Master's thesis

Characteristics of
sandy beaches used by resident shorebirds in Tasmania

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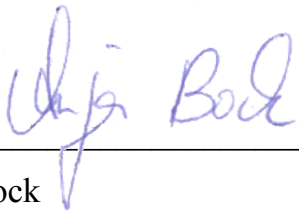
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Declaration

I hereby confirm that I am the sole author of this thesis and it is a product of my own academic research.

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Anja Bock

Abstract

Across nations, sandy beaches are highly valued for their social and economic importance. They are especially important in Australia, where 80% of the population live within 100km of the coast and beaches are viewed as a national icon. Despite that fact, biodiversity and the environmental value of sandy beaches as ecosystems is often ignored.

There has been lack of research on resident shorebirds and their habitat requirements, particularly regarding the importance of abiotic sandy beach characteristics for shorebirds. This study aimed at identifying important abiotic characteristics for selected breeding shorebird species in Tasmania, emphasising the underlying distribution and abundance patterns.

Predictors were found to contribute to different extents for the three species investigated in this study, with the surf zone width being one of the most important abiotic predictors and invertebrate abundance the most important biotic predictors. Species-specific differences were also revealed with regards to all investigated variables and the distributions of the species among regions and beaches.

Keywords: shorebirds, Tasmania, habitat use, environmental factors, sandy beaches, distribution and abundance, beach attributes

Dedicated to my Mum,

Ursula Bock,

for all her life-long support.

Foreword

This study was carried out in the European winter and Australian summer of 2013/14 and represents my final project and thesis for my Master´s Degree in Coastal and Marine Management - a degree in Natural Resource Management (MRM) offered by the University Centre of the Westfjords in Ísafjörður, Iceland, an associated University Centre of the University of Akureyri.

As a natural resource management programme, its aim is to promote understanding of different perspectives and to be able to deal with and manage different, potentially clashing interests (Leach, Mearns, & Scoones, 1999; Reed et al., 2009; Singleton, 2000). Scientific knowledge, economic interests and social values have to be linked and coordinated, (Campbell, 1996; Martínez et al., 2007) requiring a basic understanding of all at the same time (Dusen, Fegley, & Peterson, 2012). However, in order to establish and implement the most effective management strategies, scientific knowledge is often inevitable, as it is required as a base for management decisions to build upon (Clarke & Harvey, 2013). Regarding the conservation of specific species, knowledge of biology and population size is vital (Gratto-Trevor et al., 2012). Overall, decisions made by managers should be based on the best 'available scientific evidence' (Doremus, 2004; Grol & Grimshaw, 2003; Rousseau, 2006), which is referred to by the term 'evidence-based management'. This term represents the translation of research-based principles into organisational practises, where managers aim to become experts in order to make a decision (Rousseau, 2006), with often insufficient information available (Pfeffer & Sutton, 2006).

Moreover, there seems to be an overarching positive trend and raised awareness that the investigation of only one component of a system or population, such as within a marine or sandy beach ecosystem, may not be sufficient, and that it may be necessary to incorporate a range of factors and their interactions to be able to understand how it works, what it needs to maintain its functionality and to manage it in a sustainable manner (Berry, Fahey, & Meyers, 2013; Mavrommati & Richardson, 2012; Mendez et al., 2012; Peters et al., 2008). This

development is reflected e.g. in multi-species approaches in fisheries management (Harvey, Cox, Essington, Hansson, & Kitchell, 2003) or more broadly in 'ecosystem-based management' (Curtin & Prellezo, 2010; Levin, 1998). However, economic interests continue to override other values and interests (Groot et al., 2012). As a consequence, natural values and biodiversity are often located at the lower end of interest (Lucrezi, Schlacher, & Walker, 2009; Schlacher et al., 2007).

