly north of the harbour area. This widespread socialising area parallels the findings of the above mentioned studies (Norris & Dohl 1980; Heimlich-Boran 1987; Balance 1992; Wilson *et al.* 1997).

The IUCN defines a species as critically endangered using MCPs in either of two methods; if a home range MCP area is less than 100km² or if there is a reduction in home range area by 80% over 10 years (Burgman & Fox 2003). By looking at the MCP results, which do not show total home range area, each individual behaviour feeding alone spans an area greater than 100km². Even though these results are showing that the amount of area being used by the dolphins is not of critically endangered status, of primary importance to this study is the positioning of these behaviours. Ecologically, feeding is an important behaviour and therefore the area where the dolphins feed is significant to their survival. Feeding and some socialising behaviour occur in the harbour mouth and the area where the Richards Bay shark nets are. This means that the dolphins are more likely to be affected by boat traffic and development of the harbour. Most importantly, this puts the dolphins in high risk of being captured in the shark nets. Karczmarski *et al.* (2000) points out that for Algoa Bay, the prey species are highly vulnerable to habitat loss and destruction, and because the Algoa Bay humpback dolphins are restricted to such a small distribution and have small population numbers, this could impact on the population significantly.

Boat traffic, especially that of recreational boating appears to disturb humpback dolphins (Karczmarski *et al.* 1997; Karczmarski *et al.* 1998). Even if the boats do not approach the dolphins directly, their presence may well constitute a disturbance to the dolphins (Van Parijs & Corkeron 2001a,b). This human-caused disturbance stimulus may be perceived by animals as a form of predation risk and may elicit similar reactions (Frid & Dill 2002), possibly further increasing the dolphins' reckoning of predator encounter rates in an otherwise sheltered area.

As pointed out by Karczmarski *et al.* (2000), humpback dolphins are highly dependent on limited inshore resources within their restricted shallow-water distribution. As such, they are susceptible to habitat loss and destruction of near-shore environments. The Richards Bay harbour is undergoing expansion and development. The development has focused on upgrading the coal terminal capacity and will include additional plans to expand the port into the Mhlatuzi River floodplain. This expansion will reportedly make Richards Bay one of the biggest ports in the world. This will have drastic effects on habitat loss and increased boat traffic. Currently, the dolphins use the breakwaters and the mangrove and estuarine habitats inside the port as foraging areas. Mangroves (found extensively both in the harbour and Mhlathuzi Estuary) are considered to fulfil a nursery role to diverse fish communities (Weerts & Cyrus 2002) and typically increase fish species richness (Sheaves & Johnston 2009). Development of the harbour and destruction of these resources, combined with a continued capture of humpback dolphins in shark nets may prove detrimental to the survival of the Richards Bay humpback dolphin population.

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CHAPTER 3: MARK-RECAPTURE ESTIMATE OF POPULATION SIZE OF HUMPBACK DOLPHINS (*SOUSA PLUMBEA*) IN RICHARD BAY, KWAZULU-NATAL, SOUTH AFRICA.

3.1. INTRODUCTION

The KwaZulu-Natal coastline has 44.4km of shark nets (gill nets), which extend for approximately 14% of the KwaZulu-Natal coastline. These gill nets were laid as protection for bathers against shark attacks as a result of high numbers of shark attacks in the years leading up to 1952. The nets were first installed at Durban beaches and installations were then further installed along the coastline, with net installations now stretching from Richards Bay to Mzamba on the KwaZulu-Natal coastline (see Dudley & Cliff 1993).

These nets have reduced shark attacks with very few incidents occurring since installation (Davis *et al.* 1995). They have also been reported to have a high bycatch, catching high numbers of non-targeted marine animals. The mesh size (51cm stretched mesh) of the nets is large enough to let the smaller fish and sharks through, but the larger sharks, turtles, dolphins, batoids and teleosts are trapped in the nets (Dudley & Cliff 1993; Davis *et al.* 1995; Atkins & Atkins 2002).

The most northern installation of shark nets is Richards Bay. There were six nets laid in Richards Bay extending north from the northern breakwater of the Richards Bay Harbour entrance. These nets have been capturing high numbers of humpback dolphins since their installation in the 1950's (Dudley & Cliff 1993). The number of humpback dolphins caught in these nets has not decreased over the years since the nets were deployed, with an average of eight humpback dolphins being caught each year (Natal shark board, unpublished data). The population size estimates for the KwaZulu-Natal region and Richards Bay population are all below 250 individuals (Durham 1994; Atkins & Atkins 2002; Keith *et al.* 2002) with the annual *Sousa* captures for the Richards Bay installation being higher than the 2% annual sustainable mortality level of a dolphin population (International Whaling Commission 1994; Keith *et al.* 2002).

In addition, near shore cetacean species, such as *Sousa*, are highly susceptible to human influences and it has been noted that this species' numbers have been in decline from human development and over-exploitation of coastal areas (Cockcroft 2002). The capture of these dolphins adds to the list of threats already threatening and impacting these dolphins.

This study looks at the population size of the humpback dolphins inhabiting Richards Bay using six years of photo-identification data, which will provide the most robust population estimate for this species/population in the region. This population estimate will allow for sound management plans to be developed for the Richards Bay humpback dolphins.

To estimate population size, the dolphins were individually identified through a technique called photo-identification, and this data were then used in mark-recapture models to estimate population size. Mark-recapture is usually based on a sampling method which requires marking the animals. However, when applying mark-recapture techniques to cetaceans, the basic principle is the same, but the method changes slightly (Hammond *et al.* 1990; Karczmarski & Cockcroft 1998). Dolphins are free ranging animals and are not caught and tagged in the sampling process, but are photographed and identified using natural markings (Würsig & Jefferson 1990). This method is called photo-identification, where photographs are taken of the dolphins' dorsal fins to identify individual animals. For dolphins and porpoises, the shape of the trailing edge of the dorsal fin is the most useful feature used in photo-identification (Würsig & Jefferson 1990). It abrades and tatters easily, resulting in clear notches. The pattern of notches varies between dolphins, and therefore allow for individual identification. Individual identification is important because it improves the precision of the population estimate; some assumptions made in the methods can only be truly validated when the individuals are identified. It is particularly important for species such as the humpback dolphin which are rare and a small change in number will result in a large change in population. By individually

identifying the animals there is a better chance of studying the species' life history and therefore getting a better understanding of the species.

3.2. MATERIALS & METHODS

Study site

Richards Bay (28°48'S 32°06'E) is situated on the Tugela bank in KwaZulu-Natal, South Africa. It is the northern most installation in KwaZulu-Natal with six permanent gill nets, which are set offshore in an attempt to keep sharks away from the bathing area. There are two river systems in the study area, the Mzingazi River that flows into the harbour and the Mhlatuzi River which flows into the Mhlatuzi estuary. The harbour was constructed by dredging the existing estuary to an approximate depth of 20m. The study area stretches for 13km along the Richards Bay coast from the Mhlatuzi River mouth, to the Richards Bay lighthouse.

