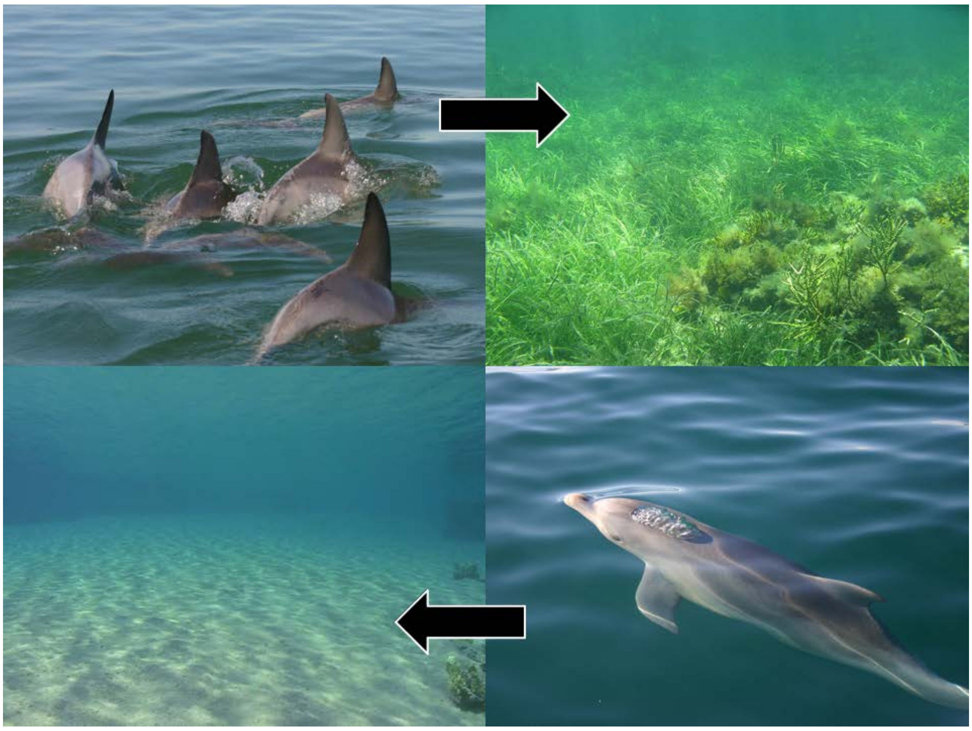
Towards an objective and quantitative approach for coastal dolphin habitat: application to management and conservation



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SUMMARY

The definition of cetacean habitat has been established as a key priority in the development of management and conservation initiatives as well as threat abatement. Our understanding of the ecological underlying drivers of how cetaceans interact with their three dimensional habitat is however, very limited for many species. This lack of understanding in many cases is a result of the variety of multiple variables and factors, which previous studies have measured to consider habitat for these animals.

The main objective of this thesis was to reach a more objective and quantitative foundation to cetacean habitat studies through the development of a rationale and standardised approach. This approach specifically, considers investigating the underlying driving factors of cetacean habitat, rather than only describing cetacean distribution patterns or just relating their presence to the supposed distribution of prey or a limited number, if any, environmental features. Furthermore, it was key to develop a pre-study focus of either of these applications so that future studies may progress with a more standardised and quantitative approach which would ultimately produce more applicable results in which to develop effective management and mitigation techniques for these animals.

As habitat varies between species, locations, studies, and management priorities, habitat definitions should be broad, measure multiple variables and be tailored to the species and region under investigation. In particular, the assessment of the underlying abiotic and biotic patterns and processes that define cetacean habitat requires the use of objective and quantitative measurements and analyses that may help the scientific community to reach a consensus on how to study cetacean habitats, and ultimately define a research framework to unambiguously define habitats across species, genera and biogeographic regions. The information collected can be assessed to see

whether it is applicable to a management context or not. Ultimately, habitat studies should be conducted with the primary aim to make them more targeted and effective in defining and describing habitat so the information obtained can also become more applicable to management.

The developed rationale and approach was primarily applied to two case studies, more specifically, two delphinid species from contrasting environments with differing life histories (*i.e. Tursiops* sp. in South Australian coastal waters and *Stenella longirostris* in a Fijian reef complex) and distinct management and threat criteria. Various field based studies examining key abiotic or biotic environmental features, and dolphin behaviour, were then applied to each location utilising a similar approach in which to identify key ecological drivers of habitat in each location. Additionally, two further non-invasive approaches (*e.g.* photo-identification techniques and fractal analyses) were applied to demonstrate their usefulness when first considering a habitat study as well as a way of considering the identification and quantification of local threats. These 2 techniques can be applied as an additional support to our primary habitat rationale and approach.

The implications of this work demonstrate that there are some unique and relevant considerations that should be addressed when undertaking a cetacean habitat study. Even though the ability to measure key factors of cetacean habitat is frequently constrained by available resources and practicality of field work, an immediate starting point is to apply a prior analyses of the species and study location and then a standardised, broad and quantitative approach which measures the primary range and optimal abiotic and biotic conditions of where the animals are sighted.

The overall findings of this thesis provide novel habitat information on two small delphinid species, but also demonstrate a useful approach to investigate cetacean habitat. Both the habitat rationale

and approach and the two additional supporting habitat techniques presented here can be applicable to other species and locations where the identification of dolphin habitat or cetacean habitat in general is crucial. Additionally, this approach can be applied on a broader context at both local and regional scales.

Ultimately, the application of this approach aims to enhance our greater understanding of what habitat means for cetaceans with the intent to provide greater and more effective levels of protection and threat mitigation.

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DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or a diploma in any university; and that to the best of my knowledge and belief it does not contain any material published or written by another person except where due reference is made in the text.

Nardi Patricia CRIBB

July 2017

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ABSTRACTS ARISING FROM THE THESIS

Following is a list of references of published and submitted peer-reviewed papers, popular articles, conference talks, and posters arising during the author's Doctor of Philosophy studies. Additional references of papers previously published by the author in relation to cetacean habitat are also presented.

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Cribb N, Miller C, Seuront L (2015) Towards a standardised approach of cetacean habitat: Past achievements and future directions. *Open Journal of Marine Science*, 92(8): 1793-1798.

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INVITED SEMINARS

Cribb N, Seuront L (2012) Introduction to Victor Harbor Land Based Dolphin Observation Project. Friends of the South Australian Whale Centre General Meeting, 1 August, 2012, Victor Harbor Council Chambers, Victor Harbor, South Australia.

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Cribb N (2010) Cetacean Habitat. North Haven Schools Dolphin Ranger Training Day, 3 March 2010, Maritime Museum, Port Adelaide, South Australia.

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Chapter 1

General Introduction

1.1 Introduction

The definition of cetacean habitat is now widely acknowledged as a key priority in the development of management and conservation initiatives as threat abatement (Bannister *et al*. 1996; Hoyt 2005; Miller & Cribb 2009; Cribb *et al*. 2015). Previously cetacean habitat has been defined in terms of their critical behaviours *e.g.* feeding and reproduction, and has also at times been considered to include parts of their distributional range which are vital for their day-to-day survival and overall fitness (Harwood 2001; Hoyt 2005; Miller & Cribb 2009). Cetacean habitat has also previously been defined by relating their distribution patterns to a range of environmental variables *e.g*. water temperature, depth, tidal cycle, sea-bed gradient and sediment type, or by linking their immediate presence to the supposed distribution of prey; see Miller & Cribb (2009) and Cribb *et al*. (2015). Finally, habitat-related cetacean studies are heavily constrained, both financially and logistically, by the fundamental nature of work at sea (Cribb *et al*. 2015).

Our understanding of the underlying ecological drivers of how cetaceans interact with their three dimensional habitat is, however, still very limited for many species over most of the worlds ocean (Bannister *et al*. 1996; Ross 2005; Hoyt 2005; IUCN 2015). This lack of understanding is essentially the result of the lack of consensus on what habitat means and is for cetaceans, hence more pragmatically how it should be defined and studied. In particular, the variables that have been used to define cetacean habitats, if any, drastically vary between published reports and eventually appear to be author-specific, which further limits our ability to increase our understanding of what cetacean habitat is (Cribb *et al*. 2015). In addition, the scientific community has been torn apart over the last decade or so by the debate related to both the ethical and biological relevance of using invasive methods such as biopsy of live tissues to study cetacean ecology (*e.g*. Noren & Mocklin 2011).

The investigation and identification of habitat for cetaceans has previously essentially been limited by an inconsistent understanding of what this term actually means for cetaceans and cetacean researchers. In particular, a previous work identified 5 critical questions (Miller & Cribb 2009):

(i) What is habitat for a cetacean?

(ii) How is habitat information meaningful if there has been nothing measured or analysed?

(iii) What are the underlying drivers of habitat?

(iv) How can habitat be quantitatively measured or defined?

(v) Why is it critical to understand cetacean habitat?

All these questions are here considered essential to further our understanding of the ecological relationships between cetaceans and their complex three-dimensional environment. This environment is intrinsically unstable, comprised of dynamic regimes of both abiotic and biotic properties, which differ in time and space (Bräger *et al*. 2003). It is hence vital to improve our understanding of their distribution, behaviour and migration patterns in the context of their environment by applying a broader and more objective approach which is on a case-by-case basis (Miller & Cribb 2009). In particular, as habitat fundamentally varies between species, locations, studies and management priorities, habitat definitions should be broad, measure multiple variables and be tailored to the species and region under investigation. The assessment of the underlying abiotic and biotic patterns and processes that define cetacean habitat requires the use of objective and quantitative measurements and analyses that may help the scientific community to reach a consensus on how to study cetacean habitats, and ultimately define a reference framework to unambiguously define habitats across species, genera and biogeographic regions. The information collected can subsequently be assessed to see whether it is applicable to a management context or not. Ultimately, habitat studies should be conducted with the primary aim to make them more targeted and effective in defining and describing habitat so the information obtained can also become more applicable to management.

1.2 Thesis Aims

In this context, the main objective of this thesis was to refine our understanding of what habitat actually means for cetaceans and cetacean researchers through:

1. The introduction of a standardised approach of cetacean habitat, which is suggested to provide a more objective and quantitative foundation to cetacean habitat studies;

2. The application of this rationale to two species of small delphinids with differing life histories and occurring in contrasted ecosystems (*i.e. Tursiops aduncus* in South Australian coastal waters, and *Stenella longirostris* in a Fijian reef complex), hence with distinct threat and management criteria. In this context, this work specifically aimed to:
   a. Assess the potential links between the physical and biological properties of the marine environment with dolphin presence and behaviour;
   b. Examine dolphin behavioural activities in relation to the physical and biological properties of the pelagic and benthic environments,
   c. Investigate individual habitat use through the application of photo-identification techniques.

3. The illustration of how standard (*i.e.* photo-identification) and non-standard (*i.e.* fractal analysis of breathing rhythms) non-invasive methods may be beneficially used to further our understanding of cetacean habitat and the role habitat may play in cetacean resistance and resilience to both acute and chronic anthropogenic disturbances.

1.3 Thesis Structure

The results of this thesis (Chapters 2 to 8) are presented in manuscript form and have either been published in peer-reviewed journals, have been submitted to peer-reviewed journals for publication, or will be submitted for publication in the near future.

In Chapter 2[1], the fundamental differences between terrestrial and marine habitats are briefly reviewed to highlight the difficulty in defining a marine habitat, with a special focus on marine mammals. Six recommendations by which future cetacean habitat studies might be approached are subsequently introduced. This recommended approach aims to amend the way in which we think and undertake investigations into cetacean habitat. It is believed that through this broadened approach, future cetacean habitat studies will increase our understanding of underlying driving factors of cetacean habitat, rather than just describing distribution patterns. Finally, it is stressed how the proposed approach will be more directly applicable within management frameworks and of benefit to conservation initiatives. This work demonstrates that there are some unique and relevant considerations that should be addressed when undertaking a cetacean habitat study. Even though the ability to measure key factors of cetacean habitat is frequently constrained by available resources and practicality of field work, an immediate starting point is to apply a prior analyses of the species and study location and then a standardised, broad and quantitative approach which measures the primary range and optimal abiotic and biotic conditions of where the animals are sighted.

In chapters 3 to 6, the developed rationale and approach was subsequently applied to two delphinid species (*Tursiops aduncus* and *Stenella longirostris*) from contrasting environments (the temperate coastal waters of South Australia and the tropical waters of a Fijian reef), with differing life histories and management, and threat and management constraints. Field based studies examining key abiotic or biotic environmental features, and dolphin behaviour were then applied to each

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[1] Published as "Cribb N, Miller C & Seuront L. Towards a standardized approach of cetacean habitat: past achievements and future directions. *Open Journal of Marine Science*, **5**, 335-357"

location utilising a similar approach tailored to identify key ecological drivers of habitat in each location.

More specifically, Chapters 3[2] and 4[3] focused on quantitatively investigating the habitat characteristics of a small resident bottlenose dolphin (*Tursiop*s *aduncus*) population in the Adelaide Dolphin Sanctuary, South Australia. Despite this area being declared a sanctuary in 2005, information regarding the specific habitat characteristics of dolphins in this area is still limited. The application of the two methods presented in these chapters therefore endeavoured to produce much needed baseline information in which to benefit ongoing local management initiatives for this area.

In Chapter 3, photo-identification techniques were applied to investigate the space-time patterns of individual dolphin habitat preference. More specifically, the aim was to potentially identify a preference between the two benthic types (*e.g.* bare sand and seagrass beds) which are present within the boundaries of the Adelaide Dolphin Sanctuary on an individual level. Boat based photo-identification surveys covering the 118 km^2 sanctuary area established a significant preference for the bare sand habitat, through the sighting frequency of individual animals. This trend was consistently observed at both annual and seasonal scales, suggesting that dolphins in this area demonstrate a consistent use of these two distinctly different habitat types. Chapter 4 compliments Chapter 3 by further investigating the overall habitat characteristics of this small population. More specifically, we applied an objective and quantitative approach, which consistently considered the abiotic and biotic variables that may be relevant to dolphin ecology in this area. This involved investigating both the biological and physical properties of the water column, local tidal fluctuations and benthic habitat type in relation to dolphin presence and behaviour. In contrast to previous

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[2] Published as “Cribb N, Miller C & Seuront L (2013) Indo-Pacific Bottlenose dolphin (*Tursiops aduncus*) habitat use in a heterogeneous, urban, coastal environment. *Aquatic Biosystems*, **9**, 3”

[3] Submitted as “Cribb N & Seuront L. On a comprehensive assessment of bottlenose dolphin habitat characteristics: example of the Adelaide Dolphin Sanctuary, South Australia” to *Estuarine, Coastal and Shelf Science*.

studies, in order to gain insight into the dolphins concealed vertical habitat, we did not limit our measurements to only the water properties to the surface, but considered the entire structure of the water column. Furthermore, water properties were also measured at both locations where dolphins were present and absent. Although differences in environmental properties were established, no direct links between oceanographic factors, group size, composition and behaviour were identified.

Spinner dolphins typically frequent shallow, sandy bays and reefs during daylight hours to rest, which are in many cases in the near vicinity of popular tourist destinations. In this context, Chapters 5[4] and 6 focus on identifying the key habitat characteristics of a small population of spinner dolphins (*Stenella longirostris*) who had been regularly observed to frequent a small tropical reef complex off the main island of Fiji, Moon Reef. The predictable presence of dolphins within this reef complex has made them a draw for tourists, with boats from surrounding tourist destinations visiting them daily. This frequent and growing disturbance therefore makes conservation initiatives for this area crucial. The aims of Chapter 5 was to identify the predominant (if any) behaviour once inside the reef and establish individual site fidelity over time. Over the duration of the study period recognisable individuals were resighted on 2 or more occasions and resting behaviour was established as the predominant behaviour whilst inside the reef complex. To further establish this reef as an important and key resting habitat for spinner dolphins in this area, we investigated the environmental factors potentially influencing their choice of resting environment. More specifically, in Chapter 6 we report the results of biological and oceanographic surveys conducted within and outside Moon Reef used and a subsequent one, in close geographical vicinity, which was not used by spinner dolphins. This enabled the evaluation of potential oceanographic differences measured inside and outside of each of the reef complexes as well as to identify any biological diversity and

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[4] Published as: “Cribb N, Miller C & Seuront L (2012) Site fidelity and behaviour of spinner dolphins (Stenella longirostris) in Moon Reef, Fiji Islands: implications for conservation. *Journal of the Marine Biological Association of the United Kingdom*, DOI: 10.1017/S0025315412000033”

structural differences. The results presented here provide baseline information, which can be applied to the future development of conservation strategies in this area.

Finally, two non-invasive approaches based on photo-identification techniques and fractal analyses of breathing rhythms were applied in Chapters 7 and 8 to demonstrate their usefulness and value-adding when first considering a habitat study as well as way of considering the identification and quantification of local threats. In Chapter 7[5], the potential changes in the behavioural complexity of bottlenose dolphins in response to human disturbance were investigated along a gradient of anthropogenically impacted environments in South Australian coastal waters. Specifically, the susceptibility of bottlenose dolphins to anthropogenic disturbance is of particular importance due to the ever increasing impact on those waters and their semi-enclosed nature. Currently, little is known about the ecology of dolphins in this region, in particular in relation to anthropogenically driven disturbances. This study investigates the level of stress experienced by bottlenose dolphins from the complexity of their patterns of dive durations recorded along a gradient of environment types defined as a function of the intensity of anthropogenically driven pollution and disturbances, including urban development and recreational boating. Dive durations were opportunistically recorded from land-based stations scattered across South Australian coastal waters in the absence of boat traffic, and in the presence of motorboats. Subsequent analyses were based on nearly 12,000 behavioural observations. No significant differences were ever found in dive durations measured in the absence of boats and when boats were present. In contrast, fractal analysis consistently identified significant differences in the complexity of dive duration patterns as a function of environment and exposure to disturbance. Specifically, bottlenose dolphins occurring in environments with less anthropogenic pressure exhibit a higher behavioural complexity. This complexity consistently significantly decreases both within each environment and between

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[5] Published as: "Cribb N & Seuront L (2016) Changes in the behavioural complexity of bottlenose dolphins along a gradient of anthropogenically-impacted environments in South Australian coastal waters: implications for conservation and management strategies. *Journal of Experimental Marine Biology and Ecology*, **482**, 127.

environments with increasing anthropogenic pressure. Our results further show that the relative changes in bottlenose dolphins behavioural complexity increases in environments less impacted by anthropogenic activities. These results are discussed in the general context of the adaptive value of fractal behaviour, the susceptibility of bottlenose dolphins occurring in distinct environments to anthropogenic disturbance, and how behavioural properties identified with our fractal methods can be used to establish baseline information that can be used for the design and implementation of conservation and management strategies.

Finally, in Chapter 8, the movements and connectivity of bottlenose dolphins between the South Australian mainland and Kangaroo Island were inferred based upon photo-identification data obtained from three photo-identification studies carried out around South Australia. Individuals were resighted over time between the mainland and Kangaroo Island. Images compared with recognisable individuals from an existing catalogue from the Adelaide Dolphin Sanctuary, identified no matches. This chapter shows that dolphins within South Australian waters are highly mobile and transient. This provides evidence of potential movement pathways and corridors in this region, which may therefore indicate the potential need for stronger conservation and management initiatives on a broader scale. Additionally, the application of a photo-identification techniques demonstrates the effectiveness of this non-invasive tool in which to preliminary identify individual ranging patterns and potential key core use areas as well as provide insight into the potential exchange between the various coastal dolphin communities.

Chapter 9 summarises the overall findings of the thesis and discusses the implications of these results within the general context of this topic and provides direction and suggestions for further studies. In particular, the findings of this thesis provide novel habitat information on two small delphinid species as well demonstrating a useful approach in which to investigate cetacean habitat.

Both the habitat rationale and approach, and the two additional supporting habitat techniques presented here can be applicable to other species and locations where the identification of dolphin habitat or cetacean habitat in general is crucial. Additionally, this approach can be applied on a broader context at both local and regional scales. Ultimately, the application of this approach aims to enhance our greater understanding of what habitat means for cetaceans in general with the intent to provide greater and more effective levels of protection and threat mitigation.

To reduce redundancy the literature cited throughout the thesis has been presented within a single ‘References” list at the end of the thesis.

Chapter 2

Towards a Standardised Approach of Cetacean Habitat: Past Achievements and Future Directions

Published as:

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N Cribb (candidate) contributed to 80% of the conception and details of the study design, data collection, data analysis, writing and editing. Dr C Miller contributed to 10% of the conception and details of the study design, writing and editing. Dr L Seuront contributed to 10% of the conception and details of the study design, writing and editing.

2.0 Abstract

The understanding of what habitat means for an organism as well as the underlying factors driving patterns of habitat use are still unknown for many species. Cetacean habitat has been described using a range of methodologies and variables measured over various temporal and spatial scales that are often author-dependent. However, in order to develop an objective and sound understanding of what habitat actually means for cetaceans, a standardised approach needs to be developed. Here, after briefly reviewing the fundamental differences between terrestrial and marine habitats, we highlight the difficulty in defining a marine habitat, with a special focus on marine mammals. We subsequently provide six recommendations by which future cetacean habitat studies might be approached. This recommended approach aims to amend the way in which we think about and undertake investigations into cetacean habitat. It is believed that through this broadened approach, future cetacean habitat studies will increase our understanding of underlying driving factors of cetacean habitat, rather than just describing distribution patterns. Finally, it is stressed how the proposed approach will be more directly applicable within management frameworks and of benefit to conservation initiatives.

2.1 Introduction

The study of habitat is essential for understanding the biological and ecological requirements of animals as well as the strategies they employ to fulfil their needs (Freitas *et al*. 2008). In addition, habitat information is a fundamental prerequisite for the implementation of both management and conservation strategies (Redfern *et al*. 2008). However, the definition of habitat is still a contentious one, and its use is far from being consistent (Krausman 1999). In particular, there is a general lack of unified definition in both terrestrial and marine ecological studies (Tables 2.1 & 2.2). As a further example, a review of the use of the term in terrestrial studies found that 82% of articles reviewed, used habitat terminology imprecisely (Hall *et al*. 1997).

Definition and research into habitat has frequently been identified as crucial for cetacean management and conservation (*e.g.* Bannister *et al*. 1996, Reeves *et al*. 2003, Hoyt 2005, Redfern *et al*. 2008, Bearzi *et al*. 2008). However, a consistent definition and understanding of what habitat actually means for cetaceans is still lacking. As a consequence, there is limited information and understanding of habitat characteristics for most species (Perrin 2009). In order to advance our understanding of the underlying drivers and processes that influence cetacean habitat, studies need to develop more a standardised and objective approach in which to examine them. This broadened approach will ultimately assist in the development and implementation of effective management, conservation and threat mitigation strategies.

In this context, the aims of the present work are: (i) to provide what we believe are representative examples between terrestrial and marine environments, (ii) to highlight the specific features of marine environments that may contribute to the current lack of consensus in defining cetacean habitat, (iii) provide a non-exhaustive review of how cetacean habitat has previously been studied, including modelling approaches and (iv) to provide objective recommendations on how to develop an approach to studying habitat in order to advance cetacean ecology, and ultimately conservation and management efforts.

2.2 Terrestrial versus Marine Habitats

Typically, habitat in its simplest terms is defined as the physical environment, where an organism actually or potentially lives (Kearney 2006). In addition, it has also been expanded to include the resources and environmental features present in an area which influences occupancy (Hall *et al*. 1997). Habitat can also be thought of as a concept, used to link potential relationships between an organism and its physical and chemical environment (Mitchell 2005). However, a mechanistic understanding of this concept and how particular features influence organisms is still critically lacking (Kearney 2006).

Accurately describing and understanding the processes that determine the distribution of organisms is often constrained by the environment itself. Terrestrial and marine ecosystems are both spatially heterogeneous, comprised of ecological entities such as forests, hills, deserts, seagrass beds, seamounts and coral reefs, but also vary in time from diel to annual cycles (*e.g.* Kolasa & Pickett 1993). In terrestrial ecosystems, habitat is often defined by the presence of relatively persistent vegetation and animal life (Ricklefs 1993). For example, the boundaries between the biotic and abiotic properties characterising structurally diverse terrestrial environments (Figure 2.1) are easily observed and identifiable (*e.g.* vegetation patches, sedimentary rocky areas, gorges and slopes of cobbles and boulders). In many cases, the relatively immediate accessibility and visibility of the terrestrial environment, enhances our capacity to identify and observe environmental differences.

In contrast, most marine environments are characterised by a limited number of landmarks both above and beneath the surface (Figure 2.2). Marine organisms typically live in a fluctuating and heterogeneous three-dimensional water mass. In addition, the inaccessibility of most of the world's ocean, and the logistical considerations inherent in effectively studying marine organisms once underwater, places additional limitations on how to define habitat for an organism, a species or a community. The characteristic wide-ranging and migratory nature of many marine animals, including cetaceans, often means that habitat boundaries are difficult to define (Hoyt 2005; Figure. 2.2), and may change on a temporal basis. Furthermore, regions within the world's oceans are often defined by broad, general definitions such as open ocean or coastal waters, although specific sea surface temperature signatures such as warm and cold core eddies (Figure 2.3A) and thermal frontal zones (Figure 2.3B) can be specified. These broad classifications are frequently applied to species such as cetaceans, particularly those rarely sighted or cryptic species (IUCN 2009). While these areas may be relatively distinct (Figure 2.3C), general classifications still lack a definitive understanding of what habitat actually means. As a consequence, the definition of marine habitat often seems arbitrary and in most cases non-existent. The application of the term habitat is often inconsistent even between marine animals of the same species or taxa (Table 2.2). These definitions highlight those potential factors (*e.g.* environmental factors) considered to be essential for the animals but again lack a thorough consideration of how the animal actually interacts with and relies on its environment.

In addition, habitat for many organisms (*e.g.* migratory birds, cryptic species), is often characterised using a limited number of observations recorded at specific encounter locations. Cetaceans are no exception, with habitat often described using only sightings or environmental measurements recorded at the surface, when the animals are exposed (Gaskin 1968, Wilson *et al*. 1997, Selzer & Payne 1998, Bräger *et al*. 2003, Kiszka *et al*. 2007). This strategy, however, disregards the properties and characteristics of the habitat concealed underneath, vertical structure of the water column. In contrast to terrestrial systems where environmental features are readily accessible and visible (Figure 2.1), in the marine environment it is considered much more difficult to gather relevant habitat information at depth. This again, potentially highlights the inaccessibility and the logistics of conducting research within these areas. Whilst some techniques (*e.g.* remote sensing imagery, animal borne sensors) can offer new perspectives and insight into detailed understanding of the vertical structure of the water column, they do not directly address the issue of habitat in order to provide sufficient information. Hence, in the marine environment, little information about the relations between species and their specific environments exists, despite their significance (Ballance *et al*. 2006).

2.3 The Concept of Cetacean Habitats So Far

Cetacean species exhibit a wide range of distribution patterns across all parts of the world's oceans (Leatherwood *et al*. 1984, Bannister *et al*. 1996, Forney & Barlow 1998, Moore 2000, Thiele *et al*. 2000, Weir *et al*. 2001, Miller 2007). As individuals and populations range widely and are not easy to observe directly, the concept of habitat is therefore difficult to grasp and define (Heithaus *et al*. 2001). The wide diversity of cetacean species in general, makes our ability to understand their habitat more problematic. For example, many delphinids are widely distributed, with smaller populations inhabiting various locations and climatic regions, whilst in contrast larger mysticetes follow migrational routes each year to familiar calving areas (Weinrich 1998). The intrinsic difference in distributions across temperate and tropical, and coastal and offshore waters between the cetacean species, not only demonstrates their great ecological flexibility (Montero & Arechavaleta 1996), but also ultimately links them to their habitat. In addition, the distinction between life history strategies and the biological requirements of the different species potentially influences their choice, and utilization of specific habitats in the marine environment; something which is also commonly dismissed in many habitat studies.

Critical cetacean habitat in a broad sense has previously been defined as '*those parts of a cetacean's range either a species or population that are essential for the day-to-day survival and maintenance of a steady population growth rate, including those areas essential for specific behaviours such as* *mating, feeding and migrational routes*' (Hoyt 2005). Cetacean habitat, and more specifically delphinid habitat, has typically been defined by investigating a number of abiotic and biotic factors ranging over various spatial and temporal scales thought to drive their distribution (Jenner *et al*. 2001, Heithaus & Dill 2002, Hastie *et al*. 2004, Watson-Capps & Mann 2005, Bedjer *et al*. 2006, Ribeiro *et al*. 2007, Miller & Cribb 2009). Factors previously investigated range from the physical and chemical features of the environment, such as water temperature, depth, salinity, topography and distance from shore, benthic habitat characteristics, and the presence of vessels, and preys and predators (Table 2.3). Measurement of these habitat variables was typically obtained using a wide variety of methodologies (*e.g. in situ* measurements, remotely sensed, obtained by boat or land based techniques), levels of precision (*in situ* vs. remotely sensed) and scales (temporal, spatial). Furthermore, variables used to assess habitat (even for a given species) were typically author and study dependent. For instance, a non-exhaustive review of pertinent studies of bottlenose dolphins (*Tursiop*s sp.) clearly demonstrates the variety of both habitat measurements and spatio-temporal scales used (Wilson *et al*. 1997, Maze & Wursig 1999, Ingram & Rogan 2002, Cribb *et al*. 2008, Miller & Baltz 2009).

Among the variables used to assess cetacean habitat, sea surface temperature represents a common measurement that is often measured with a variety of scales and resolutions (Figure 2.3). For instance, Selzer & Payne (1988) compared the distribution of white-sided (*Lagenorhynchus acutus*) and common (*Delphinus delphis*) dolphins off the coast of New Zealand with sea surface temperature and salinity measured from the survey vessel at the time of a dolphin sighting. In comparison, water temperature measurements accessed from remote sensing data were used to investigate seasonal distribution changes in striped dolphins (*Stenella coeruleoalba*) in the Ligurian Sea (Laran & Drouot-Dulau 2007). Of further note is the typically small number of environmental variables measured in many studies despite the high plausibility of other factors being instructive in describing habitat (Baumgartner 1997, Keiper *et al*. 2005, Danilewicz *et al*. 2009). This consideration and narrowed selection of assessed variables should therefore caution our application of some habitat studies for progressing management objectives and conservation strategies. More specifically, a thorough understanding of constraints, methodology and objectives needs to be made to ensure that the results of habitat studies are not being confounded by the concentration of the researcher's effort and measurement tools or access (Kenney & Winn 1986).

2.4 On the Contribution of Habitat Modelling to Cetacean Ecology

Statistical habitat modelling, although still a relatively recent topic of research, is increasingly being applied to help answer questions regarding the ecology of many cetacean species (Gregr *et al*. 2013). Since the first paper there has been a significant growth and increase in this topic (Figure 2.4), which suggests a field in rapid development.

Typically, the aim of statistical habitat modelling is to help predict and explain variation in the distribution and density of cetaceans, as well as to predict key locations by correlating observations of animals with various environmental variables (Cañadas *et al*. 2006; Palacios *et al*. 2013). These efforts may describe correlations between variables, but generally lack the ability to elucidate our ecological understanding of the relationships between cetaceans and their marine environment.

From a non-exhaustive review, we show as aforementioned for field-based habitat studies that modelling habitat studies do not converge in their approaches, methodologies, spatial and temporal scales and analyses even when they target the same species (Table 2.4). Some studies are vague in their definition of a potential focus species as well as an ecological question, and often the focus species is then defined afterwards depending upon what species were observed during surveys. The overall objective of many studies is then often limited to predict where and when cetaceans are present (*e.g*. Ferguson *et al*. 2006a). However, some studies do attempt to explain this presence further by linking them to features of the physical and biological oceanographic properties of their environment (Palacios *et al*. 2013); these properties have either been assessed using remote sensing data (*e.g*. sea surface temperature, sea surface height), variables measured *in situ* (*e.g*. depth, mixing layer thickness) or even modelled environmental data such as prey densities (Pershing *et al*. 2009), hence allow to cover a very wide range of spatial and temporal scales; see Table 2.4 for further examples. There is, however, a strong study-to-study variability in the abiotic properties considered even in modelling studies dealing with similar environments and species (Table 2.4). Biotic variables are also dramatically under-represented (especially when compared to physical variables) in most of the studies reported here (Table 2.4). Similarly, biotic factors that may be critical to understand cetacean habitat use such as behavioural and life history strategies, have still been seldom used in habitat modelling studies (Palacios *et al*. 2013; Table 2.4). Besides, studies that incorporate field-based visual and acoustic surveys (Johnston *et al*. 2007; Praca & Gannier 2008; Soldevilla *et al*. 2011) often lack information about the physical and vertical properties of the environments (Table 2.4). Also note that most synoptic studies that used remote sensing data, critically lack information about the vertical structure of the water column (Vierling *et al*. 2008). The aforementioned limitations of habitat modelling studies - which are by no means a criticism of their results and do not detract from the central point of their work - hence suggest that although habitat modelling studies provide valuable information on where and when cetaceans may be over space and time, they still ultimately lack the power in which to truly understand the mechanistic links between the presence and behaviour of cetaceans and the nature of their environment.

As a conclusion, statistical habitat modelling is undeniably a useful and promising tool to predict cetacean distributions as a function of range of descriptors (Table 2.4), in particular for those large whales and offshore cryptic species which lack baseline data and are often difficult to access. However, this approach still does not converge in the approach followed (Table 2.4), hence may prevent future progress in our ability to provide further insight into animal ecology. As stressed in the present work and in the recommendation below, there is a genuine need to refine modelling methods to move beyond correlations towards a mechanistic understanding of the processes that interact to create cetacean habitat and try to provide a more ecological explanation for their presence. Ultimately, this may also help to bridge the gap between fundamental research and conservation and management initiatives.

2.5 How to Fill in the Gaps?

To increase our understanding of cetacean habitat, we suggest to develop a more systematic and objective approach to cetacean habitat research. In particular, we stress the need to identify the underlying influences driving habitat, for example physical and chemical environmental features, social and behavioural factors, predation and anthropogenic pressures in order to determine how cetaceans interact with and use their environment. With this in mind, a number of factors should be considered on how to approach and develop methodologies in which to investigate cetacean habitat. The following six recommendations – synthesised as a logical flow chart in Figure 2.5 - demonstrates how future studies could become more targeted and effective in defining and describing habitat. The purpose of this outline is to progress towards a more standardised and objective approach to habitat studies. Specifically, the six recommendations developed hereafter are illustrated using selected case studies from the primary literature on both well-documented and more cryptic species to demonstrate the generality of the proposed approach.

2.5.1 *Identify the rationale for studying habitat*

In order to describe habitat for a species or a population, the end objectives behind conducting the study firstly need to be clearly identified and addressed. Habitat characteristics should be considered on a case-by-case basis, as each species, population and location will inherently require different strategies, requirements and management considerations. An initial consideration should be the identification of research objectives, which may include (i) assisting in the development and implementation of conservation and management strategies (*e.g.* marine parks and reserves), (ii) developing ecosystem based models, and (iii) increasing the biological understanding of the animal’s biology and ecology, or for mitigation purposes. For example, the habitat characteristics of the Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) were specifically investigated with the intention to provide baseline information for a newly declared dolphin sanctuary in Adelaide, South Australia (Cribb *et al*. 2008). Little information existed about habitat characteristics of bottlenose dolphins in this area; hence specific habitat information was required in which to assist developing management efforts. The variety of environmental types within the declared sanctuary boundaries where dolphins were regularly sighted, were taken into consideration (*e.g*. benthic characteristics, exposed vs. sheltered waters). These environmental features were then incorporated into the study as each was considered to have the potential to influence dolphin presence in this area.

Similarly, Ingram & Rogan (2002) aimed to define critical use areas for bottlenose dolphins (*Tursiops truncatus*) in the Shannon estuary, Ireland, with the intention to assist management plans for a candidate Special Area of Conservation. Specific knowledge of the habitat characteristics of dolphins in this area was therefore considered crucial in developing a management strategy. In particular, the locations of dolphin encounters, were used to identify specific areas of high use, as well as any preference for areas with particular topographic features, such as depth and benthic slope. Areas identified as high use by the dolphins were then deemed ‘critical areas’and therefore considered to be essential to the dolphins inhabiting the estuary.

2.5.2 *Identify potential influencing factors from the literature*

It is critical to identify the potential factors influencing cetacean distribution, such as environmental characteristics, that have previously been identified, as well as the research methodologies that were used to do so. In some instances, there may already be considerable knowledge available. For example, numerous global studies have documented resting spinner dolphin (*Stenella* sp.) populations showing strong site fidelity within specific bays and reefs during daytime (Karczmarski *et al*. 2005, Gannier & Petiau 2006, Notarbartolo-di-sciara *et al*. 2009). These studies demonstrate the consistent use of resting areas which have specific and common environmental features such as shallow, sheltered tropical bays or lagoons with sandy bottoms (Cribb *et al*. 2012). The identification of key environmental features provides a basis and direction in which to start the development of a habitat approach and identify the reasoning behind why these specific locations are utilised and others are not. In contrast, for those rarely sighted and data deficient species, information or potential habitat factors may be significantly lacking. In some cases only broad distribution ranges noted by a species synopsis or report may be available (Bannister *et al*. 1996, Ross 2006). This paucity of information can initially hinder the development of a habitat approach. However, general information about specific oceanographic occurrences or the oceanic waters within an animal's broad distribution presumed range may offer some place in which to start thinking about influencing habitat factors. Ultimately, the findings and level of information available from this type of review will assist to structure the scale and range of focus of the study.

2.5.3 *Species analysis*

An essential part in approaching habitat is an assessment of the life history, ecology and biology of the species in question. Therefore species need to be considered on an individual basis. Factors such as geographic range, distribution, motion behaviour and migrational patterns, home range and site fidelity need to be incorporated into the study. For rarely encountered and cryptic species, information may be limited or difficult to obtain. For example, insights into the biology, geographic range and distribution of species such as the beaked whales (family Ziphiidae) have often only been established through brief encounters and stranding occurrences (MacLeod *et al*. 2006). This paucity about a species biological and ecological requirements allows us to then only assume those potential important factors such as geographic range. In contrast, we know a lot about some species specific movement patterns such as the Southern right whale (*Eubalena australis*). Populations of this species annually migrate in the austral winter from southern Antarctic feeding grounds to sheltered waters on the Southern Australian coastline for calving (Pirzl 2008). The occurrence of these migration events, therefore allows a more systematic approach to be taken, as we can predict where these animals are going to occur at certain times of the year. Furthermore, we can also potentially assume their use of these areas, for example for calving.

In addition, the differing life strategies and diurnal behavioural patterns should also be considered (Hoyt 2005). A species life history can potentially provide insight into surrounding environmental features, as adaptations are potentially linked and influenced by it (Chivers 2009). Possible inclusions for this review might include: feeding strategies, calving intervals, resting patterns and group size. In this context, spinner dolphins (*Stenella* sp.), are considered to have a unique life history strategy, in that some populations rest during daylight hours and feed offshore at night in the mesopelgic zone (Norris & Dohl 1980). Similarly, bottlenose dolphins (*Tursiops* sp.) often engage in location specific foraging tactics and techniques (*e.g.* Smolker *et al.* 1997, Duffy-Echevariia *et al.* 2008, Torres & Read 2009).

2.5.4 *Location analysis*

An analysis of the potential study location needs to be conducted to identify what environmental factors present in the area should be addressed. More specifically, the general nature of the study area's physical features/properties needs to be identified, *e.g.* estuary, gulf, bay or reef, exposed open ocean *vs.* sheltered waters. In addition, the topography, bathymetry, substrate type and the presence of islands, reefs, submarine canyons and ice cover within the environment should also be considered as potentially influencing habitat factors. Once the key features of the environment have been identified, those obvious oceanographic features and phenomenons, specific to the area can then be included into the assessment. For example, water temperature, depth, salinity, turbidity, the presence and depth of a thermocline, current direction and intensity, eddies, upwelling events, primary productivity and the seasonal fluctuations of these environmental characteristics.

Additionally, anthropogenic presence, predation pressure and resource availability need to be considered.

In this context, a variety of environment types had been noted to occur within the Adelaide Dolphin Sanctuary, South Australia (SA- DEWNR 2013). Preliminary investigations indicated that bottlenose dolphins were frequently sighted utilising specific areas within these different environment types. The sanctuary contained 2 distinctly different physical environments (*e.g.* open waters with seagrass beds and shallow, sheltered waters with bare, sandy substrate) which also potentially caused variations in the oceanographic occurrences. Therefore, within the current study plan the physical environmental features and oceanographic parameters (including seagrass presence, sheltered estuarine versus exposed gulf waters, water temperature, depth, salinity, turbidity and dissolved oxygen) considered to influence dolphin presence the most, or be important to specific life history strategies (*e.g.* feeding, calving) were taken into consideration as part of the survey plan. This inclusion of a wide spectrum of physical, chemical and biological environmental features such as these listed above will therefore enable a thorough investigation into those abiotic and biotic potential habitat drivers.

2.5.5 *Threat analysis*

Additional factors and threats present in the marine environment should also be considered within the development of a comprehensive habitat approach. This inclusion will assist in identifying whether the presence of a threatening process drives the animal's distribution. Ultimately, this will influence how habitat is described. A study investigating the influence of repeated vessel exposure on a resident population of bottlenose dolphins (*Tursiops* sp.) in Shark Bay, Western Australia, then suggested that over time the repeated presence of vessels potentially could affect dolphin abundance, and as a result the habitat used (Bejder *et al*. 2006). Although this study did not specifically focus upon describing habitat, it demonstrated how anthropogenic impacts can potentially shift or alter the way animals distribute themselves within their surrounding environment if exposed to threats. Similarly, biological threats such as the predation of sharks also have the potential to influence distribution and ultimately the habitat used (Heithaus & Dill 2002). Therefore, threats to potentially include in a habitat approach are those that have the potential to affect and alter distribution. Impacts such as predator presence, pollution, drives hunts, tourism activities, commercial and artisanal hunting, fisheries, habitat degradation and climate change effects (*e.g.* water temperature change over time, receding ice cover) could be considered to impact distribution on an immediate, short-term or long-term level.

2.5.6 *Developing appropriate methodologies and techniques*

The five previous considerations discussed above have identified context (in terms of objectives, species and location) and a list of factors, which should be considered within the development of a sound and objective approach to researching and studying cetacean habitat. This background information enables the selected factors to be appropriately adapted in terms of spatial and temporal scale, species biology, region and current threats. When combined with the appropriate methodologies and techniques the information gained will provide a more detailed synoptic assessment of cetacean habitat, which is therefore more targeted and applicable to potential management initiatives. However, it is considered that the suitable combination of these will ultimately begin to provide an initial insight into any potential animal and environmental relationships. Currently, many methodologies, techniques and quantitative analyses (*e.g.* Mann 1999, Evans & Hammond 2004, Forney & Wade 2006, Kaschner *et al.* 2006, Redfern *et al.* 2006) are available for application within cetacean specific research. However, these can be incorporated within a cetacean habitat approach.

In this context, the following are innovative examples of some of the ways in which cetacean habitat studies could be progressed and techniques implemented. However, this approach is not limited to these, and they are provided for illustrative purposes. The focus and implementation of methodologies and technologies will differ according to the logistics of the study location (*e.g*. coastal *vs*. offshore). Currently, many have been developed to assist in overcoming logistics, particularly when investigating cetaceans in the open ocean. For example, modern technologies such as remote sensing imagery, Argo floats, gliders and animal borne sensors (*e.g*. Heithaus *et al*. 2001, McMahon *et al*. 2005, Boehme *et al*. 2009, Schorr *et al*. 2009, IMOS 2010) can provide some information about the biogeographical range of cetaceans as well as open new perspectives into a detailed understanding of the vertical structure of the water column (Figure 2.5). When coupled with distribution patterns, for example, this oceanographic information could be used to provide potential correlations between ocean processes, whales and their prey (Fiedler *et al*. 1998, Tynan *et al*. 2005).

In addition, oceanographic information has also the potential to complement data collected through opportunistic sightings, or help to correlate sighting locations, particularly for rarely sighted offshore and deep diving species. More specifically, this information may be useful, particularly for species, spending majority of their time for example, below the surface feeding such as sperm whales (*Physeter microcephalus*; Watwood *et al*. 2006). Furthermore, as well as providing information about potential habitat correlations, these technologies can offer some insight into behavioural patterns. For example, Schorr *et al*. (2009) investigated the movement patterns of Blainville’s beaked whales (*Mesoplodon densirostris*) off the coast of Hawaii using Argos-linked satellite tags. Additionally, the use of such methodologies and technologies in conjunction with *in situ* measurements, correlated with behavioural and social structure data can also potentially start to provide insight into cetacean ecology and life histories.

It is also stressed that the use of technologies in the field may also be complemented by, baseline cetacean habitat information gathered through the application of pre-existing data sets, particularly those gathered long term. When complemented with oceanographic information, gathered through the use of technologies or *in situ*, these have the potential to be of benefit to pre-existing data sets consisting of cetacean sightings and distribution patterns (Maury 1852, Townsend 1935). Additionally, pre-existing data sets of species specific distributions have the potential to provide much insight into distribution in the way of being used as predictor tools for distribution (*e.g.* Jacquet & Whitehead 1996, Kaschner *et al.* 2006, Redfern *et al.* 2006), which ultimately can help focus a study for a specific species or location. Additionally, these can now be combined with freely accessed oceanographic data through ocean portals, therefore it is possible to conduct preliminary studies based on all pre-existing data.