All these factors were supportive arguments for me to select this topic on the sandy beach-habitat use of resident shorebirds in Tasmania in collaboration with Dr Eric Woehler, with the aim of increasing the basic understanding of the habitat use by resident shorebirds. This thesis will be of value for future management decisions and for the protection of the species themselves, and, additionally, for the continued enjoyment of future generations in viewing shorebirds in their natural environment along sandy beaches
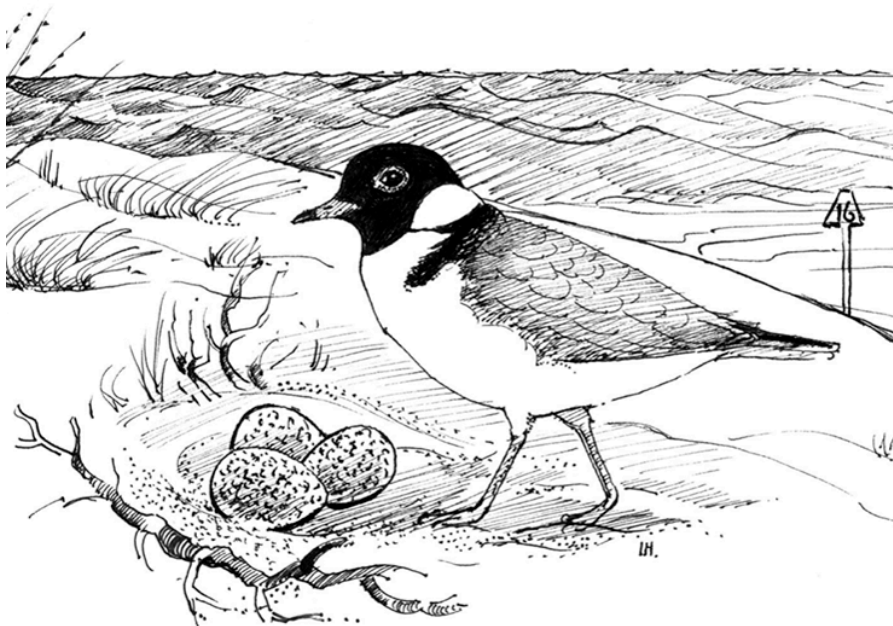

Figure 1.1.1: The Hooded Plover (Charadrius rubricollis) is an oceanic, sandy beach obligate species and endemic to Australia. As its populations are declining due to a range of impacts such as human disturbance and sea level rise, this small resident plover is likely to be dependent on effective management and conservation strategies for the future (Source: Drawing obtained from the Australasian Wader Study Group's Journal 'The Stilt').

Table of contents

List of figures

List of tables

Acronyms, abbreviations and variables

Acronyms

IUCN	International Union for the Conservation of Nature
EAAF	East Asian - Australasian Flyway
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ArcGIS	Geographic Information System(s)
GLM	Generalised Linear Model
PCA	Principal Component Analysis

Abbreviations

UTas	University of Tasmania
HP	Hooded Plover *(Thinornis rubricollis)*
OC	Pied Oystercatcher *(Haematopus longirostris)*
RCP	Red-capped Plover *(Charadrius ruficapillus)*
W	West (Coast)
N	North (Coast)
E	East (Coast)
SE	Southeast (Coast)
Flinders	Flinders Island

Variables and mathematical parameters

R	Reflective (1)
LTT	Low tide terrace (2)
TBR	Transverse bar and rip (3)
RBB	Rhythmic bar and beach (4)
R+LTT	Reflective plus low tide terrace (7)
R+LTR	Reflective plus bar and rips (8)
UD	Ultra dissipative (9)
R+SR	Reflective plus sand ridges (10)
R+SF	Reflective plus sand flats (11)
d$	Large data set with all abiotic
inv$	Small data set with the biotic data (invertebrate taxa)
Length__m	Length of beach segments in metres
Mean_width_1	Mean width of aerial sand surface of beach segment in metres
Embaymen_1	Embayment degree of beach segments from exposed (0) to sheltered (1)
Swash_Gr_1	Gradient of swash/intertidal zone in degrees
Surf_Zon_1	Mean width of surf zone of beach segment in metres
wind_speed_annual	Mean annual wind speed in metres per second
tm_an_av_1	Mean annual wave period in seconds
hs_an_av_1	Mean annual significant wave height in metres
hs_max_a_1	Maximum significant wave height in metres

Acknowledgements

There are a lot of people that I would like to thank, but first of all, I would like to thank everybody and their institutions that have contributed to this thesis with their data. Without their participation, certainly this project would not have been possible in the way in which it was currently undertaken. These comprise first of all the Surf Life Saving Association Australia and Adam Weir (Australian Coast Safe), who provided the ABSMP data set, enabling this study to investigate specific attributes of Tasmanian sandy beaches and characteristics of resident shorebird habitats. Second, I would like to thank Prof Alastair for the provision of the invertebrate data (and all his former students involved that selected the data) representing a very important component in the habitat use of shorebirds due to the availability of prey in a habitat. Third, I am very thankful for the provision of the wave data by Mark Hemer from the Centre for Australian Weather and Climate Research and for Claire Trenham helping to compile the variables out of the entire hincast data set. Also I would like to thank Dr Ben Raymond for downscaling of the wind data and adjusting it to the format used for this study (ArcGIS coordinate systems), and certainly Dr Stuart Corney from the Climate Futures Project Tasmania, who provided the wind data to Dr Ben Raymond.