Data collection

A small inflatable boat was launched in the Richards Bay Harbour when weather was suitable for dolphin based research (Beaufort scale <3). Once the mouth of the harbour was reached, the search began. When dolphins were spotted, they were followed until lost or weather conditions forced the return of the boat to shore (Beaufort scale >3). Photographs were taken of the dolphins' dorsal fin and hump with no preference for marked or unmarked animals. Each day out at sea was counted as a "search" and within each search, when dolphins were seen; this period was termed an "encounter". While a group of dolphins was being followed the size of the group was estimated and where possible, the sex of the dolphin was identified and recorded.

Data were collected from 1998 to 2005. The month in which searches were conducted are shown in Table 3.1 and the effort displayed in Table 3.2, which shows the number of successful searches conducted during each month of the study.

Table 3.1. Months in which searches were undertaken in the Richards Bay area during the research period 1998 to 2005. Grey squares with “X” indicate data collection for that particular month.

| | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|------------------|------|------|------|------|------|------|------|------|
| January | | | X | X | X | X | X | X |
| February | | | X | | X | X | X | X |
| March | | | X | X | | X | X | X |
| April | X | | X | X | | X | X | X |
| May | X | X | X | X | | X | X | X |
| June | X | X | X | X | X | X | X | X |
| July | X | X | | X | | X | X | X |
| August | X | X | X | | | | | X |
| September | X | X | X | | X | X | | |
| October | X | X | X | X | X | X | X | |
| November | X | X | X | X | X | X | | X |
| December | | X | X | X | | X | | |

Table 3.2. Search effort conducted throughout the eight year study period showing the number of successful searches each month from 1998 to 2005. Total number of searches which were considered successful (dolphins were encountered and photographed) was 225.

| | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|------------------|------|------|------|------|------|------|------|------|
| January | | | 2 | 3 | 2 | 1 | 3 | 3 |
| February | | | 5 | | 2 | 2 | 3 | 4 |
| March | | | 3 | 5 | | 1 | 2 | 2 |
| April | 4 | | 3 | 6 | | 5 | 2 | 3 |
| May | 7 | 4 | 5 | 7 | | 3 | 3 | 3 |
| June | 12 | 5 | 5 | 2 | 2 | 2 | 3 | 1 |
| July | 8 | 6 | | 1 | | 2 | 5 | 2 |
| August | 7 | 3 | 5 | | | | | 1 |
| September | 5 | 2 | 4 | | 1 | 2 | | |
| October | 6 | 1 | 5 | 4 | 1 | 3 | 1 | |
| November | 1 | 2 | 4 | 1 | 1 | 3 | | 2 |
| December | | 3 | 1 | 1 | | 1 | | |

Data analysis

The photographs were analysed using matrix photo-identification techniques (Karczmarski & Cockcroft 1998) where natural markings such as notches on the fin and colouration on the hump were examined and the dolphin was given identification. Usually animals are artificially marked, but as these dolphins have features which enable

them to be individually identified, artificial marking was not necessary (Greenwood 1996).

The individually identified animals were then catalogued and these catalogued images were then matched to identify re-sightings of identifiable individuals. The matching process had strict quality control where the quality of the photograph and the distinctiveness of the individual were classified using different quality and distinctiveness scales. Each image was scored on two criteria; firstly a quality criterion out of 20, only those which scored above 12 were then scored on the distinctiveness of the image. This ranged between two (hardly distinctive) and 14 (very distinctive). Only the images which scored higher than five were then used for analysis.

Data selection

From 1998 to 2001 the data was collected on a regular basis, but from 2002 onwards the encounters became less regular. Data was grouped in the following ways to assist in data analysis:

- 1) Encounter dataset: each group encountered was counted as an individual capture occasion, no grouping was done.
- 2) Monthly dataset: the encounters were grouped into months, where all individuals encountered in one calendar month would count as one capture occasion. No matter how many times a dolphin was seen in the month it would be counted as being seen once in that capture occasion.
- 3) Weekly dataset: the encounters were grouped into weeks where one week would count as one capture occasion as months do in the monthly dataset.

A population estimate was derived from each dataset for the full study period and for each individual year.

Model choice

Data obtained from the photo-identification were then put into a mark-recapture model. Mark recapture is based on the theory that if one takes a sample of individuals from a

population, marks them (n^1), returns them to the population and gives them enough time to mix back into the population, when another sample is taken (n^2), the proportion of marked animals caught in the second sample (m) will equal the proportion of marked animals in the entire population. Therefore, using the formula below, the population size can be estimated (Greenwood 1996).

$$\frac{m_2}{n_2} = \frac{n_1}{N}$$

The basic mark-recapture techniques do not account for the individuals being identified, therefore it was important to choose a more complex model which is designed particularly for populations where the individuals have been identified.

There is one main requirement which divides mark-recapture models, and that is whether the population is open or closed. Closed population models assume that the population stays the same size during the sampling period i.e. there are no deaths or births and there is no immigration and emigration. Sometimes, if the study period is very short then the population is treated as a closed population because the effects of violating this assumption are very small. There are three assumptions which are common to all closed population models (Amstrup *et al.* 2005):

1. The population does not change over the study time (known removals are allowed; deaths and capture).
2. There is no loss of marks or tags.
3. The animals act independently.

An open population model assumes that the population changes during the study period; i.e. the population is affected by births, deaths, immigration and emigration. An open population study often covers a long period of time and it is these changes in the population which are of interest to biologists. The main and most commonly used open population model is the Jolly-Seber model. The Jolly-Seber model estimates population size, and survival and capture probabilities using ratios of marked to unmarked animals. Therefore, the marked and unmarked animals need to be recorded at each sampling

occasion, and a complete capture history of each animal is then known (Amstrup *et al.* 2005). The assumptions made for the Jolly-Seber model (Amstrup *et al.* 2005) are:

1. Every animal in the population has the same chance of being captured (equal catchability).
2. Every animal in the population has an equal chance of survival.
3. There is no mark loss and marks are not overlooked.
4. Sampling periods are short.
5. Emigration from the population is permanent.
6. There is no behavioural response from the traps.

Due to the length of the study and nature of the population it cannot be assumed that there were no deaths, births, immigrations or emigrations and therefore it cannot be assumed that the population is closed. An open population approach, POPAN, was chosen. POPAN is a reparametisation of the Jolly-Seber model by Schwarz & Arnason (1996) used in Program MARK. POPAN includes a parameter for a super-population, N , which is the total number of animals available for capture at any time or the total number of animals ever in the sampled area during the study period (Nichols 2005).

Because the animals are individually identified and not marked as in standard mark recapture techniques, in the first sample there would be animals which are identified and animals which are not. This is unlike the basic recapture technique where all animals are marked in the first sample. So for the first sample the animals are identified where possible, and a second sample is taken and the animals are identified again, with the number of animals found in both sample, one and two being counted and these would then count as the recaptured animals. The formula, $m_2/n_2 = n_1/N$, described above would work as follows:

n_1 : Number of identifiable animals in sample one.

n_2 : Number of identifiable animals in sample two.

m_2 : The number of animals occurring in sample two which were found in sample one.

N : The total size of the identifiable population.

This method of mark-recapture, using natural marking, does not require trapping or capture of the animals, and is therefore a preferred method because it does not affect the behaviour of the animals therefore eliminating that bias.