2.6 Conclusion

Given the difficulty and complexity of adequately understanding the meaning of habitat for cetaceans, the development of a sound approach incorporating suitable techniques and methodologies is critical to enable the quantification of appropriate variables. Understanding the influences and the inter-relationships between cetaceans and their surrounding environment will not only greatly improve our understanding, but also ultimately allow us the ability to develop targeted and more effective mitigation and conservation measures.

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Table 2.1: Non-exhaustive review of habitat definitions applied and/or discussed in the terrestrial ecology literature.

Definition	Reference
A species, or population unit; an abstraction of the essential physical factors and the co-inhabitant biota, in a locality where individuals of that population regularly live and reproduce	Udvardy 1959
Place, living space where an organism lives	Odum 1963
The area of land, water and airspace required for the normal needs and survival of a species	Schreiner 1976
Area in which a wildlife community exists	Harris & Kangas 1988
Location in which organisms live, or characterised by predominant plant or animal life	Ricklefs 1993
Resources and conditions present in an area that produce occupancy – including survival and reproduction – by a given organism	Hall *et al*. 1997
Where an animal lives that can be characterized by dominant plant forms or physical features	Jones & Boulding 1999
The resources and conditions present in an area that produce occupancy, including survival and reproduction, by a given organism	Krausman 1999
Place where an animal lives, or, the collection of resources and conditions necessary for its occupancy, or, a set of specific environmental features that, is equated to a plant community, vegetative association or cover type	Garshelis 2000
A place where an animal resides	Morrison 2001
The abiotic components of the environment only	Mitchell 2005
The physical and chemical components of an organism’s environment, including the biotic environment to emphasize that an organism must integrate and adapt to all the elements of its surroundings including those that are living and those that are not	Ragen 2005
Description of a physical place, at a particular scale of space and time, where an organism actually or potentially lives	Kearney 2006

Table 2.2: Non-exhaustive review of habitat definitions applied to general or specific groups of marine organisms.

Definition	Species/Order/Taxa	Reference
A place in which a fish, population or assemblage can find the physical or chemical features required for life e.g. suitable water quality, migration routes, spawning grounds, feeding sites, resting sites, and shelter from predators and adverse weather	Fish	Orth & White 1993
Areas vital to the survival of a marine species at some phase in its life cycle	Marine species	Ray & McCormick-Ray 1995
The functioning ecological units required for successful breeding and foraging	Marine mammals	Harwood 2001
The place where an organism can be found	Marine species	Nybakken 2001
Each species lives within a certain environment, whereby it has a preference for a combination of environmental factors, e.g. substratum, temperature, salinity and hydrodynamic conditions that it is able to live within	Marine species	Connor *et al*. 2003
Parts of a cetacean's range, either a species or population of that species, essential for the day-to-day survival, as for maintaining a healthy population growth rate. Areas used for feeding, breeding, raising calves, migrating	Cetaceans	Hoyt 2005
Features related to basic needs e.g. prey; refuge from predators; suitable conditions for reproduction including mating and rearing of young, resting, and moulting; and safety from extreme environmental events	Marine mammals	Ragen 2005

Table 2.3: Common name, location and examples of variables used to define habitat and distribution in global delphinid studies from 1968 to present.

Common Name	Location	Variables Used to Define Habitat	Reference
Common dolphin, dusky dolphin, hourglass dolphin	South Pacific	SST	Gaskin 1968
Common bottlenose dolphin	Gulf of Mexico	Distribution patterns related to tidal occurrence, time of day, season	Shane 1980
White-sided dolphin, common dolphin	North Atlantic	SST, salinity, bottom topography	Selzer & Payne 1988
Common bottlenose dolphin	Moreton Bay, AU	Depth, distance from shore	Corkeron 1990
Common bottlenose dolphin	Gulf of California	Behavioural & range patterns related to estuarine & non-estuarine habitat types, depth, secchi disc depths	Ballance 1992
Pilot whale	North Atlantic	Depth, submarine topography, SST	Montero & Arechavaleta 1996
Risso’s dolphin	Gulf of Mexico	Depth, depth gradient	Baumgartner 1997
Common bottlenose dolphin	Moray Firth, SF	Photo-identification used to determine movement patterns & seasonal distribution	Wilson *et al*. 1997
Indo-Pacific humpback dolphin	Algoa Bay, SA	Distance to shore, depth, behavioural activities related to physical habitat features	Karczmarski *et al*. 2000
Tursiops sp.	Shark Bay, AU	Reproductive success, depth, SST	Mann *et al*. 2000
Common bottlenose dolphin	Gulf of Mexico	Foraging behaviour, prey presence related to benthic habitat characteristics	Allen *et al*. 2001
Hector’s dolphin	Porpoise Bay, NZ	Photo-identification & land based theodolite fixes to determine spatial, temporal distribution patterns	Bejder & Dawson 2001

Common bottlenose dolphin	Moray Firth, SF	Spatial, temporal distribution related to tidal cycle, tidal front	Mendes *et al*. 2002
Common bottlenose dolphin, Atlantic spotted dolphin	Gulf of Mexico	Depth, SST, salinity, chlorophyll-*a*	Griffin & Griffin 2003
Common bottlenose dolphin	Moray Firth, SF	Foraging observations related to local submarine habitat characteristics	Hastie *et al*. 2004
Common bottlenose dolphin	Chesapeake Bay, USA	SST, chlorophyll-*a* used as surrogates to monitor dolphin & prey movements	Armstrong *et al*. 2005
Common bottlenose dolphin	Mid Atlantic Bight	SST, chlorophyll-*a*	Fogg 2005
Atlantic spotted dolphin, Pantropical spotted dolphin, clymene dolphin, spinner dolphin, striped dolphin	SW Atlantic	Depth, SST	Moreno *et al*. 2005
snubfin dolphin, Indo-Pacific humpback dolphin	Cleveland Bay, AU	SST, proximity to habitat type, bathymetry	Parra 2005
Peale's dolphin	Straight of Magellan	Dolphin presence and behavioural activities related to kelp beds	Viddi & Lescrauwaet 2005
Tursiops sp.	Shark Bay, AU	Aquaculture presence	Watson-Capps & Mann 2005
Tursiops sp.	Shark Bay, AU	Vessel effect on abundance	Bejder *et al*. 2006
Spinner dolphin	Central Tropical Pacific	Surface tubidity, current, swell height, distance to shore, vessel presence	Gannier & Petiau 2006
Snubfin dolphin Indo-Pacific humpback	Cleveland Bay, AU	Depth, Euclidean distance to physical habitat types	Parra 2006
Common dolphin, striped dolphin, common bottlenose dolphin, harbour porpoise, pilot whale	English Channel	Distribution, encounter rate, bathymetric preference	Kiszka *et al*. 2007
Striped dolphin	Ligurian Sea	Chlorophyll-*a*, SST	Laran & Drouot-Dulau 2007
Common dolphin	Mediterranean	Calf presence, inter-specific relationships, behaviour, Chlorophyll-*a*, SST, depth, slope of seabed	Cañadas & Hammond 2008
Indo-pacific bottlenose dolphin	Gulf St Vincent, AU	Depth, SST, salinity, dissolved oxygen, turbidity, distribution in	Cribb *et al*. 2008

Indo-pacific bottlenose dolphin	Gulf St Vincent, AU	Depth, SST, salinity, dissolved oxygen, turbidity, distribution in relation to benthic characteristics	Cribb *et al*. 2008
Harbour Porpoise	English Channel	Sightings related to diurnal, tidal patterns	Goodwin 2008
Common bottlenose dolphin	Barataria & Caminada Bays, USA	SST, salinity, dissolved oxygen, depth, turbidity, distance to shore	Miller & Baltz 2009
Spinner dolphin	Red Sea	SST, distribution related to swimmer presence	Notarbartolo-di-Sciara *et al*. 2009
Common dolphin	Gulf St Vincent, AU	Depth, SST, latitude, longitude	Filby *et al*. 2010

Table 2.4: Location, species environmental variables used in modelling studies to define cetacean and habitat distribution.

Location	Species	Environmental variables used to model habitat		Reference
		Abiotic	*Biotic*	
Nova Scotia coast, Canada	M$_3$, M$_4$, M$_7$, M$_8$, O$_1$, O$_5$, O$_8$, O$_{15}$, O$_{19}$, O$_{24}$, O$_{25}$	Depth, slope, Sea Surface Temperature$^{a}_{\text{in situ}}$		Hooker *et al*. 1999
California	O$_{25}$, O$_{31}$	SST$_{\text{in situ,}}$ salinity, depth		Forney 2000
British Columbia	M$_3$, M$_4$, M$_5$, M$_8$, O$_1$	Depth, slope, SST$_{\text{in situ}}$, salinity,	Historical whaling data	Gregr & Trites 2001
Mid-west North Atlantic Ocean	M$_4$, M$_7$, M$_8$, O$_1$, Mesoplodon spp., O$_4$, O$_8$, O$_9$, O$_{15}$, O$_{18}$, O$_{19}$, O$_{20}$, O$_{21}$, O$_{25}$, O$_{32}$	SST$_{\text{in situ}}$, front occurrence, depth, slope		Hamazaki 2002
Spain	O$_1$, O$_4$, O$_5$, O$_8$, O$_{18}$, O$_{19}$, O$_{24}$, O$_{25}$	Depth, slope, SST$_{\text{sat}}$		Cañadas *et al*. 2005
Faroe –Shetland Channel	Oceanic dolphins	SST$_{\text{in situ}}$, salinity, depth, slope, ambient noise	Chlorophyll a $_{\text{in situ}}^{b}$	Hastie *et al*. 2005
Eastern Tropical Pacific	O$_4$, Mesoplodon spp.	Thermocline depth and strength, SST$_{\text{in situ}}$, salinity, depth, slope, distance	Chl $a_{\text{in situ}}$	Ferguson *et al*. 2006a
Eastern Tropical Pacific	O$_7$, O$_8$, O$_9$, O$_{10}$, O$_{11}$, O$_{12}$, O$_{13}$, O$_{14}$, O$_{18}$, O$_{19}$, O$_{20}$, O$_{22}$, O$_{23}$, O$_{24}$, O$_{25}$, O$_{26}$,	SST$_{\text{in situ}}$, salinity, thermocline depth and strength, distance, depth, slope	Chl $a_{\text{in situ}}$	Ferguson *et al*. 2006b

	O_{27}, O_{28}			
Western Antarctic Peninsula	M_8, M_6	Acoustic volume backscatter, depth, slope, temperature$_{\text{in situ}}$, distance	Chl $a_{\text{in situ}}$	Friedlaender *et al*. 2006
South central Alaska	O_2	Depth, distance, flow accumulation		Goetz *et al*. 2007
Hawaiian Archipelago	M_8	Depth, SST$_{\text{sat}}$		Johnston *et al*. 2007
Northern Adriatic Seas	O_{19}	O_2 saturation, temperature$_{\text{in situ}}$, density anomaly, turbidity, distance, depth , salinity, pH, turbidity	IVF^{c}	Bearzi *et al*. 2008
Bay of Biscay	O_{19}, O_{24}, O_{25}	Distance		Certain *et al*. 2008
SW Mediterranean	O_{25}	Depth, slope, SST$_{\text{sat}}$, distance, scattering layers	Chl a_{sat}, presence of calves, interspecific relationships, behaviour	Cañadas & Hammond 2008
The Strait of Gibraltar	O_1, O_7, O_8, O_{19}, O_{24}, O_{25}	Depth, slope		De Stephanis *et al*. 2008
Central Spanish Mediterranean	O_{18}, O_{19}, O_{24}	Depth, slope, SST$_{\text{sat}}$	Chl a_{sat}	Gómez De Segura *et al*. 2008
Pelagos sanctuary, Mediterranean	M_4, O_{24}	Depth, slope, distance, SST$_{\text{sat}}$	Chl a_{sat}	Panigada *et al*. 2008
North-western Mediterranean	O_1, O_9, O_{18}	Depth, slope, distance, SST$_{\text{sat}}$, fronts, salinity	Chl a_{sat}	Praca & Gannier 2008

Eastern tropical pacific	O_{24}, O_{23}, O_{25}, O_{18}	$\text{SST}_{\text{in situ}}$, salinity, thermocline depth and strength, depth, temperature fronts	Chl $a_{\text{in situ}}$	Redfern *et al*. 2008
Mid Atlantic Ridge	M_5, O_1	Bathymetry, slope, flow (m/s) gradient, water level (m) gradient, temperature and salinity gradients		Skov *et al*. 2007
Florida Bay, USA	O_{19}	$\text{Temperature}_{\text{in situ}}$, salinity, turbidity, dissolved O_2, distance, , benthic type	Chl $a_{\text{in situ,}}$ Dolphin prey per unit effort	Torres *et al*. 2008
Scotland	O_{19}, O_{32}	Depth, slope, distance, $\text{SST}_{\text{in situ}}$, sediment type, salinity		Bailey & Thompson 2009
Greater Minch, Scotland	O_{32}	Depth, bathymetry, distance, tidal conditions		Marubini *et al*. 2009
Gulf of Maine	M_1		Modelled prey densities, arrival date of whales in study location, sightings per unit effort	Pershing *et al*. 2009
Sundarbans mangrove forest, Bangladesh	O_6, O_{33}	Salinity, depth, turbidity, $\text{temperature}_{\text{in situ}}$, channel width, convergences		Smith *et al*. 2009
California current	M_3, M_4, M_8, O_1, O_{14}, O_{18}, O_{24}, O_{25}, O_{28}, O_{31}	$\text{SST}_{\text{in situ,sat}}$, frontal regions, oceanic zone, depth, slope		Becker *et al*. 2010
Western	O_{24}	Absolute dynamic topography, $\text{SST}_{\text{sat, in situ}}$,	Chl $a_{\text{sat, in situ}}$	Cotté *et al*. 2010

Mediterranean		absolute geostrophic velocity, sea level anomaly, geostrophic velocity anomaly, depth		
Inner Hebrides, Scotland	O_{32}	Tidal conditions, depth, slope, sediment type		Embling *et al*. 2010
Argentina	O_{15}	Depth, slope, distance, SST_{sat}	Chl a_{sat}	Garaffo *et al*. 2010
Chile	M_3, M_7, M_8, O_4, O_7, O_{10}, O_{17}, O_{19}, O_{30}, unidentified mysticetes, unidentified odontocetes	Depth, channel width, distance, coast complexity		Viddi *et al*. 2010
Oman	M_8, Balaenoptera spp.	Slope, depth, distance		Corkeron *et al*. 2011
Patagonia, Argentina	O_{15}, O_{29}	Depth, distance, SST_{sat}	Chl a_{sat}	Garaffo *et al*. 2011
Balearic Islands	O_1	Depth, slope, SST_{sat}, SS height deviation, surface wind direction	Chl a_{sat}	Pirotta *et al*. 2011
Southern Californian Bight	O_{14}, O_{18}	Echolocation click occurrence, lunar duration, upwelling index, SST_{sat}, interaction of week and region	Chl a_{sat}	Soldevilla *et al*. 2011
Southern ocean	M_7	Depth, sea ice cover,	Chl a_{sat}	Ainley *et al*. 2012

		distance, distance, slope		
Hebrides, Scotland	M_6	Bathymetry, slope, SST$_{\text{sat}}$, tidal current, depth	Chl $a_{\text{sat},}$ sandeel occurrence	Anderwald *et al*. 2012
Pelagos sanctuary, Mediterranean	M_4, O_1, O_4, O_8, O_{18}, O_{19}, O_{24}	Depth, slope		Azzellino *et al*. 2012
California current	M_4, O_{24}, O_{31}	Depth, slope, SST$_{\text{sat}}$		Becker *et al*. 2012
Atlantic east coast and Gulf of Mexico	M_1, M_8, O_1, O_7, O_{19}, O_{20}, O_{21}, O_{22}, O_{24}, O_{25}, O_{32}, Baleen whale spp., Beaked whale spp., kogia spp., lagenorhyncus spp., pilot whale spp.,	Depth, distance to shore, distance to continental shelf break, monthly SST		Best *et al*. 2012
British Columbia	M_8	Depth, slope , distance, SST$_{\text{sat}}$	Chl a_{sat}	Dalla Rosa *et al*. 2012
St Lawrence River estuary, Canada	M_3	Depth, slope, feeding	Behaviour	Doniol-Valcroze *et al*. 2012
California current, Eastern Tropical Pacific	M_3, M_4, M_8, O_1, O_3, O_4, O_{14}, O_{18}, O_{24}, O_{25}, O_{28}, O_{31}, Mesoplodon spp.	Depth, slope, SST$_{\text{sat}}$, salinity, mixed layer depth	Chl $a_{\text{in situ}}$	Forney *et al*. 2012
Hawaiian Islands	O_{22}	Aspect variety, bay area, coastline to area of a bay ratio, depth, distance,		Thorne *et al*. 2012

		proportion of bay area with depths < 250 m		
Scotland, west coast	O_{32}	Distance, depth, slope, current speed, tidal conditions, sediment type		Booth *et al*. 2013
Scotland	O_{18}	depth, slope, distance, sediment type	Prey distribution	MacLeod *et al*. 2013
Australasia	M_2	Depth, slope, temperature_{sat}, mixed layer depth, currents, distances	Historical whaling data, chlorophyll a_{sat}	Torres *et al*. 2013

[a] Sea surface temperature referred to as SST_{sat} hereafter from satellite data, and as $SST_{in\ situ}$ when measured *in situ*

[b] Chlorophyll *a* concentration referred to as chl a_{sat} from satellite data, as chl $a_{in\ situ}$ when measured *in situ*

[c] IVF *in vivo* fluorescence measured in situ as a proxy of chlorophyll *a* concentration

Mysticetes: M_1 *Eubalaena glacialis*, M_2 *Eubalaena australis*, M_3 *Balaenoptera musculus*, M_4 *Balaenoptera physalus*, M_5 *Balaenoptera borealis*, M_6 *Balaenoptera acutorostrata*, M_7 *Balaenoptera bonaerensis*, M_8 *Megaptera novaeangliae*

Odontocetes: O_1 *Physeter macrocephalus*, O_2 *Delphinapterus leucas*, O_3 *Berardius bairdii*, O_4 *Ziphius cavirostris*, O_5 *Hyperoodon ampullatus*, O_6 *Orcaella brevirostris*, O_7 *Orcinus orca*, O_8 *Globicephala melas*, O_9 *Globicephala macrorhynchus*, O_{10} *Pseudorca crassidens*, O_{11} *Feresa atenuata*, O_{12} *Peponocephala electra*, O_{13} *Steno bredanensis*, O_{14} *Lagenorhynchus obliquidens*, O_{15} *Lagenorhynchus obscurus*, O_{16} *Lagenorhynchus acutus*, O_{17} *Lagenorhynchus australis*, O_{18} *Grampus griseus*, O_{19} *Tursiopus truncatus*, O_{20} *Stenella attenuate*, O_{21} *Stenella frontalis*, O_{22} *Stenella longirostris*, O_{23} *Stenella longirostris orientalis*, O_{24} *Stenella coeruleoalba*,

O_{25} *Delphinus delphis*, O_{26} *Delphinus capensis*, O_{27} *Lagenodelphis hosei*, O_{28} *Lissodelphis borealis*, O_{29} *Celphalorhyncus comersonnii*, O_{30} *Celphalorhyncus eutropia*, O_{31} *Phocoenoides dalli*, O_{32} *Phocoena phocoena*, O_{33} *Platanista gangeti*

Figure 2.1: A terrestrial landscape, the Kata Tjuta (Northern Territory, Australia), illustrating how the boundaries between the biotic and abiotic features of a structurally diverse two-dimensional terrestrial habitat are easily identifiable and quantifiable, e.g. vegetation patches, sedimentary rocky areas, gorges and slopes of cobbles and boulders. *Image credit: L. Seuront*

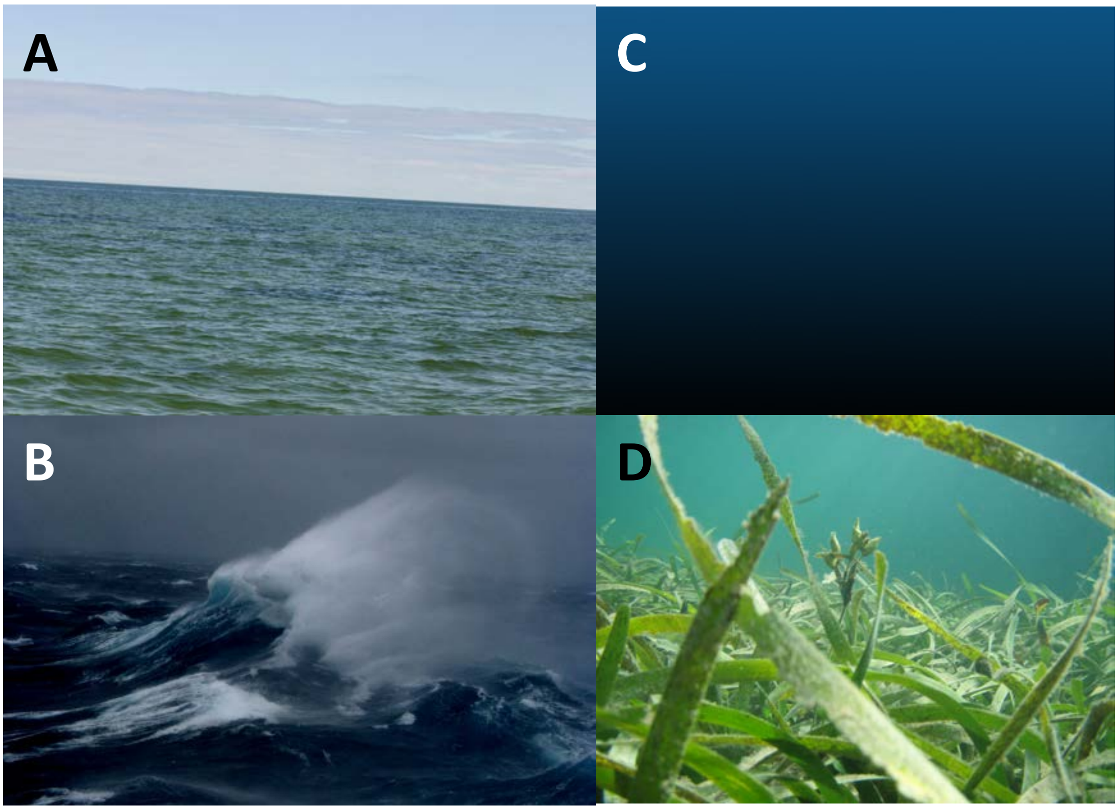

Figure 2.2: Marine landscapes, seen from above the surface in Gulf St. Vincent, South Australia (A) in water stormy weather in the Southern Ocean (B; 53ºS,145ºE), and beneath the surface in open (C) above a seagrass bed in Louth Bay, South Australia (D), illustrating the difficulties in identifying landmarks and both abiotic and biotic properties leading to define cetacean habitat. *Image credits: N. Cribb (A), V. Van Dongen-Vogels (B), L. Seuront (C, D).*

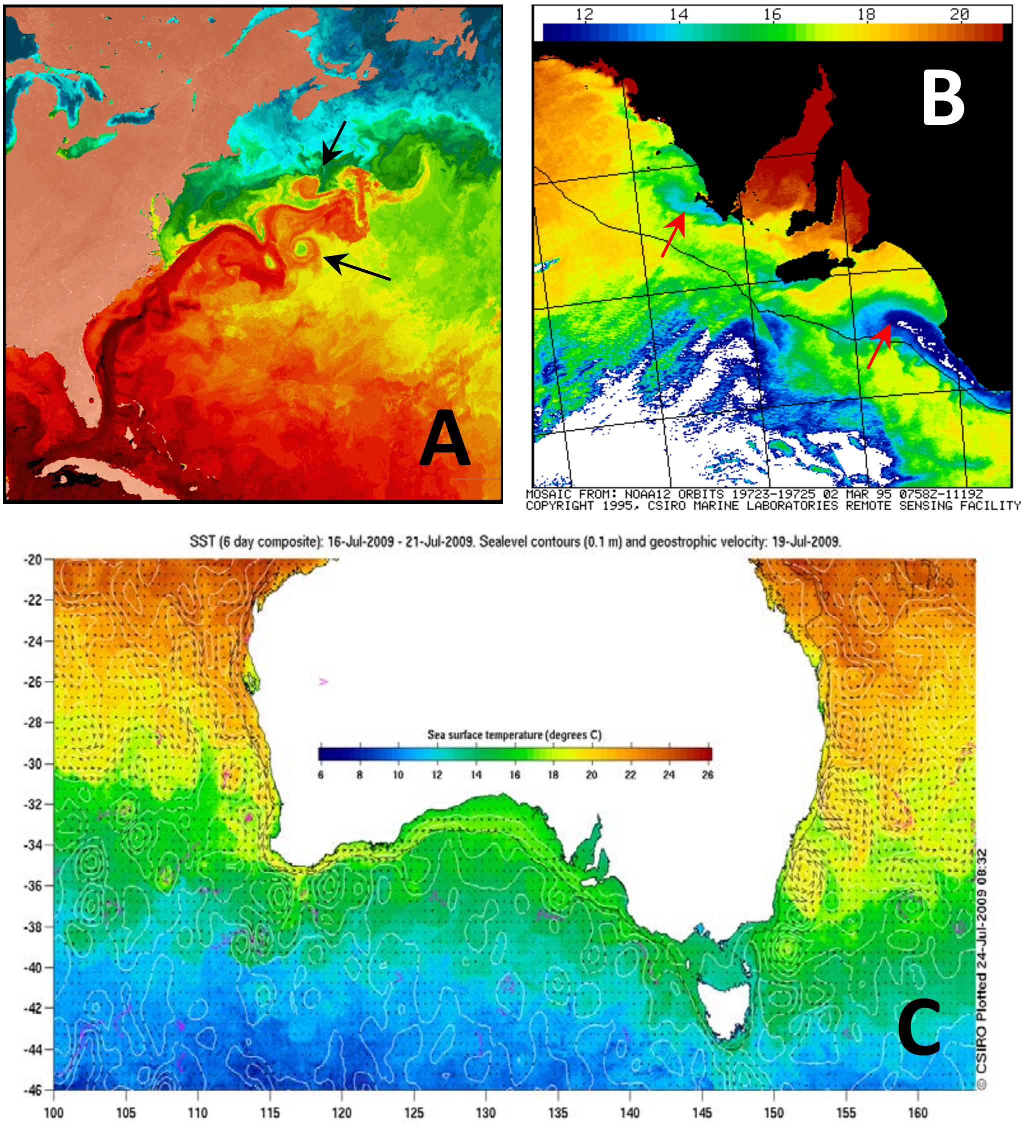

Figure 2.3: Illustration of typical sea surface temperature signatures of (A) the meandering Gulf Stream showing basin-scale thermal fronts and related warm and cold core eddies (black arrows), (B) upwelling events on South Australian shelf waters (red arrows), and (C) the Australian subtropical front that may be used to identify provinces inhabited by various cetacean species. *Image credit: Ocean Remote Sensing Group, Johns Hopkins University Applied Physics Laboratory (A), and CSIRO (B,C).*

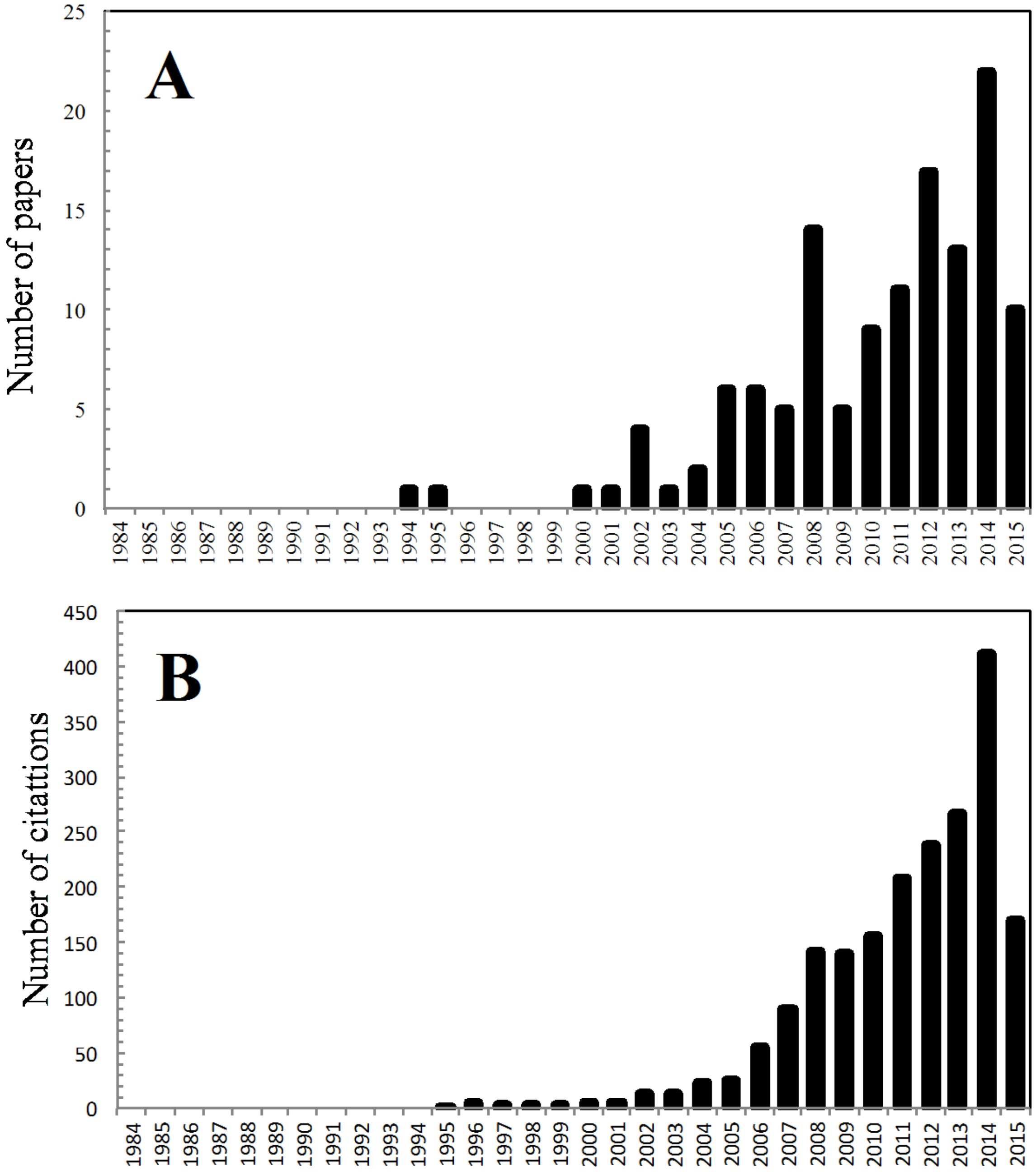

Figure 2.4: Number of papers containing the words *cetacean, habitat* and *model* in their topics published per year over the last 20 years (A) and their subsequent number of citations per year (B).

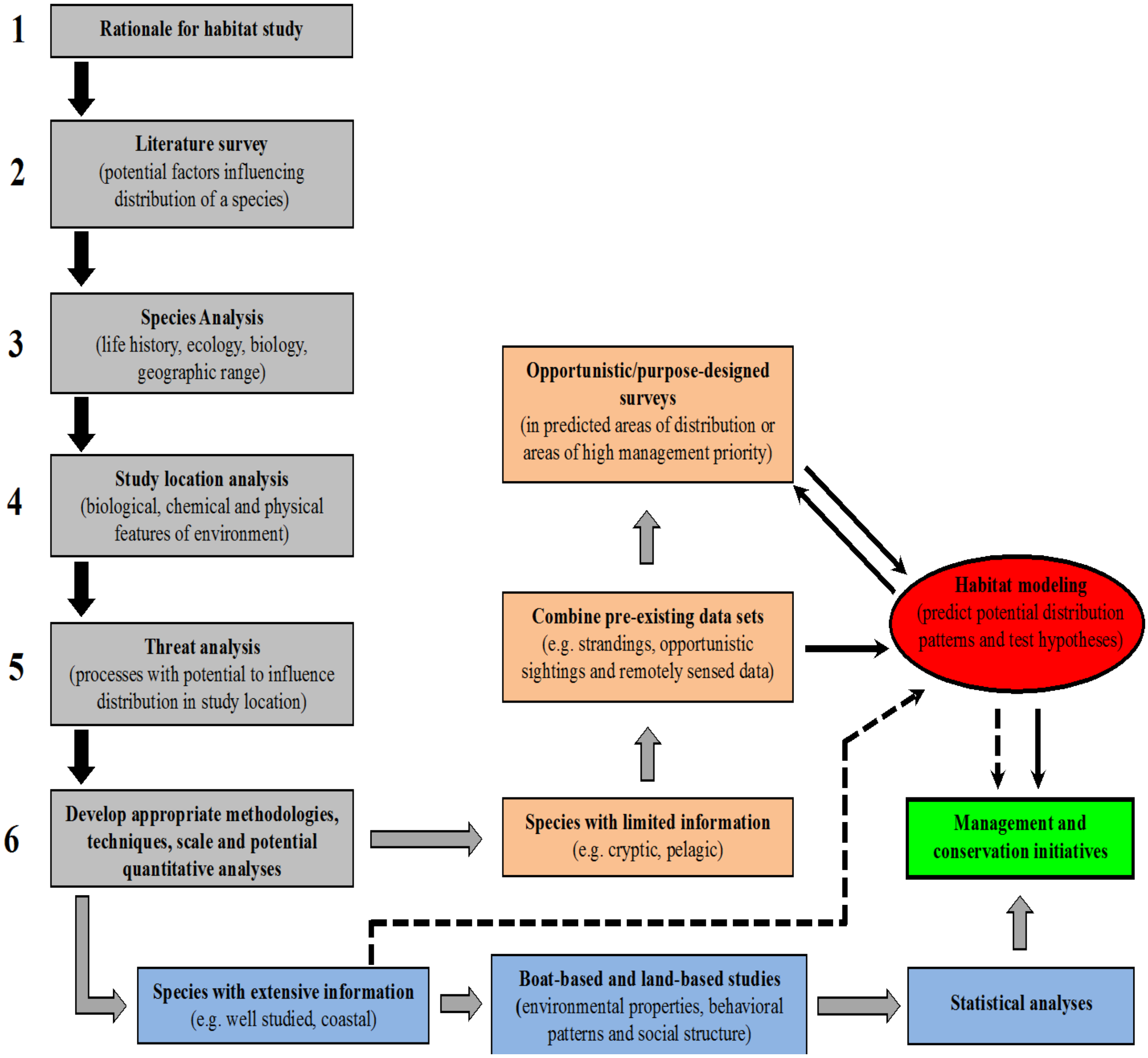

Figure 2.5: Flow chart demonstrating how future cetacean habitat studies could become more targeted and effective in defining and describing habitat.

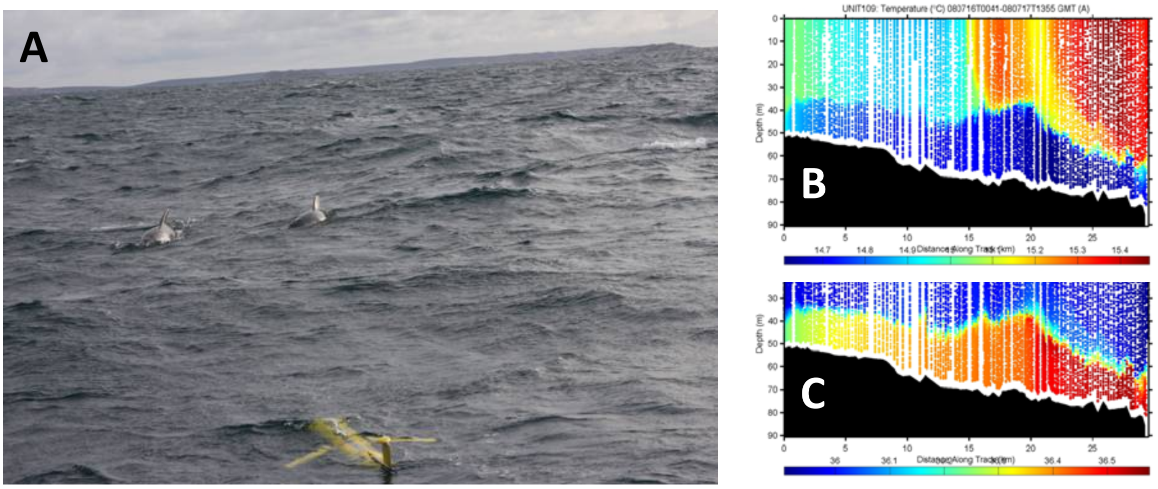

Figure 2.6: Modern technologies, here a Sloccum gliders deployed off Kangaroo Island (South Australia) being escorted by two bottlenose dolphins (*Tursiops* sp.; A), have the potential to assist in the collection of valuable cetacean habitat data, such as high-resolution temperature (B) and salinity (C) structures. *Image credit: South Australian Marine Integrated Observing System, SAIMOS.*

Chapter 3

Indo-Pacific Bottlenose Dolphin (*Tursiops aduncus*) Habitat Preference in a Heterogeneous, Urban Coastal Environment

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N Cribb (candidate) contributed to 85% of the conception and details of the study design, the data analysis and interpretation, writing and editing and 100% of the data collection. Dr C Miller contributed to 5% of the conception and details of the study design, writing and editing. Dr L Seuront contributed to 10% of the conception and details of the study design, the data analysis and interpretation, writing and editing.

3.0 Abstract

Limited information is available regarding the habitat preference of the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) in South Australian estuarine environments. The need to overcome this paucity of information is crucial for management and conservation initiatives. This preliminary study investigates the space-time patterns of habitat preference by the Indo-Pacific bottlenose dolphin in the Port Adelaide River-Barker Inlet estuary, a South Australian, urbanised, coastal environment. More specifically, the study aim was to identify a potential preference between bare sand substrate and seagrass beds, the two habitat types present in this environment, through the resighting frequency of recognisable individual dolphins. Photo-identification surveys covering the 118 km^2 sanctuary area were conducted over 2 survey periods from May to August 2006 and from March 2009 to February 2010. Sighting frequency of recognisable individual Indo-Pacific bottlenose dolphins established a significant preference for the bare sand habitat. More specifically, 72 and 18% of the individuals sighted at least on two occasions were observed in the bare sand and seagrass habitats, respectively. This trend was consistently observed at both seasonal and annual scales, suggesting a consistency in the distinct use of these two habitats. It is anticipated that these results will benefit the further development of management and conservation strategies.

3.1 Introduction

Cetacean habitats are typically heterogeneous, comprising a mosaic of patches which differ in their biological and physical properties (Ballance 1992). Understanding the space-time movement patterns and distribution of organisms within their environments can provide insight into the preference of specific areas (Ballance 1992); information considered essential in the development of management and conservation initiatives (Bearzi *et al*. 2008). In this context, bottlenose dolphins (*Tursiops* spp.) are no exception. They occur globally in both temperate and tropical waters (Leatherwood & Reeves 1983, Connor *et al*. 2000), and are common in coastal waters, in particular estuaries, over a wide range of habitat types, such as seagrass beds, sandy substrates and reefs (Hanson & Defran 1993, Grigg & Markowitz 1997, Allen *et al*. 2001, Cribb *et al*. 2008). The occurrence of bottlenose dolphins in different habitats illustrates the ecological plasticity and adaptability of this species (Wilson *et al*. 1997, Shane 2004, Sargeant *et al*. 2007, Bearzi *et al*. 2008). This highlights the need to understand at the individual and population level the key habitat types and locations they preferentially frequent (Ingram & Rogan 2002). This is especially critical for populations frequenting coastal environments, which are increasingly impacted by anthropogenic activities, such as tourism, chemical and noise pollution, habitat degradation, commercial and recreational fisheries and aquaculture (Watson-Capps & Mann 2005, Bejder *et al*. 2006, Wright *et al*. 2007, Fury & Harrison 2008, Lukoschek & Chilvers 2008, Lavery *et al*. 2009, Seuront & Cribb 2011), thus making them more susceptible to threats (Stockin *et al*. 2008, Wright *et al*. 2009).

The Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) is a prime example of a coastal dolphin species with many populations throughout the Indo-Pacific region (Ross 2006), and more specifically Australia, where they are found in a range of coastal environments such as bays, gulfs, lagoons and estuaries that are often highly urbanised (Möller *et al*. 2002, Kemper *et al*. 2006, Cribb *et al*. 2008, Fury & Harrison 2008). However, little is still known about this species habitat preference in estuarine locations (Fury & Harrison 2008).

In South Australian waters, *T. aduncus* is a known resident, especially in the Port Adelaide River – Barker Inlet estuary, where animals have been recorded year-round over the past 18 years (Kemper *et al*. 2008). This area supports a small population of approximately 30 resident individuals as well as visiting non-regular transient animals (Kemper *et al*. 2008, Steiner & Bossley 2008). Field observations indicate no other marine mammals, specifically delphinids, living in direct sympatry with this population. Fur seals and sea lions were, however, punctually observed hauled out within the study site. The Port Adelaide River – Barker Inlet estuary is situated in close vicinity to the city of Adelaide, hence it is highly urbanised and subjected to a variety of anthropogenic activities such as industrial and sewage pollution, recreational and commercial vessel traffic, dredging, urban development and habitat degradation (Edyvane 1991, Connolly 1994, Edyvane 1999, Edyvane 2000, Bryars 2003, Seuront & Cribb 2011). As a result this area was proclaimed the Adelaide Dolphin Sanctuary (ADS) in 2005 in order to protect both the resident dolphins and their habitat (Adelaide Dolphin Sancuary Act 2005).

Baseline habitat information is, however, still scarce and limited to the presence of bottlenose dolphins being independent of environmental features (Cribb *et al*. 2008). This potentially limits the development and implementation of effective conservation and management strategies, hence the long term-survival of this population. This also stresses the need to further understand and monitor the preference of habitats within this area at both the seasonal and annual scales, and to identify potential areas of high occurrence of specific individuals. In this context, the objective of this paper was to use photo-identification to assess whether recognisable individuals were consistently sighted in the same benthic habitat type at both seasonal and annual scales.

3.2 Methodology

3.2.1 *Study site*

The ADS is situated in the north-eastern region of Gulf St. Vincent (GSV), South Australia (Figure 3.1), located 15 km northwest of Adelaide. This area is characterised by high biodiversity and has both considerable commercial fisheries value and biological significance (Tanner *et al*. 2003). The sanctuary area which includes the Port Adelaide River - Barker Inlet estuary and the coastal waters extending northwards out into GSV covers an area of 118 km^2. In the absence of a map of the benthic habitat in the ADS, we conducted a preliminary sampling survey to assess the nature of the benthic habitat, which showed that the ADS supports two main benthic habitat types that may be used by dolphins (Figure 3.1). The northern part of the sanctuary extending into the open, unsheltered waters of Gulf St Vincent is characterised by the presence of seagrass beds (predominantly *Posidonia*, *Zostera* and *Heterozostera* sp.; (Connolly 1994, Bloomfield & Gillanders 2005). No seasonal fluctuations in seagrass coverage were observed. In contrast, the southern area of the sanctuary consists of shallow sheltered estuarine waters and narrow channels, bordered by mangrove forest, which are essentially devoid of vegetation such as seagrass and attached algae and consist predominantly of bare sand (Jones *et al*. 1996). There is a distinct separation between these two habitat types from the mouth of the estuary out into gulf waters due to the presence of a seasonal sand bars, which constantly change the dynamics of the environment. Water depths in both habitat types range from 0.5 to 6 m; they increase in depth ranging from 10 to 17 m in the dredged shipping channel of the Port Adelaide River.

3.2.2 *Data collection*

Photo-identification data from the ADS were collected from 5 May to 30 August 2006 and from 6 March 2009 to 6 February 2010 (Table 3.1) following the same methodology. Survey transects were designed to provide both even and representative coverage of the sanctuary and the two benthic environment types found here. Specifically, four transects were used to survey the area (Figure 3.1).

Surveys were always conducted at steady speed of 12 knots aboard either a 6 m rigid-hulled inflatable vessel powered by a 70 HP outboard engine, or a 5 m vessel powered by 70 HP outboard motor and were carried out at a Beaufort Sea state of less than 3, under daylight conditions, between 7:30 am and 3:00 pm and fluctuating tidal conditions. Whilst on transect a constant watch for dolphins was maintained by two observers who scanned the water with the naked eye ahead and to 90° either side of the transects. As boat access was limited in the estuary due the presence of exposed intertidal mud flats not accessible by dolphins and seasonal sand bars, sighting visibility was restricted to 200 m either side of the transect. Upon sighting an individual or group of dolphins (*i.e.* all animals within a 100 m radius of each other; Ingram & Rogan 2002) the survey effort was ceased to record the time of the sighting and the number of dolphins present. The vessel was then moved as close to the location of the initial sighting as possible to determine the benthic environment type and record the GPS location. Benthic environment type was determined by visual analysis, as the bottom was visible due to the shallow nature and good water clarity. Note that in waters deeper than 10 m the bottom was not visible from the surface. Specifically in the dredged shipping channels of the Port Adelaide River, preliminary benthic sampling consistently showed the benthos to be devoid of vegetation. The benthic environment type was therefore defined within the study area by the presence of seagrass or bare sand. Once the benthic environmental data was recorded the vessel approached the individual or group and it was then endeavoured to photograph as many of the dorsal fins of the animals present as possible (Würsig & Jefferson 1990, Würsig & Würsig 1997). A Canon EOS 350D digital SLR with a 75-300 zoom lens was used to take all photographs. Encounters (*i.e.* an interaction with an individual or dolphin group; Ingram & Rogan 2002) were restricted to a maximum period of 20 minutes in order to attempt to minimise disturbance to the group or until all individuals in the group were photographed. The vessel then returned to the transect and continued until the transect was completed or all of the study area had been surveyed.