Furthermore I would like to thank everybody who supported me with very valuable advice with regards to statistical analysis and programming with R. Here, I would like to thank particularly Dr Simon Wotherspoon for his invaluable help with regards to the programming. Moreover, I would also like to thank Dr Michael Sumner and Dr John McKinlay for valuable advice at the R meetings at the Australian Antarctic Division, as well as Dr Scott Carver from the Zoology Department at the University of Tasmania for advice with regards to general statistics. Also, I am very thankful to MSc Chris Sharples for his time at meetings, advice on ArcGIS and for the beach walks and talks about beach morphology. Next, I would like to say thank you to Dr John Hunter for valuable meetings, that helped shaping my project. I also wish to thank Dagný Arnarsdóttir for advice on the introduction and overall thesis structure, and generally very valuable Skype chats. Also thank you, Albertína Friðbjörg Elíasdóttir, for the Skype chat and valuable comments on

my methodology. I also do not want to forget my family and friends supporting me throughout my Thesis period, and last but not least, I want to thank my supervisors, Prof Mike Phillips and Dr Erik Woehler for enabling me to undertake this project and thesis, for taking me up as a student and for all the support. Here, I am particularly very grateful for Dr Eric Woehler and his support and advice throughout, providing me with the opportunity to come to Tasmania, undertake this project by using his data and for the beach walks to experience the birds in their natural habitat on Tasmania´s sandy beaches. Thanks a lot for that!

Thank you very much!

Figure 1.1.2: Plovers roosting and foraging, two main activities of a shorebird.
(Source: Drawing obtained from the Australasian Wader Study Group´s Journal
'The Stilt')

1 Introduction

1.1 Background

Many people value beaches for their recreational value and as a part of quality of life by living in close proximity, such as in Australia where 85% of the human population lives within a 100km distance of the coastline (Jones, Gladstone, & Hacking, 2007; Maguire, Miller, Weston, & Young, 2011). Accordingly, sandy beaches support many coastal economies worldwide (Klein, Osleeb, & Viola, 2004), but aside from the vast range of social and economic interests that need to be coordinated (Campbell, 1996; Martínez et al., 2007), sandy beaches also represent highly dynamic ecosystems providing a habitat for a range of unique biodiversity (Bessa et al., 2013; Dahl, 1952). However, ecological values of sandy beaches have barely been recognised, particularly in Australia (Glavovic, 2006; Lucrezi et al., 2009). As a consequence, most management has focused on the stability of the shoreline to protect human infrastructure against rising sea levels (Schlacher et al., 2006), and many bird species are in decline (Bamford, Watkins, Bancroft, Tischler, & Wahl, 2008; Lofty et al., 2010; Milton, 2003). One example is the Hooded Plover *(Thinornis rubricollis)*, which is an Australian endemic shorebird particularly dependent on wide, flat sandy beaches (Dowling & Weston, 1999; Weston, Ehmke, & Maguire, 2009; Weston, 2005).

Generally, it has been widely accepted that habitat loss and alteration are major reasons for species extinctions in the 21st century (multiple IPCC reports, Hunter, Dinerstein, Hoekstra, & Lindenmayer, 2010). Disturbance by recreationists was revealed to be a major reason for the decreasing numbers of this small plover (Beale & Monaghan, 2004; Lafferty, 2001; Schlacher, Weston, Lynn, & Connolly, 2013; Weston & Elgar, 2005a). As it is essential for future species management and habitat protection to have a general understanding of a species' biology and the processes in its ecosystem driving its behaviour (Dusen et al., 2012), this study aims to increase the current state of knowledge on the habitat use of three resident shorebird species in Tasmania – The Hooded Plover