Estimating population size

Once the model was chosen, eight models were run on each dataset for each year and for the full population estimate. These models were comprised of varying time dependence for the different parameters; Φ , apparent survival, p , probability of capture and b , probability that an animal from the super-population enters the sub-population (the animals occurring in the study area). The first model was the fully time-dependent Jolly-Seber model ($\Phi p_t b_t$) with subscript “t” representing time and “.” (used in other models) representing constant parameters.

A Goodness-of-Fit test using program RELEASE GOF in Program MARK was used to test for violation of assumptions and based on the results of TEST 2 + TEST 3, the models were adjusted for over-dispersion in the data using \hat{c} , a post-hoc variance inflation factor. This resulted in a quasi-Akaike Information Criterion (QAIC) which was then used to determine the model which best fit the data (Schwarz & Arnason 1996).

Because there were individuals which were not identified in the sampling process and the model estimated the population of identifiable individuals, each estimate had to be adjusted for the proportion of identifiable individuals by dividing the estimate by the proportion appropriate for that year. To determine the proportion of identifiable individuals for each year, a set of 100 good quality images from each year in the study period were randomly chosen. The dolphin distinctiveness was rated as either zero (not distinctive, notches are small and may not be visible in all reasonable photographs) or one (distinctive, notches are clearly distinctive and/or fin shape is particularly distinctive) (Williams *et al.* 1993; Leatherwood & Jefferson 1997; Atkins & Atkins 2002). If there was more than one dolphin in the image, the closest dolphin perpendicular to the camera was used. Dolphins of all age classes were included (i.e. juveniles were not excluded).

The number of images from each set with distinctive dolphins (distinctiveness rating of one) was divided by 100 (total number of images used in a set for each year in the study period) to get the proportion of identifiable individuals for each year. For the full study period an average of all the years was used.

The variance was then estimated using the delta method:

$$\text{var}(N_{\text{total}}) = N_{\text{total}}^2 \left(\frac{\text{var}(N)}{N^2} + \frac{1 - \theta}{n\theta} \right)$$

Where:

N_{total} : The population estimate adjusted for the proportion of identifiable individuals.

N : The mark-recapture estimate.

θ : The proportion of identifiable individuals.

n : The total number of photographs from which θ was estimated.

Confidence intervals for N_{total} assumed the same error distribution as the mark-recapture estimates (Wilson *et al.* 1999).

3.3. RESULTS

A total of 232 searches were conducted from 1998 to 2005 where 225 were successful in encountering dolphins. During this time 134 dolphins were individually identified. Of these dolphins, 19% (26 individuals) were seen once, 67% (90 individuals) were seen between two and 11 times and 13% (18 individuals) were seen between 12 and 73 times (Figure 3.1). Of the 1253 identified dolphin sightings, 715 of these were of dolphins whose sex was known, 23 female dolphins and 14 males. Figure 3.2 shows the sighting frequency of males versus females with males being seen an average of 10 times and females 25 times over the entire study period.

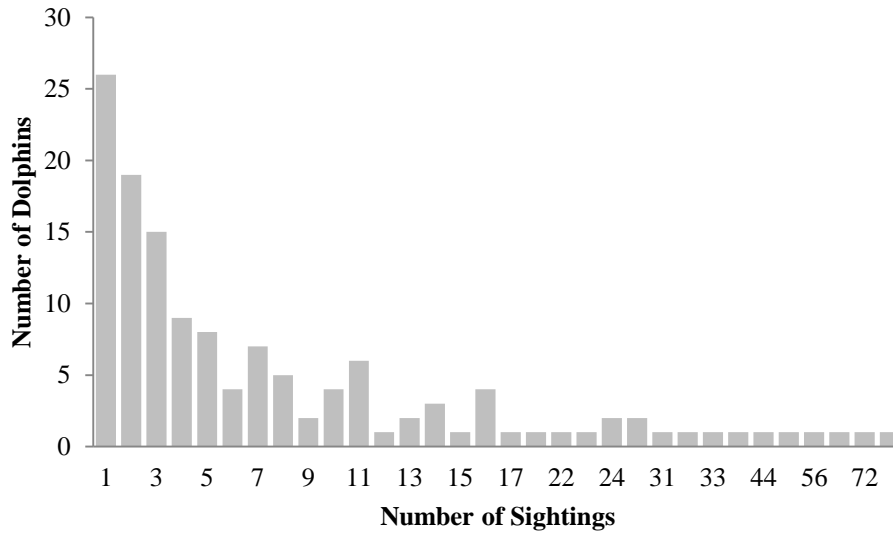


Figure 3.1. Sighting frequency distribution for identified humpback dolphins from 1998 to 2005 in Richards Bay, KwaZulu-Natal.

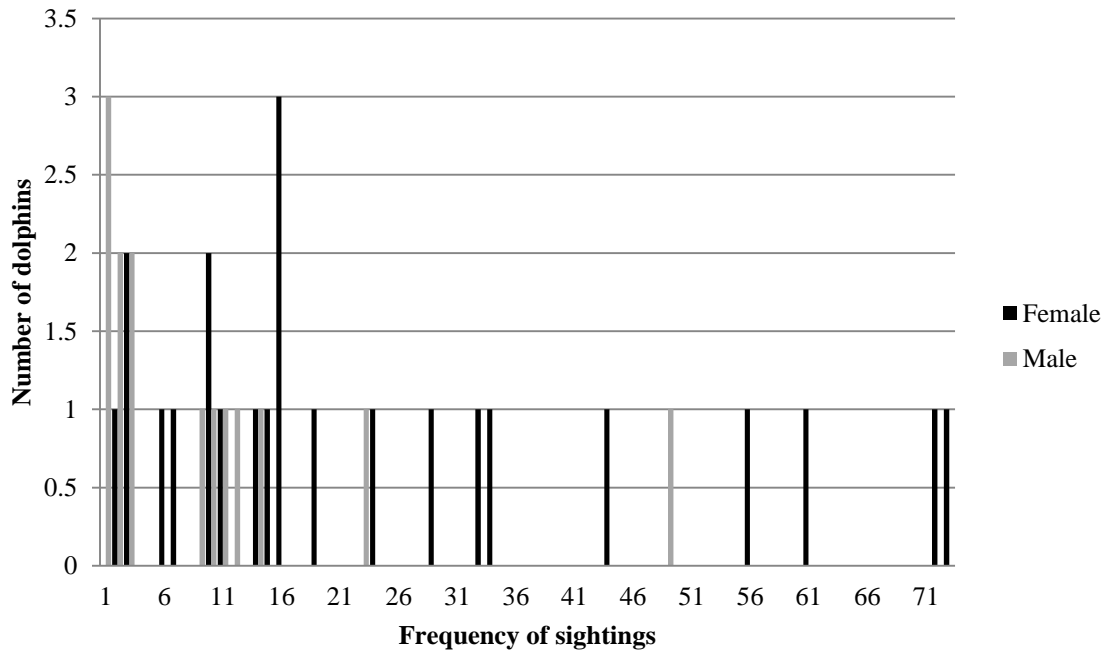


Figure 3.2. Frequency of female versus male sightings from 1998 to 2005 in Richards Bay, KwaZulu-Natal.

The cumulative number of newly identified individuals increased rapidly for the first two years (1998 and 1999), with a low rate of newly identified individuals per year (Figure

3.3). From January 2001, there was a low but steady increase in number of newly identified individuals (Figure 3.3).