3.2.3 *Photo-identification analysis*

Photo-identification of bottlenose dolphins relies on the matching of distinctive dorsal fin features, such as nicks and notches present on both the trailing and leading edges of the fin, and tip (Würsig & Jefferson 1990, Würsig & Würsig 1997). Photographs were assessed for photographic quality (*e.g.* focus, clarity, contrast, angle, portion of the fin visible and the percentage of picture filled by the fin) and graded according to quality (excellent, average, poor) using Adobe *Photoshop Elements 5.0* imaging software. Only those photographs considered to be of excellent quality were included in the analysis. Poor quality photographs were always discarded from the analysis. Photographs were checked systematically against each other to develop a master catalogue of recognisable individuals and to determine the number of re-sights. The individuals not matched with animals previously recorded were given a unique identification number and added to the catalogue.

3.2.4 *Data analysis*

The statistical package PWAS for Windows, version 18, was used for all statistical analysis. As the data failed to meet the assumptions of normality (Kolmgorov-Smirnov test, $p<0.05$), non-parametric tests were therefore used to make comparisons between data sets. In order to explore the habitat preference of bottlenose dolphins in the ADS the resighting frequency of individuals (*i.e.* the sighting frequency of recognisable individuals seen at least on two or more occasions) was estimated for each benthic habitat type. Resighting frequencies were also assessed to identify potential habitat preference between seasons, defined as spring (September - November), summer (December - February), autumn (March - May) and winter (June - August), and years. Additionally, the resighting frequencies were examined to identify habitat preferences on an individual level. Sighting frequencies between habitats were compared using the χ^2 test (Zar 1996). Specifically, our survey equally covered the two habitat types; hence we compared the observed habitat preference frequencies to theoretical frequencies (50% - 50%).

3.3 Results

3.3.1 *Survey and photo-identification effort*

Twenty two survey days were completed during the two study periods (Table 3.1). An individual or group of dolphins were sighted on 126 occasions, which resulted in a total of 1602 photographs, and 502 of excellent quality used in the analysis. Although surveys were conducted on different tidal regimes, no effect of tide on the frequency of dolphin occurrence was ever observed. Note, however, that the microtidal regime (Tomczak & Godfrey 1994) of the Adelaide Dolphin Sanctuary (and more generally in South Australian gulfs) is unlikely to affect the dynamics of bottlenose dolphins in contrast to megatidal areas such as Aberdeen harbour (Sini *et al*. 2005). A total of 75 distinct individuals were identified based on permanent dorsal fin markings ranging from tip nicks to trailing and leading edge notches. The 75 distinct individuals photographed during the study were sighted between 1 and 8 times. Forty nine of these individuals (65.3%) were sighted on only one occasion. In contrast, 21 (28%) individuals were sighted on two or three occasions and only 5 (6.7%) were sighted on 4 or more occasions (Figure 3.2).

3.3.2 *Habitat preference*

The survey effort equally covered the two habitat types. Bottlenose dolphins were observed throughout the study area over both habitat types. However, the majority of sightings (*i.e.* 76%, n = 96) was concentrated in the bare sand habitat (χ^2 test, df = 1, $p < 0.05$; Figure 3.3A). A clear seasonal (Figure 3.3B) and inter-annual (Figure 3.3C) preference for one of the two habitat types was also observed, with individuals consistently sighted in the bare sand habitat over the four seasons. However, seagrass preference increased from 0 and 10% in winter and spring to 27 and 34% summer and autumn (Figure 3.3B). The preference for the bare sand habitat was consistent throughout the 3 years of the study (Figure 3.3C), suggesting that bare sand is the preferred habitat type used by bottlenose dolphins in this area.

3.3.3 *Individual habitat preference*

Recognisable individuals sighted in the ADS on two or more occasions showed a preference for habitat type. Twenty six dolphins were sighted on 2 or more occasions, and 18 of them (69%) were consistently resighted in the same habitat over time. Only 8 individuals (31%) were sighted both over bare sand and seagrass beds (Figure 3.4A). Additionally, from the 18 animals consistently sighted in the same habitat, 13 (72.2%) and 5 (27.8%) were respectively predominantly (χ^2 test, df = 1, $p < 0.05$) resighted in the bare sand and seagrass habitats over time (Figure 3.4B).

3.4 Discussion

3.4.1 *Indo-Pacific bottlenose dolphin habitat preference in the ADS*

Our observations of dolphin presence and significantly higher sighting frequency in the bare sand habitat (76%; Figure 3.3A) at both the seasonal and annual scales (Figure 3.3B,C) and the significantly higher resighting frequency in the same habitat (69%; Figure 3.4A) are consistent with the previously reported regular occurrence and preference of bottlenose dolphins in one habitat over another (Ballance 1992, Grigg & Markowitz 1997, Allen *et al*. 2001, Shane 1990, Barros & Wells 1998). While further work is needed to specifically address this issue, our results suggest the presence of a seasonal pattern in habitat preference with an increase in dolphin frequency in the seagrass habitat in autumn and summer (Figure 3.3B). Seasonal shifts and variations in habitat preference by bottlenose dolphins have also been observed in other locations such as the San Luis Pass (Texas, USA; Maze & Würsig 1999), the Moray Firth (Scotland; Wilson *et al*. 1997) and the Hauraki Gulf (New Zealand; Berghan *et al*. 2008). However, the occurrence of nearly one-third of the individuals (31%; Figure 3.4A) over both the bare sand and the seagrass habitats may indicate that a non-negligible proportion of the *T. aduncus* occurring in the ADS has enough behavioural flexibility to use the seagrass beds found in the open waters of Gulf St. Vincent as well as the sheltered waters found in the inner estuarine part of the ADS (Figure 3.1). More specifically, respectively 72 and 28% of the resighted individuals were observed over the bare sand and the seagrass habitats (Figure 3.4B). This suggests that the bare sand habitat may be a core area for this population, in contrast to previous work stressing the vital role of seagrass beds for bottlenose dolphins (Shane 1990, Barros & Wells 1998). However, further investigation into the behavioural budget of this population is needed to determine how and why these habitats differ in their importance and use.

3.4.2 *Estuaries as important dolphin habitats*

Our observations of higher dolphin frequency in the bare sand habitat of the Adelaide Dolphin Sanctuary (ADS) further support the importance of estuarine waters for this species (Wells *et al*. 1987, Wilson *et al*. 1999, Ingram & Rogan 2002, Gubbins 2002, Zolman 2002, Irwin & Würsig 2004, Fury & Harrison 2008). This may be linked to the overall nature of estuaries and their potential for high productivity and prey abundances (Moyle & Cech Jr. 1982). Bare sand substrates may also provide a less complex habitat than seagrass in which to feed, particularly as seagrass beds impair their ability to echolocate to find prey (Nowacek 2005). In addition, the consistent high occurrence of individuals at the seasonal and annual scales in the shallow and sheltered waters of the bare sand habitat (Figure 3.3B,C) may also be related to threat avoidance, as bottlenose dolphin habitat preference is influenced by shark predation (Heithaus & Dill 2002). Specifically, in South Australian waters, dolphins are considered the primary prey of white sharks (Bruce 1992). Although occasional, the white shark (*Carcharodon carcharias*) and the bronze whaler (*Carcharodon brachyurus*) both frequent the ADS (Steiner & Bossley 2008). Despite the relatively low occurrence of sharks in the ADS compared to other locations such as Sarasota (Florida), Moreton Bay (Queensland) and Shark Bay (Western Australia) (Corkeron *et al*. 1987, Urian *et al*. 1998, Heithaus 2001, Steiner & Bossley 2008,), one dolphin observed during the study had a large healed scar on the leading edge of its dorsal fin (Figure 3.5A). This scar is likely the result of a shark and not other sources such as boat strike, entanglement or other dolphins due to its distinct crescent-shape which contrasts with the deeper penetrating laceration caused by boat strikes and entanglements (Figure

3.5B; Heithaus 2001). This suggests that predation may be a potential influencing factor for the high frequency of dolphin sightings in shallow and sheltered waters characterising the bare sand habitat. The bare sand habitat may hence provide a suitable haven from predators, in contrast to the open environment characterising the seagrass habitat.

3.4.3 *On the influence of sex and social structure on habitat preference*

The frequency of the same individuals within the same habitat over time (Figure 3.4) may be linked to other factors such as social organisation and association patterns (Sini *et al*. 2005). Specifically, bottlenose dolphin habitat preference has been explained by the home range of individuals and the social strategies which individuals or different sexes adopt (Wells 1991, Ballance 1992). It has been suggested that protected, shallow and narrow waterways which are geographically further from the open ocean such as the bare sand environment in the present work (see Figure 3.1), generally promote limited movement patterns and therefore some degree of site fidelity (Defran & Weller 1999, Gubbins 2002). In contrast, individuals found in open habitats have more extensive home ranges and a lesser degree of site fidelity (Defran & Weller 1999, Gubbins 2002). The individuals resighted consistently over time in the bare sand habitat may hence potentially represent resident individuals, and therefore those sighted on fewer occasions in the seagrass habitat may be transients. Additionally, this sighting frequency may be related to foraging or social specific strategies of male and females. Females have smaller home ranges and frequent more areas which provide a higher concentration of resources, such as estuaries that are important for reproduction and calving and the avoidance of predators (Quintana-Rizzo & Wells 2001, Gubbins 2002). In contrast, males cover wider ranges than females which has been attributed to female breeding cycles and accessibility (Wells *et al*. 1987, Quintana-Rizzo & Wells 2001). As a consequence, the animals sighted consistently in the bare sand habitat might be females utilising local resources, whilst those sighted on fewer occasions in the seagrass may be males searching for females.

3.5 Conclusion

Our results show that bottlenose dolphins in the Adelaide Dolphin Sanctuary occur predominantly in a bare sand habitat. The consistent occurrence and resighting of individuals at both the seasonal and annual scale clearly highlight the importance of the sheltered, bare sand habitat for this population. With a paucity of information available on dolphin habitat due to a lack of monitoring and research in this area, these results provide critical information, which can improve conservation and management strategies previously implemented in the ADS (Adelaide Dolphin Sanctuary Act 2005). Specifically, it is recommended to monitor future trends in dolphin spatial and temporal habitat preference, as initiated here through photo-identification surveys. Additionally, due to the presence and potential growth of anthropogenic activities in the vicinity of the ADS, it is critical to understand the details of the seasonal patterns of habitat preference and social activities of bottlenose dolphins that will ultimately help in objectively establishing restricted access to specific core locations of the Adelaide Dolphin Sanctuary. We also stress that the approach presented here may be applicable to other anthropogenically impacted coastal environments, where the identification of dolphin habitat preferences might have critical conservation and management implications. Finally, as the driving mechanisms influencing bottlenose dolphin habitat preferences may differ depending on the intrinsic properties of their environment, such as the nature of anthropogenic activities, coastal geomorphology and bottom topography, further studies are needed to understand habitat choice on both local and global scales.

3.6 Acknowledgements

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Table 3.1: Number of survey days shown as a function of both season and photo-identification survey periods.

Season	**Photo-Identification Survey Periods**	
	2006	**2009 - 2010**
Spring	1	4
Summer	2	5
Autumn	3	6
Winter	4	8

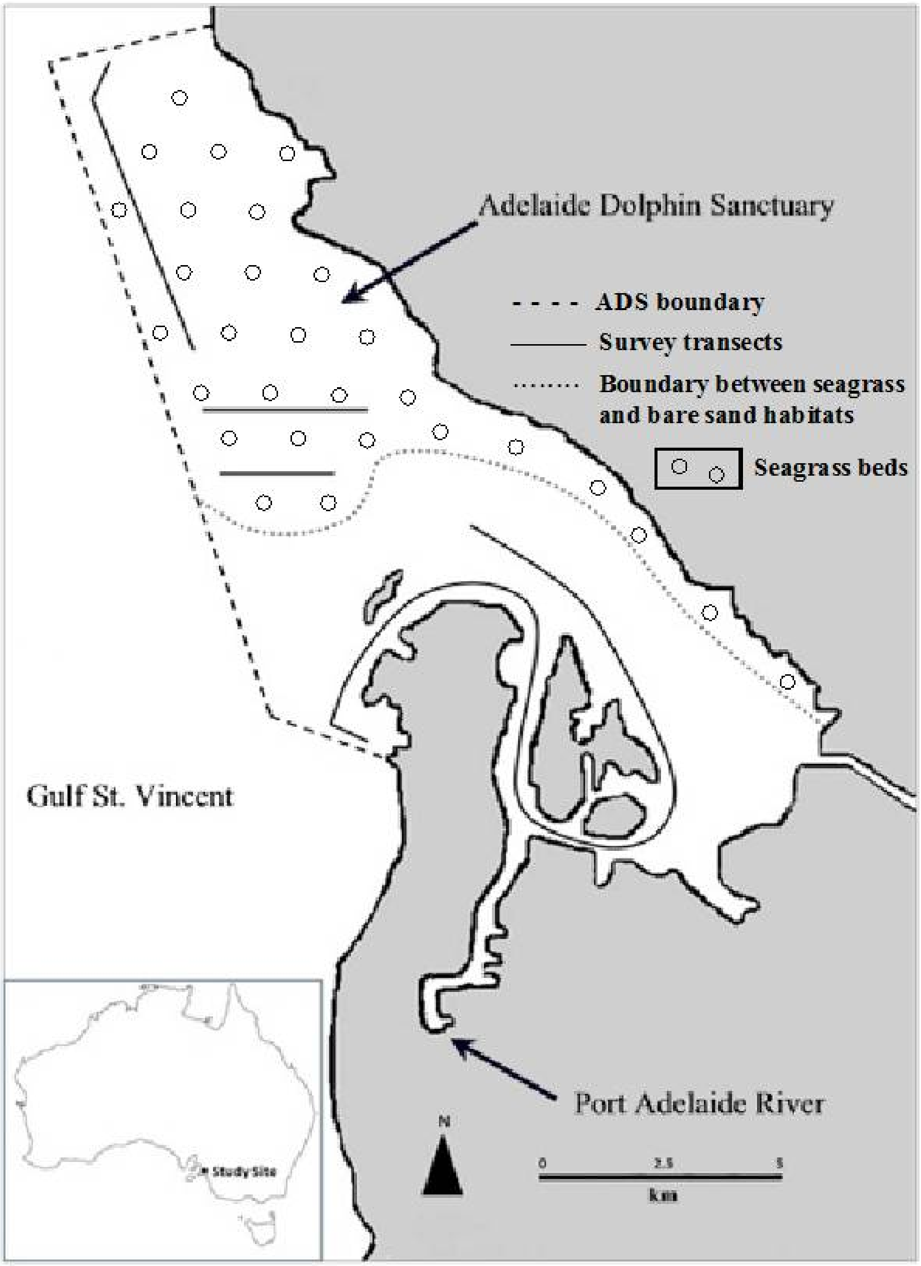

Figure 3.1: Map of the study area showing the locations of the survey transects (solid black lines), the sanctuary boundaries (dashed line) and the separation between the two benthic habitats (seagrass bed to the North and bare sand to South of the dotted line) in the Adelaide Dolphin Sanctuary, South Australia.

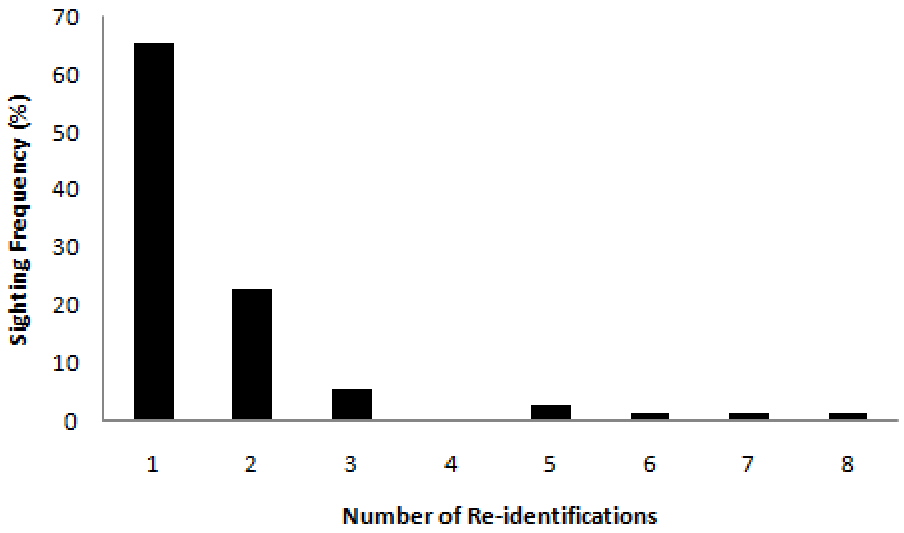

Figure 3.2: Sighting frequencies for individual dolphins identified in the Adelaide Dolphin Sanctuary in 2006 and between 2009 and 2010.

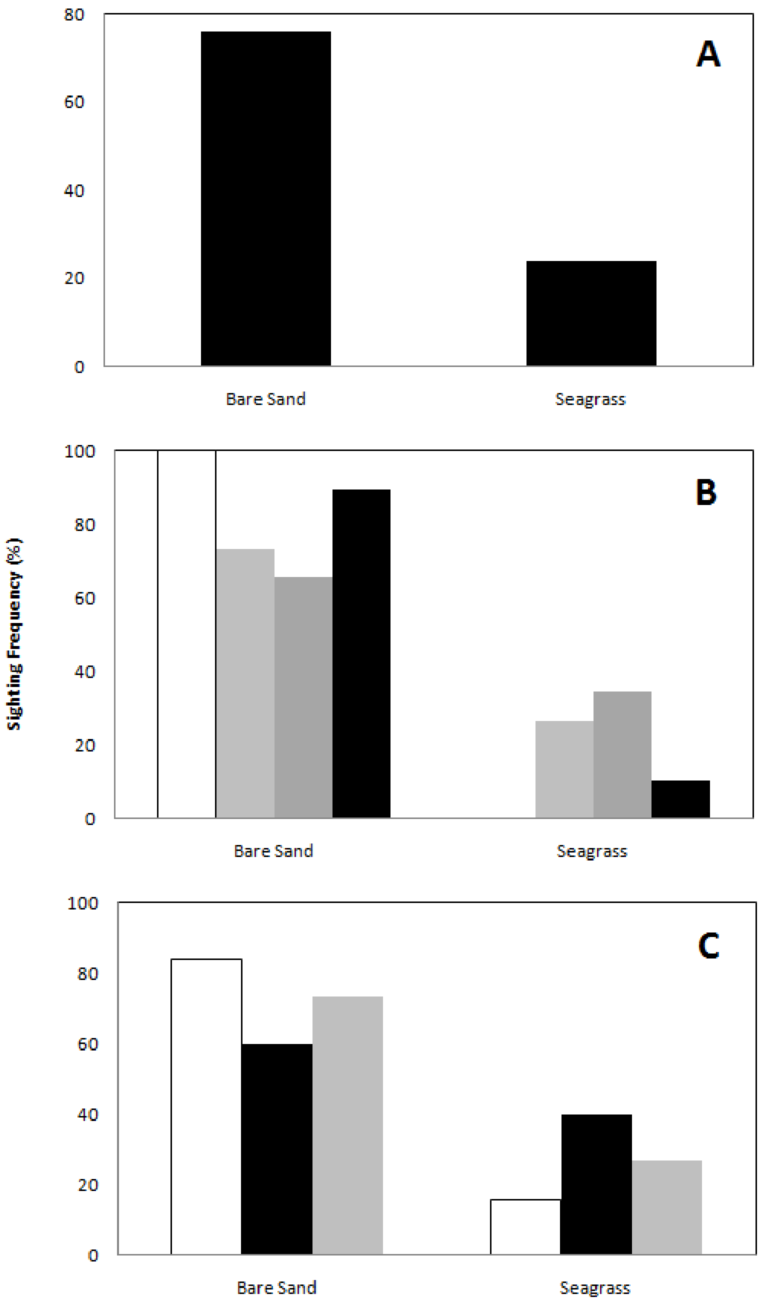

Figure 3.3: Sighting frequency of recognisable dolphins in the Adelaide Dolphin Sanctuary in relation to habitat type (bare sand and seagrass) over the duration of the whole study (A), and as a function of the season (spring: white; summer; light grey; autumn: dark grey; winter: black; B) and the year (2006: white; 2009: black; 2010: grey; C).

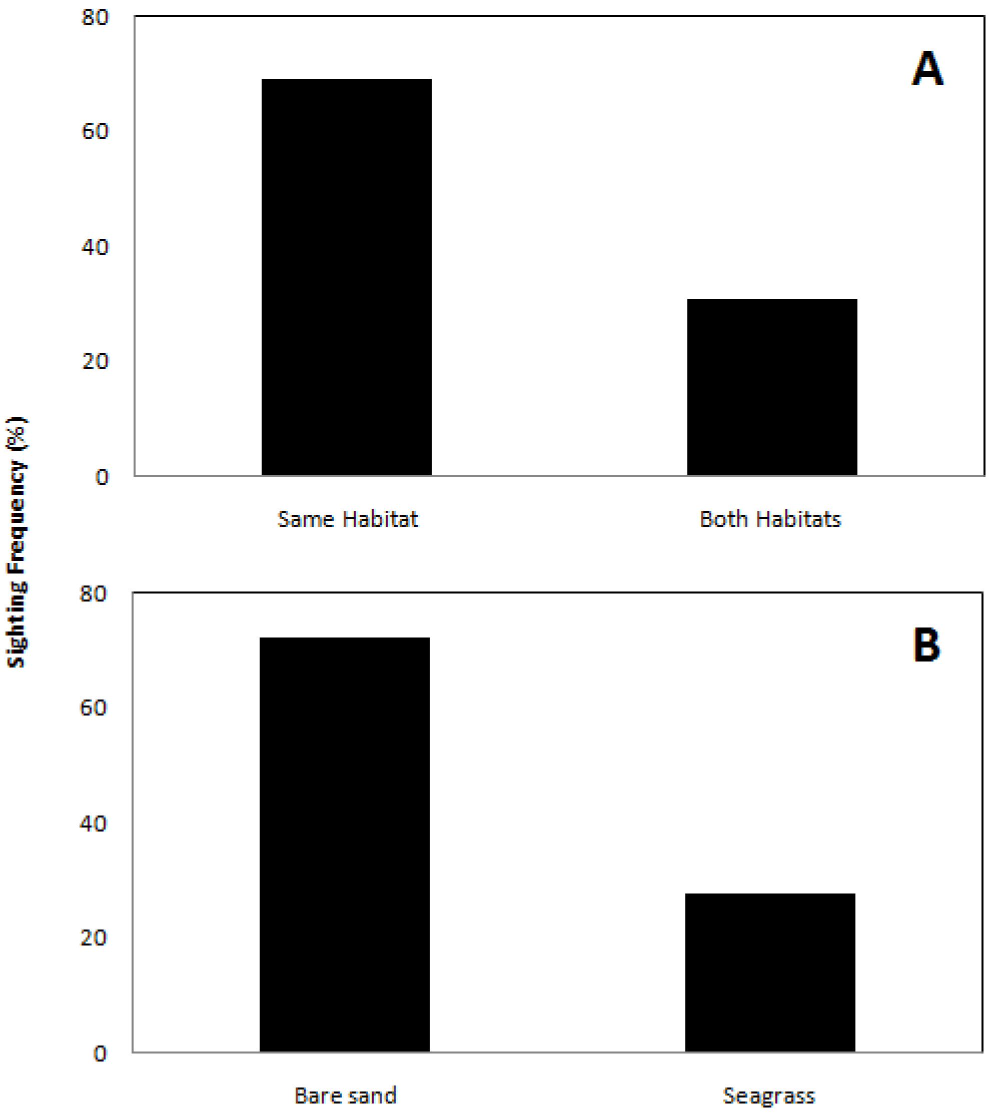

Figure 3.4: Resighting frequency of (A) individuals consistently sighted in the same habitat or sighted in both habitat types, and (B) only sighted in the same habitat as a function of habitat type.

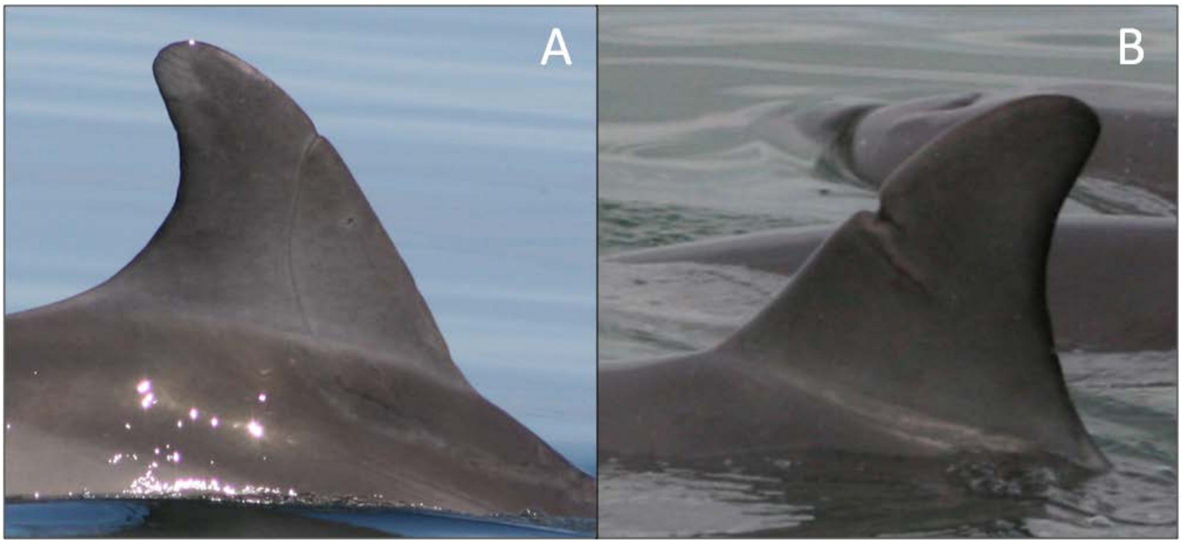

Figure 3.5: Examples of both natural (A) and anthropogenic (B) injuries observed on Indo-Pacific bottlenose dolphins photographed in the Adelaide Dolphin Sanctuary. Natural injuries considered to be inflicted by shark bites are crescent in shape, whilst in contrast those inflicted by anthropogenic causes (*e.g*. boat strike, entanglements) are usually deeper penetrating ‘slash like’ lacerations.

Chapter 4

On a comprehensive assessment of bottlenose dolphin habitat characteristics: example of the Adelaide Dolphin Sanctuary, South Australia

Article submitted as:

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4.0 Abstract

Quantitative and comprehensive information related to cetacean habitat usage is considered a priority in the establishment and further development of conservation and management plans. However, in many cases, cetacean habitat has been investigated only by relating their distribution patterns to a limited number of variables or classification to a relative habitat type, *e.g.* coastal or pelagic. In contrast to previous work, the current study quantitatively investigated the habitat characteristics of a small resident bottlenose dolphin (*Tursiop*s *aduncus*) population in the Adelaide Dolphin Sanctuary, South Australia. We applied an objective and quantitative approach which consistently considered relevant variables to dolphin ecology in this area. Specifically, we investigate the biological and physical properties of the water column, local tidal fluctuations and benthic habitat type (*i.e.* seagrass beds and bare sand) in relation to dolphin presence and behaviour. Water properties measured at locations where dolphins were present consistently differed with those where they were absent, and between the two benthic habitat types available in the sanctuary. No direct links were found, however, between oceanographic factors, group size, composition and behaviour. In contrast, the nature of the benthic substrate influenced both dolphin presence and group size. Specifically, small groups were often observed in the sheltered waters of the bare sand habitat, in contrast to large groups, which were predominantly observed over seagrass beds. Group composition seems to vary on a seasonal basis irrespective of benthic type. While *T. aduncus* behavioural repertoire is habitat-related, it is also driven at the seasonal scale by the fluctuations of the benthic habitat type, in particular the dynamic interface between seagrass beds and bare sand. The results are discussed in the context of the very unique nature of the Adelaide Dolphin Sanctuary, and it is argued that the approach presented here may be considered as a stepping-stone providing baseline information that will benefit local conservation and management initiatives as well as having broader applications to other cetacean species and regions.

4.1 Introduction

Cetaceans are difficult animals to study due to the intrinsic complex nature of their marine environment, the relative inaccessibility of most marine environments and the related costly and logistically challenging nature of marine research (*e.g*. Cribb *et al*. 2015). Additionally, their highly mobile character limits our ability to investigate the nature of their relationships with their habitats, particularly as they occur on various spatial and temporal scales (Allen *et al*. 2001). As a result, little is still known about the specific habitat characteristics of many species (Bannister *et al*. 1996, Ross 2006, Miller & Cribb 2009, Perrin 2009). This paucity of information therefore highlights the need to further identify and increase our understanding of how these animals interact with and rely on their surrounding environment. As understanding and defining cetacean habitat is now considered to be a key element in the development and implementation of management initiatives (Bearzi *et al*. 2008), the need to overcome and fill these knowledge gaps is essential. This is especially critical for delphinid species, which inhabit highly urbanised and anthropogenically threatened coastal environments (Bejder *et al*. 2006, Wright *et al*. 2007).

The bottlenose dolphin (*Tursiops* sp.) is a cosmopolitan species occurring globally in both temperate and tropical waters where it inhabits a diverse range of habitat types (Bearzi 2005). In the southern hemisphere two morphological forms, an offshore (*Tursiops truncatus*) and a coastal form (*Tursiops aduncus*) are now recognised (Hale *et al*. 2000, Natoli *et al*. 2004). More specifically, the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*), found throughout the warm, temperate to tropical Indo-Pacific region (Leatherwood & Reeves 1983), is restricted to coastal environments such as bays, gulfs, lagoons and estuaries (Hale *et al*. 2000, Ross 2006). Despite the common occurrence of *Tursiops aduncus* in coastal areas, which are often impacted by anthropogenic disturbances (Chilvers & Corkeron 2003, Lukoschek & Chilvers 2008, Seuront & Cribb 2011), information on their specific habitat characteristics is still limited (Fury & Harrison 2008, Cribb *et al*. 2008). It is hence essential to expand our understanding of their habitat characteristics by quantifying a range of environmental variables relevant to the species or population in question in order to improve our understanding of their ecology, and therefore ultimately develop more effective localised management strategies (Miller & Baltz 2009, Miller & Cribb 2009, Cribb *et al*. 2015). Although bottlenose dolphins are one of the most well studied delphinids (Connor *et al*. 2000), in many cases their habitat has only been investigated by correlating distribution patterns to a number of environmental variables such as water temperature, depth and benthic topography (Wilson *et al*. 1997, Barco *et al*. 1999, Maze & Wursig 1999). The suite of environmental variables investigated and how they are interpreted commonly vary between studies and often appear to be author specific (Miller & Cribb 2009, Cribb *et al*. 2015). Additionally, few studies have quantified more than one variable, which has placed further limitations on our understanding of their habitat (Miller & Cribb 2009, Cribb *et al*. 2015). Environmental properties were also often investigated in locations where dolphins were present (*e.g*. Bräger *et al*. 2003), which fundamentally limits our understanding of the nature and use of their potential habitat and ignores any temporal effect in habitat use. Therefore, in order to identify important habitat driving factors of their environment it is considered necessary to assess and compare the habitat properties between the locations of where they are present and absent.

Habitat characteristics may also be correlated to the animal's behaviour and social structure, hence providing further insight into the ecological function of a given area (Hastie *et al*. 2004). More specifically, previous studies have assessed the behaviour of individuals in relation to habitat type and identified key areas important for activities such as feeding or socialising (*e.g.* Harzen 1998, Cribb *et al*. 2008, Miller & Baltz 2009, Cribb *et al*. 2012, Eierman & Connor 2014). Furthermore, particular habitat characteristics may also influence or drive the social strategies of certain individuals *e.g*. nursing mothers and calves (Quintana-Rizzo & Wells 2001). These observations stress the need to delineate waters that are used for specific behaviours, such as mating or calving. Therefore, exploring both bottlenose dolphin presence and activity in the context of important environmental features, will progress our understanding of the distribution and behavioural ecology of the species, as well as examining their relationships with environmental properties. This is particularly important in the Port Adelaide River-Barker Inlet estuary, where *Tursiops aduncus* is a known resident (Kemper *et al*. 2008, Steiner & Bossley 2008). This estuary is a highly industrialised environment impacted by a number of anthropogenic activities ranging from sewage pollution, horticultural water runoff, recreational and commercial vessel traffic, dredging, urban development, habitat degradation and altered flow regimes (Edyvane 1991, 1999, 2000, Connolly 1994, Bryars 2003, Seuront & Cribb 2011). The recognition of the potential threats in this area therefore led to the declaration of the Adelaide Dolphin Sanctuary (ADS) in 2005, with the intent to protect and conserve both the dolphins and their habitat. However, although now a declared sanctuary, little is still known about the specific environmental habitat characteristics and related behavioural ecology of dolphins in this area. This therefore places potential limitations on future effective developments of management initiatives. In this context, the objectives of this study were to comprehensively and quantitatively expand our understanding of the habitat characteristics and behavioural ecology of bottlenose dolphins within the boundaries of the ADS. In order to do this we applied a fine scale *in-situ* approach, which specifically investigated potential links between dolphin presence, group size and behaviour with both the abiotic and biotic properties of both the water column and the nature of the benthic substrate of their environment.

4.2 Methodology

4.2.1 *Study site*

The ADS, an initiative between the Government of South Australia, industry and community was declared a sanctuary in 2005. Located on the north-eastern side of Gulf St. Vincent, South Australia (34°39’S 138°25’E, 34°51’S 138°30’E; Figure 4.1), 15 km north of the metropolitan city of Adelaide, the sanctuary area covers 118 km^2 and ranges in water depths from 0.5 to 17 m. The southern area of the sanctuary comprised of the Port Adelaide River - Barker Inlet estuary, is a sheltered water complex, fringed by mangrove forest, and dissected by numerous shallow bare sand channels (Jones *et al*. 1996), which are essentially devoid of vegetation such as attached algae and seagrass. In contrast, the northern area of the sanctuary, extending northwards out into the open and exposed waters of Gulf St. Vincent, is dominated by the presence of seagrass beds, predominantly *Posidonia* sp., *Zostera* sp. and *Heterozostera* spp. occur (Connolly 1994, Bloomfield & Gillanders 2005). Both of these habitat types represent important areas utilised by dolphins in this area.

4.2.2 *Sampling strategy*

To investigate dolphin presence and behaviour in relation to habitat characteristics in the ADS we therefore designed a specific survey in order to provide equal spatial coverage of the sanctuary and the two benthic habitat types. Four survey transects with 30 predefined sampling stations were used to survey the area of the sanctuary. Sampling stations were placed at 1 km apart within gulf waters or at a distance of 1.5 km inside the estuary (Figure 4.1). Stations located on the predefined transects were defined as grid stations.

4.2.3 *Dolphin sighting data collection*

Standardised boat-based surveys were conducted within the boundaries of the ADS between March 2009 and January 2011. Surveys were conducted aboard a 6 m rigid-hulled inflatable vessel powered by a 70 HP outboard engine. All surveys were conducted in good sea state conditions (Beaufort Scale < 3), and during daylight hours (*i.e.* both in the morning and afternoon). When on transect the vessel travelled at a steady speed of 12 knots. Two observers scanned the water with the naked eye for the presence of dolphins ahead and to 90° either side of the transect using scan sampling methods (Mann 1999). Sighting visibility was restricted to approximately 200 m on either side of the trackline due to the shallow nature of the area and limited boat access resulting from the presence of a seasonal sand bar and shallow intertidal mud flats.

Upon encountering an individual or group of dolphins the boat was stopped and survey effort ceased and the following information was recorded: time of sighting, GPS location and bearing to the group from the transect line. A group was defined as all animals within a 100 m radius of each other engaged in a similar activity (Ingram & Rogan 2002). The behavioural activity (categorised as travelling, milling, resting, feeding and socialising; Table 1) of the individual or group was determined upon the initial sighting. Group size and composition was also recorded, based upon the number of individuals initially observed at the surface. Composition of the age class of individuals was determined by the count of adults, juveniles and neonates present within the group. Neonates were recognised by the presence of fetal folds and folded dorsal fin and uncoordinated surfacing, juveniles were animals two thirds or less the length of an adult, that swam independently, but at times still accompanied an adult. Adults were those animals approximately 3 m in total length with either visible marks or unmarked in particular on their dorsal fin (Mann & Smuts 1998, Mann *et al*. 2000). Once the necessary data was recorded the vessel was then moved as close as possible to the location where the dolphins were initially sighted to obtain quantitative information on the structure of the water column and the benthic habitat type of the sighting location. These measurement stations were defined as sighting stations. Once obtained the vessel returned to the transect line and survey effort was resumed until the transect was completed or all of the study area had been surveyed.

4.2.4 *Oceanographic data collection*

In order to identify potential factors defining dolphin habitat, the properties of the water column were measured together with the benthic substrate type at grid stations along the predefined transects and at sighting stations for those defined by the presence of dolphins. Note that in contrast to a range of previous dolphin habitat-related work (*e.g*. Selzer & Payne 1988, Ballance 1992, Barco *et al*. 1999, Zolman 2002, Bräger *et al*. 2003), we did not limit our investigations to surface water properties. Instead, we consistently investigated the properties of the whole water column, including the nature of the bottom. Temperature (C°), salinity, chlorophyll-*a* (µg/L) and turbidity (ppm) were measured continuously from the surface to the bottom of the water column with a Compact-CTD HD (Alec Electronics Inc., Kobe, Japan) with a 10 cm vertical resolution. Water depth was determined by a dual frequency sonar fishfinder, Navman FISH 4500. Additionally, the benthic environment type, (*i.e.* either bare sand or seagrass) was also noted at both the grid and sighting stations by visual assessment due to good water clarity. The influence of tidal regime on dolphin sightings and environmental water properties was also investigated. The vertical stratification of the water column was calculated from the potential energy E_p, which corresponds to the amount of energy required to redistribute mass in a complete vertical mixing (Pond & Pickard 1983). E_p (J m^{-3}) was estimated as $E_p = (1/H)\int_{-H}^{0}(\rho - \bar{\rho})gz\,\mathrm{d}z$, where H, ρ and $\bar{\rho}$, g and z are respectively the depth of the water column (m), the density of the water (kg.m^{-3}), the vertically averaged density of the water column (kg.m^{-3}), the gravitational acceleration (m s^{-2}) and the depth (m).

4.2.5 *Data analysis*

Since our first objective was to assess the space-time properties of our study site, we first applied a method similar to the space-time approach initially introduced to characterize sampling processes in plankton ecology (Ibanez 1973) and further used to link the structure of the physical environment to the complexity of phytoplankton distribution patterns (Seuront & Lagadeuc 1998). Specifically, we selected variables related to the spatial and temporal scales of our surveys and a principal component analysis (PCA) was performed on the observations (*i.e.* stations along each transect, *Q* mode) and the variables (*R* mode, *sensu* Legendre & Legendre 1984). The variables considered were latitude, longitude, tidal conditions (*i.e.* outgoing and incoming tide), depth (m), temperature (°C), salinity, *in vivo* fluorescence of chlorophyll *a* (used as a proxy of phytoplankton concentration; µg l^{-1}), turbidity (ppm), the potential energy E_p, and habitat type (*i.e.* seagrass vs. bare sand). The identification of the components of the multivariate analyses was carried out using the factor loadings of the variable in the *R* mode of PCA analysis since the factor loading of a given factor could be related to the variance explained by such a factor (Legendre & Legendre 1984). Because a criterion is needed for deciding upon appropriate stations to group in the data space, a cluster analysis based on an unweighted centroid algorithm (Sokal & Michener 1958) has been carried out on a (Euclidean) distance matrix calculated from the first two principal components of the multivariate analysis. We also conducted a PCA on the space-time properties of the environment using the aforementioned variables when dolphins were sighted. Besides we further introduced in this PCA additional variables related to group size, and behavioural activity (*i.e.* travelling, feeding, socialising, resting and milling) in order to infer the potential linked between dolphin ecology and the properties of their environment.

Further analyses were used to describe the potential differences in environmental properties observed at grid stations and grid stations, and how they could be related to dolphin presence, group size and behavioural activities. Specifically, as the data failed to meet the assumptions of normality (Kolmgorov-Smirnov test, $p < 0.05$), non-parametric tests were therefore used to make comparisons between data sets. Wilcoxon Signed Rank tests were used to explore potential differences between environmental parameters measured at sighting stations and grid stations, between habitat types (bare sand and seagrass) and for each of the environmental water properties measured within the same habitat type for both sightings and grid stations. Similarly, Wilcoxon Signed Rank tests were also used to explore the effect of outgoing and incoming tides on both dolphin sightings and each of the environmental water properties. A Mann-Whitney *U* test was used to compare whether dolphin group size differed between habitat types. Chi-square tests for independence analyses were conducted to explore whether there was a relationship between dolphin age class and habitat type. Multiple comparisons between sampling sites were conducted using the Kruskal-Wallis test and a subsequent multiple comparison procedure based on the Tukey test was used to identify distinct groups of measurements (Zar 2010). More specifically, we used these to identify potential seasonal differences between the environmental properties measured at dolphin sighting locations for each of the two benthic habitat types. Additionally, sighting frequencies using multiple comparisons were also assessed to identify whether dolphins showed a seasonal habitat preference, and whether seasonal variability of the environmental water properties had any effect upon dolphin group size and behaviour whilst in each of the two habitat types. Seasons were defined as: spring (September - November), summer (December - February), autumn (March - May) and winter (June - August). Finally, the presence of correlations between the 5 environmental water properties measured and dolphin group size was assessed through Spearman’s rank correlation analysis.

4.3 Results

4.3.1 *Survey effort*

A total of 11 surveys were completed, with survey effort being relatively limited across the seasons due to poor weather conditions. Note, however, that dolphins were encountered on all surveys, and in both habitat types. More specifically, our surveys were characterized using a principal component analysis (PCA) ran on latitude, longitude, tidal conditions, depth, temperature, salinity, *in vivo* fluorescence, turbidity, the potential energy E_p, and habitat type (Figure 4.1). The results of the PCA showed that the first three components explained 68.9% of the variance. The first component explained 34.5% of the variance, and was significantly correlated with habitat type, latitude, longitude and depth, and clearly showed a north-south and east-west gradient in habitat type. In contrast, the second and third components of the PCA, which respectively explained 20.1 and 14.3% of the variance, were significantly correlated with both physical and biological properties of the water column, *i.e.* temperature, salinity, *in vivo* fluorescence and turbidity. Note that potential energy was not significantly correlated with any of the first three components, indicating that vertical stratification did not play a significant role in the space-time properties of our surveys. The projections of the stations in the two-dimensional planes defined by the first three components showed two distinct groups of stations, that were segregated by their differences in benthic habitat type (Figure 4.1C,D). This observation is specified by the results of the unweighted centroid clustering that showed two groups of observations, one group includes the stations which are within the inner part of the survey area and characterized by a sandy bottom (stations 1 to 17), and the other one the stations that were investigated over seagrass beds (stations 18 to 30). These observations indicate that the nature of the benthic substrate is by far the most discriminant variable to take into account as a classification tool of the stations investigated over our survey period.

4.3.2 *Water properties, benthic type, seasonality and dolphin presence*

Temperature, salinity, chlorophyll *a* and turbidity exhibited a similar range of variability for both sampling locations (Table 4.2). Significant differences were found between grid stations and sighting stations only for salinity and turbidity ($p < 0.05$; Table 2). No significant differences were observed in tidal phase observed in either the presence of dolphins or 5 environmental water properties ($p > 0.05$; Table 4.2).

Significant differences were found between the bare sand and seagrass habitats for each of the considered environmental water properties in the locations where dolphins were present ($p < 0.05$; Table 4.3). Similarly, highly significant differences were found between the benthic types for temperature, salinity, chlorophyll-*a* concentration and depth at the grid stations ($p < 0.05$; Table 3). In contrast, turbidity did not significantly differ with benthic type ($p > 0.05$; Table 4.3).

No significant differences were found in any of the variables between dolphin sighting and grid stations in the bare sand habitat. In contrast, only water temperature and depth ($p < 0.05$) differed between dolphin sighting and grid station in the seagrass habitat (Table 4.3).

Finally, significant seasonal variations were found for water temperature and salinity ($p < 0.01$; Table 4.4) in the bare sand habitat, specifically with temperature significantly differing between autumn and summer. In contrast, in the seagrass habitat, only water temperature significantly differed between autumn and summer ($p < 0.01$; Table 4.4)

4.3.3 *Dolphin group composition, size and behavioural activity*

Group composition

Adults were the most frequently observed age class of dolphins sighted within the ADS. Adults comprised 78.5% ($n = 142$) of the dolphins encountered, with the remaining 21.6% ($n = 39$) classified as either juveniles or neonates. Neonates were, however, only observed on one occasion. Although both adults and juveniles were observed in both benthic habitat types, neither showed a preference for one habitat type over the other ($p > 0.05$).