(Thinornis rubricollis), the Pied Oystercatcher *(Haematopus longirostris)* and the Red-capped Plover *(Charadrius ruficapillus)*. A couple of studies (Godet, Jaffré, & Devictor, 2011; Lunardi, Macedo, Granadeiro, & Palmeirim, 2012; Placyk & Harrington, 2004; Tarr, Simons, & Pollock, 2010) have been carried out on migratory species, but resident species might be particularly at risk as they might not be as flexible in changing to a different habitat, location or to a new territory. This is because they are believed to select only once in their life-time a territory which the breeding pair will occupy for their entire life (West, Goss-Custard, Durell, & Stillman, 2005). Moreover, new territories have to be vacant (Orians & Wittenberger, 1991), and there may be increased competition for higher quality habitats (Osnas, 2003) or risk of predation (Angelstam, 1986). Accordingly, if changes in a habitat have reached a limit where conditions are not suitable anymore, it might drive this species to local extirpation or potentially to extinction (Gu, Heikkilä, & Hanski, 2002; Peters et al., 2008). Moreover, sandy beaches are not only affected by anthropogenic activities, but also by sea level rise (Boer & Prins, 2002; Lafferty, Rodriguez, & Chapman, 2013; Lucrezi et al., 2009; Schlacher, Nielsen, & Weston, 2013). If important habitat or sandy beach characteristics for the shorebirds could be identified, it would help to improve the general understanding of the species and their habitat use, and also the establishment of the most effective conservation measures (Clarke & Harvey, 2013; Grol & Grimshaw, 2003).

As most studies (Brazeiro, 2005; Lawrence & Soame, 2004; Pienkowski, 1983; Rodil, Lastra, & López, 2007; Schlacher, Richardson, & McLean, 2008) have mainly investigated the invertebrate fauna of sandy beaches or the general habitat use of shorebirds, but not the impacts that abiotic characteristics may have on resident shorebirds (Brown & McLachlan, 2002; Colwell & Sundeen, 2000), this study aims to explore the role of a range of beach attributes and environmental factors on the observed distributions and abundances of resident beach-nesting shorebirds in Tasmania. The aims of this study are to (1) look for relationships among the species distributions and abundances and the biotic and abiotic characteristics of their environment, (2) to identify the variables with the greatest role(s) in the observed distributions and (3) to investigate whether there are species-specific differences present in these variables.

1.2 Aims, purpose and objectives

1.2.1 Aims

The aim of this research is to investigate the abiotic characteristics that may affect resident shorebird habitat use, and to look for distribution and abundance patterns that might be a result of specific conditions on sandy beaches. Three Tasmanian species, the Hooded Plover, Pied Oystercatcher and Red-capped Plover, will be used as model organisms and may provide the basis for further similar studies on similar species. Overall, a focus is placed on the physical attributes of the beaches and the environmental factors surrounding and shaping them, but also biotic components of sandy beach ecosystems will be considered such as invertebrate taxa, because of their importance as prey for the birds.

1.2.2 Expectations and hypotheses

As species, such as shorebirds, have evolved within a certain type of ecosystem (Butler, Davidson, & Morrison, 2001; Peters & Otis, 2007; Recher, 1966), it is likely to find various relationships and associations among the abiotic environmental characteristics and the species present (Brown, 1984; Danufsky & Colwell, 2003; Duong & Fairweather, 2011; McConkey & Bell, 2005; Ribeiro, Iribarne, Navarro, & Jaureguy, 2004), resulting in non-random distributions (Buenrostro, Warnock, & de la Cueva, 1999; Colwell & Landrum, 1993; Spruzen, Richardson, & Woehler, 2008). It is possible that along a sandy beach or along different beaches, there will be better or poorer conditions for the shorebird species (Brown, Mehlman, & Stevens, 1995; Lercari, Bergamino, & Defeo, 2010; Mysterud & Ims, 1998). Therefore, it is possible to predict that resident shorebirds will be influenced by various abiotic attributes of their sandy beach habitats, and by the environmental factors involved in establishing and maintaining the different conditions, as well as the availability of prey (biotic component), resulting in differences in the distributions and abundances of shorebirds along a coast (Blanco, Yorio, Petracci, & Pugnali, 2006; Clark, Niles, & Burger, 1993; Ribeiro et al., 2004; Rogers, Battley, Piersma, Gils, & Rogers, 2006; Sirot, Maes, & Gélinaud, 2012).

The aim of this study is to identify patterns that show a relationship between the distributions and abundances of the Tasmanian resident shorebird species (Hooded Plover, Pied Oystercatcher and Red-capped Plover) and their environmental habitat characteristics.

The hypotheses and predictions investigated in this study are the following:

(0)   Main question:

Does the distribution and abundance of resident Tasmanian shorebirds differ according to biotic and abiotic sandy beach characteristics, and environmental factors?