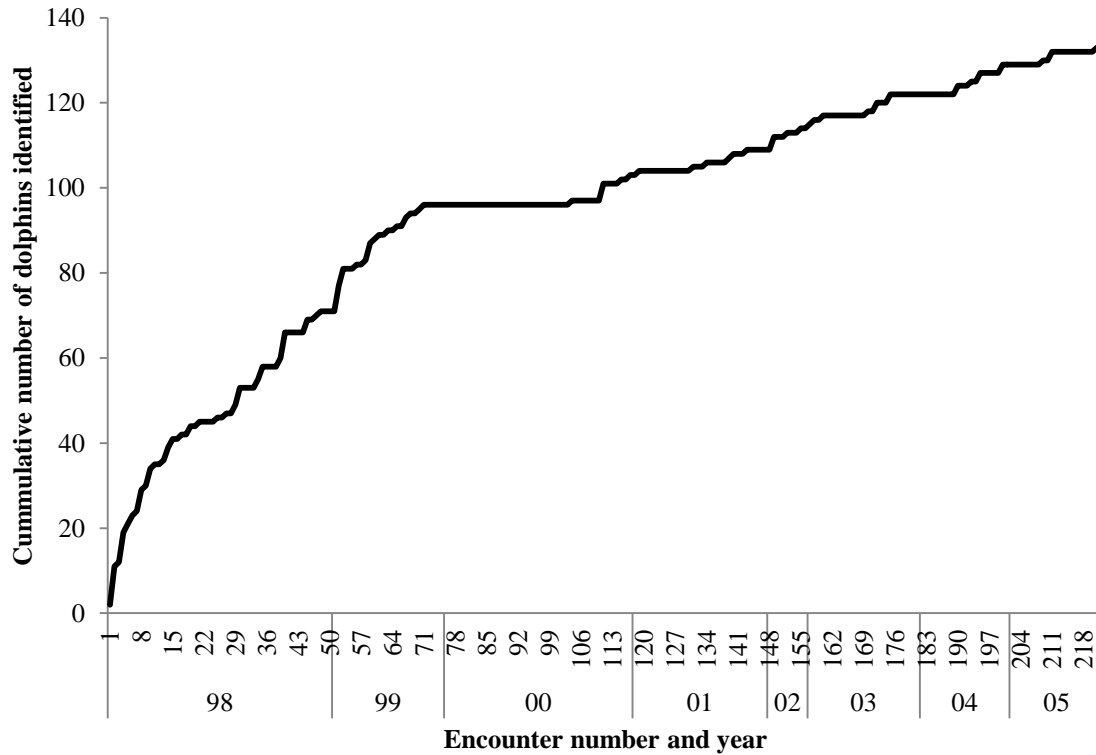


Figure 3.3. Discovery curve showing the cumulative number of humpback dolphins identified during the study over 225 encounters from 1998 to 2005 in Richards Bay, KwaZulu-Natal.

For each year during the study, there was a relatively consistent collection of data over the months during the year (Table 3.1), but the number of dolphins identified during each month varied (Figure 3.4).

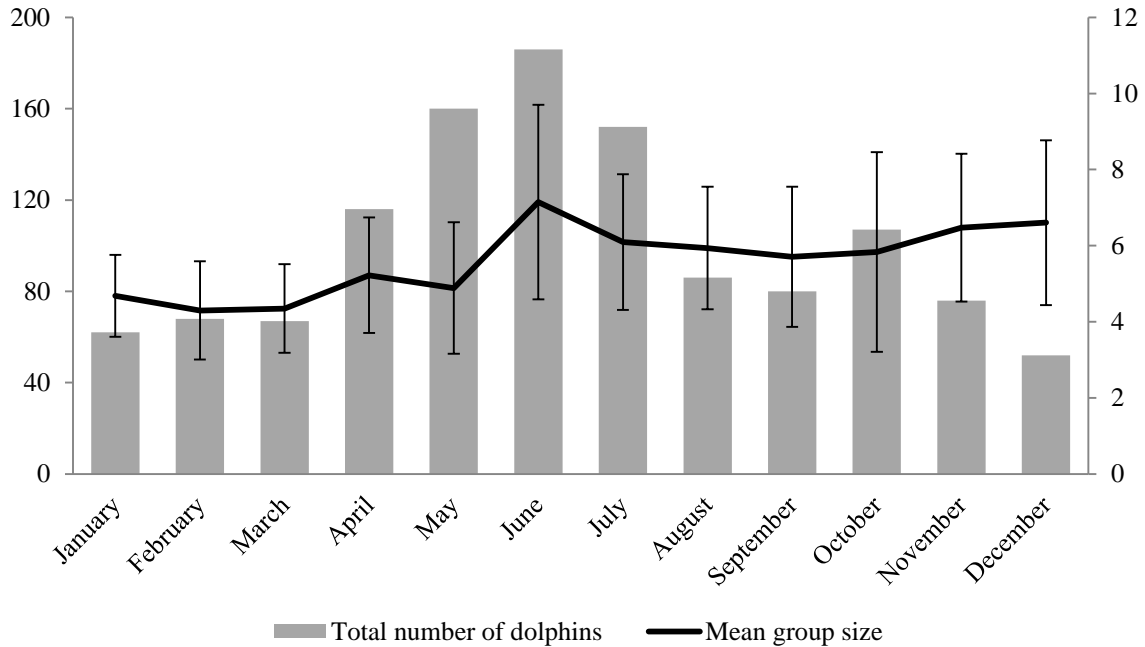


Figure 3.4. Total number of dolphins identified per month and mean group size (with standard deviation) for each month over the entire study period: 1998 to 2005. Number of dolphins is on the left y-axis and group size on the right y-axis.

The average minimum group size was slightly lower in the earlier months in the year with an average of 4.20 for January to May and 5.94 for June to December (Figure 3.4) (total average minimum group size 5.79). Data collection only commenced in April 1998, with no searching from January to March in 1998 and from January to April in 1999. This, together with the low average group size in the early months from subsequent years, contributes to the low number of dolphins identified from January to March (Figure 3.4).

The model chosen allows for the survival and capture probabilities to be constant while the probability of entry varies with time. The results of TEST 2 + TEST 3 showed a lack-of-fit in the data, but the result was ≤ 3 , and therefore the lack-of-fit was considered acceptable and an inflation factor (\hat{c}) was applied thereby adjusting the estimate accordingly (Manley *et al.* 2005). Of the 64 population models run for the encounter data, 14 did not meet numerical convergence, and the best model according to the Akaike Information Criterion (AIC) was chosen for each year (Table 3.3). Sixty-four models were run for each of the monthly and weekly datasets. In the monthly dataset, 13 models did not meet numerical convergence and the best models according to the AIC, are shown

in Table 3.4. This is the same for the weekly dataset, although in this case, 15 models did not reach numerical convergence and the best models according to the AIC are shown in Table 3.5.