Group size

In total 75 groups of bottlenose dolphins were encountered totalling 181 individuals sighted. Group size ranged from 1 individual up to 9 animals, with an average group size of 2.4 (SD = 1.63). Groups of 2 or more animals were most commonly sighted (65.3%, $n = 49$), with single animals comprising 34.7% of group encounters. Dolphins were encountered in both habitat types over the duration of the study. However, they were only sighted in both habitats in 45% of the surveys. Dolphins were predominantly sighted in the bare sand habitat with 113 (62.4%) individuals and 49 groups (65.3%) encountered, compared to 68 (37.6%) individuals and 26 (34.7%) groups in the seagrass habitat. The size of groups observed in the two habitat types was significantly different ($p < 0.01$), with the largest group sizes observed in the bare sand. Although, the largest dolphin group size (*i.e*. 9 animals) was observed during summer, no significant seasonal difference was found ($p > 0.05$).

Behavioural activity

Over the duration of the study bottlenose dolphins were observed travelling, feeding, socialising, resting and milling. Travelling (42.3%) and feeding (42.3%) were the most frequently observed behaviours, followed by milling (9.9%), socialising (4.2%) and resting (1.4%; Figure 4.3A). Group size was observed to significantly differ ($p < 0.01$) according to the behavioural activity dolphins were engaged in (Figure 4.3B). Mean group size was largest when resting, followed by socialising, milling, feeding and travelling.

Seasonal variability and habitat preference

All behavioural activities were observed in both the bare sand and seagrass habitats except resting, which was only observed in the bare sand habitat. Travelling was the most frequently observed behaviour in the bare sand (23%) habitat followed by feeding (18%), socialising, resting (1%), and milling (5%). In comparison, feeding (12%) was the most frequently observed behaviour followed by travelling in the seagrass habitat (7%; Figure 4.4).

A seasonal shift in behavioural activity was also found over the duration of the study. In particular, resting and socialising were only observed during summer, with feeding being the most frequently observed activity during autumn and travelling during the winter months (Figure 4.5). Finally, no statistically significant correlations between dolphin group size and each of the 5 environmental water properties were observed ($p > 0.05$).

Environmental properties and dolphin ecology

A principal component analysis ran on the space-time environmental properties of the stations where dolphins were observed specified the aforementioned results (Figure 4.6). Specifically, the first principal component is essentially related to seasonality and the oceanographic properties of the water column (Figure 4.6A,B). The second and third principal components respectively characterized a strong habitat gradient and both seasonal and inter-annual variability (Figure

4.6A,B). The additional variables relative to group size, behavioural activity and habitat variables were weakly correlated to the first three principal components (Figure 6A,B). Significant correlations exist, however, between some behavioural activities and the principal components. Specifically, group size and resting behaviour were significantly correlated with the first and third principal component, indicating significantly higher group size in summer and a predominance of resting behaviour in summer (Figure 4.6B). In addition, travelling and socialising were significantly positively and negatively correlated with the second principal component (Figure 4.6C,D). This result indicates that travelling and socialising mainly respectively occurred over bare sand and seagrass beds, irrespective of season, water depth and oceanographic properties.

4.4 Discussion

4.4.1 *No evidence of oceanographic control on bottlenose dolphin presence, group size and behaviour*

The present work shows that oceanographic factors do not drive group size, behaviour and group composition in the Adelaide Dolphin Sanctuary (ADS). This is in contrast with previous studies showing that oceanographic factors such as tidal state (Fury & Harrison 2011), water depth and benthic topography (Wilson *et al*. 1997, Ingram & Rogan 2002), influence bottlenose dolphins in other coastal locations and in particular estuaries. In most cases though, these estuaries differ from the ADS in that they open into (or are adjacent to) oceanic waters which potentially effects the estuaries overall hydrographical dynamics. The estuarine and coastal waters of the ADS open into Gulf St. Vincent, a shallow (mean water depth 21 m; Käempf 2014) and sheltered inverse estuary characterised by low energy waters which are protected and restricted to the Southern Ocean by the location of Kangaroo Island (Tanner 2005). The sheltered nature of the ADS is consistent with the relatively low variability observed over the course of our surveys in the considered water properties, especially temperature, salinity, chlorophyll-*a* fluorescence and turbidity (Tables 4.1-4.3). It is hence likely that the very specific nature of the ADS limits the influence of oceanographic forcing on dolphin presence and behavioural activities. This observation is consistent with the fact that the nature of the benthic substrate is the most influential potential driver of dolphin presence, group size and behavioural activity.

More generally, dolphins being apex predators, the influences of locally observed oceanographic properties is intrinsically not direct (Ballance *et al*. 2006). As environmental conditions are constantly changing and both predator and prey species are mobile, identifying relationships between oceanographic conditions and animals such as dolphins may be difficult to ascertain (Stevick *et al*. 2001). Therefore, despite the observed lack of clear relationships between dolphins and hydrographic properties, it must be considered that the bottlenose dolphins in this area may be responding directly to other factors in their environment such as prey distribution. However, as prey and dolphin relationship information within the ADS is limited, further work is required to develop a greater understanding.

4.4.2 *Habitat type does not influence group composition but season does*

No significant relationships between dolphin age class and habitat were observed within the ADS. The composition of dolphin groups has, however, been observed to vary elsewhere according to habitat and location (McHugh *et al*. 2011, Rossman *et al*. 2014). The presence of both adults and juveniles over both the bare sand and seagrass habitats suggests that the nature of the substrate does not influence group composition in the ADS. Alternatively, our results, in particular the observed potential link between group size and season (Figure 4.6C,D), suggest, in turn, that group composition may also be driven by a combination of other influences such as time of reproduction, associations between males and females and social organisation.

4.4.3 *Habitat type influences dolphin presence and group size*

Both the presence of dolphins and their group size vary worldwide and are suggested to be influenced by various environmental factors (Bearzi *et al*. 2008). In the ADS the small group sizes observed (*i.e*. ranging from 2 to 9 individuals, 2.4±1.63; mean ± SD) and the high occurrence of dolphin sightings in the sheltered waters of the bare sand habitat is consistent with observations conducted in other coastal locations (Shane 1980, Ballance 1992, Campbell *et al*. 2002). Dolphin group size has previously been suggested to be influenced by the nature of abiotic and biotic features of the environment (Ballance 1990, Lusseau 2003, Merriman *et al*. 2009). This is not the case, however, in the present study as group size was not correlated with any of the investigated environmental water properties. Larger groups of bottlenose dolphins have been observed to occur more frequently in deeper, exposed and open waters such as the seagrass habitat (Weller *et al*. 1987, Toth 2012). These observations are consistent with our observations (see Figure 4.6C,D). Besides, this increased presence of animals in the seagrass habitat is thought to assist in the cooperation of feeding, as well to provide a greater level of protection from the threat of potential predators (Weigle 1987, Campbell *et al*. 2002). In contrast, smaller groups have been observed to occur in shallow and protected coastal areas such as the bare sand estuarine waters of the ADS (Ballance 1990). Our observations of different group size between the two benthic habitats (*i.e*. bare sand and seagrass) and the contrasting open and sheltered waters of the ADS further supports this hypothesis. Note, that the relatively sheltered nature of the ADS combined with both the low level of predation within the boundaries of the ADS (Steiner & Bossley 2008) and the frequency of observations of small groups (Figure 4.3), suggest that the ADS provides conditions that are optimal to support small group sizes. However, the seasonal differences in group size observed in the ADS with the largest being observed during summer, may be a reflection of social factors or foraging strategies rather than the environmental or habitat features of the ADS. Additionally, this may be a reflection of environmental conditions specific to the ADS, resulting from the lack of variation in measured environmental properties.

4.4.4 *Habitat properties and dolphin social organisation*

The study of the social structure and group composition and the habitat use among dolphin groups is considered important for their conservation, as this can provide much insight into the driving processes behind it (Louis *et al*. 2015). Dolphin group composition has been considered to vary due to the availability of prey resources and predation as well as by the social and reproductive strategies which individuals or the different sexes adopt (Lusseau *et al*. 2003, Gowans *et al*. 2007). In the ADS, adults were the most frequently observed age class, with neonates only being observed on one occasion, during early Autumn (9 April, 2009). Seasonal reproduction has been observed in bottlenose dolphins in other locations (*e.g*. North Carolina, Florida & Texas, USA), with neonates most frequently observed during the summer period (Urian *et al*. 1996, Thayer *et al*. 2003). Though this should be considered with caution, our observation of a neonate in the ADS during early Autumn is consistent with previous work which identified the pattern of a distinct calving season in this area, where calves were being born only between December to May each year (Steiner & Bossley 2008). Additionally, adults and juveniles were observed in both benthic habitat types.

As cetaceans spend majority of their time concealed under the surface of the water their social interactions remain hard to determine (Gero *et al*. 2005). Group composition may also be related to the cultural transmission of specific behaviours, such as those noted in bottlenose dolphins elsewhere (*e.g.* Patterson & Mann 2011). However, dolphin social organisation has also been observed to be affected by anthropogenic activities. Disturbances within their environment may effect group composition causing separation between group members and therefore ultimately effecting overall their associations (Constantine *et al*. 2004). Anthropogenic activities also have the potential to effect dolphin distribution within key areas of their environment (Garcia-Vital *et al*. 2015).

The overall organisation of the bottlenose dolphin community within the ADS is, however, beyond the scope of this study. Further studies to quantify the social structure and specific associations between individuals and sex would be beneficial to further identify how group structure is influenced by environmental conditions within the ADS. Specifically, how certain age classes and males and females utilise their environment and does this differ over time and more specifically benthic habitat type as well as their behaviour. As dolphins are considered sentinel animals in marine ecosystems (Wells *et al*. 2004), any changes in this sociality could also potentially be linked to changing environmental conditions (Kelley *et al*. 2011.)

The dolphins of the ADS represent a unique situation. Our results first demonstrate the need for further studies in order to understand the complex behaviours and social structure within the ADS. The potential complexity within this ADS population is likely to be driven by the multifaceted nature of the environment in which they live, including the ever increasing anthropogenic pressure. This stresses the need for conservation and management initiatives to be tailored accordingly. Further studies which focus specifically on particular behavioural activities *e.g.* feeding strategies as demonstrated by Miller & Baltz (2009) between the two benthic habitat types would hence be beneficial.

4.4.5 *On the potential environmental drivers of dolphin behaviour*

The behaviour of bottlenose dolphins is closely related to the local abiotic and biotic properties of their environment (Shane 1990, Miller & Baltz 2009, Bailey & Thompson 2010). No relationships were found, however, between oceanographic properties and dolphin behaviour within the boundaries of the ADS, in accordance with previous findings in this area (Cribb *et al*. 2008). Our results then suggest that the nature of the benthic habitat rather than the oceanographic properties may be the underlying driver of dolphin behaviour in the ADS (see Figure 4.4) as also observed elsewhere (Harzen 1998). Specifically, Hanson & Defran (1993) observed behaviours such as socialising, feeding and travelling to occur more frequently in estuarine areas consisting of reef and sand. These behavioural preferences indicate that different benthic habitat types favour different ecological functions (Hastie *et al*. 2004), as previously suggested for the ADS (Cribb *et al*. 2013) and Fijian reefs (Cribb *et al*. 2012). As suggested for bottlenose dolphins elsewhere, dolphins may alter their behaviour according to the conditions and features of the local environment (Martinez-Serrano *et al*. 2011). These observations have critical implications in terms of conservation and management initiatives, as strategies applied in an environment dominated by a given benthic habitat type, may not be as successful in another (Sargeant *et al*. 2007).

The home range of apex predators such as dolphins includes patches of environments that characterize different communities of organisms (Eierman & Connor 2014). This is particularly relevant in the ADS, due to its overall nature, consisting of various microhabitats (*e.g*. deep channels, shallow bare sand, mangrove fringed creeks, open seagrass beds, shallow open sand bars, mangroves, mud flats) occurring in a small geographic location and separated by physical barriers between (*e.g*. breakwaters, islands, mangrove forest, mud flats, sand bars). This is a very unique situation, and dolphins in this area need to have enough behavioural flexibility to forage etc. and use such a variety of microhabitats. For example, the way in which they feed in the deep shipping channels may differ from the way they feed in the shallow waters of Barker Inlet which is fringed by mangroves and in the more open waters of the northern seagrass habitat. Besides, beyond the intrinsic high level of structural complexity of seagrass beds (*e.g*. Manzanera & Romero 2000), they may also potentially present a more complex environment in which to feed, by *e.g*. limiting the acoustic ability of dolphins to detect prey as well as providing a refuge for fish within the seagrass structure (Allen *et al*. 2001). As dolphins in other locations use various behavioural strategies according to benthic substrate and environment type (Eierman & Connor 2014), the variation in prey species (*e.g*. bare sand *vs*. seagrass) within the ADS could be another potentially contributing influence on behaviour in this area. Further investigation into this would be beneficial for future management initiatives.

The ADS is an area exposed to a large range of human activities (*e.g.* industry, shipping, recreational vessel activity, tourism) which induce modifications in dolphin behaviour depending on the nature of these activities (Seuront & Cribb 2011). Dolphin behaviour and physiology is negatively affected by anthropogenic activities (*e.g.* La Manna *et al.* 2013, New *et al.* 2013). They have also been observed elsewhere in other highly impacted environments to use man-made structures such as jetties and shipping channels to their advantage (Henningsen & Würsig 1991). Furthermore, the large amount of vessel traffic within the area may also imply that dolphins are consistently adjusting their behavioural states to adapt. Seuront & Cribb (2011) hence showed subtle behavioural changes in *T. aduncus* in response to boat presence and type. Specifically, the complexity of dive duration patterns did not significantly differ between control behavioural observations conducted in the absence of boat and behavioural observations conducted in the presence of kayaks. A significant increase in behavioural stress was, however, induced by the presence of fishing boats, motorised inflatable boats and powerboats (Seuront & Cribb 2011). Further work is nevertheless needed to relate the potential effects habitat type may have on the behavioural response of bottlenose dolphins to chronic and acute anthropogenic disturbance.

4.4.6 *On the seasonality of dolphin behaviour*

Identifying potential shifts in behaviour over time and space is crucial for effective conservation and management initiatives. Furthermore, behavioural changes potentially indicate that the surrounding environment has also altered over time (Arthur *et al.* 1996). In the ADS a seasonal change in dolphin behavioural activity was observed over the duration of the study, with resting and socialising only observed during summer, and feeding predominantly observed during autumn, with travelling noted during the winter months (See Figure 4.5). Seasonal shifts in behavioural activities have also been noted elsewhere (Waples 1995, Miller *et al*. 2010). In particular, our results are consistent with observations conducted in the Mississippi Sound, where bottlenose dolphins were socialising more during spring and feeding more in autumn (Miller *et al*. 2010).

Dolphins have also notably been observed to change their overall distribution in relation to season (Young & Phillips 2002). These seasonal shifts in behaviour and in some cases distribution may be attributed to the distribution of prey species rather than a direct result of environmental water properties (Maze & Würsig 1999). Miller & Baltz (2009) noted bottlenose dolphin foraging habitat and distribution to be indicatively linked to water temperature irrespective of season. However, as studies focusing on specific behavioural activities are limited in this area, it must be considered that behavioural activity may be related to social structure or related to the differences between individual strategies. Additionally, the unique characteristics of the ADS environment could also potentially influence or favour certain life history traits as has been noted in other delphinid species, such as spinner dolphins, *Stenella longirostris*; (see Cribb *et al*. 2012, Tyne *et al*. 2015).

The lack of variation seasonally in the measured water properties within the ADS may also suggest that fish prey species are abundant and common all year round. Dolphin distribution elsewhere has been noted to shift seasonally from deep channels to seagrass beds presumably as a response to a shift in prey species (Waples 1995). Dolphins in the ADS potentially may be supported by the local primary production irrespective of season and therefore may not need to shift their distribution. Furthermore, as estuaries in general are considered to be highly productive environments (Ballance 1992), and as the population within the ADS is estimated to be approximately 30 resident dolphins, with frequent transients (Kemper *et al*. 2008) this area may be sufficient enough to support this small number of animals. However, our small sample size over time may have also limited any potential observed links in this area.

The northern seagrass benthic habitat is characterised by the presence of a seasonally shifting, shallow sand bar that makes this area a volatile environment. In contrast, there is no observed variation in the locations and structure of the deep shipping channels or the shallow bare sand waters of the Barker Inlet. This fact creates a dynamic interface between the benthic seagrass and bare sand habitats at the mouth of Barker Inlet that dolphins may have to be constantly adapting to, hence behavioural patterns are not consistent in this location. This was consistent with the observed seasonal shift in behaviour within the open seagrass habitat. Physically shifting environmental features may mean that dolphins have to be flexible in their behaviour, whereby they apply multiple social and behavioural strategies. Furthermore, if the whole environment is not consistent over time and season their behavioural activities, group size and social associations would be variable and individuals may therefore be utilising their own strategies rather than relying on group strategies, which would support our small group size presence within the ADS. Additionally, this hypothesis is also consistent with the fusion-fission societies observed within bottlenose dolphin populations elsewhere (Connor *et al*. 2000). Ultimately, the specificities of the ADS may make this population difficult to compare with other populations globally or even locally *e.g*. dolphins present along the metropolitan coast of Adelaide who live in an environment that is increasingly exposed to the influence of the Southern Ocean along the North-South axis of South Australian coastal waters.

4.4.7 *Perspectives: towards a fine scale* in-situ *approach to dolphin habitat studies*

Given the concerns regarding the lack of information available for some dolphin species and the need to fill these knowledge gaps (Miller & Cribb 2009, Cribb *et al*. 2015), habitat studies need to be more tailored to the area in question as well as investigating a broad scope of variables. Ultimately, a thorough *a priori* understanding of the habitat characteristics and requirements of an area is required in order to effectively manage a given area. In this context, the present study used an approach, which has allowed us to comprehensively explore the habitat use of bottlenose dolphins within the ADS. Many physical features are considered to influence dolphin habitat usage

(Cribb *et al*. 20015). Our study has hence investigated a broad range of physical and biological variables, something which has been critically lacking in numerous studies (Miller & Cribb 2009, Cribb *et al*. 2015). The inclusion of numerous variables in a dolphin habitat study does provide us with a greater understanding of dolphin habitat in the ADS, but also essentially valuable information with potential value to support management initiatives in this area. Additionally, rather than just relying on oceanographic surface measurements we measured the whole water column. This has been especially significant as it has not placed any limitations on our study and has allowed us to consider the whole habitat of these animals rather than just the area where they surface to breathe. Given the complexity of sufficiently understanding habitat in a specific location, the application of a sound approach measuring a broad suite of variables is therefore considered vital in order to progress management.

4.5 Conclusion

Our results provide insight into the habitat characteristics of Indo-Pacific bottlenose dolphins in the Adelaide Dolphin Sanctuary (ADS), South Australia, specifically, information regarding habitat use. No significant relationships were identified between oceanographic features and dolphin presence, group size or behavioural activity. In contrast, dolphin presence, group size and behaviour were essentially related to the type of benthic habitat (*i.e*. bare sand *vs*. seagrass beds), the depth of the water column and the season. The use of different parts of the ADS for behaviours such as resting and feeding as well potential seasonal shifts in behaviour provides much needed information about habitat use. Such information is of critical importance in the further development of successful management initiatives for this area. In order to regularly evaluate the efficiency of these initiatives as well as to assess whether management requirements need to be altered, we recommend continuous monitoring of habitat use, specifically with the aim to identify any potential shifts of usage within key areas over time. Finally, this study has enabled the development of a broad and quantitative technique in which to investigate dolphin habitat use, which can be applied to other coastal systems. Investigating a broad range of variables ultimately provides more useful information for more effective management initiatives.

4.6 Acknowledgements

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Table 4.1: Classification of behaviour adapted from Shane (1990) used to assess observed dolphin behavioural activities

Behavioural Activity	**Definition**
Travel	Individuals involved in persistent, directional movement at a constant speed.
Feeding	Individuals involved in any effort to catch or consume prey. Identified by direct pursuit of prey, rapid circling surface behaviour, unsynchronised, rapid or deep dives, fish in mouth.
Socialising	Animals engaged in close contact with other individuals. Includes aspects of both play and reproductive activities.
Rest	Slow bobbing movements and lack of relative motion.
Milling	Movement slow and with no apparent change in direction. Frequent changes in direction associated with a shift between behaviours.

Table 4.2: Overall comparison between the environmental water properties measured at locations where dolphins were observed and not present.

Location Variable	Sightings	Stations
Temp (Cº)		
Mean	21.51	22.10
SD	3.17	3.04
Min	14.41	12.97
Max	26.54	29.00
Salinity		
Mean	38.70	38.56
SD	1.54	3.01
Min	36.26	0.01
Max	43.52	45.03
Chl.*a* (ppb)		
Mean	1.48	1.54
SD	1.11	1.15
Min	0.42	0.05
Max	7.22	12.08
Turbidity (ppm)		
Mean	5.43	3.35
SD	13.08	4.19
Min	0.29	0.23
Max	93.36	24.59
Depth (m)		
Mean	4.39	5.77
SD	3.78	3.95
Min	0.09	0.50
Max	15.80	16.40

Table 4.3: Comparisons between the environmental water properties measured in each of the two benthic habitat types as well as between the locations where dolphins were sighted and not present.

Location	**Sightings**		**Stations**	
Habitat Type	**Bare Sand**	**Seagrass**	**Bare Sand**	**Seagrass**
Temp (Cº)				
Mean	21.33	21.90	22.14	22.01
SD	3.37	2.72	3.35	2.17
Min	14.41	18.01	12.97	13.47
Max	26.54	26.05	29.00	25.49
Salinity				
Mean	38.99	38.09	38.89	37.80
SD	1.70	0.89	3.52	0.61
Min	36.26	36.55	0.01	36.58
Max	43.52	39.53	45.03	40.23
Chl.*a* (ppb)				
Mean	1.57	1.30	1.65	1.28
SD	1.18	0.92	0.90	1.57
Min	0.44	0.42	0.05	0.26
Max	7.22	4.81	5.12	12.08
Turbidity (ppm)				
Mean	4.80	2.78	3.40	4.76
SD	8.92	3.34	4.14	13.37
Min	0.45	0.29	0.33	0.23
Max	45.15	16.01	24.58	108.40
Depth (m)				
Mean	5.99	2.52	6.75	3.48
SD	6.35	1.11	4.27	1.42
Min	0.90	0.30	1.20	0.50
Max	38.00	4.90	16.40	6.50

Table 4.4: Seasonal variability observed for each of the environmental water properties measured at dolphin sighting and non-sighting locations and between benthic habitat type.

Season	**Summer**		**Autumn**		**Winter**		**Spring**	
Habitat Type	**Bare Sand**	**Seagrass**	**Bare Sand**	**Seagrass**	**Bare Sand**	**Seagrass**	**Bare Sand**	**Seagrass**
Temp (Cº)								
Mean	24.48	23.81	21.27	18.94	14.97	-	22.92	-
SD	1.54	1.44	0.77	0.83	0.46	-	-	-
Min	21.16	22.08	19.34	18.01	14.41	-	-	-
Max	26.54	26.05	23.15	20.42	15.83	-	-	-
Salinity								
Mean	38.87	37.80	39.80	38.55	37.15	-	37.35	-
SD	1.40	0.87	1.65	0.74	0.54	-	-	-
Min	36.78	36.55	37.40	37.91	36.26	-	-	-
Max	40.99	39.53	43.52	39.52	37.73	-	-	-
Chl.*a* (ppb)								
Mean	2.17	1.54	1.28	0.94	1.21	-	1.3	-
SD	1.85	1.10	0.47	0.39	0.34	-	-	-
Min	0.44	0.57	0.55	0.42	0.84	-	-	-
Max	7.22	4.81	2.43	1.50	1.74	-	-	-

Turbidity (ppm)								
Mean	4.57	3.88	2.04	1.18	2.54	-	7.61	-
SD	4.47	3.97	1.02	0.88	1.03	-	-	-
Min	0.45	0.76	0.51	0.29	1.37	-	-	-
Max	14.24	16.01	5.40	2.37	4.28	-	-	-
Depth (m)								
Mean	4.06	2.41	6.64	2.70	6.78	-	15.8	-
SD	3.49	1.25	7.88	0.91	5.04	-		-
Min	1.40	0.30	0.90	1.80	2.00	-		-
Max	14.40	4.90	38.00	4.60	14.50	-		-

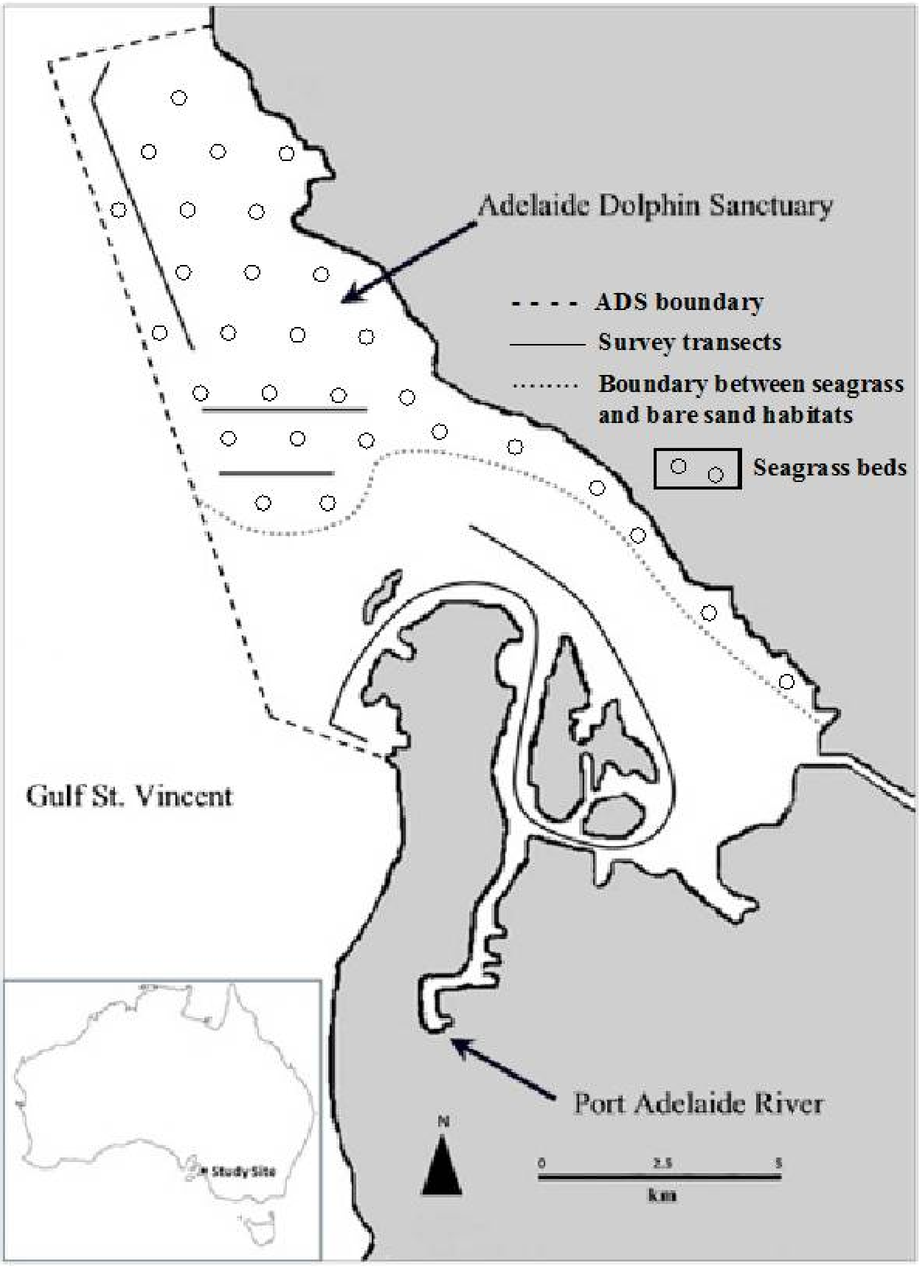

Figure 4.1: Map of the study area showing the locations of the survey transects (solid black lines), the sanctuary boundaries (dashed line) and the separation between the two benthic habitats (seagrass bed to the North and bare sand to South of the dotted line) in the Adelaide Dolphin Sanctuary, South Australia.

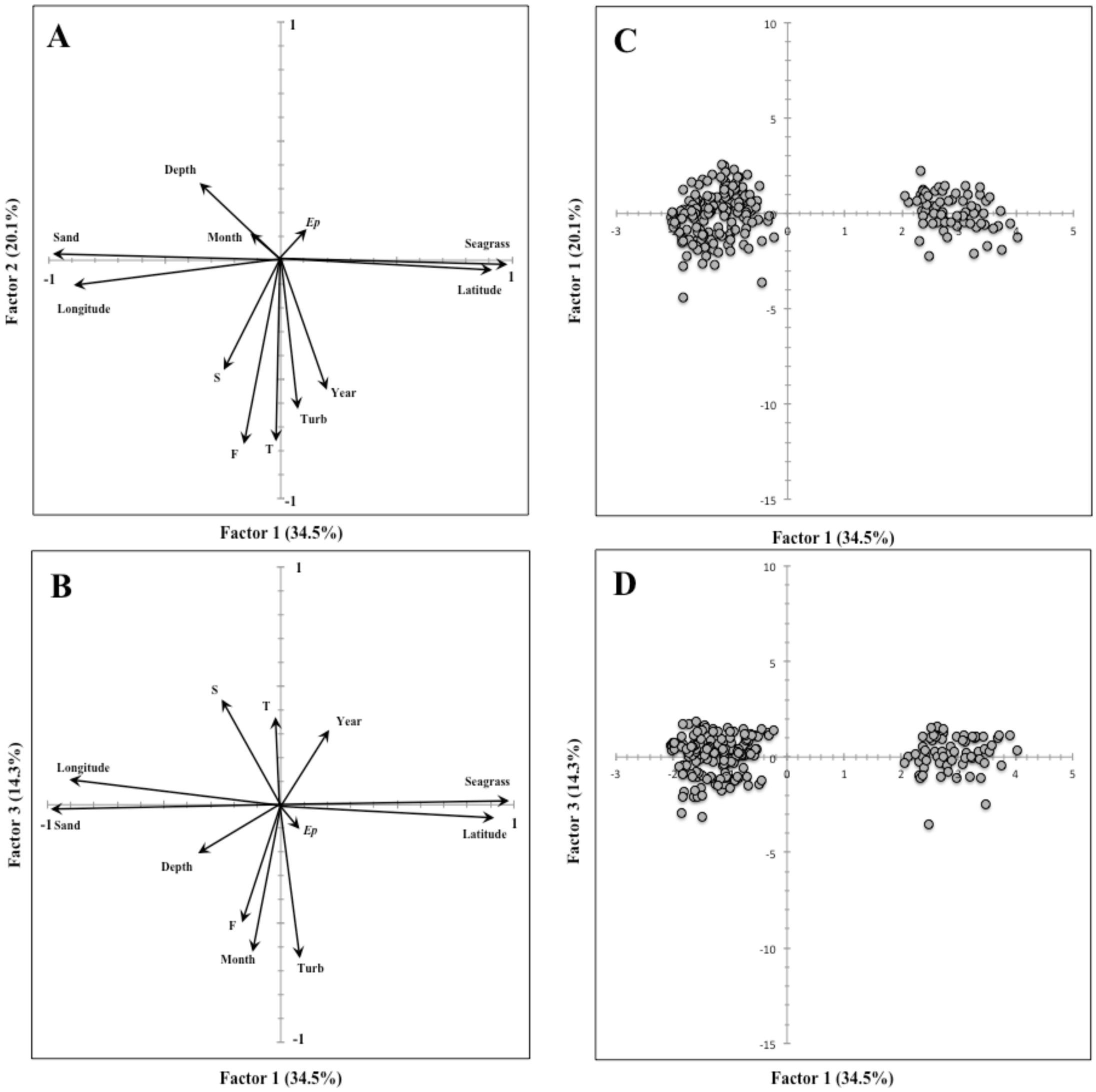

Figure 4.2: Principal component analysis (PCA) showing the correlation between the environmental variables characterizing the survey conducted in the Adelaide Dolphin Sanctuary from 2009 to 2011 and the three first principal components (A,B) and the position of the stations in the two-dimensional spaces defined by the first and second principal components (C) and the first and third principal components (D). T: temperature; S: salinity; F: *in vivo* fluorescence (a proxy of phytoplankton concentration); Turb: turbidity; Depth: depth of the water column; E_p: potential energy.

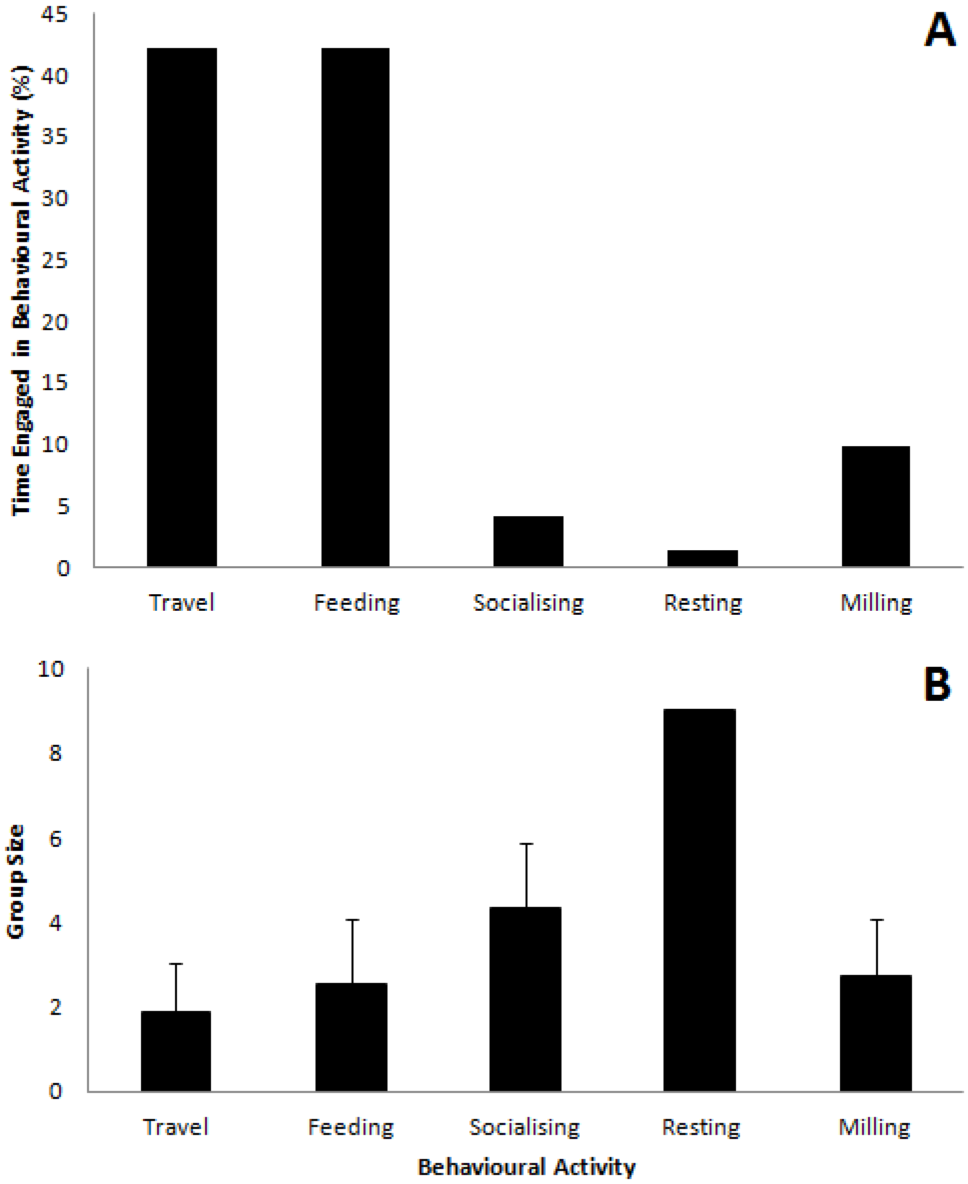

Figure 4.3: Frequency of occurrence of behavioural activities observed (A) and variation of group size according to the behaviour (B) bottlenose dolphins in the ADS engaged in between March 2009 and January 2011(A).

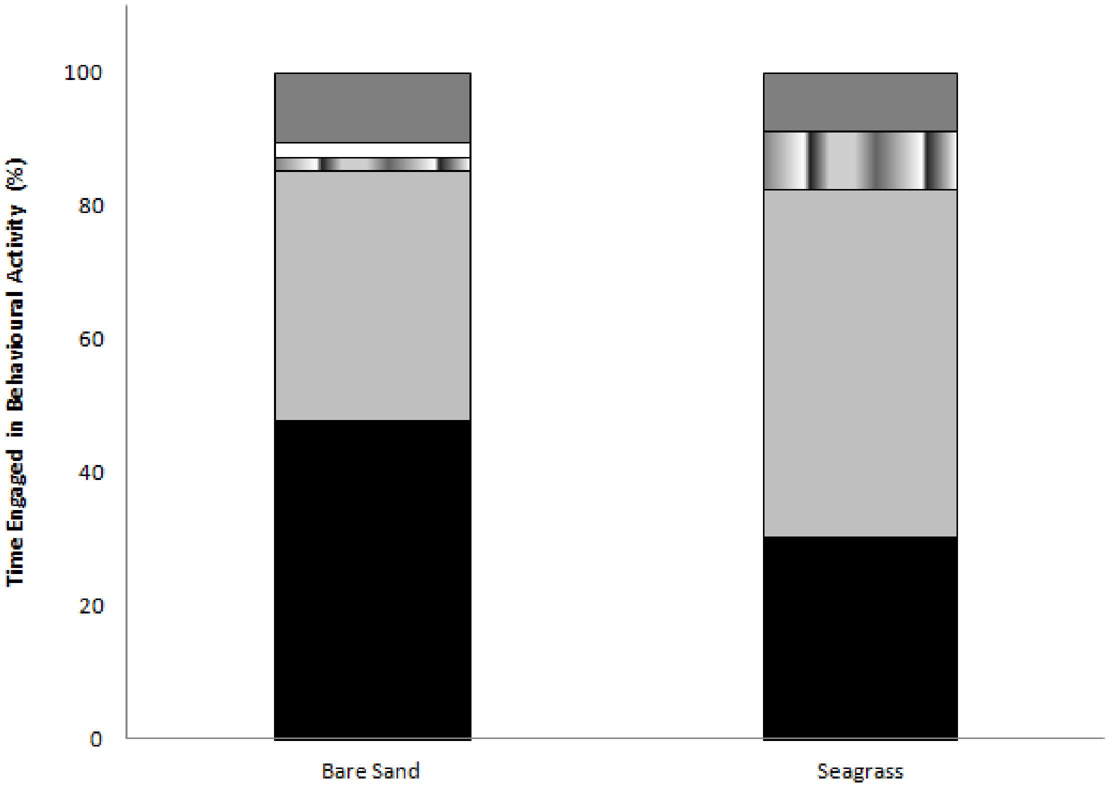

Figure 4.4: Percentage of time bottlenose dolphins spent engaged in each behavioural activity in relation to benthic habitat type. Black: travel; light grey: feeding; grey texture: socialising; white: resting; dark grey: milling.

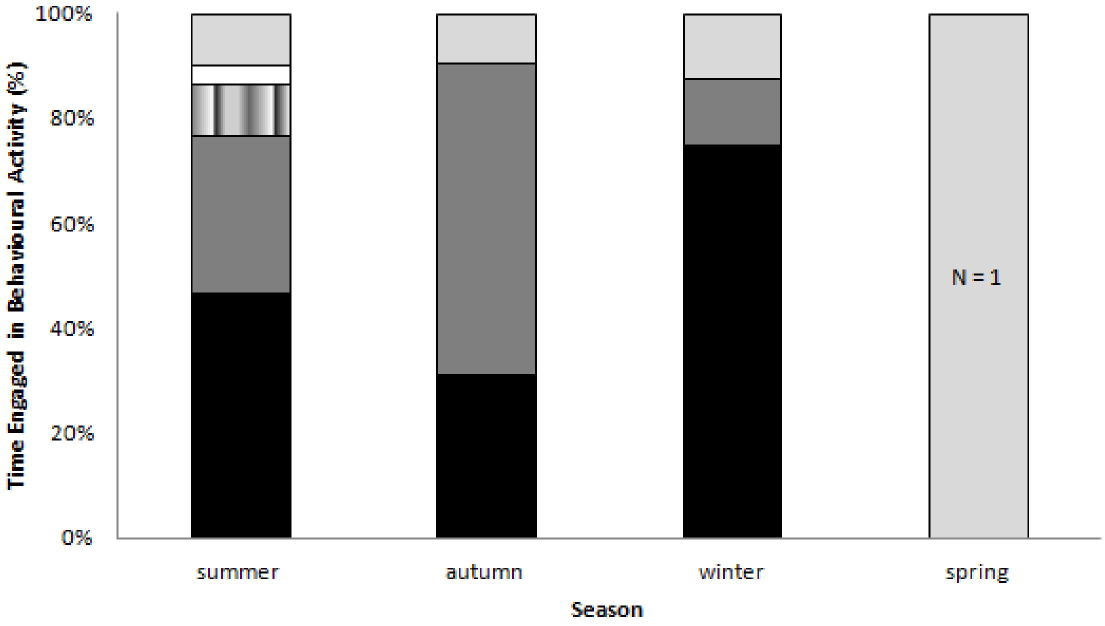

Figure 4.5: Percentage of time bottlenose dolphins spent engaged in each behavioural activity as a function of season. Black: travel; dark grey: feeding; grey texture: socialising; white: resting; light grey: milling.

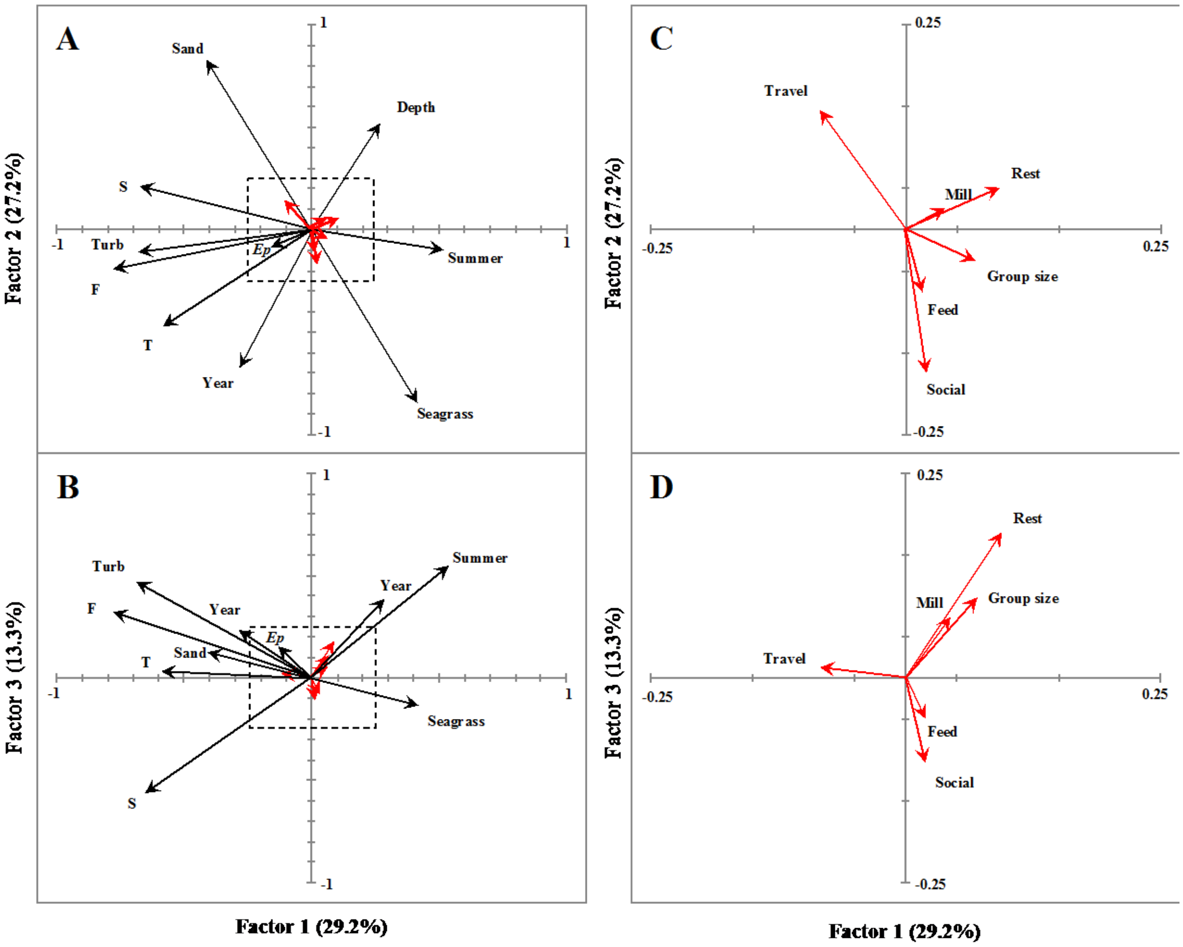

Figure 4.6: Principal component analysis (PCA) showing the correlation between the three first principal components and (A,B) the environmental variables characterizing the stations where dolphins were observed in the Adelaide Dolphin Sanctuary from 2009 to 2011 and (C,D) the variables relative to group size and behavioural activity. T: temperature; S: salinity; F: *in vivo* fluorescence (a proxy of phytoplankton concentration); Turb: turbidity; Depth: depth of the water column; E_p: potential energy; Travel: travelling; Feed: feeding; Social: socialising; Rest: resting; Mill: milling.