Table 3.3. Best Jolly-Seber POPAN model results for Encounter data for each year (only best model for each year is displayed) for the Richards Bay humpback dolphins study for 1998 – 2005. QAICc – Quasi Akaike Information Criterion, AICc W – AIC weight, NP – number of Parameters, X^2 and df – chi-squared and degrees and freedom from results of TEST 2 + TEST 3, \hat{c} – c-hat calculated from TEST 2 + TEST 3, N – population estimate, SE – standard error, CI – confidence interval

| Model | QAICc | AICc W | NP | X2 | df | \hat{c} | N | SE | 95% CI | |
|--------------------------|---------|---------|----|-------|----|-----------|-------|------|--------|--------|
| | | | | | | | | | Lower | Upper |
| 1998{ Φ, p_t, b_t } | 1678.92 | 0.99987 | 59 | 46.06 | 68 | 0.6773 | 98.17 | 6.78 | 84.89 | 111.46 |
| 1999{ Φ, p_t, b_t } | 2008.2 | 1 | 30 | 15.53 | 45 | 0.3451 | 96.93 | 4.81 | 87.51 | 106.35 |
| 2000{ Φ, p_t, b_t } | 1178.1 | 1 | 49 | 39.84 | 54 | 0.7378 | 50.14 | 3.24 | 43.79 | 56.48 |
| 2001{ Φ, p_t, b_t } | 882.1 | 0.9974 | 37 | 6.68 | 40 | 0.6671 | 51.38 | 4.21 | 43.12 | 59.64 |
| 2002{ Φ, p_t, b_t } | 208.88 | 0.9992 | 11 | 8.24 | 10 | 0.824 | 48.67 | 8.65 | 31.72 | 65.63 |
| 2003{ Φ, p_t, b_t } | 469.5 | 0.56044 | 31 | 67.94 | 44 | 1.5441 | 53.99 | 6.91 | 40.45 | 67.52 |
| 2004{ Φ, p_t, b_t } | 554.37 | 0.99998 | 28 | 29.09 | 27 | 1.0774 | 66.88 | 7.7 | 51.79 | 81.98 |
| 2005{ Φ, p_t, b_t } | 631.85 | 1 | 2 | 32.9 | 34 | 0.9676 | 53.66 | 3.11 | 47.57 | 59.75 |

Table 3.4. Best Jolly-Seber POPAN model results for Monthly data for each year (only best model for each year is displayed) for the Richards Bay humpback dolphin study for 1998-2005. QAICc – Quasi Akaike Information Criterion, AICc W – AIC weight, NP – number of Parameters, X^2 and df – chi-squared and degrees and freedom from results of TEST 2 + TEST 3, \hat{c} – c-hat calculated from TEST 2 + TEST 3, N – population estimate, SE – standard error, CI – confidence interval

| Model | QAICc | AICc W | NP | X2 | df | \hat{c} | N | SE | 95% CI | |
|--------------------------|--------|---------|----|-------|----|-----------|-------|-------|--------|--------|
| | | | | | | | | | Lower | Upper |
| 1998{ Φ, p, b_t } | 296.09 | 0.53126 | 9 | 17.52 | 14 | 1.2515 | 89.3 | 7.1 | 75.38 | 103.21 |
| 1999{ Φ, p, b_t } | 748.23 | 0.7812 | 11 | 8.42 | 16 | 0.5262 | 97.51 | 6.59 | 84.6 | 110.43 |
| 2000{ Φ, p, b_t } | 1.89 | 0.99892 | 10 | 32.38 | 21 | 1.5418 | 47.21 | 3.29 | 40.76 | 53.65 |
| 2001{ Φ, p, b_t } | 267.12 | 0.98875 | 7 | 16.53 | 16 | 1.0329 | 48.94 | 3.89 | 41.31 | 56.58 |
| 2002{ Φ, p, b_t } | 135.32 | 0.95472 | 5 | 6.8 | 6 | 1.1337 | 48.01 | 7.98 | 32.37 | 63.65 |
| 2003{ Φ, p_t, b_t } | 357.99 | 0.9997 | 20 | 21.6 | 21 | 1.0284 | 63.06 | 18.76 | 26.3 | 99.83 |
| 2004{ Φ, p_t, b_t } | 316.44 | 0.87297 | 14 | 11.05 | 12 | 0.9212 | 60.62 | 4.07 | 52.65 | 68.6 |
| 2005{ Φ, p_t, b_t } | 294.44 | 0 | 14 | 19.52 | 16 | 1.2202 | 51.98 | 2.86 | 46.38 | 57.57 |

Table 3.5. Best Jolly-Seber POPAN model results for Weekly data set for each year (only best model for each year is displayed) for the Richards Bay humpback dolphin study for 1998-2005. QAICc – Quasi Akaike Information Criterion, AICc W – AIC weight, NP – number of Parameters, X^2 and df – chi-squared and degrees and freedom from results of TEST 2 + TEST 3, \hat{c} – c-hat calculated from TEST 2 + TEST 3, N – population estimate, SE – standard error, CI – confidence interval

| Model | QAICc | AICc W | N P | X2 | df | \hat{c} | N | SE | 95% CI | |
|------------------------|---------|---------|--------|-------|----|-----------|--------|-------|-----------|--------|
| | | | | | | | | | Lower | Upper |
| 1998{ Φ, p, b_t } | 872.14 | 0.99969 | 34 | 44.6 | 49 | 0.9103 | 96.83 | 7.59 | 81.95 | 11171 |
| 1999{ Φ, p, b_t } | 1639.75 | 0.57356 | 19 | 11.09 | 31 | 0.3579 | 102.23 | 5.95 | 90.58 | 113.89 |
| 2000{ Φ, p, b_t } | 618.78 | 0.99995 | 35 | 37.13 | 36 | 1.0314 | 49.96 | 3.82 | 42.48 | 57.44 |
| 2002{ Φ, p, b_t } | 626.71 | 0.99692 | 26 | 19.95 | 29 | 0.6878 | 47.32 | 3.23 | 40.98 | 53.66 |
| 2003{ Φ, p, b_t } | 212.13 | 0.99692 | 12 | 8.11 | 10 | 0.8111 | 46.64 | 7.72 | 31.51 | 61.77 |
| 2004{ Φ, p, b_t } | 632.97 | 1 | 31 | 30.89 | 35 | 0.8826 | 65.93 | 12.17 | 42.08 | 89.79 |
| 2005{ Φ, p, b_t } | 481.61 | 0 | 24 | 22.11 | 22 | 1.0052 | 65.49 | 7.26 | 57.34 | 88.96 |
| 2006{ Φ, p, b_t } | 703.11 | 1 | 21 | 18.59 | 26 | 0.7151 | 53.83 | 2.67 | 48.6 | 59.07 |

The estimates for each year (Table 3.7) and the full study period from 1998 to 2005 were adjusted for the identifiable individuals using the proportion of identifiable individuals calculated for each year (Table 3.6).