Chapter 5

Site Fidelity and Behaviour of Spinner Dolphins (*Stenella longirostris*) in Moon Reef, Fiji Islands: Implications for Conservation

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N Cribb (candidate) contributed to 80% of the conception and details of the study design, 100% of the data collection, 90% of the data analysis and interpretation, and 85% of the writing and editing. Dr C Miller contributed to 10% of the conception and details of the study design and 5% of the writing and editing. Dr L Seuront contributed to 10% of the conception and details of the study design, 10% of the data analysis and interpretation, and 10% of the writing and editing.

5.0 Abstract

Spinner dolphins (*Stenella longirostris*) were observed to frequent a tropical reef complex off the coast of Fiji on a regular basis. Boats from surrounding tourist destinations visit this reef on a nearly daily basis to observe the dolphins and partake in various tourist activities, such as snorkelling. The aim of the study was to determine whether this reef is a resting habitat for this population. Specifically, we objectively and quantitatively investigated whether spinner dolphins were primarily resting whilst present within the reef and also assessed whether the same individuals revisited the reef over time. Photo-identification techniques and boat based observations were conducted over two study periods (September 2009 and May 2010). Fifty-six recognisable individuals were identified during this period, with 70% resighted on 2 or more occasions. Resting was identified as the most consistent behaviour dolphins engaged in whilst present inside the reef. These preliminary results provide vital information which can be used as a tool in the development and implementation of conservation initiatives as well as providing a basis for future studies investigating the habitat characteristics of this reef.

5.1 Introduction

Spinner dolphins (*Stenella longirostris*) are commonly found during daylight hours associated with shallow, sandy bays and reefs near islands and coral atolls (*e.g.* Norris *et al*. 1994, Karczmarski *et al*. 2005, Notarbartolo-di-Sciara *et al*. 2009). Spinner dolphins typically utilise these protected inshore areas for resting and social interaction, after having spent the night offshore foraging in the mesopelagic zone (Norris & Dohl 1980, Benoit-Bird 2004).

In mammals, a lack of rest and sleep deprivation leads to vision and memory impairments, and to a lack of co-ordination (Sternemann *et al*. 1997, Smith *et al*. 1998, De Gennaro *et al*. 2000). More specifically, in spinner dolphins resting behaviour is considered to be important to their survival; hence any disturbances affecting either their resting behaviour or resting location is likely to have detrimental impacts on other facets of their ecology such as their ability to feed and reproduce successfully (Courbis 2004, Courbis & Timmel 2009). Resting locations of spinner dolphins have often been reported in the close vicinity to popular, tropical tourist destinations (*e.g.* Notarbartolo-di-Sciara *et al*. 2009). While the possibility of getting up close and personal with a spinner dolphin in its natural environment represents a strong asset for the tourism industry, it also becomes a direct concern for the health of animals involved. This issue has recently received a considerable amount of attention, for example in the Hawaiian Islands, where it has led to the proposal of regulations aimed at protecting them from human disturbances (see Department of Commerce 2005).

Off the north-east coast of Viti Levu, the main island of Fiji, a small population of spinner dolphins has been regularly observed by local fisherman from the Dawasamu district and surrounding ecotourism ventures. On a daily basis they occur within the inside lagoon of a small tropical reef complex. This predictable presence has made these spinner dolphins a major draw for tourists to this destination. Boat trips from the local ecotourism lodges occur nearly daily and tourists are taken out to the reef to observe the dolphins and snorkel. With the potential for tourism growth and development in this area, the establishment of this reef as an important resting habitat is considered a crucial issue for their conservation. In this context, the objective of the present study was to quantitatively and objectively assess the use of Moon Reef by spinner dolphins, based on their site fidelity and behaviour. More specifically, because resting behaviour is considered important to the fitness, hence survival of spinner dolphins (Courbis & Timmel 2009), a specific care was given to assess whether this population were primarily utilising Moon Reef as a resting habitat and additionally identify whether the same individuals were frequenting the reef over time.

5.2 Methodology

5.2.1 *Study site*

Moon Reef is a tropical reef complex located in the South Pacific Ocean (17º 31.7’S, 178º 30.7’E; Figure 5.1), belonging to the southernmost end of a group of patch reefs bordering the Vatu-I-Ra channel. This circular shaped reef is located 9 km from the coastline of the main island of Fiji, Viti Levu. We measured the reef as being 1500 m in diameter, and covering an area of approximately 1.7 km^2. The waters in the inner lagoon utilised by dolphins are approximately 15 m deep at maximum depth and consist of a sandy bottom substrate (covering an area of approximately 0.38 km^2) with scattered patchy coral structures. This reef has 2 distinct natural entrances. First, there is a 66 m wide and 12 m deep channel, oriented on the south-western side of the reef. Second, there is an opening into the surrounding waters on the north-west of the reef that has a 15 m wide and 5 m deep channel. This smaller entrance is separated in its centre by a solid reef structure, which splits the entrance into two distinct smaller openings.

5.2.2 *Photo-identification and observational data*

Photo-identification surveys and behavioural observations were conducted within the Moon Reef complex between the 1 and 28 September 2009 and 3 and 12 May 2010 (Table 5.1). All surveys were conducted aboard a 7 m fibreglass vessel powered by an 85 HP outboard engine. Surveys were carried out at a Beaufort Sea state of less than 3, under daylight conditions, with all observations conducted before midday due to weather conditions. In addition, because sampling occurred non-ambiguously within the same time period, this has ensured that the study was not influenced by the animal's diurnal patterns (Sini *et al*. 2005, Silva & da Silva Jr. 2009). Access to the reef over the two study periods was relatively limited due to poor sea state and weather conditions. This resulted in a total effort of 12 days of behavioural observations and 22 photo-identification surveys. This totalled 1130 minutes spent conducting behavioural observations of spinner dolphins and 635 minutes dedicated solely to conducting photo-identification surveys.

Upon entering the Moon Reef complex, a binocular scan was used to locate a dolphin group and to record its initial behaviour before the vessel entered the inside lagoon. Once the initial behavioural activity was noted, the vessel approached the group. Dolphins were approached slowly at a speed of approximately 5 knots at an angle parallel to the group's direction of travel and the vessel was kept at a distance of approximately 20 to 50 m. Photo-identification surveys were conducted for a maximum period of 20 minutes, in order to minimise disturbance to the animals. Standard photo-identification techniques were applied, and as many as possible of the individuals present in the group were photographed (Würsig & Würsig 1977, Würsig & Jefferson 1990). A Canon EOS 50D with a Tamron VC telephoto lens (18-275 mm), UV filter, and high-speed shutter was used to take all photographs.

Additional behavioural observations were conducted whilst the boat was anchored at a fixed mooring position with the motor off over a section of reef structure (Figure 5.1). This enabled a continuous clear view of the group and was an attempt to minimise disturbance by the vessel. As part of the dolphin group was always visible at the surface when inside the reef's lagoon, observations were made with the naked eye. However, binoculars were used to observe the group when sea state inside the reef's lagoon became greater than 2, which limited the visibility of the group when they moved more than approximately 200 m away from the vessel. The group was scanned at regular 5 minute intervals back and forth from the left side of the lagoon to the right side. The predominant behavioural activity of only those animals visible at the surface of the water at the time of observation was then recorded. An ethogram was adapted from Norris & Dohl (1980) and Danil *et al*. (2005), and behavioural states were defined as resting, travelling, milling, deep-rest, engaging in aerial activities and socialising (Table 5.2). This resulted in 201 behavioural observations. Additional opportunistic observations of disturbances related to either the presence of additional boats and snorkelers in Moon Reef were also noted during each observational survey.

5.2.3 *Data Analysis*

Analysis to identify individuals was based on distinctive fin features, such as nicks and notches present on both the trailing and leading edges of the fin and tip nicks (Würsig & Würsig 1977, Würsig & Jefferson 1990). Each photograph was assessed for its photographic quality according to its focus, clarity, contrast, angle, portion of the fin visible and the percentage of picture filled by the fin. Photographs were then graded by their quality (excellent, average, poor; Baird *et al*. 2008, Baird *et al*. 2009; Figure 5.2). Only photographs deemed excellent (*e.g.* fin angled parallel, sharp focus, no water droplets present, minimal glare, fin occupying large proportion of the frame) were used in the analysis (Baird *et al*. 2008). However, photographs considered average (*i.e.* those photographs of slightly lower resolution that still provided a clear identification and therefore a non-ambiguous match of the individual) were occasionally deemed sufficient in order to make a match and were included. Those considered poor (*e.g.* out of focus, poor contrast, high glare, fin only filled small proportion of frame, water droplets, features not distinguishable) were discarded from the analysis. Photographs were checked systematically against each other to develop a master catalogue of recognisable individuals and determine whether these individuals had been sighted using the reef complex on more than one occasion and between the two study periods. In order to establish whether recognisable individuals were revisiting and frequenting Moon Reef over time their degree of site fidelity was determined by their frequency of re-identification. Site fidelity has previously been defined as ‘the tendency of an individual to return to an area previously occupied or remain in an area for an extended period” (Baird *et al*. 2008). Therefore, for the purpose of this study we considered those individuals sighted on 2 or more occasions during each of the 2 study periods and resighted in both years to be regular users of Moon Reef.

Frequencies of occurrence of each behavioural category were determined for each survey from the number of 5 minute observation bins over which a given behaviour was observed, and subsequently averaged for each survey day. When more than one behavioural category was observed on a survey day, behavioural frequencies were compared within each day; the frequency of each behavioural category was also inferred between days. In both cases, potential differences among frequencies of occurrence of each behavioural category were inferred using the Kruskal-Wallis test and specified using a subsequent multiple comparison procedure based on the Tukey test to identify distinct groups of measurements (Zar 2010). Computations were ran using a Fortran code, programmed following the methods described in Zar (2010). Non-parametric statistics were used throughout this work as our observations did not satisfy the normality assumption (Kolmogorov-Smirnov test, $p < 0.05$); hence medians and inter-quartile range (IQR) were used to describe their variability. The confidence level was always set at 5%.

5.3 Results

5.3.1 *Behavioural observations*

Over the two study periods spinner dolphins were present within the Moon Reef complex on all surveys except one, 22 September 2009. Over the duration of the study, spinner dolphins were observed resting, travelling, milling, engaging in aerial activities and socialising. Deep-rest was never observed during behavioural observations. Resting was the only behaviour observed on 4 of the 12 survey days (Figure 5.3). When resting was not the only behavioural activity, it was consistently the most frequently observed behaviour (KW test, $p < 0.05$; Figure 5.3), ranging between 53 and 100% depending on the day of observations. This behaviour (76.9%) was 20 times more frequent than travelling (3.8%) and nearly 12 times more frequent than milling (6.5%).

Note that no specific behaviours such as rest and travel were ever observed in the presence of vessels and snorkelers. Strong and direct disturbances were, however, observed on 2 occasions during our behavioural surveys when a tourist vessel was directly engaged in approaching and following the dolphins at a close distance which led the dolphin group to cease resting and flee directly over the side of the reef structure.

5.3.2 *Site fidelity and photo-identification*

Two thousand two hundred and ninety three (2293) photographs were obtained over the study period. From these 457 were used in the photo-identification analysis. A total of 56 recognisable individuals were identified and catalogued. Examples of dorsal fin markings of recognisable individuals included in the catalogue ranged from tip nicks to trailing and leading edge notches. The rate at which new animals were identified linearly increased over the two study periods (Figure 5.4), with new animals identified on 17 of the 22 surveys. Forty-five individuals were identified in September 2009, 11 individuals in May 2010, and 11 animals (20%) were resighted in both years. Resightings of identified animals within the reef ranged from 1 to 11 sightings (Figure 5.5). Of the 56 animals identified, 70% (n = 39) were resighted within Moon Reef on 2 or more separate surveys and between years. These individuals were therefore considered to be regular users of Moon Reef.

5.4 Discussion

Spinner dolphins were found to consistently occur in groups inside Moon Reef with 70% of the 56 animals identified being resighted on various occasions over the two survey years. This is consistent with previous work conducted in Hawaii, Tahiti and South Western Atlantic showing spinner dolphins regularly congregating in large groups (Karczmarski *et al*. 2005, Martens Silva-Jr. *et al*. 2005, Gannier & Petiau 2006) with specific individuals being resighted over time (Marten & Psarakos 1999, Martens Silva-Jr. *et al*. 2005). However, both the linear increase in the cumulative number of new individuals observed (Figure 5.4) and the relatively low resighting rates observed in Moon Reef (Figure 5.5) suggest that this reef may be supporting a larger population than first thought and that not all individuals present within the group on any given survey day were photographed. However, to date, there is no current estimation of abundance available for this population, and our sample size is too small to draw reliable conclusions about population structure and size. The observed low resighting rates may be consistent with individuals having extended home ranges and choosing other locations in which to rest during daylight hours. This low resighting rate might also be related to technical issues such as poor photo quality or limited encounters resulting from our restricted and relatively limited field effort over the 2 survey periods.

The regular presence of the same individuals in particular and spinner dolphins in general, potentially makes them a source of attraction and interest for tourists, as previously stressed in Hawaiian waters (Courbis 2007). Hence, this may induce additional threats to the fitness of individuals and ultimately the survival of the population. As such, this makes Moon Reef susceptible to anthropogenic threats, especially as, to our knowledge, it is the only site where spinner dolphins have been reported to congregate in Fijian waters; see Global Vision International (2008). This is consistent with resting being by far the most frequent behaviour observed in Moon Reef (Figure 5.3), and with the behaviour of other spinner dolphin populations occurring in various tropical locations around the globe (*e.g.* Danil *et al*. 2005, Notarbartolo-di-Sciara *et al*. 2009). More specifically, spinner dolphins congregating in sheltered environments are generally using them to rest (Norris & Dohl 1980). This regular behavioural pattern and more specifically their unique life history strategy of resting during daylight hours when tourism-related activities occur potentially makes them more susceptible to disturbances in their environment (Samuels *et al*. 2003, Danil *et al*. 2005, Delfour 2007).

Anthropogenic impacts, such as tourism activities and vessel presence, are known to alter both the short and long-term behaviour of dolphins and, in some cases even their distribution (Lusseau 2003, Constantine *et al*. 2004, Bejder *et al*. 2006, Seuront & Cribb 2011). More specifically, the increase in tourism activities occurring in places such as Hawaii and Egypt (*e.g.* Delfour 2007, Shawky & Afifi 2008) where resting spinners are subjected to anthropogenic activities such as swim-with dolphin programs, snorkelling and vessel presence, has previously raised concerns for their welfare (Notarbartolo-di-Sciara *et al*. 2009). Disturbances to spinner dolphins whilst in the resting phase ultimately have the potential for detrimental effects to their overall fitness (Lammers 2004, Courbis & Timmel 2009). Specifically, spinner dolphin resting behaviour has also been characterised by a 'deep-rest phase', when there is minimal aerial activity and dolphins are predominantly observed engaged in longer dives and spending less time at the surface (Norris & Dohl 1980, Danil *et al*. 2005). This behaviour was, however, never observed during our surveys (Figure 5.3). This might suggest that the presence of our vessel, despite our care to minimise its potential disturbance, was still a relatively weak and indirect disturbance sufficient to prevent the dolphins from reaching this deep-rest phase. This is consistent with (i) the observed decrease in spinner dolphins (Danil *et al*. 2005) and common dolphins (Kyngdom *et al.* 2003) resting behaviour during presence of swimmers and the occurrence of deep-rest behaviour once the swimmers are gone (Danil *et al*. 2005), and (ii) the stress identified in bottlenose dolphins' surfacing rhythms in response to even *a priori* negligible disturbances (Seuront & Cribb 2011). This is even more important in cases in which vessels and swimmers are in direct pursuit of the animals (Danil *et al*. 2005, Gannier & Petiau 2006). This is in agreement with our observations of the dolphin group ceasing to rest and fleeing directly over the side of the reef structure with the presence of the tourist boat. Additionally, Moon Reef is regularly used as a fishing ground by locals from the surrounding villages; both fishing boats and spear fishermen frequent this reef and in the near vicinity, potentially leading to an additional source of disturbance that is still difficult to assess. Disturbances such as those observed at Moon Reef may then have the potential to keep these dolphins in a constant state of alertness that prevents them from reaching a deep-rest phase (Danil *et al*. 2005). To date, however, these disturbances and their potential impacts upon dolphin behaviour in Moon Reef have not been investigated and, as such, are not considered to be detrimental. Concerns about the impacts of human activities on spinner dolphins such as those observed in Moon reef have previously led other locations such as Hawaii to begin initiating regulations in which to help minimise disturbance to the animals whilst in their resting habitats (Courbis 2007). Given the example of the proposed regulations for spinner dolphin management in Hawaii; see Department of Commerce (2005), regulations such as these could similarly be included in the preliminary management initiatives establishing Moon Reef as a Marine Protected Area (www.pacificcetaceans.org/features_all.php). However, the potential impacts of tourism-related activities occurring within Moon Reef should still be monitored and considered in future studies. Alternatively, the population of spinner dolphins investigated in Moon Reef might potentially not reach the above mentioned deep-rest phase. While the resolution of this specific issue is far beyond the scope of the present study, it should nevertheless be taken into consideration in future studies to ensure the efficiency of future management and conservation strategies.

5.5 Conclusion

The regular presence of individuals and the consistent resting behaviour displayed by spinner dolphins in Moon Reef clearly indicate the importance of this reef complex as a resting habitat to this population. However, the discovery rate of identified individuals suggests that this population is much larger than the animals identified during this study, hence stressing the need for further investigation to determine the abundance of this population. The potential subsequent application of a social network approach (*e.g.* Baird *et al*. 2009, Stanton *et al*. 2011), would also be beneficial in helping to understand the relationships and associations of those individuals resighted on more than one occasion. With the potential of tourism growth in this area, the needs for management and conservation initiatives are indeed crucial. These preliminary findings provide information that may be used as a baseline for their development and implementation. Additionally, the establishment of Moon reef as a spinner dolphin resting environment may provide a stepping stone for future studies to investigate the specific biological and physical environmental features required by spinner dolphins.

5.6 Acknowledgements

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Table 5.1: Behavioural observation and photo-identification survey days for each of the two study periods conducted in Moon reef, Fiji.

Behavioural	**Photo-Identification**	
September 2009	September 2009	May 2010
2	1	3
4	2	6
7	4	7
8	7	8
9	8	9
16	9	10
17	10	12
18	16	
21	17	
24	18	
26	21	
28	24	
	25	
	26	
	28	

Table 5.2: Classification of spinner dolphin behavioural activities observed in Moon Reef (adapted from Norris & Dohl, 1980, Danil *et al*., 2005).

Behaviour	**Classification**
Rest	Individuals swimming slowly in the same direction, with synchronous breathing and reduced surfacing.
Deep-rest	Minimal aerial and activity and more than 50% of the group dives for more than 30 seconds.
Travel	Individuals involved in persistent, directional movement.
Milling	Animals displaying frequent changes in direction.
Aerial activity	Leaps, spins, body slaps.
Socialising	Animals engaged in close contact with other individuals. Includes aspects of both play and reproductive activities.

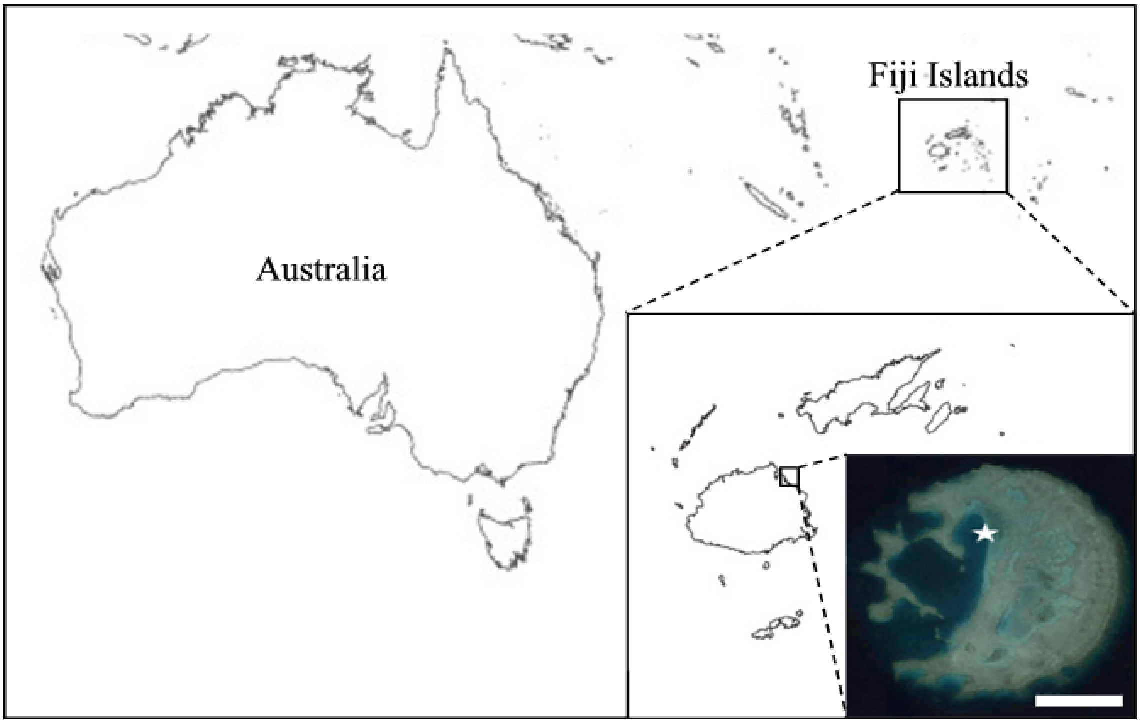

Figure 5.1: Location of the study site, Moon Reef, with regards to Australia and the Fiji Islands. The mooring location of the vessel during observations is indicated as a white star, and the scale bar represents 500 m.

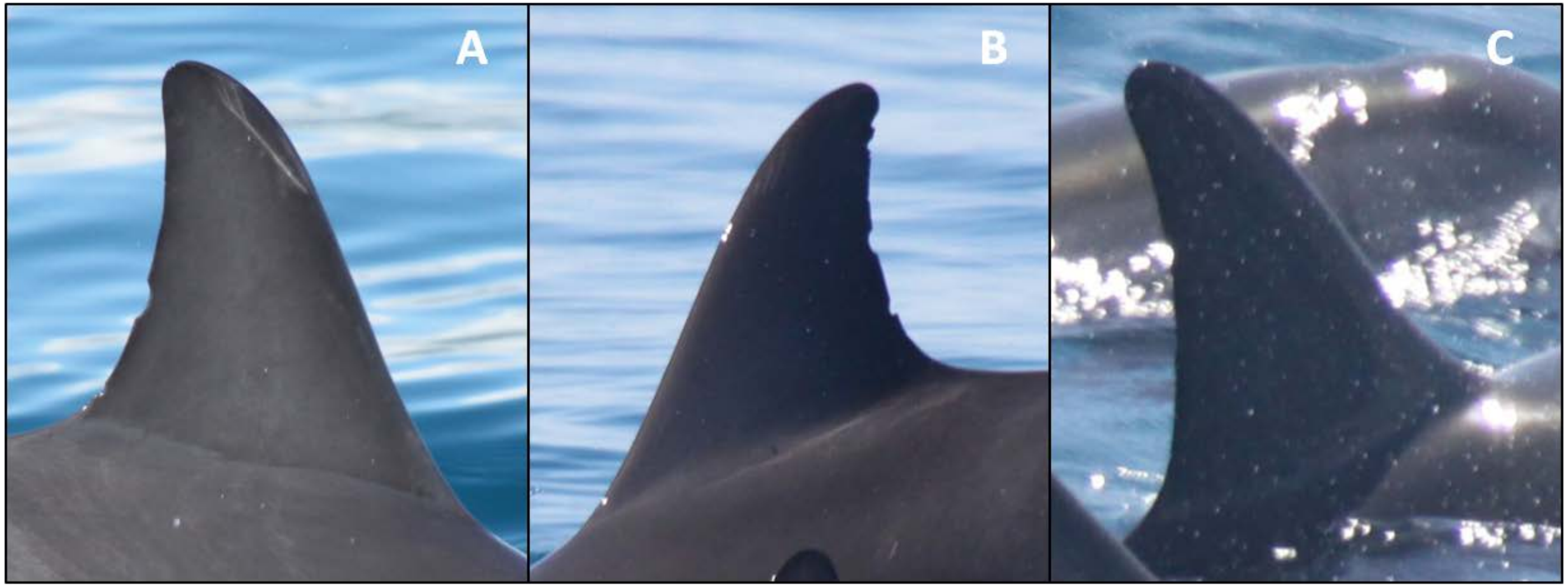

Figure 5.2: Examples of excellent (A), average (B) and poor (C) quality photographs of individual spinner dolphins used in the photo-identification analysis

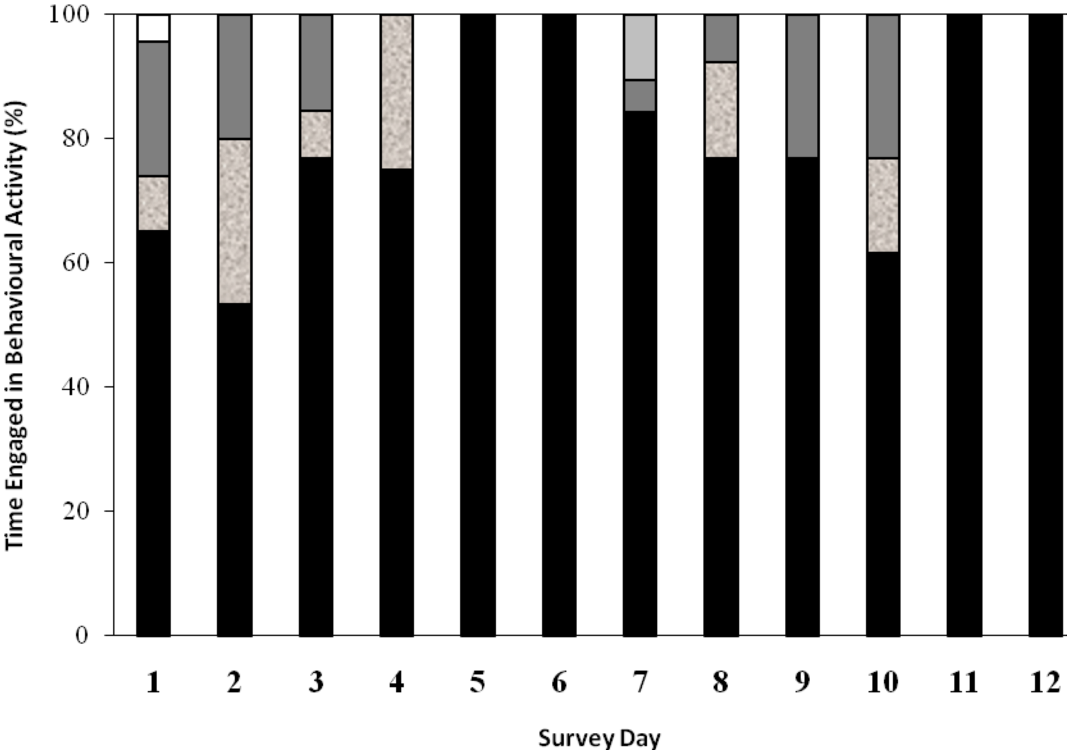

Figure 5.3: Percentage of time group spent engaged in each specific behavioural activity whilst congregating in Moon reef across the 12 survey days. Black: resting. Grey texture: travel. Light grey: socialising. Dark grey: milling. White: aerial activity.

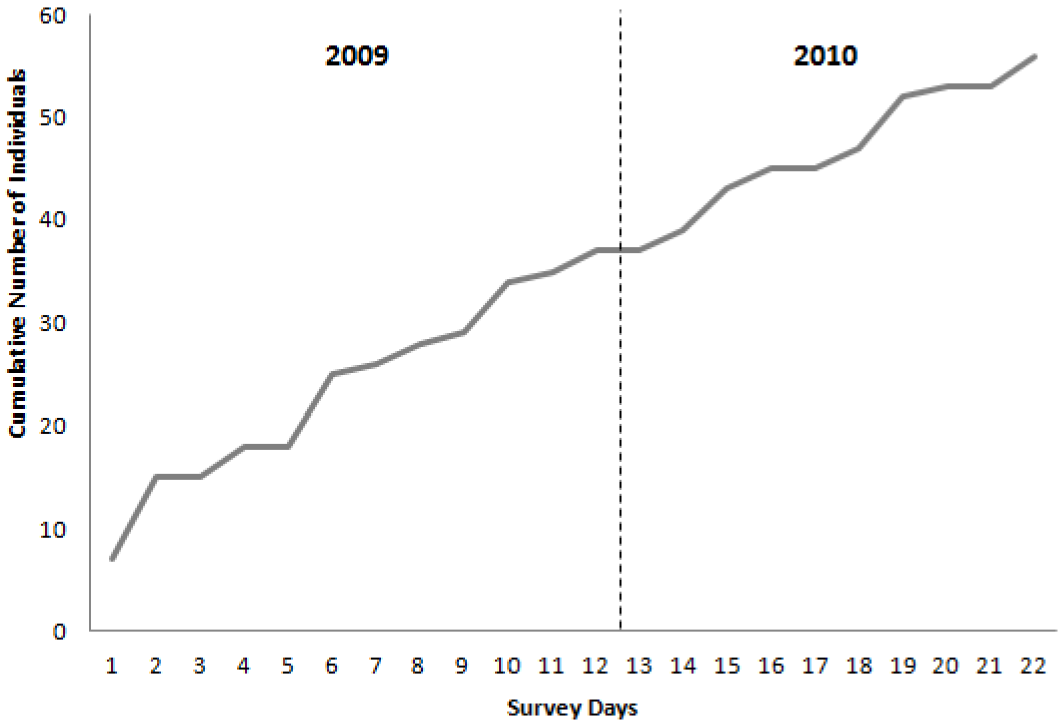

Figure 5.4: Rate of discovery of newly identified spinner dolphins in Moon Reef. The dashed line separates the two study periods (September 2009 and May 2010).

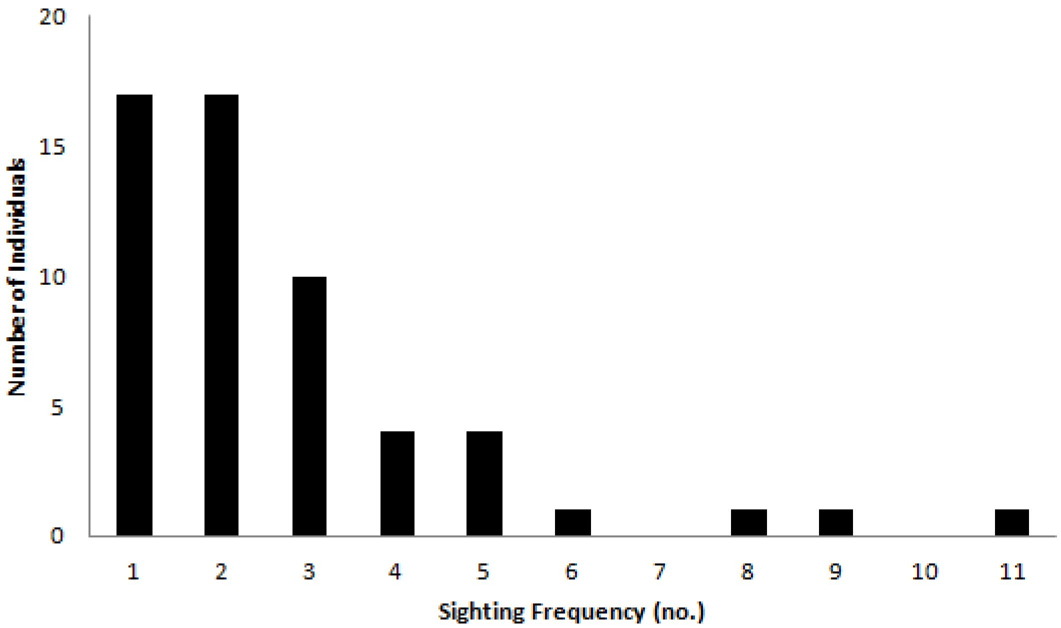

Figure 5.5: Re-identification frequency of individual spinner dolphins identified in Moon Reef.

Chapter 6

What's so special about Moon Reef? Identification of key resting habitat features of spinner dolphins (*Stenella longirostris*), in a Fijian tropical reef complex

6.0 Abstract

Comprehensive assessment of dolphin habitat characteristics is essential for the development of effective management strategies. This is especially important for populations whose distribution overlaps with human activities. Previous studies have focused on spinner dolphins whilst in their resting habitat; however, few have investigated those environmental factors potentially influencing their choice of resting environment. The aim of the present study was to investigate the environmental properties of two similar and nearby reefs, Moon Reef and Horseshoe Reef, located off the north-east coast of the main island of Fiji that are respectively used as a resting habitat by the spinner dolphin (*Stenella longirostris*). An assessment of the structural properties of the reef, and the structure of their invertebrates and fish communities, and biological and oceanographic surveys of their inner and outer waters were conducted in May 2009 and May 2010 at both reefs. No striking differences were found between Moon Reef and Horseshoe Reef in terms of (i) the abiotic structure of the reefs itself and the nature of their benthic substrate, (ii) fish and invertebrate community structure, and (iii) physical and biological water properties. The essential differences between Moon Reef and Horseshoe Reef are hence (i) a larger and much deeper lagoon in Horseshoe Reef, (ii) a much wider channel connecting Horseshoe Reef lagoon to open oceanic waters, and (iii) the regular presence of reef sharks inside Horseshoe Reef lagoon, that may represent a threat that does not exist in Moon Reef. The exclusive choice of Moon Reef as a resting site is discussed in terms of both the protection it offers from oceanic waters and their related disturbances and threats, and by its proximity to sustainable feeding grounds. Our results are finally discussed in the context of their management implications, and directions are suggested for the future conservation and management strategies to be implemented to ensure the sustainable future of this spinner dolphin population .

6.1 Introduction

Both the definition of cetacean habitat and the identification of habitat characteristics has widely been acknowledged as a key factor in the development of effective management and conservation initiatives (Bannister *et al*. 1996, Hoyt 2005); see also Miller & Cribb (2009) and Cribb *et al*. (2015) for reviews. However, for many species – including very well studied ones such as the bottlenose and spinner dolphins – the understanding of both the most pertinent variables to be used to define their habitat and the reasons why they utilise specific environments is still limited. Cetacean habitat has indeed been typically described using a range of methodologies and variables measured over a variety of temporal and spatial scales that are often non-consistent between studies and may even be author-dependent (Cribb *et al*. 2015). The development and implementation of effective management strategies hence necessitate a quantitative and comprehensive assessment of the abiotic and biotic nature of the environment. This is especially critical for dolphin populations, which occur and regularly utilise locations overlapping with human activities, such as the spinner dolphin (Tyne *et al*. 2014, 2015).

The spinner dolphin (*Stenella longirostris*) is a cosmopolitan species occurring in tropical and subtropical waters around the globe (Perrin & Gilpatrick Jr. 1994). In coastal waters, spinner dolphins are known to rest during daylight hours in protected and shallow bays and forage over deeper adjacent waters at night (Norris & Dohl 1980). Although spinner dolphins are one of the most well studied species of delphinids, little is still known about the specific characteristics of their chosen resting habitats. Many studies have primarily focused on their behaviour whilst they are present within their associated resting habitats; see *e.g*. Notarbartolo-di-Sciara *et al*. (2009) and Cribb *et al*. (2012). More specifically, despite the variety of variables used to describe the resting environment of spinner dolphins, a non-exhaustive review identifies consistent environmental features of resting locations (Table 6.1), *i.e*. protected, shallow, sheltered tropical bays or reefs with sandy bottoms, adjacent to deep waters. Among the various driving factors suggested to explain why spinner dolphins congregate in such areas to rest and socialise, protection from predators whilst resting, proximity to deep water and maximisation of foraging as well as the carrying capacity of the area seem to be the most acknowledged ones (Norris & Dohl 1980; Norris *et al*. 1994; Benoit-Bird & Au 2009). However, the potential underlying ecological influences or relationships they may have with their surrounding marine environment are still unresolved. Noticeably, in most instances these resting locations overlap with human activities (*e.g.* Delfour 2007; Notarbartolo-di-Sciara *et al*. 2009). This is concerning, as disturbances to spinner dolphins whilst resting may have detrimental effects on various aspects of their ecology (Lammers 2004; Danil *et al*. 2005; Courbis & Timmel 2009).

Moon Reef, Fiji Islands, is a known regular resting habitat for a small population of spinner dolphins (Cribb *et al*. 2012). To date it is the only known resting habitat for spinner dolphins in this area (see Cribb *et al*. 2012), even though other reef complexes with *a priori* similar physical characteristics are in close vicinity. The specific environmental and physical features of this reef complex and why *Stenella longirostris* utilise it to rest is, however, still unknown. Their dependence on this particular reef complex as a resting habitat has further been demonstrated through their consistent daily presence to rest as well as the consistent occurrence of the same individuals over time (Cribb *et al*. 2012). In recent times, due to the consistent daily presence of resting dolphins and the reef's accessibility, an increase in interest and visitors to the reef has been noted. This has made these animals susceptible to potential disturbances and has therefore led to growing concerns for their welfare and ultimately the development and implementation of management initiatives for Moon Reef, which has culminated in the declaration of Moon Reef as a new marine protected area for spinner dolphins in 2011; see http://uk.whales.org/blog/2011/05/new-marine-protected-area-declared-for-spinner-dolphins-in-moon-reef-fiji. In addition, it appears from our preliminary observations and from discussions with local villagers and fishermen (Miller, unpublished data) that while Moon Reef is used by spinner dolphins on a very regular and frequent basis, the surrounding reefs are not. This triggered the question to understand what is so special about Moon Reef, hence the need to identify key environmental features whether oceanographic or structural that may influence or be critical to this population’s choice of resting habitat. The aim of the present study was therefore to investigate the abiotic and biotic properties of Moon Reef and a nearby similar reef complex (Horseshoe Reef) not used by dolphins. Specifically, we compared environmental water properties measured inside and outside of each of the reef complexes to identify any oceanographical differences as well as any biological diversity and structural differences.

6.2 Methodology

6.2.1 *Study Site*

Moon Reef and Horseshoe Reef are tropical reef complexes located in the South Pacific Ocean, belonging to the southernmost end of a group of patch reefs bordering the Vatu-I-Ra channel (Figure 6.1). Both reefs are located in the traditional fishing grounds for the Dawasamu District, and as such are regularly subjected to various fishing and ecotourism activities (Cribb *et al.* 2012). Moon Reef is located 9 km northeast off the main island of Fiji Viti Levu (17º31.7‟S, 178º30.7‟E) and represents the southern tip of a group of patch reefs bordering the Vatu-I-Ra channel. It is a crescent shaped reef approximately 1500 m in diameter, which covers an area of *ca.* 1.8 km^2. The inner lagoon, which covers approximately 20% of the reef surface (*i.e.* 0.38 km^2) consists of a sandy bottom substrate scattered with patchy coral structures and maximum depth of 15 m. The inner lagoon waters were consistently very clear, with the bottom consistently visible from the surface. This reef connects to the open ocean through two distinct natural channels. The first channel is 66 m wide and 12 m deep and oriented on the south-western side of the reef. The second channel is oriented on the north-west side of the reef and is 15 m wide and 5 m deep. This channel is further dichotomized into two smaller ones by a reef structure, which is submerged in approximately 0.5 m of water at low tide. Preliminary observations showed that this entrance is consistently preferentially used by spinner dolphins when coming in and out Moon Reef (Cribb personal observation).

Horseshoe Reef is located further offshore from Viti Levu (*ca*. 15 km) in the Vatu-I-Ra channel (17°29.8‟S, 178° 35.6‟E) approximately 7.5 km north-east of Moon Reef (Fig. 1). This circular reef is slightly larger than Moon Reef in diameter (*ca*.1700 m) and also has two distinct openings towards the open ocean. Both openings are close to one another and orientated to the north west of the reef complex. The northernmost one is a 30 m wide channel, further dichotomized into two narrow (*i.e*. 5-6 m wide) channels by a solid reef structure. The southernmost one is a 250 m wide channel. In contrast to Moon Reef, these two channels were 15 to 20 m deep, with the reef slopes characterized by very steep drop-offs: the inner lagoon of Horseshoe Reef covers most of the reef surface (Figure 6.1) and is also much deeper than at Moon Reef, with the bottom not being seen from the surface.

6.2.2 *Biological reef assessments*

Underwater biological assessments were conducted from May 11 to May 15, 2010, in order to compare the community and benthic substrata and related communities between Moon and Horseshoe Reefs. Specifically, a team of 4 divers conducted replicate underwater surveys to provide a description of the benthic substrata *i.e*. coral and algae, as well as the presence of fish and invertebrates. Visual surveys were conducted at 4 stations at Moon Reef and 3 stations at Horseshoe Reef (Figure 6.2). Each replicate was conducted over two depth ranges (*i.e*. 1 to 4 m and 8 to 10 m) to assess the reef flat (hereafter referred to as MR_F and HR_F at Moon Reef and Horseshoe Reef, respectively) and reef slope (hereafter referred to as MR_S and HR_S at Moon Reef and Horseshoe Reef, respectively). At each depth the Point Intercept Transect (PIT) method (English *et al*. 1997) was used to clarify the nature of the reef benthic substratum and communities following the AIMS life-form categories (English *et al*. 1997; Table 6.2). Additionally, a 50 x m x 5 m x 5 m (1250 m^3)

cube belt transect and a 50 x m x 5 m, (250 m^2) belt transects were used for fish and invertebrate counts, respectively. This approach resulted in 3750 m^3 and 5000 m^3 surveyed at each depth for fish as Moon Reef and Horseshoe Reef. Corals were classified by genera (Table 6.3), and fish and invertebrates classified by family (Table 6.4). Benthic substrata were categorized as hard coral, algae, soft coral and reef matrix (*i.e.* sand, rock and rubble). Reef profiles, reef topography general observations of each reef system were also noted. Specifically, reef topography was assessed through a 5-point scale as 1: flat topography; 2: low, widespread topography; 3: moderate topography; 4: complex vertical topography; and 5: complex vertical topography with fissures, caves and/or overhangs (WCS 2010; Figure 6.3).

6.2.3 *Oceanographic surveys*

Oceanographic sampling was conducted between May 2 and May 27, 2009 and between May 8 and May 11, 2010 in Moon Reef and in May 11 to 15, 2010 in Horseshoe Reef. All surveys were conducted aboard a 7 m fibreglass vessel powered by an 85 HP outboard engine. The sampling strategy of the survey was designed to provide the best spatial coverage of each of the two reefs. In order to compare the hydrographic properties between the two reefs, predetermined transects and sampling stations were positioned accordingly inside and outside of the reefs (Figure 6.2). Specifically, the oceanographic properties of the inner reefs were investigated from a series of stations providing an even spatial coverage of each lagoon; 9 and 17 stations were considered in Moon Reef in 2009 and 2010, and 10 and 21 stations were considered in Horseshoe Reef in 2010 (Figure 6.2). The biophysical properties of the outer waters of both Moon and Horseshoe Reefs were investigated on the basis of 8 transects, each with 6 sampling stations (Figure 6.2). Sampling stations were placed at a distance of 100 m along each transect. At each station a Compact-CTD HG (Alec Electronics Inc. Kobé, Japan) was deployed to obtain a vertical profile of the water column measuring water temperature (C°), salinity, chlorophyll-*a* (µg/L), turbidity (ppm) data. Due to the boat not being equipped with a depth sounder the water depth was measured with a weighted line.

The vertical stratification of the water was calculated from the potential energy E_p, which corresponds to the amount of energy required to redistribute mass in a complete vertical mixing (Pond & Pickard 1983). E_p (J m^{-3}) was estimated as $E_p = (1/H)\int_{-H}^{0}(\rho - \bar{\rho})gz\,\mathrm{d}z$, where H, ρ and $\bar{\rho}$, g and z are respectively the depth of the water column (m), the density of the water column (kg.m^{-3}), the vertically averaged density of the water column (kg.m^{-3}), the gravitational acceleration (m s^{-2}) and the depth (m).

6.2.4 *Data Analysis*

Data was analysed using PASW for Windows version 18. As the data did not meet the assumptions of normality (Kolmogorov-Smirnov test, $p < 0.05$), non-parametric tests were used throughout this work. Additionally, as no stratification was present in each of the oceanographic profiles, indicating a vertically mixed water column (in accordance with the low potential energy consistently observed in the inner and outer waters of both reefs, *i.e.* E_p in the range 1 to 5 to J m^{-3}, the average of each profile was used for the following analyses. Pearson correlation analyses were run between each of the above-mentioned oceanographic parameters and the actual distance from the reef to infer the presence of monotonous gradients along each transect. Multiple comparisons between transects were conducted using the Kruskal-Wallis test (KW test hereafter), and a subsequent multiple comparison procedure based on the Tukey test was used to identify distinct groups of measurements (Zar 2010). Mann-Whitney U tests (MW hereafter) were also used to identify potential differences in the oceanographic properties perceptible from the transects located closest to the entrances and non-entrance side of both Moon and Horseshoe Reefs. More specifically, transects 4, 7 and 8 at Moon Reef and transects 1,2 and 3 Horseshoe Reef were classified as near entrance. Transects 1,2,3,5 and 6 at Moon Reef, and transects 4,5,6,7 and 8 at Horseshoe Reef were classified as non-near entrance. Finally, Mann-Whitney U tests were used to compare the oceanographic properties inside and outside within and between the two reefs. Finally, we used a cluster analysis based on an unweighted centroid algorithm (Sokal & Michener 1958) carried out on a Euclidean distance matrix as an objective criterion to decide upon appropriate stations to group based on (i) benthic properties, fish and invertebrate data, and (ii) the biophysical structure of the water column.

6.3 Results

6.3.1 *Abiotic and biotic reef assessments*

Reef abiotic structure

Qualitative observations showed that corals were subjected to recent bleaching and storm or cyclone damage. Many *Acropora* sp. table corals were either bleached or dead and overturned on the reef flat at both sites. Coral recruits were nevertheless seen on the reef flat at both sites and in general, coral diversity was high indicating good resilience from the local disturbances (Table 6.3).

More specifically, on both reefs, the reef flat was consistently dominated by reef matrix (*i.e.* including rubble, sand and rock), which covered 63.2% and 77.3% of the available substrata at Moon Reef and at Horseshoe Reef, respectively (Figure 6.4A). Furthermore, rubble derived from branching coral was by far the dominant component of the reef matrix indicative. This is consistent with the impact of storm and cyclone events that hit the central and eastern Viti Levu in 2009 and 2010, as cyclones were reported to cause waves to break corals from the crest of the reef flat and subsequently deposit large banks of coral debris (Howorth *et al.*, 1993). Hard corals were the other dominant feature of both Moon Reef and Horseshoe Reef flats, representing respectively 29.2% and 22% of substrata (Figure 6.4A). Other substrata ranged from 0 to 5% cover (Figure 6.4A). Reef matrix coverage was significantly lower at Moon Reef than at Horseshoe Reef ($p < 0.05$). In contrast, hard coral cover was significantly higher at Moon Reef than at Horseshoe Reef ($p < 0.05$). The slopes of both reefs were consistently dominated by hard corals and reef matrix, which accounted for 54.2 and 42.7% of benthic cover at Moon Reef and 42.0% and 39.3% at Horseshoe Reef (Figure 6.4B). No significant differences were found in benthic cover between reefs for both hard coral and reef matrix, nor between hard coral and reef matrix cover within each reef ($p > 0.05$).

Reef slopes were consistently steeper at Horseshoe Reef than at Moon Reef. While this observation is consistent with higher incident light at Moon Reef, it did not significantly impact the hard coral cover. Other substrata ranged from 0 to 5.5% cover (Figure 6.4A), and did not significantly differ between reefs. These results are comparable with surveys conducted by the Wildlife Conservation Society on other reefs in the vicinity of Moon Reef and Horseshoe Reef, which reported a 40-60% coral cover on reef flat and slopes (Marnane *et al*. 2003). The cluster analysis related to the nature of the benthic substrata led to identify two groups of stations. First, a small group including the three reef flats of Horseshoe Reef, and a larger group clustering the three reef slopes of Horseshoe Reef, and both the reef flats and slopes of the sites sampled at Moon Reef. This result indicated that while the structure of the reef flats of Horseshoe Reef was very dissimilar from the other sites, there was no significant dissimilarity in the nature of the benthic substrata between the reef flat and slope of Moon Reef, and the reef slope of Horseshoe Reef.

Fish community

The fish community found on the reef slope of both Moon Reef and Horseshoe Reef was more diverse and abundant than on the reef flat (Figure 6.5). This observation is consistent with the higher hard coral cover and more complex structure found on reef slopes, which are likely to provide more habitats. Significant differences ($p < 0.05$) were found in the abundance of some fish species between Moon Reef and Horseshoe Reef on both reef flats (Figure 6.5A) and reef slopes (Figure 6.5B). A few low abundance species (*i.e*. grouper, squirrel fish and sweetlips) were never observed on the reef flats of both reefs (Figure 6.5A), and only were found punctually and in very low abundance on the slope of either Moon Reef or Horseshoe Reef (Figure 6.5B). Similarly, the reef flats and slopes essentially differ in the abundance and diversity of low abundance species, with fish communities being relatively similar between reefs. This observation is confirmed by the cluster analysis, which did not reveal any significant dissimilarity between the fish communities found on the flats and slope of Moon Reef and Horseshoe Reef. Note that reef sharks were regularly observed in Horseshoe Reef lagoon, in contrast to Moon Reef where white tip sharks were only punctually spotted outside the lagoon.

Invertebrate community

The invertebrate community was very poor, in both diversity and abundance. The community was limited to sea cucumber seen on the flats and slopes of both reefs, giant clam and blue starfish, *Linckia* sp., which were both only found on the flats of Moon Reef and Horseshoe Reef. Sea cucumbers were only found at a frequency of 2-3 and 2-4 individuals per survey at Horseshoe Reef and Moon Reef, respectively. Giant clam and *Linckia* sp. were also found at very low abundance (1 per survey at Horseshoe Reef, and 4 to 8 per survey at Moon Reef). These observations are specified by the cluster analysis (not shown), which segregated the invertebrate community found on the flat of Moon Reef from the communities found (i) on the flat of Horseshoe Reef, and (ii) on the slopes of both Moon Reef and Horseshoe Reef.

6.3.2 *Oceanographic Properties*

Note that no significant differences were observed at Moon Reef in any of the observed variables measured along the transects observed in 2009 and 2010; as such data recorded in 2009 and 2010 were pooled for further analysis. Similarly, no significant differences were observed in any of the environmental variables recorded inside Moon Reef and Horseshoe Reef in 2009 and 2010, hence 2009 and 2010 data have been pooled for further analysis. Significant ($p < 0.05$) increases in temperature were observed from the reef edge to offshore waters along all transects except along transects 2,6,5 and 6 at Moon Reef and transects 5 and 6 at Horseshoe Reef ($p > 0.05$). Salinity significantly decreased ($p < 0.05$) away from both reefs, except along transects 5,6 and 8 at Horseshoe Reef. Chlorophyll-*a* concentration consistently significantly increased ($p < 0.05$) away from Moon Reef, except along transect 1. In contrast, Horseshoe Reef, chlorophyll-*a* concentration significantly increased ($p < 0.05$) along transects 2,3,5 and 7, but no trends were observed along any of the other transects ($p > 0.05$). Turbidity significantly decreased ($p < 0.05$) along all transects at both reef complexes except along transects 1 and 8 at Moon Reef and transect 8 at Horseshoe Reef ($p > 0.05$). Water depth significantly increased ($p < 0.05$) away from the reef edge along all transects at Moon Reef except transects 1,2,5 and 8 ($p < 0.05$). In contrast, depth only significantly increased with distance from Horseshoe Reef along transects 1,2 and 3 ($p < 0.05$).

More specifically, significant differences were found between transects for all the parameters investigated at both Moon Reef and Horseshoe Reef (KW test, $p < 0.05$). Subsequent multiple comparison procedures did not indicate, however, any specific structure characterising any of the reefs. Only depth was found not to be significantly different for Horseshoe Reef ($p < 0.05$). All water properties observed at the near entrance side of Moon Reef were significantly different from those of the outer non-entrance side of the reef (MW test, $p < 0.05$) except water depth ($p > 0.05$). In contrast at Horseshoe Reef, only salinity and turbidity significantly differed between the near entrance and non-entrance reef side (MW test, $p < 0.05$). Significant differences were found (MW test, $p < 0.05$) between all environmental water properties measured inside and outside Moon Reef except water depth ($p > 0.05$). More specifically, salinity, turbidity and chlorophyll-*a* concentration were consistently significantly higher ($p > 0.05$) in the outer waters of Moon Reef. In contrast significant differences ($p < 0.05$) were found between all the outside and inside environmental water properties for Horseshoe Reef except water depth ($p > 0.05$). Temperature and turbidity were significantly higher in outer waters ($p > 0.05$), while salinity was significantly higher inside the reef ($p > 0.05$). The inner reef temperature (27.56 ± 0.07C$^{\circ}$, mean ± SD) and salinity (35.47 ± 0.05) observed at Horseshoe Reef did not significantly differ from observations conducted at than Moon Reef (temperature 27.49 ± 0.10C$^{\circ}$; salinity 35.44 ± 0.02; MW test, $p < 0.05$). Inner Moon Reef chlorophyll-*a* concentrations (0.37 ± 1 0.30 μg l^{1}) and turbidity (0.92 ± 1.85 ppm) were significantly higher than chlorophyll-*a* concentrations (0.33 ± 0.15 μg l-^{1}) and turbidity (0.40 ± 0.64 ppm) observed at Horseshoe Reef. These observations were specified by the cluster analysis (not shown), which did not reveal any specific grouping of stations based on the oceanographic properties of the investigated water column that may help in distinguishing Moon Reef from Horseshoe Reef.

6.4 Discussion

6.4.1 *What's so special about Moon Reef?*

Previous work identified Moon Reef as a resting habitat for *S. longirostris* through their consistent daily presence to rest as well as the consistent occurrence of the same individuals over time (Cribb *et al*. 2012). This is noticeable as this is — to the best of our knowledge — the only resting habitat for spinner dolphins in this area of Fijian waters, despite the presence of other reef complexes with similar physical characteristics in close vicinity (Marnane *et al*. 2003). This is especially the case for Horseshoe Reef, a reef complex very similar in size, shape and location to Moon Reef, which according to local villagers and fishermen is never visited by spinner dolphins.

No striking differences were found between Moon Reef and Horseshoe Reef in terms of (i) the abiotic structure of the reefs itself and the nature of their benthic substrate, (ii) fish and invertebrate community structure, and (iii) physical and biological water properties. In addition, the outer waters located in the vicinity of the reef entrances both share properties that significantly differ from those of the water masses located away from the entrances. This is indicative of similar mixing processes occurring over the channels separating the inner waters of the reefs from offshore waters. The inner and outer waters of both reefs differ in their physical and biological properties. However, no significant differences were found between temperature and salinity. In contrast, the inner waters of Moon Reef were significantly more turbid than at Horseshoe Reef. This result contradicts previous evidence of a negative influence of surface turbidity on both dolphin presence and residency (Gannier & Petiau 2006), and suggests that the link between turbidity and spinner dolphins may potentially be more complex than previously thought and therefore necessitates further investigation. Chlorophyll-*a* concentrations were also significantly higher at Moon Reef than those of Horseshoe Reef. These differences are, however, unlikely to affect directly top predators such as dolphins. Indirect effects through *e.g.* differences in abundance and/or diversity of invertebrates and fish which may benefit from different phytoplankton standing stock are also unlikely due to the extreme similarity found between reefs in terms of invertebrates and fish communities. The essential differences between Moon Reef and Horseshoe Reef are hence (i) a larger and much deeper lagoon in Horseshoe Reef, (ii) a much wider channel connecting the Horseshoe Reef lagoon to open oceanic waters, and (iii) the regular presence of reef sharks inside Horseshoe Lagoon, that may represent a threat that does not exist in Moon Reef.

The choice of Moon Reef as a resting site may hence be motivated by the fact that this reef offers safe, shallow waters that are isolated from oceanic waters and their related disturbances and threats. In addition, this observation is consistent with an optimization of their fitness as during the night resource acquisition is the primary focus of spinner dolphins because they feed on small, individual prey and have high energetic needs (Norris *et al*. 1994) and very limited time to forage due to their physiology and the behaviour of their prey (Benoit-Bird & Au 2003). Even though relatively limited information are available on the feeding behaviour of spinner dolphins, they are believed to feed offshore at night in the mesopelagic zone (Benoit-Bird & Au 2003). As such, the choice of Moon Reef as a resting site during the day may also be motivated by the proximity of sustainable feeding grounds. While both reefs are located in the traditional fishing grounds of the Dawasamu District (Cribb *et al*. 2012), this hypothesis is consistent with Moon Reef being closer to the richer coastal waters of the main island of Fiji Viti Levu (Marnane *et al*. 2003; see Figure 6.1).

6.4.2 *Management implications*

A spinner dolphin population may be especially vulnerable to disturbance when it is small (Tyne *et al*. 2014) and genetically isolated (Andrews *et al*. 2010), and because it is unlikely to rest outside sheltered bays (Tyne *et al*. 2015). The spinner dolphin population investigated in Moon Reef in 2009 and 2010 is likely to be small, *i.e.* 56 individuals were identified (Cribb *et al*. 2012). Even if at this preliminary stage we do not have information about the potential genetic isolation of this population, the daily presence of spinner dolphins in Moon Reef and the reef proximity to Viti Levu led to an increase in interest and related number of visitors over the last few years. Boat trips from the local ecotourism lodges hence occur nearly daily and tourists are taken out to the reef to observe the dolphins and snorkel. Moon Reef spinner dolphins are hence susceptible to potential anthropogenic disturbances and has therefore led to growing concerns for their welfare and ultimately the development and implementation of management initiatives for Moon Reef. Even if this triggered the declaration of Moon Reef as a new marine protected area for spinner dolphins (see http://uk.whales.org/blog/2011/05/new-marine-protected-area-declared-for-spinner-dolphins-in-moon-reef-fiji), cumulative exposure to human interactions within resting habitats may be detrimental to spinner dolphins and has still barely been rationalised and quantified (Cribb *et al*. 2012; Tyne *et al*. 2015). Moon Reef is not an isolated case, as the increase in tourism activities occurring in various places such as Hawaii, Egypt and Bali (Delfour 2007; Shawky & Afifi 2008; Mustika *et al*. 2014, 2015; Tyne *et al*. 2015) where resting spinners are subjected to anthropogenic activities such as swim-with dolphin programmes, snorkelling and vessel presence, can have detrimental effects on their behaviour and has previously raised concerns for their welfare (Notarbartolo-di-Sciara *et al*. 2009; Tyne *et al*. 2015). For instance, energetic models of spinner dolphins in Hawaiian waters indicate that they are less likely to rest when swimmers approach within 150 m (Tyne *et al*. 2015). However, no attempt has been made to develop energetic models for Moon Reef spinner dolphins and the current level of exposure to anthropogenic activities in this reef has still to be determined. These two tasks are critical for the future of this small - potentially genetically isolated population - as the assessment of the contribution of anthropogenic activities to their energetic deficits will be the stepping-stone that may be used to determine the maximum energetic deficit they can tolerate before being driven into an energetic debt.

6.5 Conclusion

This work identified the potential reasons why spinner dolphins chose Moon Reef as an exclusive resting site in the studied area, *i.e.* the reef complexes located off the main island of Fiji Viti Levu in the vicinity of the Vatu-i-Ra channel. This work also, and more fundamentally, identified the knowledge gaps that need to be bridged to ensure that the recurrent presence of this small population of spinner dolphins on this easily accessible — and increasingly accessed — reef does not create an anthropogenically-driven threat. In particular, we stress the need for (i) a careful assessment of the level of harassment they are subject to [harassment is here defined following the Marine Mammal Protection Act (MMPA 1972) as "*…any act of pursuit, torment, or annoyance which (i) has the potential to injure a marine mammal or marine mammal stock in the wild; or (ii) has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioural patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering.*"], (ii) the subsequent development of energetic models of spinner dolphins in Fijian waters as stepping-stones for the development and implementation of objective conservation and management plans, a task particularly challenging in developing countries (Mustika *et al*. 2013), and (iii) disentangling the potentially synergistic or antagonistic effects of natural phenomena (*e.g.* global change) and human activity in the alteration of behavioural and energetic budgets.

6.6 Acknowledgements

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Table 6.1: A non-exhaustive review of environmental features evident within the most commonly identified spinner dolphin resting habitats.

Variables	**Midway Atoll, Hawaiian Archipelago**	**Baie des Pecheurs, Tahiti**	**Kealake'akua Bay, Hawaii**	**Baia dos Golfinhos, Brazil**	**Samadai Reef, Egypt, Red Sea**	**Moon Reef, Fiji, Pacific**	**SW Coast of Mauritius**
Reef / Bay / Cove	Reef	Cove	Bay	Bay	Reef	Reef	Bays / Reef
Latitude	28 05 25 N	-	-	3 51 S	24 59 N	17º 31.7‟S	20 17 S
Longitude	177 10 30 W	-	-	32 25 W	34 59 E	178º 30.7‟E	57 33 E
W / L / Area	10 km diameter	-	715 m, 1575 m, 11.13 km^2	500 m, 1 km, 3 km^2	1 km, 1.4 km,	1.4 km, 1.46 km, 1.8 km^2	75 km^2
Distance from Shore	-	-	-	-	6 km	9 km	-
Lagoon / Bay Mean Depth	1-30 m	10-30 m	10-30 m	15-25 m	< 20 m	15 m	-
Outside Depths	2000 m	1000 m	-	-	-	-	100 m
Steep Drop off Outside	Yes	Yes	Gradual	-	-	Yes	-
Shape	Crescent	-	Crescent	-	Horseshoe	Crescent	-
Sheltered	-	Yes, barrier reef	Yes	-	Sheltered from northerly winds	Yes	Yes, Reef fringed
Benthic Characteristics	Sandy, coralline outcrops	Sandy, rock, coral patches	Sandy	Sandy, coral patches	Sand, coral patches	Sand, coral structures	Sandy
Oceanographic Occurrences	-	Strong currents produce swell on S part of cove	-	-	-	-	-
No. Of Entrances	2	-	-	-	1	2	-

Direction Entrance is Used	South 300 m, West W 5 km	Leeward side of Tahiti	Leeward side of Hawaii	-	Opens to the south	NW	-
Core area used	-	-	Yes	-	Yes	Yes	-
Average Group Size	211	37-63	-	-	39.2 -39.34	-	52.4
Daily Dolphin Presence	Yes	Yes	-	Yes	Yes	Yes	Yes
Seasonal Variation in Group Size	-	Yes	-	Yes	Yes	-	-
Reference	Karczmarski *et al*. 2005	Gannier & Petiau 2006	Norris *et al*. 1994; Courbis 2007, Timmel *et al*. 2008	Camargo & Bellini 2007; Silva & Silva Jr 2009	Notarbartolo-di-sciara *et al*. 2009	Cribb *et al*. 2012	Webster *et al*. 2015

Table 6.2: The AIMS life-form categories for benthic strata (English *et al*. 1997).

Life Form Categories	
Abbreviation	**Life Form Type**
RC	Rock
RB	Rubble
SD	Sand
SI	Silt
DA	Dead coral
CA	Coralline algae
ACB	*Acropora* branching
ACD	*Acropora* digitate
ACT	*Acropora* table
ACS	*Acropora* submassive
ACE	*Acropora* encrusting
CB	Coral branching
CE	Coral encrusting
CF	Coral foliose
CM	Coral massive
CS	Coral submassive
SC	Soft coral
CMR	Coral mushroom
SP	Sponge
ZO	Zoanthids
OT	Other biota
MA	Macro-algae
TA	Turf algae

Table 6.3: Corals identified on Moon and Horseshoe Reefs as classified by genera.

Moon Reef	Horseshoe Reef
Montipora	Echinopora
Pocilliopora	Monastrea
Seriatopora	Psammocora
Stylopora	Pachyseris
Diplostrea	Hydnophora
Acropora	Symphyllia
Porites	Fungia
Pavona	Herpolitha
Isopora	Ctenactis
Coscinaraea	Turbinaria
Galaxea	Trachyphyllia
Oxypora	Goniopora
Millepora	Alevopora
Platygyra	Tubastrea
Favia	Merullina

Table 6.4: Fish and invertebrates classified by family.

Fish	Invertebrates
Butterflyfish	Starfish
Sweetlips	Sea cucumber
Snapper	Giant clam
Emperor	
Grouper	
Rabbitfish	
Wrasse	
Parrotfish	
Surgeon / Unicorn	
Goatfish	
Squirrelfish	
Monocle bream	

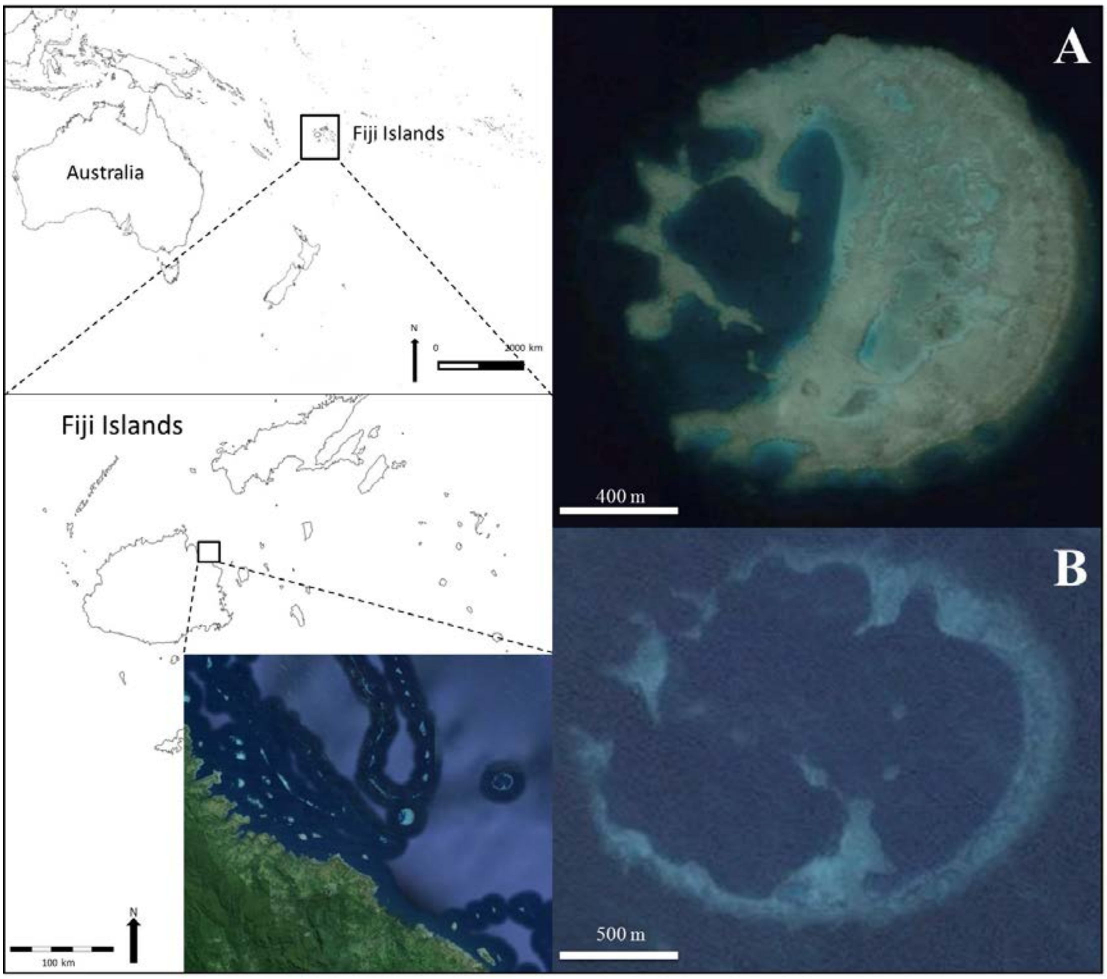


Figure 6.1: Location of the study sites, Moon Reef (A) and Horseshoe Reef (B), related to Australia and the Fiji Islands archipelago.

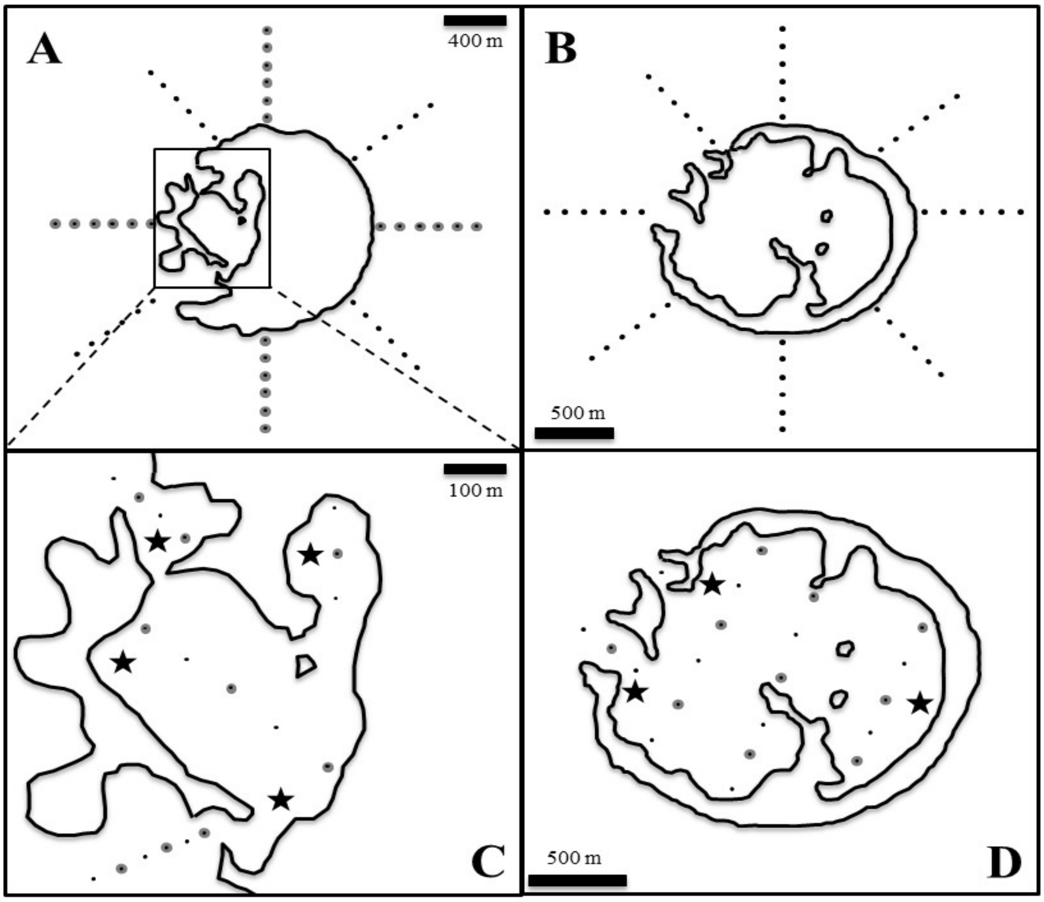


Figure 6.2: Localisation of the underwater benthic surveys conducted in May 2010 (★□, and the sampling stations of the oceanographic surveys conducted outside (A,B) and inside (C,D) Moon Reef (A,B) and Horseshoe Reef (B,D) in both 2009 and 2010 (●), and in 2010 only (•).

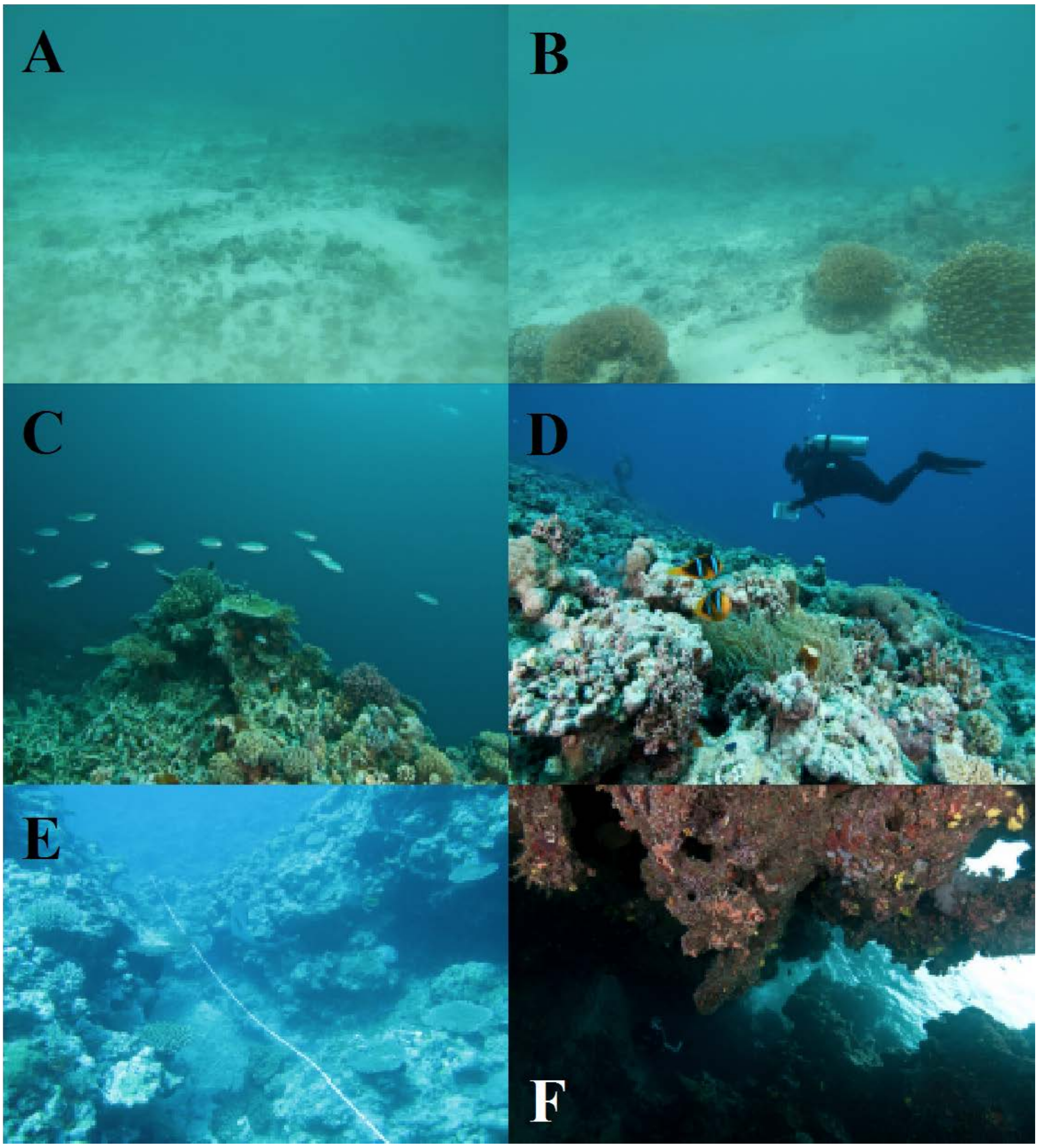


Figure 6.3: Illustration of the semi-quantitative 5-point scale used to assess reef topographic complexity. 1: flat topography A); 2: low, widespread topography (B); 3: moderate topography (C,D); 4: complex vertical topography (E); and 5: complex vertical topography with fissures, caves and/or overhangs (F).

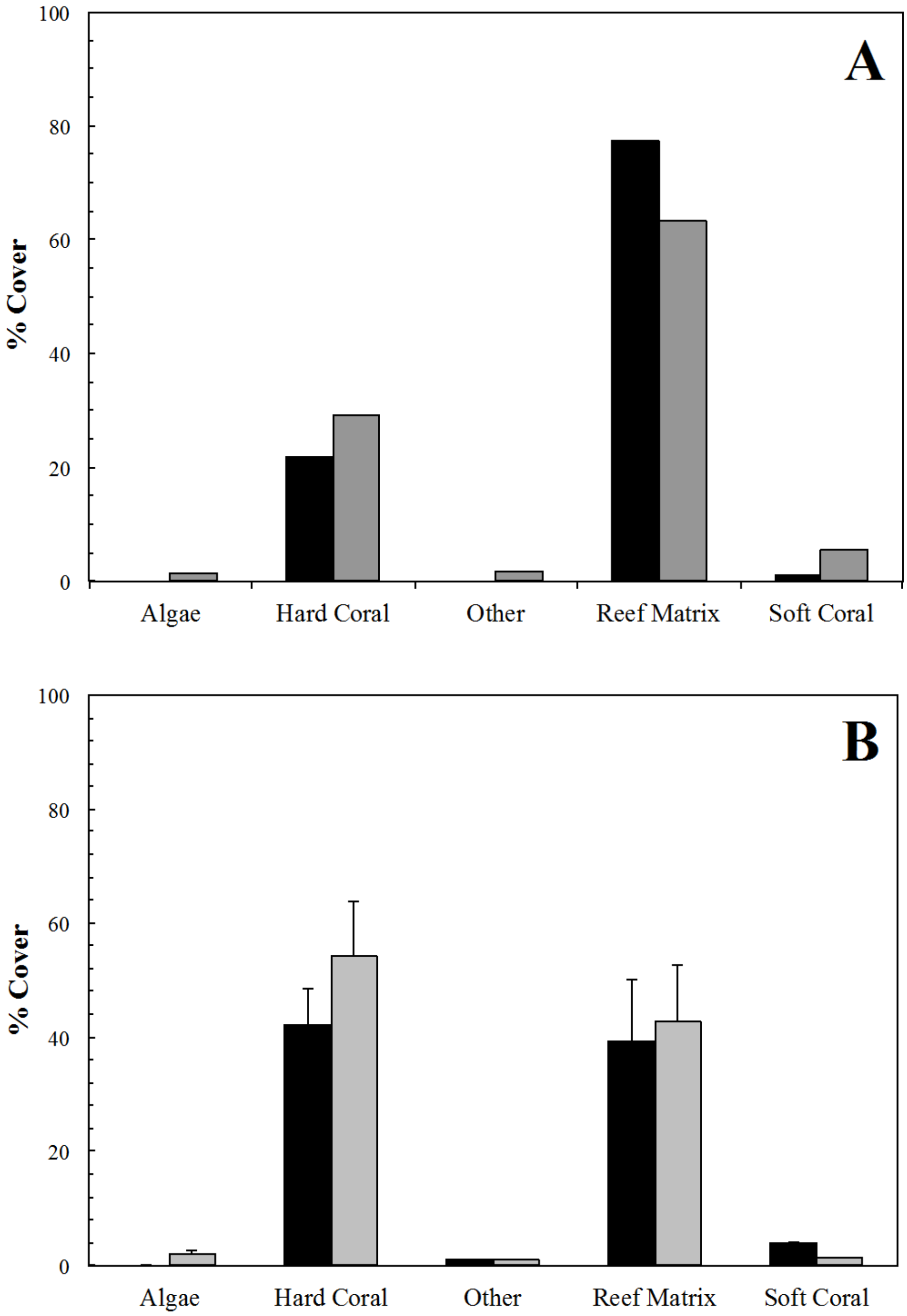
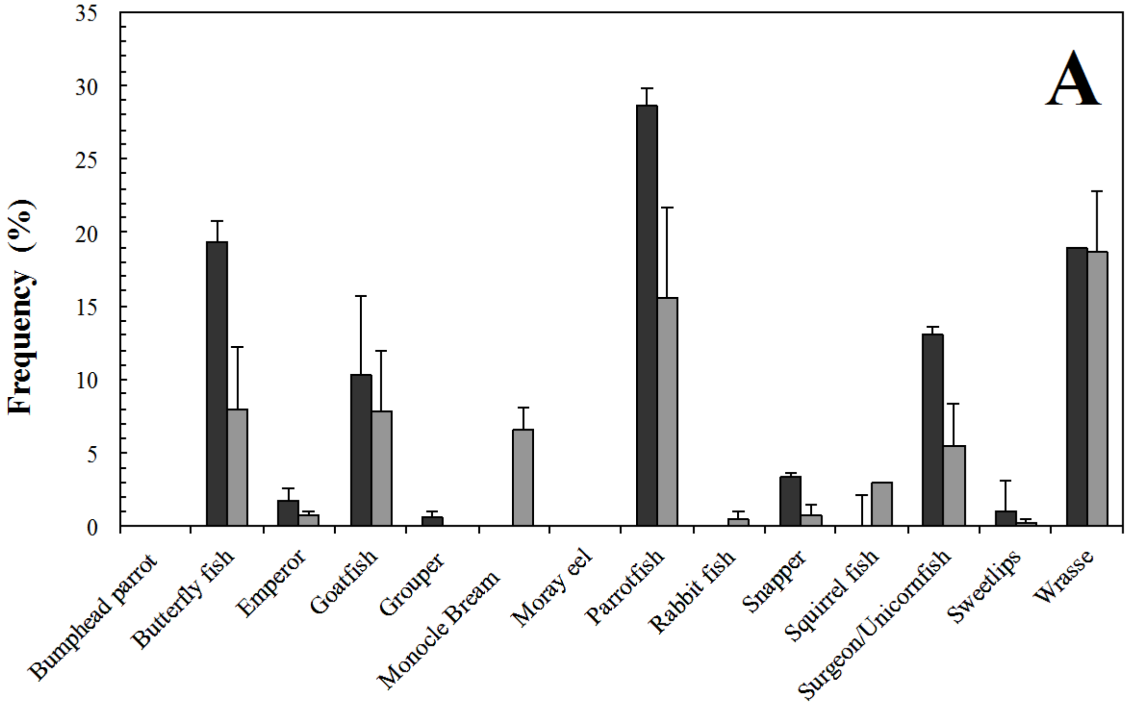


Figure 6.4: Percentage cover of benthic substrata on reef flat (A) and reef slope (B) at Moon Reef (grey bars) and Horseshoes Reef (black bars). The error bars are the 95% confidence intervals.



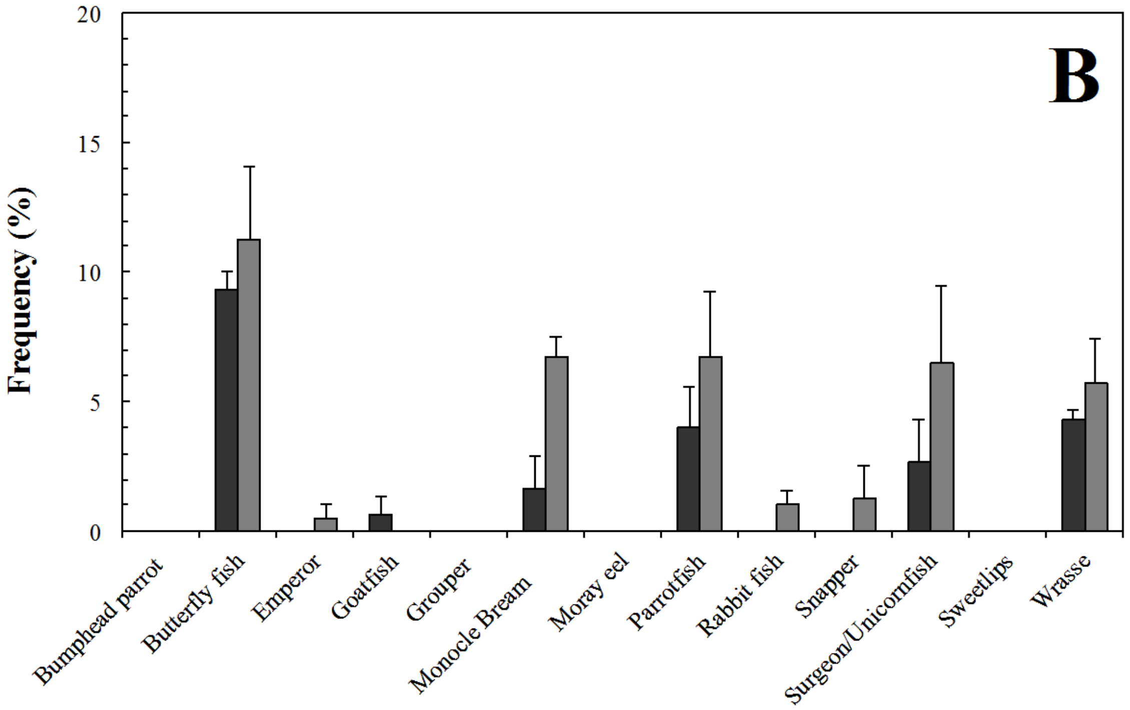


Figure 6.5: Frequency of occurrence of fish on reef flat (A) and reef slope (B) at Moon Reef (grey bars) and Horseshoe Reef (black bars).

Chapter 7

Changes in the behavioural complexity of bottlenose dolphins along a gradient of anthropogenically-impacted environments in South Australian coastal waters: implications for conservation and management strategies

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7.0 Abstract

The susceptibility of bottlenose dolphins (*Tursiops* sp.) to anthropogenic disturbance within South Australian coastal waters is of particular importance due to the ever increasing impact on those waters and their semi-enclosed nature. Currently, little is known about the ecology of dolphins in this region, in particular in relation to anthropogenically-driven disturbances. This study investigates the level of stress experienced by bottlenose dolphins from the complexity of their patterns of dive durations recorded along a gradient of environment types defined as a function of the intensity of anthropogenically-driven pollution and disturbances, including urban development and recreational boating. Dive durations were opportunistically recorded from land-based stations scattered across South Australian coastal waters in the absence of boat traffic, and in the presence of motorboats. Subsequent analyses were based on nearly 12,000 behavioural observations. No significant differences were ever found in dive durations measured in the absence of boats and when boats were present. In contrast, fractal analysis consistently identified significant differences in the complexity of dive duration patterns as a function of environment and exposure to disturbance. Specifically, bottlenose dolphins occurring in environments with less anthropogenic pressure exhibit a higher behavioural complexity. This complexity consistently significantly decreases both within each environment and between environments with increasing anthropogenic pressure. Our results further show that the relative changes in bottlenose dolphins behavioural complexity increases in environments less impacted by anthropogenic activities. These results are discussed in the general context of the adaptive value of fractal behaviour, the susceptibility of bottlenose dolphins occurring in distinct environments to anthropogenic disturbance, and how behavioural properties identified with our fractal methods can be used to establish baseline information that can be used for the design and implementation of conservation and management strategies.

7.1 Introduction

The assessment of the nature and intensity of the interactions between anthropogenic activities and cetaceans has been the focus of considerable research effort over the last decade, essentially due to the extensive overlap of human activities with cetaceans in general and dolphins in particular (*e.g.* Nowacek *et al.* 2001, Lusseau 2003a, 2005, 2006, Williams *et al.* 2006, Baş *et al.* 2015). Beyond the extreme cases related to propeller strike injuries, blunt trauma caused by vessel collisions and eventual subsequent death (Martinez & Stockin 2013, Dwyer *et al.* 2014) and reports of fast boats disrupting dolphin behaviour and social life (Lusseau 2005, Lemon *et al.* 2006), dolphins chasing fishing vessels (Jefferson 2000), fleeing from motorboats (La Manna *et al.* 2013), and changing their acoustic behaviour to compensate for the masking noise in the presence of trawlers (La Manna *et al.* 2013), dolphins are exposed to numerous chronic anthropogenic stressors.

This situation is particularly important in coastal waters where dolphins are increasingly exposed to a variety of potential human disturbances (Kelly *et al.* 2004), and their consequences in terms of *e.g.* environmental contamination (Schwacke *et al.* 2002) and habitat degradation (Adams *et al.* 2008). These disturbances include commercial (Burdett & McFee 2004) and recreational (Barco *et al.* 2010) fisheries, and the drastic increase in the occurrence of recreational motorized vessels (Buckstaff 2004), recreational fishing (Powell & Wells 2010), dolphin watching (Mustika *et al.* 2015) and swim-with-dolphin tourism (Peters *et al.* 2013). The understanding of dolphin responses to anthropogenic disturbance (*e.g.* the presence and type of boats and their related noise) are, however, not straightforward as a variety of sometimes conflicting responses have been reported. They include dolphins chasing fishing vessels (Jefferson 2000) and fleeing from motorboats (La Manna *et al.* 2013), as well as a range of avoidance and anti-predator strategies such as increase in swimming speed, decrease in resting behaviour, directional changes, decreased inter-animal distance, increased breathing synchrony, and longer dive durations (Ribeiro *et al.* 2005, Lemon *et al.* 2006, Williams *et al.* 2006, Christiansen *et al.* 2013). Note, however, that the observed responses also depend on habitat, social context, physiological conditions and previous encounters with specific stressors (Lemon *et al*. 2006, Lusseau 2003b, 2004, Sini *et al*. 2005). It is hence particularly difficult to disentangle the combined effects of disturbance and habitat on dolphin responses (Balmer *et al*. 2013, Pirotta *et al*. 2013), especially because it seems likely that dolphins tolerate chronic disturbance rather than flee from exposed areas (Bejder *et al*. 2009) given the plethora of anthropogenically-impacted coastal waters where dolphins are nevertheless known residents.

Under chronic exposure to disturbance, dolphins have been shown to develop subtle behavioural responses, such as changes in activity budgets (Gill *et al*. 2001, Bejder *et al*. 2009) and the complexity of behavioural patterns (Seuront & Cribb 2011). Specifically, our recent work conducted in a highly urbanized coastal environment, the Port Adelaide River-Barker Inlet Estuary (South Australia), showed that dive durations of the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) were not significantly affected by either boat presence or boat type (*i.e*. kayaks, inflatable motor boats, powerboats and fishing boats). In contrast, the complexity of the temporal dynamics of dive duration - quantified using fractal analysis and used as a proxy of stress, *i.e*. behavioural complexity decreases under stressful conditions; see MacIntosh (2014) and Seuront (2015) for reviews - was affected by boat presence and type (Seuront & Cribb 2011). Specifically, the complexity of dive duration patterns did not significantly differ between control behavioural observations conducted in the absence of boat, and behavioural observations conducted in the presence of kayaks. A significant increase in behavioural stress was, however, induced by the presence of fishing boats, motorized inflatable boats and powerboats (Seuront & Cribb 2011). These results suggest that standard behavioural metrics such as time allocated to different behavioural sequences, and the related statistical comparisons of mean duration or frequency may not be sensitive enough to detect subtle behavioural changes, and that the behavioural changes induced by a chronic exposure of dolphins inhabiting anthropogenically-impacted coastal areas to various boat disturbances may be much more difficult to detect those related to the acute source of stress reported above; see also MacIntosh (2014) and Seuront (2015) for reviews on the value of fractal analysis to assess behavioural complexity and stress levels in a range of organisms. In addition, due to the semi-enclosed nature of South Australian coastal waters (Figure 7.1), any anthropogenic impact to marine life may be considered as a conservation threat (Hoyt 2005) as subsequent effects on the natural environment are likely to be particularly severe (Notarbartolo di Sciara & Birkun 2002). In this context, the present work investigates how the fractal properties of dive duration patterns can be used to relate the behavioural complexity of *Tursiops* sp. to the nature of their habitat along a gradient of habitat types defined as a function of the intensity of anthropogenically-driven pollution and disturbances, including urban development and recreational boating.