Table 3.6. Proportion of identifiable individuals for each year and for all years for humpback dolphins identified in the Richards Bay area for the period 1998-2005.

| Year | Proportion of identifiable animals |
|-----------|------------------------------------|
| 1998 | 0.79 |
| 1999 | 0.70 |
| 2000 | 0.69 |
| 2001 | 0.77 |
| 2002 | 0.67 |
| 2003 | 0.69 |
| 2004 | 0.7 |
| 2005 | 0.73 |
| All Years | 0.72 |

Table 3.7. Summary of best fit population models (lowest QAIC) for each year using encounter, monthly and weekly adjusted for the proportion of identifiable individuals, with the standard error (SE) and upper and lower confidence limits (CL) for each estimate.

| | Encounter | SE | Upper CL | Lower CL | Monthly | SE | Upper CL | Lower CL | Weekly | SE | Upper CL | Lower CL |
|-------------|-----------|------|----------|----------|---------|-------|----------|----------|--------|------|----------|----------|
| 1998 | 124 | 6.48 | 131 | 118 | 113 | 7.44 | 120 | 106 | 123 | 8.06 | 131 | 115 |
| 1999 | 138 | 9.12 | 148 | 129 | 139 | 13.07 | 152 | 126 | 146 | 13.7 | 160 | 132 |
| 2000 | 73 | 4.97 | 78 | 68 | 68 | 6.72 | 75 | 62 | 72 | 7.1 | 80 | 65 |
| 2001 | 67 | 3.78 | 71 | 63 | 64 | 4.62 | 68 | 59 | 61 | 4.47 | 66 | 57 |
| 2002 | 73 | 5.2 | 78 | 67 | 72 | 7.57 | 79 | 64 | 70 | 7.36 | 77 | 62 |
| 2003 | 78 | 5.34 | 84 | 73 | 91 | 8.93 | 100 | 82 | 96 | 9.34 | 105 | 86 |
| 2004 | 96 | 6.33 | 102 | 89 | 87 | 8.16 | 95 | 78 | 94 | 8.81 | 102 | 85 |
| 2005 | 74 | 4.58 | 78 | 69 | 71 | 6.02 | 77 | 65 | 74 | 6.22 | 80 | 68 |

The abundance estimate for the entire dataset could not be calculated using the encounter or weekly dataset as the goodness-of-fit test could not be conducted and therefore an overall estimate could not be estimated. Using the monthly dataset, an estimate of 146 was calculated (CI = 7.17, 95% confidence limits 132 – 160) for the period between 1998 and 2005. With the adjustment for the identifiable individuals of 0.72 (Table 3.6), the population estimate for the Richards Bay population was 203 (CL: 185 - 221).

3.4. DISCUSSION

Populations of humpback dolphins all around the world are generally small, less than 300 individuals (Durham 1994; Atkins & Atkins 2002; Guissamulo & Cockcroft 2004; Parra *et al.* 2006). The Richards Bay humpback dolphin population is estimated at 203 (CL: 185 – 221) based on the best estimate with the lowest QAIC. To date this estimate is the most robust considering it is calculated from the largest dataset ranging over the longest time period for a study on this species in this region. In Algoa Bay (Eastern Cape, South Africa), the population is estimated at 466 (confidence intervals 447 - 485) which is double the estimated population size for this study. Studies in Australia in Cleveland Bay and Moreton Bay, estimated humpback dolphin populations for those regions to be between 163 and 100 individuals (Parra *et al.* 2006), much lower than the present

estimate of 203. Parra *et al.* (2006) points out that small populations are highly vulnerable and have a higher chance of depletion due to anthropogenic effects. The International Whaling Commission (IWC) (IWC 1994) states that small cetacean populations can only handle an annual anthropogenic mortality rate of 2%. With an average of eight humpback dolphins being caught in the shark nets each year (Natal shark board, unpublished data) this means there is a mortality rate of about 4%, double the sustainable rate recommended by the IWC (IWC 1994).

A seasonal peak in identification of dolphins was seen from April to May over all the years (Figure 3.4), indicating a possible seasonal change in population or an influx of dolphins into the area. A seasonal trend in population numbers was also seen in Algoa Bay, but in this situation, an increase in numbers was seen over the summer months as apposed to the winter months (as in this study) (Karczmarski *et al.* 1999). The increase in number over the summer months in Algoa Bay was probably related to food abundance (Karczmarski *et al.* 1999). No searches occurred from January to March in 1998 and from January to April in 1999 (Table 3.1). The low number of dolphins identified from January to March (Figure 3.4) could potentially be seasonal variation, however the variation could also potentially be related to reduced search effort and/or environmental conditions limiting launching. This could be a reason for the increase in identification during the summer months because the weather conditions are better for boat launching and searching during this time (South African Weather Service 2003). Considering the average minimum group size for the earlier months of the year (4.2 from January to May), it is slightly lower than that of the rest of the year. Even though these numbers are lower, dolphin identification does start to increase from April as apposed to average group size, which stays low until May (average group size from May to December = 5.94) (Figure 3.4). It can be assumed then that this increase in group size, which could indicate a seasonal pattern, rather does not and the implied pattern in the dolphin identification could be attributed to the lack of searching in the earlier months during 1998 and 1999 (Table 3.1 and 3.2).

The average group size from the current study for the Richards Bay humpback dolphins is 5.94 (Figure 3.4). For other regions the group size was larger than that of Richards Bay (see Saymaan & Tayler, 1979, Ross et al. 1989, Findlay et al. 1992, Durham 1994, Karczmarski et al. 1999b). Guissumulo & Cockcroft (2004) report an average group size of 14.9 (SD: 7.32, n: 37) for the humpback dolphins off the coast of Mozambique. Guissumulo & Cockcroft (2004) explain this as being the result of a coalescence of smaller groups in the deeper waters at low tide as many areas are not available to the dolphins at low tide. However, the reason for the coalescence is unclear. Gygax (2002) investigated fluctuating group sizes in different species of dolphins and porpoises, and states that group size is not predictable and can be different for populations of species which occur in different areas or habitats. The group size may depend on food availability, predators, or even just a random historical process of evolution (Gygax 2002). The reasoning for the smaller group size in the Richards Bay humpback dolphin is unclear from this study and would need further investigation and focussed study to determine the reasoning.

The treatment of the population in the mark-recapture estimate as open is supported by the discovery curve constantly increasing, and never reaching an asymptote (Figure 3.3). There is a decrease in the rate of discovery (slope of the curve), but the initial high rate is due to the high numbers of new discoveries, this initial increase was also found by Karczmarski *et al.* (1999) in Algoa Bay in a study conducted over three years. Keith *et al.* (2002) and Durham (1994) suggest that the Richards Bay population is open, whereas Atkins & Atkins (2002) looked at the population as if it was both open and closed stating there is a degree of closure due to a decrease in the rate of discovery. In this study the decrease in the rate of discovery can be attributed to the length of the study where new dolphins were discovered less frequently as the length of the study increased. The decrease can also be linked to a reduction in sampling intensity in the later years of the study.

The number of dolphins seen only once was relatively low, 19%, in comparison to both Atkins & Atkins (2002) and Keith *et al.* (2002) who found high numbers of dolphins

which were seen only once, 39% and 63% respectively. In these other studies, very few dolphins were seen more than ten times and in the present study dolphins were seen up to 73 times. Keith *et al.* (2002) uses the assumption that a dolphin seen at least four times in the study period of one year is considered a resident. Fifty percent of the dolphins in this study were seen less than four times in the entire study period, this high number suggests that a large proportion of the population cannot be regarded as permanent residents in the Richards Bay area, suggesting that there is a small group of resident dolphins to Richards Bay and is part of a larger population which ranges over a large distribution along the KwaZulu-Natal coast. Additionally it was females which were seen more often throughout the study period (Figure 3.2) therefore indicating that there is some sort of population structure with the females being more resident than the males.

Durham (1994) states that the KwaZulu-Natal population in itself can be regarded as a closed population, with the Richards Bay population a “sub-population”. This suggests that a large proportion of dolphins use the Richards Bay area as thoroughfare or transition zone between other unknown areas within the KwaZulu-Natal area (Keith *et al.* 2002). This is supported by the long distance movement recorded by Keith *et al.* (2002) and long distance movement in Algoa Bay (Karczmarski *et al.* 1998). All of these factors seem to be an important component in the high number of captures in the Richards Bay shark net installation. The dolphins may only encounter shark nets in this transition zone once or twice in their lifetime and therefore would not know where the nets are and will have a higher chance of getting caught in the nets (Peddemors 1995; Keith *et al.* 2002).

The results from the current study also seem to infer there are permanent residents in this area, for example one dolphin was seen 73 times throughout the study. The high level of residency, suspected by Keith *et al.* (2002) and Atkins & Atkins (2002), resulted in a resident population estimate of 58 (± 10.95) individuals by Keith *et al.* (2002). These permanent residents will only make up a small proportion of the total number of dolphins which use this area. It is however believed that these resident individuals know the layout of the shark nets, and thus have a lower “risk of capture” (Peddemors 1995). The high level of “transient” individuals being caught in the nets, supports why the number of

dolphins being caught in the shark nets is not decreasing; the dolphins entering the area are doing so once or twice in eight years and therefore do not know the area and will get caught in the nets. In addition, Karczmarski (1996) further indicates that there is limited connectivity between the KwaZulu-Natal population and southern coast population (Algoa Bay, South Africa). This coupled with a low estimated population size of approximately 200 individuals and experiencing large annual mortality from the shark nets increases the vulnerability of the population (Cockcroft *et al.* 1989; Cockcroft 1990). Parra *et al.* (2006) points out that depicting changes in population trends in small populations is very difficult. Therefore, when trying to understand the impact of the shark nets and other anthropogenic stressors placed on this region, the small population size does not help. Depicting these trends is much easier when a population is large in number (Parra *et al.* 2006)

Cockcroft (1990) suggested that the capture of humpback dolphins in the shark nets possibly exceeds the annual replacement rate of the population. This population is not anywhere near a number as high as it should be for survival and has many other pressures acting on it because of them being an inshore species reliant on vulnerable and limited resources. The inshore population of Richards Bay also face heavy polychlorinated biphenyl (PCB) and dichlorodiphenyltrichloroethane (DDT) pollutants from coastal runoff. The Richards Bay humpbacks have shown to have a high accumulation of these pollutants, and females nursing their calves can pass these pollutants on through lactation possibly posing a fatal threat to the calves. The high vulnerability of this species raises alerts for its conservation. Ongoing capture in the shark nets could be detrimental to the survival of this species in this area especially considering the assumption that this might be an isolated population along the KwaZulu-Natal coastline. Management practices need to be put into place to ensure the ongoing survival of this species. Karczmarski (2000) and Karczmarski *et al.* (1998) highlight the conservation issues related to this species, some of which have been outlined in this study. These management recommendations call for limitations on the human impact to the coastal environment through the use of protected areas. In order to ensure the survival of this species it is important to reduce the negative impacts imposed. By reducing the human impact to the coastal zone which is the

biggest threat to this species we will achieve our goal of ensuring the long term survival of this species.

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CHAPTER 4: CONCLUSION

This study provides a synthesis of nine years of research on the population of humpback dolphins in Richards Bay, South Africa. Humpback dolphins have a number of worldwide threats posed to them which results in the Near Threatened status by the IUCN Red List (Reeves *et al.* 2010). Human induced habitat loss through mangrove removal and infrastructure development, accidental mortality in netting, indirect effects such as tourism and siltation of rivers and estuaries, loss of prey species from overfishing, and chemical and industrial pollution are some of the regional threats listed for the South African populations (Friedman & Daly 2004). Richards Bay is a well-used port in South Africa with a large amount of boat traffic. Further development of the port will exacerbate the current levels of dredging, and construction in the estuary areas of the harbour will lead to increased siltation, loss of prey habitat, increased pollution as well as an increase in boat traffic.

An increase in boat traffic will result in an increase in possible interactions with the dolphins. It has been shown that an increase in boat based dolphin watching tourism which is not conducted according to strict guidelines, can increase the amount of stress related behaviours, alter the behaviour, movement and dive patterns of nursing females (Englund & Berggren 2002; Stensland 2004). Stensland *et al.* (2006) highlights the impact boat based “swim with dolphin” tourism can have but at the same time shows how it has replaced dolphin hunting in Zanzibar and the impact is far less than that of hunting. Even though there are negatives to the dolphin tourism industry there are also positives where data can be collected on the dolphins as well as introducing an alternative livelihood for those who were once involved in the dolphin hunting. The threats posed to humpback dolphins is different in different areas, where in Zanzibar the threat was once dolphin hunting, in Richards Bay the threat is capture in the shark nets and an increase in boat traffic through their main feeding area (Atkins *et al.* 2004; current study).

It is often not easy to detect changes in populations or predict what effect human activities are going to have on our wild marine animals so it is important to look to other

areas to learn from them. Jefferson & Hung (2004) conducted a review of the status of the humpback dolphin in Chinese waters. This area is a rapidly growing industrial area with structures such as a new airport which was built on mostly reclaimed land in 1998 as well as many aquaculture facilities being erected in the coastal waters. All these developments have affected the humpback dolphins, to what extent is unknown, but there were observations of changes in behaviour during the building of the airport. On the coast of Taiwan there has been an obvious loss of preferred habitat for the humpback dolphins due to river alteration and reclamation works (Jefferson & Hung 2004).

Along with these plans for development of the harbour, the Richards Bay humpback dolphins have another threat along the KwaZulu-Natal coast line, the shark net installation. These shark nets, which act like gill nets, are to protect bathers from sharks by capturing the sharks in the nets, and reducing the number of sharks in the bathing areas (Cockcroft 1990; Davis *et al.* 1995). These nets are not selective and therefore do not only capture sharks but capture many other species including the humpback dolphin (Dudley & Cliff 1993; Durham 1994; Atkins & Atkins 2002; Keith *et al.* 2002). The number of humpback dolphins being caught in these nets has remained high since their installation in the 1950's (Natal Shark Board, unpublished). Atkins & Atkins (2002) reported that the annual bycatch of humpback dolphins in the KwaZulu-Natal shark net installation is about 4% of the estimated population. The current study confirms that the capture of humpback dolphins in the shark nets can be up to 4% of the population as an average of 8 dolphins caught per year (Natal Shark Board, unpublished) of the estimated population size, 203, is 4%. This is double the recommended sustainable level for anthropogenic mortalities.