7.2 Methodology

7.2.1 *Study species*

Two species of bottlenose dolphins, *Tursiops truncatus* and *T. aduncus,* have been recognised worldwide (Rice 1998, Wang *et al*. 1999). *T. truncatus* has a broad distribution and is found both inshore and offshore in cool temperate to tropical waters around the world (Leatherwood *et al*. 1983). In contrast, *T. aduncus* is only present in coastal and estuarine waters of the Indian and western Pacific Oceans, including south-eastern Australia (Rice 1998, Wang *et al*. 1999). *Tursiops truncatus* and *T. aduncus* occur in sympatry and parapatry (Wang *et al*. 1999, Hoelzel *et al*. 1998) and over a range of different habitats (Bearzi *et al*. 1997).

In South Australia, *T. aduncus* is found in coastal waters and Gulfs (Kemper & Ling 1991), in particular the Port Adelaide River–Barker Inlet estuary, which supports a population of resident individuals (Cribb *et al*. 2008). However, recent genetic evidence, based on both mtDNA and microsatellite data, suggests that coastal bottlenose dolphins from South Australia, Victoria and Tasmania are evolutionarily distinct from the *T. truncatus* and *T. aduncus* (Charlton *et al.* 2006).

The former is likely to represent an undescribed dolphin taxon more closely related to the common bottlenose dolphins *T. truncatus* than to the Indo-Pacific bottlenose dolphin *T. aduncus* (Charlton *et al.* 2006). As a consequence, we refer to bottlenose dolphins as *Tursiops* spp. throughout this study.

7.2.2 *Study site*

The complexity of *Tursiops* sp. breathing rhythms was investigated from South Australian coastal waters exhibiting a gradient of environments defined as a function of the intensity of anthropogenically-driven pollution and disturbances, including urban development and recreational boating. Specifically, the identification of dolphin stress levels is particularly important in the Port Adelaide River-Barker Inlet estuary (South Australia), where *Tursiops aduncus* is a known resident (Kemper *et al*. 2008, Steiner & Bossley 2008). This estuary, located on the northeastern side of Gulf St. Vincent, is a sheltered, marine dominated estuary (Connolly 1994) and is considered to have unique conservation significance and commercial value (Tanner *et al.* 2003). It is, however, in its southern part highly impacted by a number of anthropogenic activities ranging from sewage pollution, horticultural water runoff, recreational and commercial vessel traffic, dredging, urban development, habitat degradation and altered flow regimes (Edyvane 1991, 1999, Connolly 1994, Bryars 2003, Seuront & Cribb 2011). The recognition of the potential threats in this area therefore led to the declaration of the Adelaide Dolphin Sanctuary (ADS) in 2005, with the intent to protect and conserve both the dolphins and their environment. However, although a declared sanctuary, little is still known about the potential links between the nature of their environment and the behaviour of dolphins in this area (Cribb *et al*. 2008).

To ensure the generality of our approach, our study investigated thirteen sites scattered in three distinct areas across South Australian coastal waters. These include the Adelaide Dolphin Sanctuary, the sandy beaches of the metropolitan coasts of Adelaide in Gulf St. Vincent, and Boston Bay in the Spencer Gulf. Specifically, four sites were chosen inside the Adelaide Dolphin Sanctuary

(ADS) along a gradient of increasing anthropogenic activities (Figure 7.1C). These sites include the Angus Inlet at Garden Island, a relatively pristine sheltered water complex, fringed by mangrove forest, and dissected by numerous shallow bare sand channels (Figure 7.2A), North Arm in the Barker Inlet which hosts a harbour for fishing, recreational and research vessels (Figure 7.2B), Dock 2 (Port Adelaide) a cargo loading facility (Figure 7.2C) and the highly urbanized Port Adelaide Inner Port (Figure 7.2D). In addition, six sites located along the sandy beaches of the metropolitan coast of Adelaide in the St. Vincent Gulf (*i.e.* Semaphore, Grange, Henley, Glenelg, Brighton and Port Noarlunga) and in Boston Bay in the Spencer Gulf were used as controls as they are much less impacted by anthropogenic activities. In contrast to the Adelaide Dolphin Sanctuary, the coastal waters of the Adelaide metropolitan area and Boston Bay are only impacted by both recreational non-motorized and motorized vessels and recreational fishing vessels.

7.2.3 *Behavioural observations*

Dive duration has previously been shown to increase under boat traffic conditions, and it is considered as a typical avoidance behaviour (Nowacek *et al.* 2001, Janik & Thompson, 1996, Ng & Leung 2003, Lusseau 2003b). Here, we specifically investigate the dive durations D_t as the time intervals between two successive surface exhalations, while *T. aduncus* individuals were traveling, *i.e.* moving in a persistent, directional way (Constantine *et al.* 2004). Dolphin behaviour was observed using binoculars, and dive durations were recorded using a hand held stopwatch and internally stored until analysis. To avoid any bias related to interactions between individuals, behavioural observations were always limited to solitary individuals. Note that all behavioural observations were conducted in areas with a 4 knot speed restriction to limit the potential bias due to strong discrepancies in boat speed. Control observations were conducted at each site in the absence of any boat on the water, and the potential for boat interactions was investigated when a motorized vessel was within 100 m from a traveling individual. Direct signs of boat avoidance or attraction were never observed. All observations were opportunistically conducted from land-based sites from January 2008 to December 2013 in the Port Adelaide River-Barker Inlet Estuary, in December 2002, 2003, 2004, 2005, 2006, 2007, April 2009, 2010 and 2012 in Boston Bay, and from November 2002 to December 2013 along the metropolitan coast of Adelaide (Table 7.1).

7.2.4 *Behavioural analysis*

In a previous study, Seuront & Cribb (2011) introduced a method to quantify the complexity observable from the temporal patterns of diving durations T_D based on the scaling properties of the cumulative probability distribution function (CDF) of dive duration T_D greater than a determined duration *t* as:

$$P\ (t \leq T_D) = k_1 t^{-\phi}$$

where k_1 is a constant, and ϕ the scaling exponent describing the distribution. In the presence of a fractal structure, Eq. (1) will manifest itself as a linear behaviour in a log-log plot of $P(t \leq D_t)$ versus t. The exponent ϕ is then estimated as the slope of $P(t \leq D_t)$ versus t in log-log plots, and is expected to decline under stressful conditions; see *e.g.* Alados *et al*. 1996, Seuront & Leterme 2007, Seuront 2010, 2011, 2015). Note that for the sake of simplicity and ease of implementation, Eq. (1) can be rewritten in simpler terms following (Seuront & Mitchell 2008):

$$T_D\,(r) = k_2 r^{-\alpha}$$

where k_2 is a constant, r is the rank of the dive duration $T_D(r)$ - in a series of n dives, the longest dive has a rank $r = 1$ and the shortest a rank $r = n$, and α ($\alpha = 1/\phi$) is the slope of the log-log plot of $T_D\,(r)$ versus r. The exponent α, hereafter referred to as a stress exponent, is expected to increase under stress, which indicates a decrease in behavioural complexity; see MacInstosh (2014) and Seuront (2015) for more details and reviews on this topic.

7.2.5 *Data analysis*

Given that dive durations T_D were consistently non-normally distributed, both in the absence and the presence of boats (Kolmogorov-Smirnov test, $p < 0.01$), and the relatively low number of the fractal exponent α estimates (Table 7.1), non-parametric statistics were used throughout this work. More specifically, all pairwise comparisons between observations conducted in the absence and the presence of boats were conducted using the Wilcoxon-Mann-Whitney U-test. Multiple comparisons between sites were conducted using the Kruskal-Wallis test (referred to as KW test hereafter), and a subsequent multiple comparison procedure based on the Tukey test was used to identify distinct groups of measurements (Zar 1999).

7.3 Results

7.3.1 *Dive durations*

Besides being non-normally distributed, dive durations T_D (Figure 7.3) were consistently positively skewed. This result indicates the presence of long dives interspaced among a background of short dives (Figure 7.3). Dive durations typically ranged between 6 and 89 seconds, and no significant differences were observed within a site (Wilcoxon-Mann-Withney U-test, $p > 0.05$) or among sites (KW test, $p > 0.05$) between observations conducted in the absence and presence of boats. In contrast, the variability in dive duration was significantly higher when boats were present ($p < 0.05$) in all of the 13 sites investigated. Note, however, that no significant differences in dive duration variability were found between the three investigated areas, nor between sites within a given area.

7.3.2 *Fractal analysis of dive duration patterns*

Log-log plots of dive durations $T_D(r)$ versus their rank r (see Eq. 2) were consistently very significantly linear ($p < 0.01$) across sites for observations conducted in the absence and presence of boats (Figure 7.4). This observation indicates the existence of a power-law behaviour, the signature of an underlying fractal structure. Note that as stressed elsewhere (Seuront & Cribb 2011), this result is fundamental as the nested structure of fractal patterns - see *e.g.* Seuront (2010) for further details - implies that comparing experiments with different durations using mean values of behavioural metrics (here dive duration) are unlikely to be meaningful, because those mean values intrinsically depend on the duration of the experiment.

The stress exponents α ranged from 0.27 to 0.69 in the absence of boats, and from 0.57 to 0.78 when boats were present. More specifically, dive durations recorded in the absence of boats were characterized by exponents α that were consistently significantly smaller than those obtained when boats were present ($p < 0.01$), except at the two innermost sites (Dock 2 and Inner Port) of the Port Adelaide-Barker Inlet estuary where no significant differences could be detected ($p > 0.05$; Figure 7.5A,B). This observation indicates a decrease in behavioural complexity in the presence of boats, irrespective of the overall level of anthropogenic activities in *Tursiops* sp. environment.

In the absence of boats, significant differences were found in the stress exponent α between sites within each of the three areas considered ($p < 0.05$). Specifically, in the Adelaide Dolphin Sanctuary, α significant differed between all sites ($p < 0.05$), with $\alpha_{\text{Garden Island}} < \alpha_{\text{North Arms}} < \alpha_{\text{Dock 2}} < \alpha_{\text{Inner Port}}$ (Figure 7.5a). This result suggests a significant decrease in behavioural complexity along a gradient of increasing anthropogenic activities. In the Adelaide metropolitan area, no significant differences were found between the exponents α estimated from Semaphore to Brighton ($p > 0.05$). In Port Noarlunga, α was, however, significantly smaller than anywhere else ($p < 0.05$), suggesting a higher level of complexity in dive duration patterns (Figure 7.5A). Finally, in Boston Bay, no significant differences were found in α between Port Lincoln Jetty and Lincoln Marine Science Centre ($p > 0.05$), while $\alpha_{\text{Billy Lights Point}}$ was significantly smaller, hence *Tursiops* sp. behaviour was less complex, than at the other two sites (Fig. 5a). Overall, the exponents α significantly differ between all study areas ($p < 0.05$), with $\alpha_{\text{ADS}} < \alpha_{\text{Boston Bay}} < \alpha_{\text{Adelaide}}$ (Figure 7.5B).

When boats were present, no significant differences were found in the stress exponent α between sites within each of the three study areas ($p > 0.05$; Figure 7.5A). The exponents α significantly differed, however, between study areas ($p < 0.05$), with $\alpha_{\mathrm{Adelaide}} < \alpha_{\mathrm{ADS}} = \alpha_{\mathrm{Boston\ Bay}}$ (Figure 7.5B). Finally, highly significant differences were found between the stress exponents α estimated in the absence and presence of boats at all sites, but Dock 2 and Inner Port in the Adelaide Dolphin Sanctuary (Figure 5A). These differences results in relative differences between the stress exponents estimated in the absence and presence of boats, *i.e.* the ratio $\alpha_{\mathrm{Boat}}/\alpha_{\mathrm{No\ Boat}}$, ranging from 1.07 to 1.35 in the Adelaide Dolphin Sanctuary, from 1.45 to 2.3 in the Adelaide metropolitan area, and from 1.42 to 1.57 in Boston Bay (Figure 5C).

7.4 Discussion

7.4.1 *Standard behavioural metrics are not sensitive enough to assess the behavioural effect of exposure to anthropogenic disturbance*

The dive durations of *Tursiops* sp. did not significantly differ between our three study areas, nor between sites within each area. This is consistent with previous work that assessed the effect of boat presence and type (*i.e.* kayaks, motorized inflatable boats, powerboats and fishing boats) on *Tursiops* sp. dive durations in the Adelaide Dolphin Sanctuary (Seuront & Cribb 2011). Specifically, in this preliminary work no significant differences were found in *Tursiops* sp. dive durations between control observations conducted in the absence of boat and observations conducted when boats were present. As stressed earlier (Seuront & Cribb 2011), the non-significant differences induced by boat presence and type in *Tursiops* sp. dive durations would erroneously indicate the absence of behavioural impact of boat traffic. The related stress induced by boats was hence referred to as *pernicious* (Seuront & Cribb 2011) as standard metrics (here dive duration) did not seem sensitive enough to detect any behavioural changes.

In contrast, we consistently observed a greater variability in dive durations irrespective of areas and sites, when boats were present. This result is consistent with the increase in dive duration variability observed from control observations to observations conducted in the presence of boats, with a clear increase in variability from kayaks, motorized inflatable boats and powerboats, with fishing boats having a milder effect (Seuront & Cribb 2011). As suggested earlier (Seuront & Cribb 2011), this observation is consistent with an increase in inter-individual variability under the punctual acute stress caused by the presence of boats. The lack of differences in variability estimates between sites and areas reported in the present work suggests, however, that dive duration variability is not sensitive enough to infer differences in the behavioural properties of dolphins inhabiting environments that essentially differ in their level of chronic exposure to anthropogenic disturbances.

7.4.2 *On the fractal nature of bottlenose dolphin dive duration patterns*

Our results show that the dive duration patterns of *Tursiops* sp. consistently followed a power-law behaviour in the absence of boats and when boats were present in the three distinct environments investigated here (Figure 7.4). This indicates the presence of an underlying fractal structure, which is independent on both the nature of the environment and the level of stress exposure. The presence of fractal fluctuations in biological systems is adaptive because it serves as an organizing principle for highly complex, nonlinear processes and it avoids restricting the functional response of an organism to highly periodic behaviour (Goldberger *et al.* 2000). Fractal fluctuations are also error tolerant, as they allow organisms to cope with stress and unpredictable environments (Goldberger *et al*. 1990). Over the last three decades, fractal fluctuations have hence been reported in a range of biological systems. These systems include human physiology - *e.g.* neuronal discharges during sleep (Yamamoto *et al*. 1986), heart rate (Meesman *et al*. 1993), the stride interval of human gait (Haussdorff *et al*. 1995, 1997), human eye-movement (Yokoyama *et al*. 1996, Billoc *et al*. 2001), displacement of center-of-pressure during upright stance (Delignières *et al*. 2003), lung function (Thamrin & Stern 2010), wielding behaviours underlying haptic perception (Stephen *et al*. 2010) - but also tree growth (Zeide & Gresham 1991), respiratory intervals in cats (Kawahara *et al*. 1989), cat vascular structure (Herman *et al*. 2001), mammalian social hierarchies (Hill *et al*. 2008) and the foraging behaviour of a range of aquatic and terrestrial organisms including both invertebrates and vertebrates (see *e.g*. Seuront (2010) for a review) including marine mammals (Laidre *et al*. 2004). Note, however, that fractal fluctuations are not unique to biological systems, but can virtually be found everywhere (Barnsley 2014). In particular, fractal properties have been identified in abiotic and biotic systems related to dolphin behaviour such as the topographic complexity of coral and rocky reefs (Bradbury *et al*. 1984, Le Tourneux &Bourget 1988), coastline (Simon & Simon 1998, Chattopadhyay & Kumar 2007) and seafloor (Ashalatha 2007), the spatial patterns of seagrass meadows (Manzanera & Romero 2000), the architecture of sessile flora and fauna (Burlando *et al*. 1991; Abraham 2001), sound attenuation in sediment (Qian 1996), wave propagation (Dimri & Srivastava 2007), oil spills (Redondo & Platonov 2009), marine traffic (Hu *et al*. 2009; Chen & Hu 2009) and the foraging behaviour of fish and fish schools (Shinicki *et al*. 2001, Tikhonov *et al*. 2001, Medvinsky *et al*. 2002). As a consequence, the distribution of information needed to fulfil basic activities such as foraging and navigation fundamentally spans from relatively short temporal (changes in the trajectory of fish and fish schools, or in wave field) and small spatial scales (sound propagation in sediment when scanning for prey) to much longer temporal (migratory patterns of prey species) and larger spatial (coastline topography) scales. Because behaviour is the product of continuous interactions between the internal state of an organism and the nature of its environment, the fractal properties identified in the present work in the dive duration pattern of *Tursiops* sp. are consistent with the fractally-coloured environment in which they are embedded. In particular, the adoption of fractal strategies is highly adaptive as it allows an organism to efficiently scan a wide range of scales (Sagan 1994), and optimize key processes such as searching patterns (Sims *et al*. 2012, Humphries *et al*. 2012) and predator-prey encounter rates (Seuront & Stanley 2014).

7.4.3 *Environment-dependent dive duration patterns in bottlenose dolphins*

Our results show that in the absence of boats the complexity of *Tursiops* sp. dive duration patterns significantly differs between the three study areas (Figure 7.5). Specifically, the stress exponents α were the highest, hence the related behavioural complexity the lowest, in the Adelaide Dolphin

Sanctuary (ADS). This is consistent with the overall high level of anthropogenic activities impacting this area, especially compared to the Adelaide metropolitan coast and Boston Bay, and to previous work consistently showing a reduction in behavioural complexity under stressful conditions (Alados & Huffman 2000, María *et al*. 2004, Seuront & Cribb 2011, MacIntosh *et al*. 2011, 2013). The observed differences in behavioural complexity may hence be related to an adaptive response to different levels of chronic stress that decrease from the ADS, where the background anthropogenic activities are the highest, to the Adelaide metropolitan coast. Note, however, that the four sites investigated in the ADS also differ from the other ones as their waters are typically embedded in relatively shallow channels or harbour basins with bare sand bottoms. These waters sharply contrast with the deeper open coastal waters characterizing Boston Bay and the metropolitan coast of Adelaide (Figure 7.1). It is hence likely that the lower levels of behavioural complexity observed in the Adelaide Dolphin Sanctuary in the absence of boats may also be related to differences in the nature of the environment, as dolphin behaviour has widely been shown to be influenced by environmental features such as water depth, bottom topography and coastal features (Cribb *et al*. 2015). This hypothesis is consistent with the observed increase in behavioural complexity observed from the ADS to the Adelaide metropolitan coast (Figure 5A,B). This increase in behavioural complexity hence matches the increase in foraging space, the variety of available environments (typically a patchwork of bare sand and seagrass meadows) and the related resources occurring in Boston Bay and along the metropolitan coast of Adelaide, and suggests a potential environment-dependence of the complexity of *Tursiops* sp. dive duration patterns.

7.4.4 *Environment-dependent behavioural response of bottlenose dolphin to pernicious anthropogenic stress*

Fractal analysis has early been introduced in the study of human physiology to distinguish between systems operating in normal or pathological states (Ivanov *et al*. 1999, Mishima *et al*. 1999). The complexity of a range of biological systems has hence been shown to decrease under stressful conditions. For instance, beat intervals in healthy subjects have more complex fluctuations than patients with severe cardiac disease (Ivanov *et al.* 1999). Similarly, the geometry of the lung terminal airspace branching architecture is more complex in normal subjects than in patients with chronic obstructive pulmonary disease (Mishima *et al*. 1999). Fractal analysis is also increasingly acknowledged as a novel analytical tool in the field of behavioural ecology (Asher *et al*. 2009), especially because fractal analysis has the desirable properties to be independent of measurement scale and to be very sensitive to even subtle behavioural changes that may be undetectable to other behavioural variables (Coughlin *et al*. 1992; Rutherford *et al*. 2004). Besides, because stressed (*i.e.* diseased and parasited) animals typically reduce the complexity of their behavioural display (Alados *et al*. 1996), fractal analysis has been extensively used as a non-invasive assessment of the general health of wild and captive animals (Rutherford *et al*. 2004, MacIntosh 2014, Seuront 2015).

The presence of boats consistently significantly decreases *Tursiops* sp. behavioural complexity across areas and sites, except at Dock 2 and Inner Port in the Adelaide Dolphin Sanctuary (Figure. 5A). This observation is consistent with the generally expected decrease in behavioural complexity under stressful conditions. However, it also suggests that there may exist a threshold of chronic anthropogenic disturbance above which the occurrence of more acute stress (here boat presence) may not induce further decrease in behavioural complexity. This hypothesis is consistent with the high level of anthropogenic pressure occurring at Dock 2 and Inner Port, where water bodies are entirely contained by concrete walls, crossed by a series of bridges constantly holding heavy traffic, and in direct proximity of a range of anthropogenic disturbances related to urban development (both residential and industrial estates have been constantly growing in this area over the last 10 years), recreational activities such as dolphin-watch tours, yachting and fishing. Besides, even in the absence of significant differences between the stress exponents α between the metropolitan coast of Adelaide and Boston Bay (Figure 5A,B), the clear increase in the relative difference in behavioural complexity induced by boat presence, i.e. the ratio α_{Boat} / $\alpha_{\text{No boat}}$ (Figure 5C) suggests that *Tursiops* sp. were much more sensitive to boat disturbance along the metropolitan coast of Adelaide (especially in Port Noarlunga) and Boston Bay than in the Adelaide Dolphin Sanctuary.

7.4.5 *Fractal analysis of diving patterns as a tool to identify distinct bottlenose dolphin populations?*

The clear differences in behavioural complexity exhibited by bottlenose dolphins may also be related to different dolphin populations or species. If *T. aduncus* is a known resident in the Adelaide Dolphin Sanctuary (Cribb *et al*. 2008, Kemper *et al*. 2008, Steiner & Bossley 2008), there is still no information on its biogeography in South Australian coastal waters and on potential connectivity patterns between the Spencer Gulf and Gulf St. Vincent. A recent photo-identification survey conducted over the last 10 years in both the Adelaide Dolphin Sanctuary and at the southernmost part of Gulf St. Vincent show no evidence of latitudinal connectivity in Gulf St. Vincent (Cribb, unpublished data). Under the hypothesis that there is similarly no longitudinal connectivity between bottlenose dolphins populating Gulf St. Vincent (hence occurring along the metropolitan coast of Adelaide) and the Spencer Gulf, we suggest that distinct populations evolving in different environments may indeed be characterized by distinct dive duration patterns. Note that this hypothesis is supported by a study using data from mitochondrial DNA control region sequences and 6 microsatellite loci showing marked genetic differentiation and low migration between dolphins of Spencer Gulf and dolphins inhabiting coastal areas west of the gulf in the Great Australian Bight of the gulf (Bilgmann *et al*. 2007). Further work is still needed, however, to unambiguously assess the level of relatedness and connectivity patterns of *Tursiops* sp. in general and *T. aduncus* in particular in South Australian waters, and the resolution of this issue goes far beyond the scope of the present work.

7.4.6 *On the importance of assessing pernicious stress for dolphin conservation*

Chronic exposure to even low levels of stress has implications for energy balance, physiological conditions and vital rates (New *et al*. 2013), and is likely to induce long-term consequences at the population level (Lusseau 2004, Bejder *et al*. 2006). This is a critical issue for dolphin welfare as well as the related development and implementation of effective mitigation and management strategies because the habituation to boat traffic reported for bottlenose dolphins (Sini *et al*. 2005) did not imply the absence of stress, hence may be thought as a pernicious threat as suggested in a preliminary study (Seuront & Cribb 2011). As such, it is stressed that the assessment of the potential impacts of boat traffic, hence the identification of potential long-term ramifications, may require more efficient ways to infer the behavioural stress of dolphins inhabiting anthropogenically-impacted coastal areas.

Specifically, bottlenose dolphins occurring in environments with less anthropogenic pressure exhibit a higher behavioural complexity. This complexity consistently decreases both within and between environments with increasing anthropogenic pressure. Our results further show that the behaviour of *Tursiops* sp. occurring along the metropolitan coast of Adelaide and in Boston Bay is more affected to the boat presence than those living in the Adelaide Dolphin Sanctuary (ADS). This observation may indicate that bottlenose dolphins are more susceptible to be affected by the development of human activities than in Boston Bay and the ADS. In turn, this may imply that their baseline behavioural repertoire is richer, hence allow them more behavioural flexibility to respond to disturbances, than in dolphins living in less pristine habitats. Similarly, the relatively moderate differences in behavioural complexity observed in the ADS in the absence of boat and when boats were present does not necessarily imply a habituation to boats as observed elsewhere (Sini *et al*. 2005). This may indicate instead that they have a limited ability to modify their behaviour in response to boat traffic in particular and anthropogenic disturbance in general.

7.5 Conclusion

This work illustrates how standard behavioural metrics failed to identify changes in the patterns of dive durations of bottlenose dolphins occurring in distinct environments under different levels of exposure to anthropogenic chronic and acute disturbances. In contrast, the fractal methods used here, beyond being very easy to implement, provides an objective and quantitative and non-intrusive way to quantify subtle behavioural changes. This method is then suggested as a potential powerful tool to assess both absolute and relative behavioural changes in bottlenose dolphins. It may hence provides baseline information on the actual level of stress and related behavioural flexibility of bottlenose dolphins - and ultimately any marine mammal - might have to respond to anthropogenic disturbance, a prerequisite to the development of conservation and management strategies.

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Table 7.1: Locations of the observation sites in the three distinct habitats studied in South Australia coastal waters. *n* and *N* are respectively the number of observation sessions and the related number of dive durations recorded. T_D is the range of dive durations observed in the absence of boats (Control) and when boats were present (Boat). LMSC: Lincoln Marine Science Centre.

Location	**Latitude**	**Longitude**	***n***	***N***	T_D (sec)	
					Control	Boat
Port Adelaide-Barker Inlet Estuary						
Garden Island	34°48'21 S	138°32'38 E	5	554	6-77	6-81
North Arms	34°48'39 S	138°31'22 E	3	466	7-88	6-82
Dock 2	34°50'12 S	138°30'29 E	6	778	8-89	7-79
Inner Port	34°50'37 S	138°29'57 E	7	1112	6-67	6-70
Adelaide Metropolitan beaches						
Semaphore	34°50'13 S	138°28'28 E	5	620	6-78	10-89
Grange	34°54'09 S	138°29'08 E	7	978	7-86	11-88
Henley	34°55'11 S	138°29'27 E	8	888	6-89	8-80
Glenelg	34°58'49 S	138°30'29 E	11	1358	11-88	7-81
Brighton	35°01'02 S	130°30'43 E	7	842	12-80	6-70
Port Noarlunga	35°08'57 S	138°27'52 E	8	1484	10-85	7-84
Boston Bay						
Port Lincoln Jetty	34°42'49 S	135°52'12 E	6	596	10-80	8-83
LMSC	34°43'34 S	135°53'08 E	5	424	8-78	7-81
Billy Lights Point	34°44'40 S	135°53'32 E	12	1554	6-83	6-79

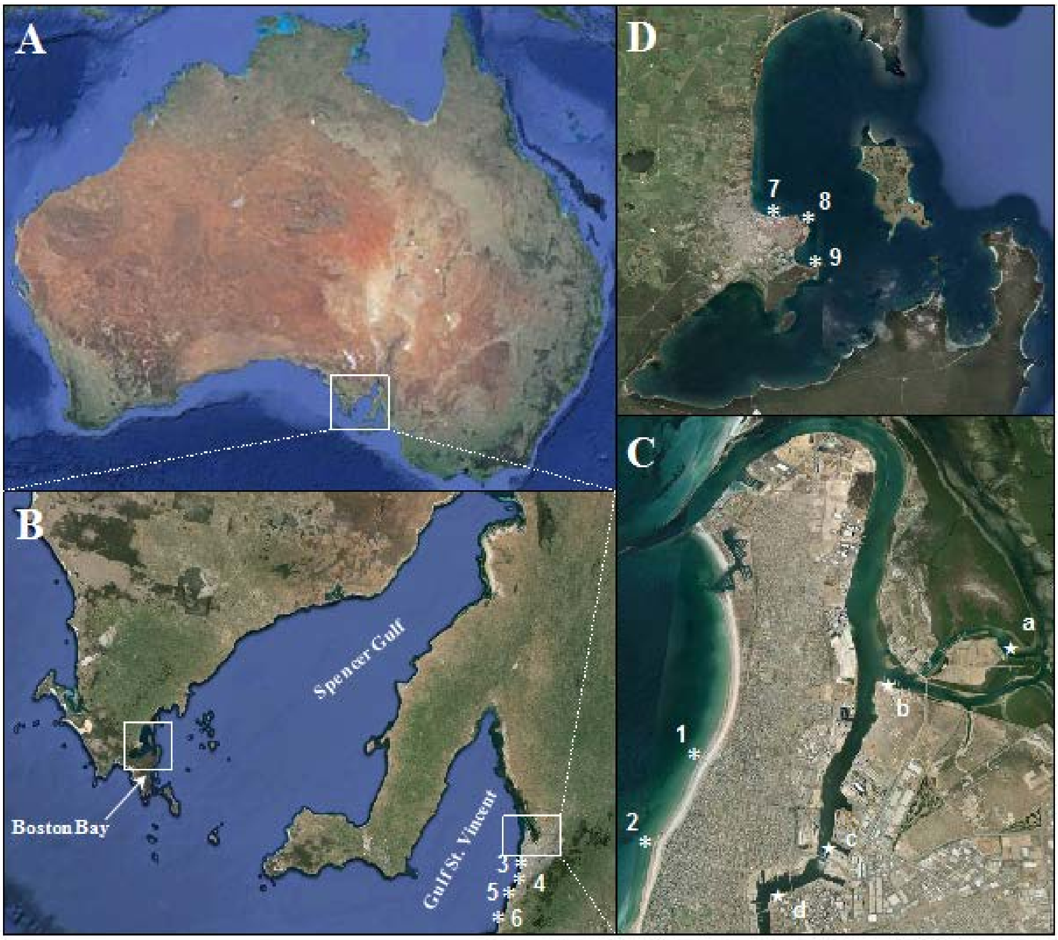

Figure 7.1: Locations of the observation sites in South Australia (B), with stars and asterisks respectively indicating the locations impacted by anthropogenic activities within the Port Adelaide River-Barker Inlet Estuary (C) and the control observation sites located both along the metropolitan coast of Adelaide (B,C) and in Boston Bay (D). The numbers indicate the sites investigated along the Adelaide metropolitan coast (1: Semaphore; 2: Grange; 3: Henley; 4: Glenelg; 5: Brighton; 6: Port Noarlunga) and in Boston Bay (7: Port Lincoln Jetty; 8: Lincoln Marine Science Centre (LMSC); 9: Billy Lights Point). The letters indicate the sites investigated within the Port Adelaide River-Barker Inlet Estuary (a: The Angus Inlet at Garden island; b North Arm in the Barker Inlet; c: Dock 2 in Port Adelaide; d: Port Adelaide Inner Port).

Figure 7.2: Details of the study sites within the Port Adelaide River-Barker Inlet Estuary; The Angus Inlet at Garden Island (A), North Arms in the Barkers Inlet (B), Dock 2 in Port Adelaide (C), and the Port Adelaide Inner Port (D). The inset in (A) shows an archetypical example of the environment experienced by dolphins along the metropolitan beaches of Adelaide.

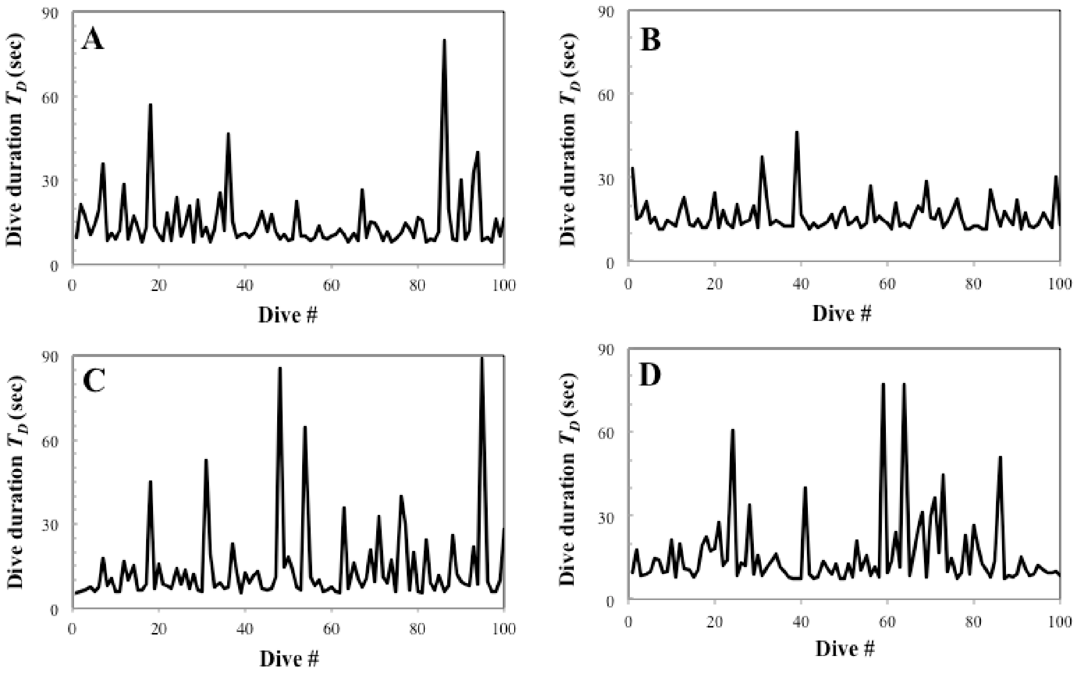

Figure 7.3: Examples of dive duration patterns observed in *Tursiops aduncus* in the absence of boats (A,B) and where boats were present (C,D) at Garden Island in the Adelaide Dolphin Sanctuary (A,C) and in Port Noarlunga, the southernmost site investigated along the Adelaide metropolitan coastal waters (B,D).

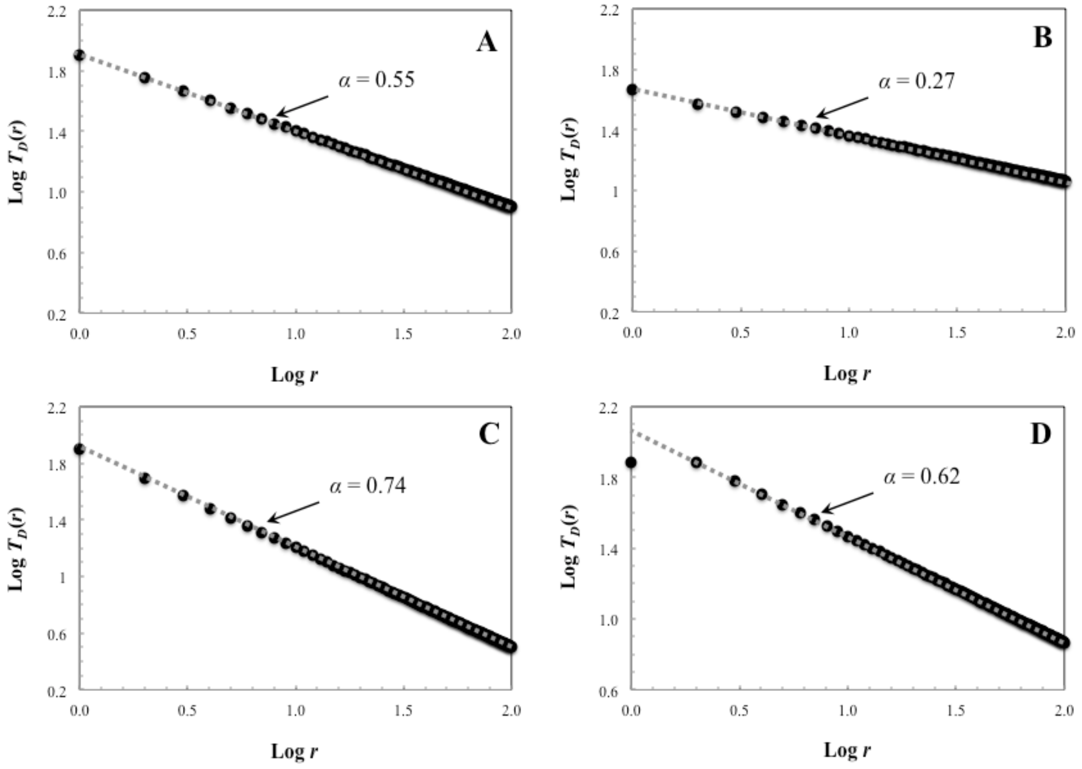

Figure 7.4: Log-log plots of dive durations $T_D(r)$ versus their rank r observed in *Tursiops aduncus* in the absence of boats (A,B) and where boats were present (C,D) at Garden Island in the Adelaide Dolphin Sanctuary (A,C) and in Port Noarlunga, the southernmost site investigated along the Adelaide metropolitan coastal waters (B,D). The dotted line is the best linear regression fit of the empirical function $T_D(r) = k_2r^{-\alpha}$.

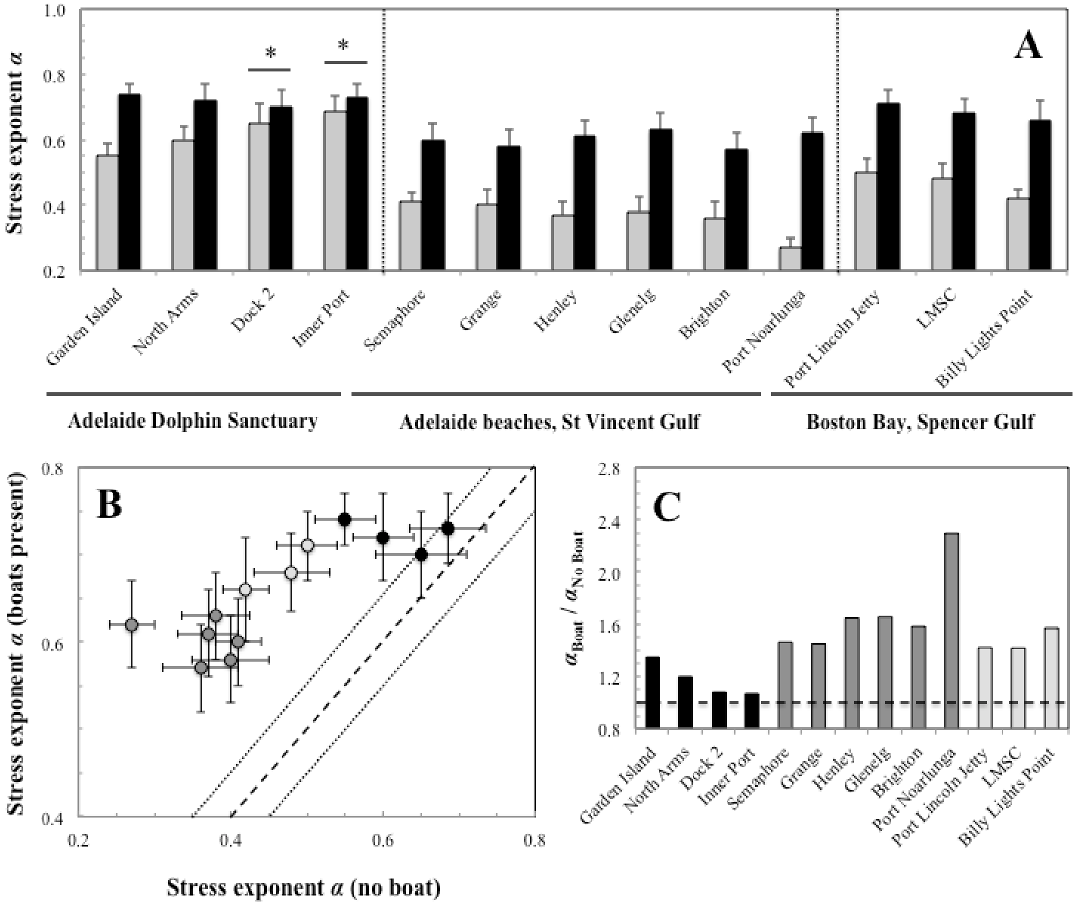

Figure 7.5: (A) The stress exponent α estimated in the absence (grey bars) and presence (black bars) of boats at 13 sites scattered over 3 distinct areas across South Australian coastal waters. (B) The stress exponent α estimated in the absence of boat ($\alpha_{\text{No boat}}$) and when boats were present (α_{Boat}) in the Adelaide Dolphin Sanctuary (black dots), Boston Bay (light grey dots) and along the metropolitan coast of Adelaide (dark grey dots). (C) The relative difference in behavioural complexity induced by boat presence, estimated as the ratio between the stress exponents estimated in the absence and presence of boats, *i.e.* α_{Boat} / $\alpha_{\text{No boat}}$. The dashed line in (B) is the first bissectric, *i.e.* $\alpha_{\text{No boat}} = \alpha_{\text{Boat}}$, and the dotted lines its 95% confidence limits. The dashed line in (C) indicate the case where α_{Boat} / $\alpha_{\text{No boat}}$, i.e. $\alpha_{\text{No boat}} = \alpha_{\text{Boat}}$. The error bars in (B) and (C) are the 95% confidence interval.

Chapter 8

New Evidence for Bottlenose Dolphin (*Tursiops spp.*) population connectivity between Kangaroo Island and South Australian Mainland waters

8.0 Abstract

Limited information regarding the movements of bottlenose dolphins around the South Australian coastline exists. The need to overcome this paucity of information is considered crucial for effective conservation and management initiatives in these waters. This preliminary study aims to identify potential movements of bottlenose dolphins (*Tursiops* spp.) between Kangaroo Island and the South Australian mainland. Images of bottlenose dolphins were examined from three separate photo-identification catalogues collated from around the South Australian coastline. Ten individuals were identified between Kangaroo Island and the Fleurieu Peninsula, whilst no matches were made between these two locations and the Adelaide Dolphin Sanctuary catalogue. Our results presented here demonstrate the highly mobile nature of this species within South Australian waters as well as establish photo-identification as an effective non-invasive tool in which to monitor long-term movements. It is anticipated that results will benefit the development of effective management and conservation initiatives in this area.

8.1 Introduction

Bottlenose dolphins (*Tursiops* spp.) are found globally throughout temperate and tropical seas, and are frequently observed in shallow coastal habitats as well as offshore oceanic waters (Leatherwood & Reeves 1983). This species is commonly occurring in South Australian waters (Kemper & Ling 1991, Kemper 2004; Cribb *et al*. 2012). Baseline information regarding the ecology, distribution and movements on this species and the potential connectivity between local populations in this region is, however, still very limited, with most information based upon stranding records (Kemper & Ling 1991, Kemper 2004). However, previous studies have provided evidence of bottlenose dolphins occurring within both Spencer Gulf and Gulf St. Vincent as well as in the vicinity of Adelaide (Kemper *et al*. 2006, Bilgmann *et al*. 2007, Kemper *et al*. 2008). and in particular the Port River – Barker Inlet estuary (The Adelaide Dolphin Sanctuary) where they are known to be resident all year round (Kemper *et al*. 2008, Cribb *et al*. 2012).

Information on the movements of individuals between populations is considered key in understanding their space-time, preference and use of specific locations (Cribb *et al*. 2012). Providing evidence of such movements and the use of specific locations is therefore the first stage in establishing and implementing effective management strategies (Robinson *et al*. 2012). This is particularly relevant for South Australian waters with the ever increasing range of human impacts in this region, for example, habitat degradation, costal and industrial development, aquaculture, fisheries, intentional killings and pollution (Kemper & Gibbs 2001, Kemper *et al*. 2006). This is even more of a concern for bottlenose dolphins in this region due to their wide and coastal distribution and their vague population units which therefore potentially exposes them to a wider variety of threats and makes them more vulnerable.

The recognition of animals from naturally occurring markings is an important tool for the study of animal populations and their movements (Stevick *et al*. 2001). In particular, this technique has been applied to examine the ecology, behaviour and movement patterns of cetaceans (*e.g*. Katona & Whitehead 1981, Neumann *et al*. 2002). More specifically, the application of this technique has provided insight into the movements and distribution of bottlenose dolphins in numerous locations at the global scale (O'Brien *et al*. 2010, Laska *et al*. 2011, Cribb *et al*. 2012, Tobena *et al*. 2014). Photo-identification of bottlenose dolphins is used to identify individuals non-invasively by using distinctive dorsal fin features, for example nicks and notches present on both the trailing and leading edges of the fin and tip (Würsig & Würsig 1977, Wursig & Jefferson 1990). It is cost-effective, can benefit from citizen science approaches and also has the great advantage of avoiding physical capture, handling, application of a mark (Wells 2009), as well as the potential short-term and long-term harm related to the biopsy samples used in genetic tagging studies (Kiszka *et al*. 2010, Noren & Mocklin 2011).

This study documents the first evidence of movements and connectivity of bottlenose dolphins between Kangaroo Island and the South Australian mainland, based upon photo-identification data obtained from 3 separate studies carried out around South Australia.

8.2 Methodology

Potential movements of bottlenose dolphins in South Australian waters were investigated through photo-identification techniques applied to dorsal fin images obtained from three distinct sites (Figure 8.1), which are representative of the gradient of oceanographic conditions, hence the related variety of habitat types, encountered in South Australian waters.

Kangaroo Island is located at the edge of the South Australian continental shelf, and both its location and geometry shelter Gulf St. Vincent - a shallow (mean water depth 21 m), low energy inverse estuary (Käempf 2014) - from the predominantly southwest swell generated by the Southern Ocean (Fuller *et al*. 1994, Harris 1994, Porter-Smith *et al*. 2004). As such, Kangaroo Island is characterised by contrasted oceanographic conditions; its southern coasts are directly exposed to the Southern Ocean swell, while its northern shores are more similar to the sheltered conditions encountered in Gulf St. Vincent. The 16 stations considered in the coastal waters of Kangaroo Island were consistently characterised by soft benthic substrates consisting of a mosaic of bare sand and seagrass meadows.

Two mainland sites - the Port Adelaide River-Barker Inlet estuary and the southern Fleurieu Peninsula, including Cape Jervis on the west coast and Victor Harbor in Encounter Bay - were chosen for their distinct exposure to the open ocean. First, the Port Adelaide River-Barker Inlet estuary, where *Tursiops* spp. is a known resident (Kemper *et al*. 2008, Steiner & Bossley 2008), is located on the north-eastern side of Gulf St. Vincent, 15 km north of the metropolitan city of Adelaide. This estuary, declared the Adelaide Dolphin Sanctuary (ADS) in 2005, with the intent to protect and conserve both the dolphins and their habitat covers 118 km^2 of shallow waters (*i.e*. 0.5 to 17 m; Cribb *et al*. 2008, 2012). Specifically, the southern area of the sanctuary is a sheltered water complex, fringed by mangrove forest, and dissected by numerous shallow bare sand channels (Jones *et al*. 1996). In contrast, the northern area extending northwards out into the open waters of Gulf St. Vincent, is dominated by the presence of seagrass beds, predominantly *Posidonia* sp., *Zostera* sp. and *Heterozostera* spp. occur (Connolly 1994, Bloomfield & Gillanders 2005). Both of these habitat types represent important areas utilised by dolphins in this area (Cribb *et al*. 2012). Second, Victor Harbor is located on the western side of Encounter Bay, a large shallow and sheltered embayment where southern right whales, *Eubalaena australis*, are recurrently observed forming aggregations (Burnell & Bryden 1997); both unaccompanied individuals and females typically return annually to these nearshore waters to give birth, raise young, and socialize (Burnell & Bryden 1997, Carroll *et al*. 2014). At Cape Jervis, and the 6 locations considered in Encounter Bay, the benthic substrates were consistently made of a mosaic of bare sand and seagrass meadows.

Photographs were taken over the period from 2005 to 2015, and dorsal fin images were maintained in three distinct catalogues according to each of the three study locations. These catalogues were used to identify individual dolphins from matches of distinctive dorsal fin features, such as nicks and notches present on both the trailing and leading edges of the fin and tip; see Würsig & Jefferson (1990) and Würsig & Würsig (1997). Photographs were all taken using high resolution digital cameras and fin images were downloaded and sorted using either Windows Office Picture Manager (as accessible to everyone) or using Adobe *Photoshop Elements* imaging software. Images were analysed using standard photo-identification methods (Würsig & Jefferson 1990, Mazzoil *et al*. 2004) and were graded according to their quality (*i.e.* excellent, average and poor; Baird *et al*. 2008, 2009). Those photographs deemed excellent (*e.g.* fin angled parallel, sharp focus, no water droplets present, minimal glare and fin occupying a large proportion of the screen) were then used in the analysis. However, some photographs that were considered of average quality (*i.e.* those photographs of slightly lower resolution, but still providing a clear and non-ambiguous match of the animal) were occasionally deemed sufficient in order to provide a match were included. Poor quality photographs were always discarded from the analysis. Photographs from each of the 3 catalogues was then checked systematically against each other in order to assess whether animals had been resighted between locations and additionally to determine the number of resights of individuals. Individuals resighted in both locations were also additionally checked across a pre-existing catalogue from the ADS.

8.3 Results

8.3.1 *Kangaroo Island*

Photo-identification surveys have been running from Kangaroo Island since November 30, 2005. A total of 170 boat based surveys have been conducted with dolphins having been sighted on 165 occasions. In total 3518 dolphins were sighted, with 233 recognisable individuals catalogued. Specifically, 69 individuals (29.6%) were sighted on only one occasion, and 164 (70.3%) on 2 or more occasions. Specifically, 33 were seen on 2 occasions (14%) and 107 were sighted on 3 to 10 (46%) occasions. Eighteen. (8%) individuals were sighted on 11-20 occasions and 6 (3%) were sighted on 21 or more occasions.

8.3.2 *Fleurieu Peninsula*

Boat based surveys were initiated in the Southern Fleurieu Peninsula, including Cape Jervis and Encounter Bay on its east and west coasts on April 20, 2011 and has been ongoing since. To date 60 surveys have been completed, with dolphins sighted on 53 occasions. These surveys led to 654 dolphins sighted, with 74 recognisable dolphins catalogued. The resighting frequency is similar to Kangaroo Island, with 56 individuals (75.7%) resighted on 2 or more occasions. Specifically, 13 individuals were seen on 2 occasions (18%) and 30 were sighted on 3 to 10 (41%) occasions. Ten (14%) individuals were sighted on 11-20 occasions and 3 (4%) were sighted on 21 or more occasions.

8.3.3 *The Adelaide Dolphin Sanctuary*

Standardised boat based surveys were conducted in the boundaries of the Adelaide Dolphin Sanctuary between the 6 March 2009 and 19 January 2011. In total 11 surveys were completed, with dolphins sighted on all 11 occasions. In total 181dolphins were sighted over this period with 1039 images being taken and 487 deemed of excellent quality being used in the analysis. This resulted in 40 recognisable individuals being catalogued. These 40 individuals were sighted between 1 and 3 times. Of the 40 recognisable individuals only 14 (35%) were resighted, with 12 and 2 individuals seen on 2 occasions (30%) and 3 (5%) occasions respectively. Overall 18 resightings, (39%) over bare sand, (61%) over seagrass.

8.3.4 *Interstudy matches and Resightings*

None of the bottlenose dolphins catalogued in the Adelaide Dolphin Sanctuary were resighted either in Kangaroo Island or in the Southern Fleurieu Peninsula. In contrast, 10 individuals were matched between the Kangaroo Island and Victor Harbor/Cape Jervis catalogues during the study period (Table 8.1). These resightings have consistently occurred from 2011 to 2015, and ranged between 1 and 7 (Table 8.1). Nine of these individuals were first in the coastal waters of the Fleurieu Peninsula, resighted 1 to 4 times in various locations before being subsequently resighted in Kangaroo Island after a time-lag ranging from 6 days to 15 months (Table 8.1). Two of them were observed back in Kangaroo Islands 4 to 9 months after their last sighting in the Fleurieu Peninsula. Only one individual was first sighted in Kangaroo Island, where it was resighted twice in nearly two years, before being resighted in the Fleurieu Peninsula 15 months later and making the trip back to Kangaroo Island in 6 days (Table 8.1).

8.4 Discussion

Our results provide the first evidence of connectivity between *Tursiops* spp. observed in the coastal waters of mainland South Australia and Kangaroo Island. These exchanges are, however, limited to the southern waters of the Fleurieu Peninsula and Kangaroo Island, as no match was found between the dolphins catalogued in the Adelaide Dolphin Sanctuary and either in Kangaroo Island or in the Fleurieu Peninsula. These results suggest that (i) there is no latitudinal connectivity between the *Tursiops* spp. populations of the north (*i.e.* Adelaide Dolphin Sanctuary) and south (*i.e.* Kangaroo Island and southern Fleurieu Peninsula) waters of Gulf St. Vincent, and (ii) there are regular longitudinal cross-overs between Kangaroo Island and the southern Fleurieu Peninsula through Backstairs Passage for time scales ranging from a few days to 15 months.

These results are consistent with previous results showing that the Adelaide Dolphin Sanctuary supports a small population of approximately 30 resident individuals - a figure compatible with the 40 recognisable individuals catalogued in the present work - as well as visiting non-regular transient animals (Kemper *et al*. 2008, Steiner & Bossley 2008). More specifically, these observations are also consistent with evidence that protected, shallow and narrow waterways which are geographically further from the open ocean such as the Adelaide Dolphin Sanctuary (see Figure 8.1D) generally promote limited movement patterns and therefore some degree of site fidelity (Defran & Weller 1999, Gubbins 2002). This is in contrast with open habitats where dolphins have more extensive home ranges and a lesser degree of site fidelity (Defran & Weller 1999, Gubbins 2002). In this context, a recent study conducted in the Adelaide Dolphin Sanctuary to assess potential habitat preference (*i.e.* bare sand *vs.* seagrass meadows) hypothesized that individuals resighted consistently over time in the bare sand habitat may hence potentially represent resident individuals, and therefore those sighted on fewer occasions in the seagrass habitat may be transients (Cribb *et al*. 2012). This hypothesis is consistent with the preference of the dolphins observed in Kangaroo Island and in the southern Fleurieu Peninsula for seagrass meadows. More generally, our observations are also congruent with studies conducted in the western Atlantic and Ireland (Scott *et al*. 1988, O'Brien *et al*. 2010) that suggested that coastal stocks of bottlenose dolphins are comprised of residents (which are confined to certain areas) and transients (which migrate seasonally in and out of areas), which do not mix. These dolphins have also been reported to travel routinely back and forth between coastal locations, with movements occurring along narrow specific corridors close to shore (Defran *et al*. 2015), an observation consistent with the cross-overs observed between Kangaroo Island and the southern Fleurieu Peninsula. It is suggested however, that further, work investigating potential connectivity between the two southern study sites and the northern waters of the Adelaide would however beneficial.

Potential exchanges between South Australian populations of bottlenose dolphins have previously been investigated across Spencer Gulf and coastal waters west of the gulf in the Great Australian Bight (Bilgmann *et al*. 2007). Using data from mitochondrial DNA control region sequences and 6 microsatellite loci, Bilgmann *et al*. (2007) found marked genetic differentiation and low migration between bottlenose dolphins of the Spencer Gulf and those inhabiting coastal areas west of the gulf. These authors hypothesized that the restriction to dolphin gene flow is related to the oceanographic front that builds up at the mouth of Spencer Gulf over the austral summer due to strong differences in water temperature and salinity between surface and bottom waters that culminate in winter when the salty dense waters formed in the Spencer Gulf during summer cascade as a density current following winter cooling (Lennon *et al*. 1987, Petrusevics 1993). In contrast to Spencer Gulf, vertical stratification (and density currents) rarely exist in Gulf St. Vincent where it is more horizontal (Bye 1976, de Silva Samarasinghe & Lennon 1987), due to the strong tidal flows (up to 1 m^{s-1}) occurring in Backstairs Passage that operate to destroy any vertical density stratification. Vertical stratification does, however, occur in northern Spencer Gulf, South of the swift tidal flows (*i.e.* up to 1 m^{s-1}; Noye & Grzechnik 1995) in Backstairs Passage that operate to destroy any vertical density stratification. Vertical stratification does occur, however, in the northern part of Gulf St. Vincent, south of the the Port River – Barker Inlet estuary (Käempf 2006), and may hence represent a barrier to a southward dispersal of the bottlenose dolphin population of the Adelaide Dolphin Sanctuary. This hypothesis is consistent with previous evidence of both direct and indirect influence of oceanographic properties (*e.g.* temperature and salinity) on bottlenose dolphins. In the Black Sea, the distribution of bottlenose dolphin populations matched areas segregated by their oceanographic properties (Natoli *et al*. 2005). The distribution of coastal bottlenose dolphins may also be indirectly influenced by the effects physical oceanographic barriers such as fronts have on their prey distribution (Dowling & Brown 1993).

This study demonstrates the ability of non-invasive and cost-effective techniques such as photo-identification as a reliable tool that can be used as a basis to design habitat studies, but also to study dolphin movement and population connectivity without using much controversial tools based on live biopsy samples (Noren & Mocklin 2011). This issue is particularly critical in terms of management and conservation of South Australian bottlenose dolphins particularly as the taxonomy of the species in South Australian waters is still debatable and additionally as these waters are also increasingly threatened by a range of anthropogenic disturbances such as the development of desalination plants, fisheries, aquaculture, anthropogenic sound and oil and gas exploration (Kemper & Gibbs 2001, Käempf & Clarke 2013, Bilgmann *et al*. 2014). Specifically, genetic evidence, based on both mtDNA and microsatellite data, suggests that coastal bottlenose dolphins from South Australia, Victoria and Tasmania are evolutionarily distinct from the 2 other recognised bottlenose dolphin species (Charlton *et al*. 2011). As such, if some populations do not mix with other ones and others use specific migration corridors - as this seems to be the case from our results - the unique diversity of South Australian coastal waters and gulfs offer a rare opportunity to develop a more focused approach of the management and conservation of their bottlenose dolphin populations.

8.5 Acknowledgements

Nedra Haines, Rob Laver, Verity Gibbs, Brett Williams, Kangaroo Island Marine Adventures, The Big Duck Boat Tours are acknowledged for providing resources and support in the collection of data. Volunteers from Kangaroo Island and Victor Harbor Dolphin Watches are acknowledged for their timeless effort and contribution to the collection of data in the field and the countless hours of photo-identification analysis and the establishment and organisation and maintenance of photo-identification catalogues.

Table 8.1: Summary of the number of individual bottlenose dolphin (*n*) movements according to the initial sighting (S) and subsequent resightings (RS) according to date (D) and location (L).

n	**1st S**		**1st RS**		**2nd RS**		**3rd RS**		**4th RS**		**5th RS**		**6th RS**		**7th RS**	
	D	**L**	**D**	**L**	**D**	**S**	**D**	**L**	**D**	**L**	**D**	**L**	**D**	**L**	**D**	**L**
1	20.5.11	*YR*	2.5.12	*WI*	27.7.12	*SA*	10.8.12	*SA*	14.10.13	**CR**	25.11.13	**NC**	22.12.13	**NC**	21.7.14	**NC**
2	2.5.12	*WI*	21.12.12	*OR*	14.1.13	*YR*	27.3.13	*YR*	8.10.13	*YR*	5.6.14	**AB**	8.3.15	*WR*		
3	30.8.11	*GI*	11.2.14	*GI*	27.4.15	**BB**										
4	13.11.12	*YR*	21.12.12	*OR*	14.1.13	*YR*	8.6.13	*WI*	8.10.13	*YR*	5.6.14	**AB**	15.10.14	*WI*		
5	2.7.13	*OR*	3.12.13	*WTI*	30.3.15	**NC**										
6	3.12.13	*WTI*	8.12.14	**HB**												
7	5.4.11	**BBH**	6.3.13	**HB**	31.5.14	*CJ*	5.6.14	**AB**	8.12.14	**HB**	13.6.15	**HB**				
8	3.12.13	*WTI*	5.6.14	**AB**	8.12.14	**HB**										
9	31.5.14	*CJ*	9.8.14	*CJ*	5.6.14	**AB**										
10	31.5.14	*CJ*	5.6.14	**AB**												

The Fleurieu Peninsula and Kangaroo Island observation site locations are respectively shown in italics and bold;

Yilki Reef: YR; Wright Island: WI; Shark Alley, SA; Olivers Reef: OR; Granite Island: GI; West Island: WTI; Cape Jervis: CJ, Cape Rouge: CR; North Cape: NC; Boxing Bay: BB; Hog Bay: HB; Browns Beach: BBH

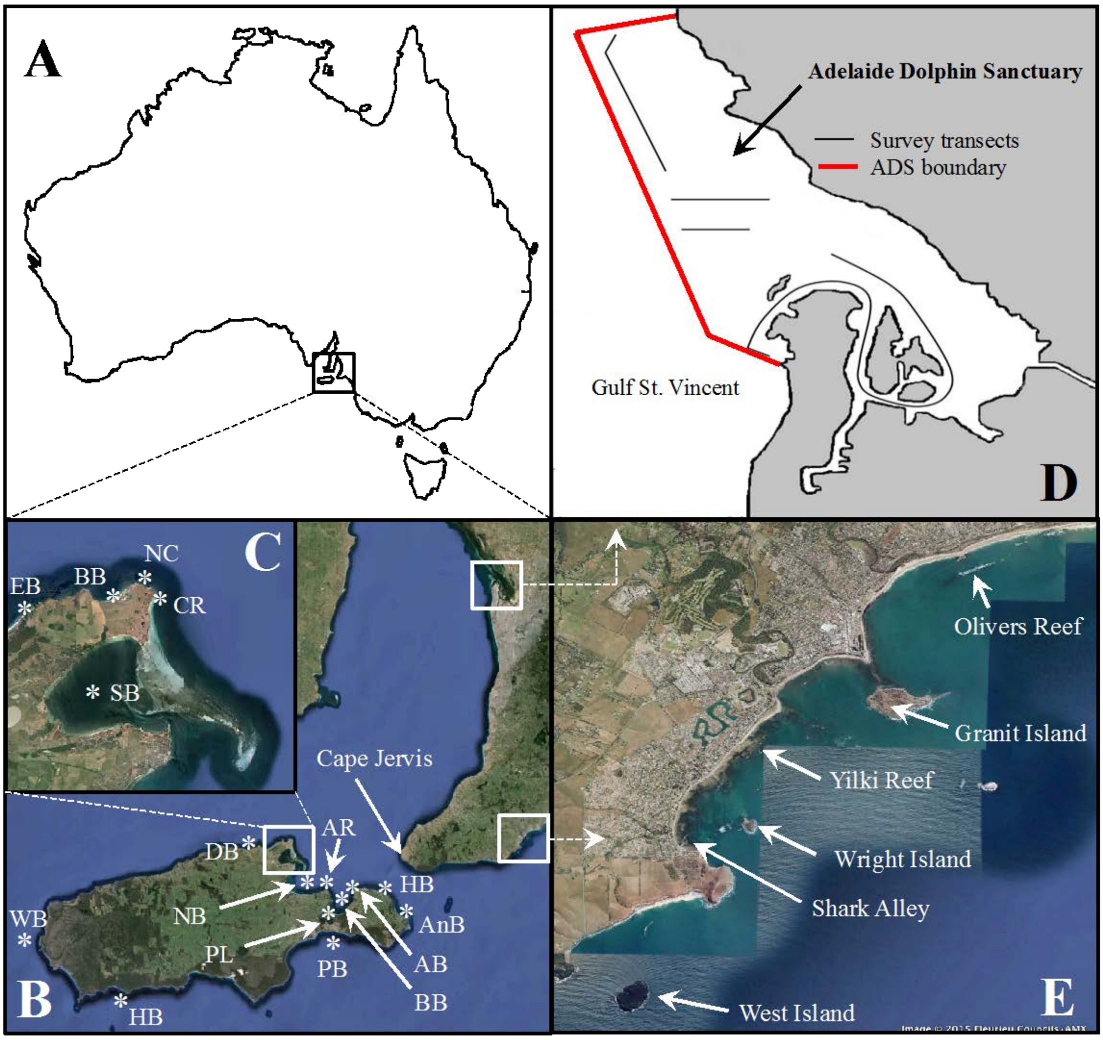

Figure 8.1: Location of the study area in South Australian waters (A,B). Our study considered five sites in Kangaroo Island (B,C), and two mainland locations, the southern Fleurieu Peninsula (B,E) and the Adelaide Dolphin Sanctuary (D) that include respectively seven sites (one at Cape Jervis and six around Victor Harbor in Encounter Bay), and 4 survey transects. EB: Emu Bay, BB: Boxing Bay; CN: North Cape; CR: Cape Rouge; SB: Shoal Bay; NB: Nepean Bay; AR: American River; PL: Pelican Lagoon; BB: Browns Beach; AB: American Beach; HB: Hog Bay; AnB: Antechamber Bay; PB: Penington Bay; HB: Hanson Bay; WB: West Bay.

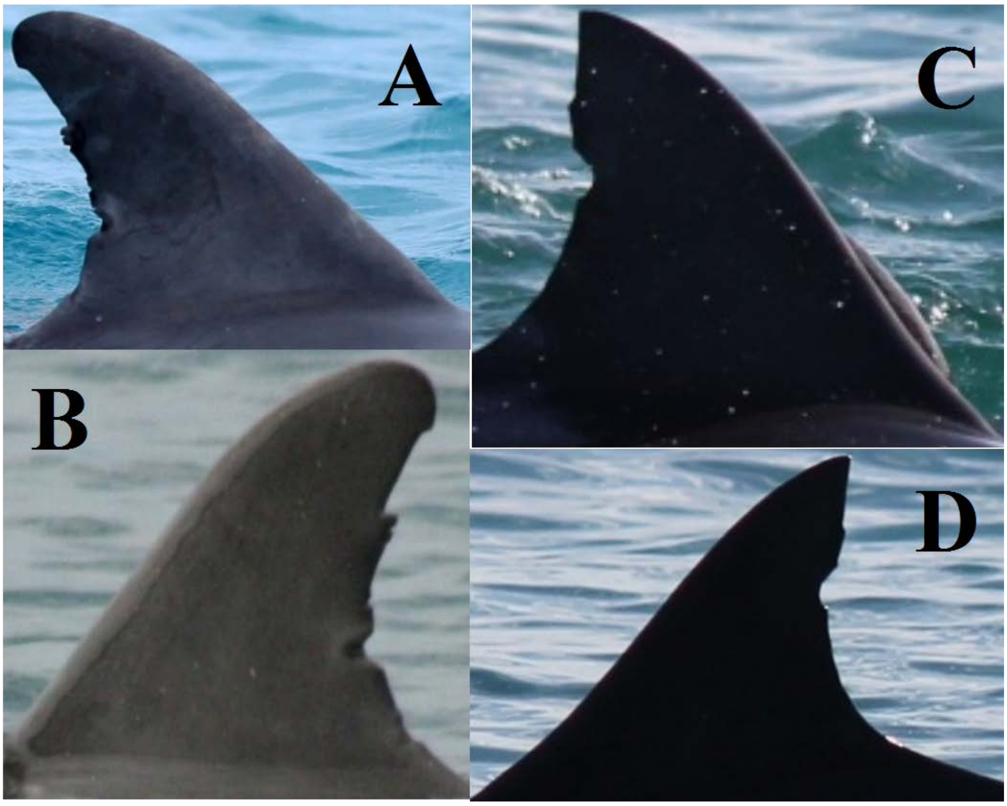

Figure 8.2: Examples of photo-identification of dolphins based on the distinctive features of their dorsal fin for an individual first sighted in Kangaroo Island (A) and resighted in Encounter Bay (B), and an individual first sighted in Encounter Bay (C) and resighted in Kangaroo Islands (D).

Chapter 9

General Discussion

9.1 Overview

The research presented in this thesis was stimulated by the current lack of knowledge and concerns raised regarding the habitat and much needed conservation and management efforts of many cetacean species. The recurring theme and observation throughout this thesis has been that in order to progress our efforts to conserve these animals, we must first develop a greater ecological understanding of their relationships with their surrounding marine environment by applying a more systematic and objective approach to habitat studies. This final chapter summarises the major findings and outcomes of the thesis, by addressing the results from each of the chapters, within the context of the specific objectives which were exposed in Chapter 1.

9.2 Synthesis of Results

9.2.1 *Describing cetacean habitat and moving towards a more standardised rationale and approach to habitat studies*

The purpose of Chapter 2 was to provide an overview of what habitat means for an organism and how it has previously been defined, with the aim of providing a possible explanation as to why there is a lack in consensus within defining cetacean habitat. The overview of the various similarities and differences between terrestrial and marine environments provided a context in which to demonstrate that our limitation to understanding habitat generally lies in the environment itself. Cetaceans live in a three-dimensional, fluctuating and heterogonous environment, which implies that the actual conditions of the marine environment potentially are the ultimate factor driving their choice of environments, rather than other factors *e.g.* resource availability (see Miller & Cribb 2009; Cribb *et al*. 2015). However, without investigating these factors further, the way cetaceans are interacting with their environment may only be based upon assumptions of distribution patterns (Miller & Cribb 2009; Cribb *et al*. 2015). Furthermore, as the marine environment differs in time and space it cannot be assumed that populations of the same species are using their environment in the same manner as individuals in a different location.

Additionally we summarised the distinctions in how habitat has been measured for various cetacean species. We then provided discussion as to the possible reasons behind these differences found in the variables measured for different species (Table 2.3), as well as some thoughts on the application of these studies to understanding cetacean habitat. Furthermore, we also discussed the application of modelling (Table 2.4) within field-based habitat studies and highlighted again the lack of convergence in the approaches, methodologies, spatial and temporal scales and analyses applied, even when applied to same species (Cribb *et al*. 2015).

In this context the consideration of a standardised approach of cetacean habitat, was suggested as a way to provide a more objective and quantitative foundation to cetacean habitat studies. Measuring variables ultimately leads to analysis which enables the examination of underlying biological processes and the understanding of the marine environment that a cetacean inhabits (Miller & Cribb 2009; Cribb *et al*. 2015). Furthermore, it provides a wider insight into the ecosystem the individual or population interacts with. Such an approach, hence, offers the opportunity to produce information which is more applicable and useful in a management context.

Chapter 2 highlighted and demonstrated the unique and relevant considerations that should be addressed when undertaking a cetacean habitat study. Even though the ability to measure key factors of cetacean habitat is frequently constrained by available resources and practicality of field work, an immediate starting point is to apply a prior analyses of the species and study location and then a standardised, broad and quantitative approach which measures the primary range and optimal abiotic and biotic conditions of where the animals are sighted.

9.2.2 *On the application of a rationale to two species of small delphinids with differing life histories occurring in contrasted ecosystems*

The identification and understanding of the underlying ecological drivers of dolphin habitat is vital in order to implement effective management initiatives within sanctuaries and small marine protected areas (MPAs; Cañadas *et al*. 2005, Hoyt 2005, Miller & Cribb 2009, Hooker *et al*. 2011, Pérez-Jorge *et al*. 2015). Chapters 3 to 6 demonstrated the application of our rationale and approach to two small delphinid species (*Tursiops aduncus* and *Stenella longirostris*) from contrasting environments, with differing life histories, threat and management constraints.

Indo-Pacific bottlenose dolphins in the Adelaide Dolphin Sanctuary, South Australia

Chapters 3 and 4 investigated the habitat characteristics of a small bottlenose dolphin population inhabiting the temperate coastal waters of the Adelaide Dolphin Sanctuary, South Australia. The data presented in Chapter 3 demonstrated the application of the non-invasive technique of photo-identification to identify a potential preference between the two benthic habitat types present within the ADS; *i.e*. bare sand and seagrass. Specifically, through the resighting frequency of individual animals, our findings established a significant preference of the bare sand habitat, with this trend consistently observed over both seasonal and annual scales. This suggests the importance of this benthic habitat for this population and is consistent with previous findings that reported dolphins preferring one habitat type to another, especially in estuarine areas adjacent to open waters (Shane 1990; Ballance 1992; Allen et *al*. 2001).

In Chapter 4, we extended our investigation to include those variables potentially impacting dolphin distribution and behaviour by using a fine scale *in situ* technique. This involved comparing environmental water properties where dolphins were present and absent over both space and time.

In contrast to previous studies, we did not limit our sampling of environmental water properties to surface waters but considered the entire water column. Additionally, we also encompassed behavioural observations in relation to benthic habitat type, which provided a unique opportunity to help understand the general ecology of animals in this area. Although differences in the measured environmental water properties were observed, no direct links were identified between oceanographic factors, dolphin group composition and size and behavioural activity. Although these findings are in contrast to those identified by previous studies (*e.g*. Wilson *et al*. 1997; Ingram & Rogan 2002; Fury & Harrison 2011), our results still provide inside to the habitat characteristics and requirements of this small population. Additionally, this poses further questions as to whether habitat choices are in fact driven by the social structure of the resident animals observed within the sanctuary boundaries or are a result of the behavioural response of dolphins in this area to the various chronic and acute anthropogenic activities that occur within the ADS.

Spinner dolphins within a tropical reef complex, Fijian Islands

Chapters 5 and 6 aimed to identify the key habitat characteristics of a small population of spinner dolphins (*Stenella longirotris*) who had been regularly observed to frequent a small tropical reef complex off the main island of Fiji, Moon Reef. No prior knowledge exists about this population and they are now at risk from increasing tourism activities. As such preliminary information would ultimately assist in the management plans that have been proposed for this recently declared marine protected area (see http://uk.whales.org/blog/2011/05/new-marine-protected-area-declared-for-spinner-dolphins-in-moon-reef-fiji). In Chapter 5 we aimed to quantify whether spinner dolphins were primarily using this reef as a resting habitat and whether individuals were repeatedly frequenting this location. Spinner dolphins are known to typically utilise protected and shallow reefs and bays during daylight hours to rest and socialise (Norris & Dohl 1980). With the application of photo-identification techniques we established rest as the most consistent behaviour the animals engaged in, as well as 70% of all individuals identified being resighted within the reef on 2 or more occasions.

As previous studies on spinner dolphins have predominantly focused on their behaviour whilst in their chosen resting habitats (see *e.g.* Notarbartolo-di-Sciara *et al*. 2009; Cribb *et al*. 2012), we specifically tried to specifically try to identify why they potentially choose them. In this context, in Chapter 6 we conducted biological and oceanographic surveys within and outside Moon Reef and, Horseshoe Reef in close geographical vicinity, which was never used by spinner dolphins to potentially identify what is so special about Moon Reef. No differences were identified between the two reefs in terms of the abiotic structure of the reefs and their benthic substrates, their fish and invertebrate communities present or the physical and biological waters properties. The choice of Moon Reef as a resting habitat for this population may therefore be linked to the lack of predators observed and its proximity to offshore feeding grounds.

9.2.3 *On the application of standard and non-standard non-invasive methods to further our understanding of cetacean habitat.*

Bottlenose dolphin behavioural complexity in response to human disturbance

The results presented in Chapter 7 presented the findings of dolphin dive behaviour complexity in relation to anthropogenically driven stresses. Dive durations opportunistically recorded from land-based stations located across South Australian coastal waters found no significant differences in the absence of boat traffic, and in the presence of motorboats. In contrast, the application of fractal analysis consistently identified significant differences in the complexity of dive duration patterns as a function of environment and exposure to human disturbance. The results presented in this chapter demonstrate how standard behavioural metrics and the application of traditional marine mammal behavioural assessment techniques may not be sensitive enough to identify potential behavioural changes in the presence of human disturbances as previously stressed in a different context (Seuront & Cribb 2011). This is particularly pertinent valid for coastal areas such as the Adelaide Dolphin Sanctuary, which are extremely vulnerable to human impacts (Kelly *et al*. 2004).

Bottlenose dolphin connectivity within South Australian waters

In Chapter 8 the movements and connectivity of bottlenose dolphins between the South Australian mainland and Kangaroo Island were investigated using photo-identification data obtained from three photo-identification studies carried out around South Australia (Kangaroo Island, southern Fleurieu Peninsula, Adelaide Dolphin Sanctuary). Individuals were consistently resighted over time between the mainland and Kangaroo Island. In contrast, images compared with recognisable individuals from an existing catalogue from the Adelaide Dolphin Sanctuary, identified no matches. The results presented in Chapter 8 demonstrated the highly mobile and transient nature of bottlenose dolphins within South Australian waters. Although exchanges between the southern waters of the Fleurieu Peninsula and Kangaroo Island were limited, our results (i) demonstrate the effectiveness of non-invasive and cost-effective techniques such as photo-identification as a basis to design and support habitat studies such as those demonstrated in our two case studies and, (ii) it also highlights the need for more tailored and focused management and conservation effort in both South Australian coastal and gulf waters.

9.3 Comments on the Results and Future Directions

9.3.1 *Application of habitat rationale and approach*

In order to establish Marine Protected Areas (MPAs) and sanctuaries for cetaceans, it is crucial to identify key areas which are used for important life processes such as reproduction, feeding and migration (Clark *et al*. 2010). Additionally, when describing and measuring cetacean habitat there are some unique and relevant considerations such as scale of movement and migratory patterns, primary prey and foraging strategies and general area of distribution (Miller & Cribb 2009; Cribb *et al*. 2015). In turn, there is frequently a priority for delineating what constitutes ‘critical habitat’ to a given species (Bannister *et al*. 1996; Hoyt 2005; Miller & Cribb 2009; Cribb *et al*. 2015). However, in order to move forward with our understanding of cetacean habitat and its conservation and management we need to initially develop a comprehensive understanding of cetacean habitat, and ultimately what this actually means for them. As suggested in Chapter 2, we need to identify on a case-by-case level what this means for the species in question, the location and the threat objectives (see Chapters 3 to 6). Our approach suggested in Chapter 2, offers a foundation or framework in which to do so.

9.3.2 *Adelaide Dolphin Sanctuary, South Australia*

The dolphins of the Adelaide Dolphin Sanctuary, South Australia are a unique situation. There are only few other locations in the world where dolphins where dolphin communities occur in such close proximity to major population centres (Australian Marine Conservation Society 2005). The results shown in Chapters 3 and 4 demonstrate the application of our rationale and approach. Although our findings did not establish any direct links between the environmental water properties measured and dolphin group size, composition and behaviour, it did highlight the importance of the sheltered, bare sand habitat to this population. This result was also supported by the findings of a preliminary study in the ADS which identified that bottlenose dolphins in this area utilise particular areas for specific behaviours *e.g.* socialising, leading to the identification of core use areas (Cribb *et al*. 2008). In this context, it is suggested that further studies within the ADS are required in order to understand in more detail the complex behaviours and social structure present within this population. It should be considered that there is a complexity within this ADS population which could be attributed to the multifaceted environment in which they live, which is potentially in contrast to non-resident bottlenose dolphins. This also stresses the need for the existing management initiatives to be tailored accordingly. Further studies which focus specifically on particular behavioural activities *e.g.* feeding strategies as demonstrated by Miller & Baltz (2009) between the two benthic habitat types would additionally be beneficial. The management scheme already in place in this location needs to further encompass the relationship between dolphin behaviour and benthic habitat type. It is suggested that ongoing surveys are conducted both at the individual and group levels to assess and monitor dolphin habitat use in this area. It is hoped that the data presented here can be used as a stepping-stone to assist the current management scheme in this area. Additionally, it is endeavoured that fine scale *in-situ* technique applied within Chapters 4 can also be applied to other small coastal bottlenose dolphins both locally and globally.

9.3.3 *Moon Reef, Fiji Islands*

The confirmation and understanding of areas that are important for spinner dolphins to use as resting habitats is crucial to their management and conservation as well as providing insight into the life history and ecology of this unique species. To date there has been no dedicated studies investigating the spinner dolphins of Moon Reef and their resting habitat. Chapter 5 and 6 therefore represent the first insight into this population. Specifically, the results presented in Chapter 5 definitively established Moon Reef as a resting habitat with the same individuals frequenting it over time. With the recent establishment of Moon Reef as a Marine Protected Area (http://au.whales.org/blog/2011/05/new-marine-protected-area-declared-for-spinner-dolphins-in-moon-reef-fiji) these preliminary findings can provide much needed information.

The results presented in Chapter 6 are unique and this study is potentially the first of its kind to actually investigate the abiotic and biotic properties of a resting habitat used by spinner dolphins. Previous studies have primarily focused on their behaviour whilst in the reef, particularly in the presence of humans (see *e.g.* Courbis 2007; Delfour 2007, Shawky & Afifi 2008), whilst other studies have also just modelled where suitable locations for resting could potentially be located *e.g.* Hawaii (Thorne *et al*. 2013). However, these approaches fail in providing us with comprehensive information about the specific location and population in question.

With resting behaviour being considered vital to the survival of spinner dolphins (ref) it is therefore crucial to identify key habitat features of these resting habitats. As resting locations are repeatedly noted to be draw cards for tourists or in the direct vicinity of tourist destinations (Courbis & Timmel 2009) and with the increase of negative impacts on spinners as a result more frequently reported in the literature it is endeavoured that appropriate measures be put in place. It is recommended that the disturbances reported at Moon Reef are investigated and monitored. Specifically, to see whether the cumulative presence of vessels within the lagoon while dolphins are in rest phase has the potential to keep them in a constant state of alertness. The long-term monitoring of this population and the health of the reef would be beneficial particularly with the increased threat of global warming. In addition, the potential detrimental effects anthropogenic activities (and climate change) may have on the reef and coral species presents the potential to directly and indirectly affect dolphin fitness through the loss of reef and related fish communities.

Further studies investigating where these dolphins go to at night to feed would also be beneficial to increase our understanding of their ecology and their energy budget, a critical parameter in this species as they have high energetic needs (Norris *et al*. 1994). For instance, energetic models of spinner dolphins in Hawaiian waters indicate that they are less likely to rest when swimmers approach within 150 m (Tyne *et al*. 2015). However, no attempt has been made to develop energetic models for Moon Reef spinner dolphins and the current level of exposure to anthropogenic activities in this reef has still to be determined. These two tasks are critical for the future of this small - potentially genetically isolated - population as the assessment of the contribution of anthropogenic activities to their energetic deficit they can tolerate before being driven into an energetic debt. In addition, a population estimate would be beneficial, as well as an attempt to assess their degree of relatedness with other Fijian populations.

Additionally, the consideration of culture within the population would be valuable. Dolphins may choose to use this reef as it is passed down from generation to generation. The use of this space may be socially learned. Social differences may be different according to the population and the location. The habitat may be the driving or influencing choice in resting habitat, behaviour and social structure (Andrews *et al*. 2010). This also potentially is the case within the ADS. Some species of dolphins have been noted to keep using traditional areas even though they are now heavily polluted chemically or by noise (Whitehead 2010).

It is nevertheless worth noticing that long term monitoring may be difficult to implement and sustain due to the remoteness of the location and the extreme difficulty to develop and implement objective conservation and management plans in developing countries (Mustika *et al*. 2013, 2015).

9.3.4 *Application of non-standard behavioural techniques to monitor anthropogenic impacts on bottlenose dolphins*

Chronic exposure to even low levels of stress has implications for energy balance, physiological conditions and vital rates (New *et al*. 2013), and is likely to induce long-term consequences at the population level (Lusseau 2004, Bejder *et al*. 2006). This is a critical issue for dolphin welfare especially for those living in heavily impacted coastal waters, and particularly as previous studies have related the development and implementation of effective mitigation and management strategies because the habituation to boat traffic reported for bottlenose dolphins did not imply the absence of stress (Sini *et al*. 2005). Hence, these findings may be thought of as a pernicious threat as suggested in a preliminary study (Seuront & Cribb 2011). In this context, our results presented in Chapter 7 demonstrate how traditional behavioural sampling methods may not be sensitive enough to be able to provide the 'true' behavioural stress response to boats in dolphins living in heavily impacted coastal locations, such as the Adelaide Dolphin Sanctuary. It is therefore suggested in cases such as these that fractal analyses be applied to behavioural data as an additional method in which to help further elucidate any potential responses to stress which would not be detected through the use of standard techniques. Ultimately, this ability to assess and quantify potential stressors in more detail will essentially allow for more effective, management and conservation initiatives for these areas.

9.3.5 *Bottlenose dolphin conservation in South Australian waters*

Information on the movements of individuals between populations is considered a key in understanding their preference and use of specific areas both in space and time (Ballance 1992). Additionally this information should be considered the first stage of establishing and implementing management strategies. A different approach to conservation and management in this area needs to be considered as suggested by the identification of bottlenose connectivity in other locations (see Laska *et al*. 2011; Robinson *et al*. 2012).

As no link between Kangaroo Island, the Fleurieu Peninsula and the Adelaide Dolphin Sanctuary is apparent, it must be considered that there are potentially multiple populations of bottlenose dolphins present in South Australian waters. Bilgmann *et al*. (2007) noted no movement between inside and outside Spencer Gulf due to the presence of frontal systems. The division and lack of interaction between estuarine dolphins and adjacent coastal dolphins has however been identified elsewhere (see *e.g*. Laska *et al*. 2011). If this is the case between dolphins the inside and outside waters of

Gulf St Vincent would present a complex case of communities, with each requiring their own management plans. Additionally, as Kangaroo Island and the Fleurieu Peninsula are in closer vicinity to the Southern Ocean, some of the animals involved in these two studies might originate from alternative offshore populations of *Tursiops turncatus* rather than those coastal *Tursiops* spp. that generally have a limited coastal range (O'Brien *et al*. 2010; Hale *et al*. 2000; Kemper 2004). Hence, also limited movement between the southern and northern study locations. From this it is therefore evident that a greater collaboration between researchers in South Australian waters would be invaluable in order to further our understanding of dolphins in this area and ultimately maximise the benefit of conservation and management initiatives for this region.

The findings presented in Chapter 8 additionally demonstrate the effectiveness of photo-identification as an effective tool in which to identify and monitor long-term movements of dolphins in South Australian waters and elsewhere (see *e.g*. Wood *et al*. 1998; O'Brien *et al*.; Robinson *et al*. 2012). Additionally, the success and easy application and transfer of this scientific tool outside the research community (*e.g*. community citizen science programs such as Kangaroo Island and Victor Harbor Dolphin Watch, who have monitored dolphin populations on the long-term), demonstrate its potential in collecting much needed baseline information as well as monitoring long-term resightings of specific individuals. This is of prime importance as this approach is unlikely to be restricted by funding, which may definitely be a strong asset in an era of research budgetary restrictions.

Our results also highlight the need for concentrated management and conservation efforts in this region. Particularly, if there is a restricted amount of connectivity and movement between these populations and they are fairly independent of one another utilising multiple areas. Examples of such cases have been identified in the United Kingdom and the Republic of Ireland, which has led to the development of Special Areas of Conservation (SACs) for their resident bottlenose dolphins inhabiting for example the Moray Firth and the Shannon Estuary (Ingram & Rogan 2002, Wilson *et al*. 2004). These designated SACs under the European Habitats Directive (92/43/EEC) clearly demonstrate that developing a network of protected areas is achievable and that dolphins in key habitats and high usage areas can be afforded the protection they deserve. Something to which can only be aspired to here in South Australia. Specifically, as suggested for Irish waters (O'Brien *et al*, 2010; Robinson *et al*. 2010) an approach using small networks of sanctuary areas such as the Adelaide Dolphin Sanctuary, with linking corridors for movement may be a more vigorous and effective approach to this species conservation and management.

Additionally, with the increasing number of anthropogenic threats (*e.g*. oil and gas exploration, anthropogenic sound, fisheries) occurring in South Australian it is suggested that long-term continued monitoring efforts be conducted to further evaluate the movements of individuals as well as elucidate potential connectivity between these 3 study locations, particularly the movements between the southern study sites and the Adelaide Dolphin Sanctuary in the north. Furthermore, establishing another study site between Victor Harbor and the Adelaide Dolphin Sanctuary to potentially fill the gap would be beneficial.

9.4 Conclusion

Throughout this thesis it has consistently been demonstrated that a comprehensive and quantitative assessment, incorporating suitable techniques and methodologies is essential in which to define cetacean habitat and ultimately develop effective conservation, management and threat mitigation initiatives. Developing conservation and management strategies is good in theory on paper, however, without the appropriate information, these serve to be of little if any benefit for the species and/or the location in question. It is also recommended where possible that studies are continued long-term in order to monitor changes of habitat use and human disturbances over time and season. This is especially important considering abundance patterns have been reported to differ according to season and this may just be a reflection of the researcher's survey effort at particular times of the year *e.g.* winter rather than the animal's actual true abundance. Given the complexity of the marine environment in which cetaceans live and the ever increasing threat of anthropogenic activities and climate change, the application of the approach presented in this thesis will not only provide us with a greater understanding of their distribution and migratory patterns and behaviour in the context of their life history and ecology, but also endeavours to better equip us to develop and implement more sound and effective mitigation and management and conservation initiatives for the future.

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Fractal analysis reveals pernicious stress levels related to boat presence and type in the Indo–Pacific bottlenose dolphin, *Tursiops aduncus*

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The stress induced in the Indo–Pacific bottlenose dolphin, *Tursiops aduncus*, by boat presence and type was investigated in a highly urbanized coastal environment, the Port Adelaide River-Barker Inlet Estuary, South Australia. The level of stress experienced by bottlenose dolphins was inferred from the distribution patterns of their dive durations. Dive duration has previously been shown to increase under boat traffic conditions, and is considered as a typical avoidance behavior. Dive durations were opportunistically recorded from land-based stations between January 2008 and October 2010 in the absence of boat traffic, and in the presence of kayaks, inflatable motor boats, powerboats and fishing boats. Subsequent analyses were based on nearly 6000 behavioral observations. No significant differences in dive durations were found between control observations (i.e. absence of boats) and boat interferences, which could erroneously lead to conclude that boat traffic did not induce any stress in *T. aduncus*. In contrast, the scaling exponents of the cumulative probability distribution of dive durations obtained in the absence of boat traffic and under different conditions of boat interferences show (i) that the presence of boats affected the complexity of dive duration patterns and (ii) that stress levels were a function of boat type. Specifically, the complexity of dive duration patterns (estimated by the scaling exponent φ) did not significantly differ between control behavioral observations and behavioral observations conducted in the presence of kayaks. A significant increased in behavioral stress (i.e. decreasing values of φ) was, however, induced by the presence of fishing boats, motorized inflatable boats and powerboats. This demonstrates that traditional approaches based on the analysis of averaged behavioral metrics may not be sensitive enough to detect changes in the distribution pattern of behavioral sequences, hence underestimate the potential consequences of e.g. chronic exposure to low levels of stress. It is finally emphasized that fractal analyses of behavioral variables, and in particular the analysis of their cumulative probability distribution function, may provide a non-invasive, objective and quantitative framework that can be used to assess the changes in stress response, and subsequently evaluate the welfare status of organisms under various conditions of abiotic and/or biotic stress.

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