The population estimate from the current study showed that the population of humpback dolphins in Richards Bay is around 200 individuals which is a low number for dolphin populations. There was also some evidence that almost half of the population is transient and therefore not resident to Richards Bay. In previous studies (Durham 1994; Keith *et al.* 2002) it has been suggested that the Richards Bay population is part of a larger population which extends along the KwaZulu-Natal coastline and Richards Bay is merely

a transition zone between other areas on the KwaZulu-Natal coast. This is evidently supported by results from the current study based on the high number of individuals (almost 50%) which were photographed and identified less than four times during the study period, which according to Keith *et al.* (2002) is the number of times a dolphin should be seen in a year to be considered resident.

Humpback dolphins of Richards Bay have clear behaviour patterns with each behaviour occurring in a small core area (feeding, resting and socialising) except for travelling which is explained by the nature of the behaviour. The core feeding area was found to be around the harbour mouth and shark net area. Humpback dolphins feed on estuarine and reef associated fishes (Barros & Cockcroft 1991; Ross *et al.* 1994; Atkins *et al.* 2004). The breakwaters of the harbour as well as the shark nets act as artificial reefs which therefore attract the dolphins. Core resting behaviour was found away from the feeding area more to the south of the harbour and feeding area, with socialising found throughout the study area. Because the dolphins are feeding in the main boat traffic area and the shark net area they are highly susceptible to interacting with boats or being caught in the nets (Peddemors 1995; Keith *et al.* 2002). Along with this it has been shown that there are a high number of non-resident dolphins in Richards Bay (Keith *et al.* 2002; current study). The high catches of humpback dolphins in the shark nets can be attributed to the high numbers of non-resident dolphins visiting the Richards Bay area. The reason for this is that these non-resident dolphins are not familiar with shark nets and the threat they pose (Peddemors 1995; Keith *et al.* 2002). So, the Richards Bay population is a small population (around 200 individuals), most of which are not resident and they are feeding in an area which poses a high a risk of capture.

The KwaZulu-Natal Sharks Board is an organisation which is mandated to protect bathers from shark attacks. They maintain and monitor these shark nets and have been for the past 40 years. The KwaZulu-Natal Sharks Board also conducts research on sharks to better understand the animals they are working with. Another area of research they are involved in is finding alternative ways to protect bathers from sharks without impacting on the shark populations as well as other species which are affected by the shark nets

such as the humpback dolphin (KwaZulu-Natal Sharks Board 2011). Kearney & Jones (unpublished) conducted a study on the environmental effects of shark nets, the study highlighted possible alternatives to shark nets. These alternatives along with alternatives and research the KwaZulu-Natal Sharks Board investigating is explained below.

There are a few recommendations for alternative to shark nets, one of which has been tested, the drumline (Dudley *et al.* 1998). A drumline is a large anchored float which has a baited hook attached to it, this is used to catch the sharks in the same way the net would. Drumlines have proven to be more selective for sharks and the drumline non-shark bycatch is much lower than that of the nets (Dudley 1997; Dudley *et al.* 1998). This has become common practise on most beaches with some beaches having either two shark nets or one shark net and four drumlines. There have been some nets in KwaZulu-Natal which have been removed altogether but this is due to the high cost of the maintenance of the nets. Nets are removed during the sardine run around June and July to reduce the impact the nets will have on all the other species which are attracted to that area during that time. In Queensland, Australia, drumlines have been used in conjunction with nets from the beginning (Dudley 1997). KwaZulu-Natal, Queensland and New South Wales, Australia, have shown to all have the same effectiveness on reducing shark attacks even though they all use different method (e.g. drummlines vs no drumlines; permanent nets vs seasonal nets). It is therefore not necessarily important to have many nets all the time but rather to place the nets strategically in position and timing (Dudley 1997). This will reduce the amount of nets used as well as the amount of time the nets are used during the year which will have a positive effect on the humpback dolphin population.

The KwaZulu-Natal Sharks Board has also been testing electrical shark repellent devices which would deter the sharks using an electrical current therefore eliminating the need for the shark net (KwaZulu-Natal Sharks Board 2011; Kearney and Jones unpublished). The implementation of this device would be highly beneficial to the humpback dolphin as there would be no nets for the dolphins to get caught in. In Cape Town, South Africa they have implemented a program called Shark Spotters. This program works on the basis that

there are no nets or other physical barriers to allow sharks into the surf zone. There are people who are strategically placed in viewing points who will scan the water looking out for any signs of sharks near to the shore, on sight of a shark they will send a signal down to the beach and a warning siren and flag will be raised (Shark Spotters 2012; Kearney and Jones unpublished).

These are all very innovative and exciting methods which can be used in place of the shark net but they are predominantly based on reducing the impact to sharks. There is another method which the KwaZulu-Natal Sharks board has been testing which involved using a device called a pinger. This device sends out a signal which in preliminary studies carried out by the sharks board has shown to deter dolphins from the shark nets. These studies have been testing dolphin behaviour around the nets and capture in the nets with and without the pinger. There have been no captures of dolphins in the nets with the pinger. These results are still preliminary and would require further testing (KwaZulu-Natal Sharks Board 2011). Pingers have been tested on harbour porpoises in the Gulf of Maine and showed a reduction in mortality of the porpoises in the nets (Kraus *et al.* 1997; Kraus & Brault 1998). Kraus *et al.* (1997) and Kraus & Brault (1998) do caution against using their results for other species as different species respond to acoustic sounds differently and therefore testing on other species would be essential.

Shark nets are of great concern to the humpback dolphin population and there is a lot of on-going research into how to reduce the impact the nets have on the dolphins. This study has shown that the dolphins are feeding in the areas where the shark nets are placed.

Sousa only breed once every few years, they start breeding later into their life and only have one young at a time (Jefferson & Karczmarski 2001). This life history makes them highly vulnerable to extinction and therefore it is very important to ensure that the population numbers stay at a level which will enable the species to continue breeding and ensure survival. In order to ensure stable population numbers and in turn reduce the impact of the shark nets on the KwaZulu-Natal humpback dolphin population, it is important to implement the correct conservation management plans for the area. First and

foremost the importance of the shark nets needs to be re-evaluated. It is important to ensure that the placement of the shark nets is done in such a way that they reduce the impact on the dolphins as far as possible.

It is also important to be aware that the current development of the harbour will impact the Richards Bay humpback dolphin population. The harbour is consistently used by the dolphins for a variety of behaviours with some areas used as feeding areas. It is very important that the construction does not impact highly on the dolphins' habitat and feeding zones ensuring the preservation of the dolphins and their prey species' habitats. The humpback dolphin is an iconic species on our South African coastline and it is essential to ensure the survival of this species through a well-researched conservation management plan. A management plan will not be efficient without the correct information on the species it is intended to be conserving.

Parra *et al.* (2006) studied the Australian snubfin and Indo-pacific humpback dolphin in Australia and also found a small population which was not entirely resident to the area, showing long range movement outside of the area. Parra *et al.* (2006) illustrates two important points:

1. "Detection of population trends should not be a necessary criterion for enacting conservation measures of both species in this region."
2. "Efforts to maintain viable populations of both species in Cleveland Bay must include management strategies that integrate anthropogenic activities in surrounding areas."

Even though it is essential to have the correct and most detailed information to make a well-designed management plan it is also important to recognise that there are anthropogenic activities affecting these dolphins at present and there is evidence of a negative effect. Therefore there is no reason to not implement management strategies based on the limited information at present and to include a data collection and analysis component into that management plan to continuously improve it.

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