H0: The distributions and abundances of Tasmanian resident shorebirds are not affected by the biotic and abiotic characteristics of their habitat.

H1: The distributions and abundances of Tasmanian resident shorebirds are affected by the biotic and abiotic characteristics of their habitat.

- If H0 is true, habitat characteristics do not affect the habitat use of Tasmanian resident shorebirds, and the birds are distributed randomly on beaches.
- If H0 is false, this would indicate that habitat characteristics affect the habitat use of Tasmanian resident shorebirds, revealed by differences in distribution and abundance of the birds.

(1)

H0: There will be no difference in the extent and degree of influence among the biotic and abiotic variables investigated on the distributions and abundances of shorebirds.

H1: The extent and degree of influence among the biotic and abiotic variables investigated will vary among species and localities, thus some variables might have a greater influence on the habitat use of resident shorebirds compared to others.

- If H0 is true, the extent and degree of influence among the biotic and abiotic variables investigated does not vary among species and localities, thus no variable would be more important or have a greater influence on a shorebirds habitat use than another.
- If H0 is false, this would indicate that the biotic and abiotic variables investigated vary among species and localities, revealed by specific characteristics being significantly more important to the shorebirds.

(2)

H0: There will be no difference in the role and influence of the biotic and abiotic variables investigated among the three focal species.

H1: The role and influence of the biotic and abiotic variables investigated will vary among the three focal species.

- If H0 is true, the role and influence of the biotic and abiotic variables investigated does not vary among the three focal species.
- If H0 is false, this would indicate that the role and influence of the biotic and abiotic variables investigated varies among the three focal species, revealed in certain characteristics being more important to one species than to another.

1.3 Data and methods

Long-term environmental data have been gathered from five different sources in order to explore the relationship among a range of physical abiotic habitat characteristics and three resident shorebird species in Tasmania (Hooded Plover, Pied Oystercatcher and Red-capped Plover). These environmental data comprise of (1) wave data that have been generated by the Bureau of Meteorology and CSIRO (Mark Hemer and Claire Trenham), (2) mean annual wind speed datum that has been provided by the Climate Futures Tasmania Project (Stuart Corney), and (3) physical beach attribute data that have been collaboratively collected and generated by Andrew Short and the Surf Life Saving Association Australia. In addition, the (4) biotic components have been provided and collected by Prof Alastair Richardson and his students (UTas) comprising four invertebrate taxa, and (5) the shorebird observations were recorded by Dr Eric Woehler. More specific information on the variables and their collection will be provided in the methodology section (Chapter 4), due to the high number of variables that have been investigated. An extensive literature review has been included in this study, due to its exploratory and interdisciplinary nature cutting across the fields of biology, ecology, and physical processes and coastline morphology.

The variables were divided into three groups, (1) beach attributes such as width of the beach, (2) environmental variables that affect and shape the beaches such as waves, and (3) the invertebrate taxa representing the biotic component of sandy beach ecosystems. An essential component for the thesis proceedings was the merging of all five data sets for analysis, which had to be carried out via the spatial information contained in the data sets such as longitude/latitude or eastings/northings, using ArcGIS. Data analyses were undertaken in the statistical programming language R (Ihaka & Gentleman, 1996).

1.4 Delimitation of scope

This study focuses mainly on the roles of abiotic habitat characteristics on a shorebirds habitat use. Beaches, or rather beach segments, have specifically been selected according to the known presence of resident shorebirds. This study analyses the bird data at the macro scale and uses the beach segments as the basis for comparisons using the total number of birds per beach segment per species. Beach segments of different length are assigned an abiotic value for the total number of breeding pairs per species. As previously stated, only ocean sandy beaches were considered for this habitat study, no other wetland types. Furthermore, it should also be pointed out that the necessary long-term data were obtained from five different sources and therefore been selected by a range of different people, with different methodologies and equipment.

Sandy beaches represent highly complex and dynamic ecosystems with shorebirds high in the food chain as top predators. Therefore, there may be many factors influencing the habitat use by Tasmanian shorebirds, such as human disturbance, predation, or competition. However, such additional factors will be mentioned, but not investigated further in this study. Also, the term 'breeding pair' is frequently been used throughout this thesis only in order to refer to a territory that is occupied and its resources defended by a resident shorebird pair, thus a female and a male. No investigations with regards to breeding success were undertaken within this study, neither were attempts to look for nests during beach walks. This study investigates exclusively the resources within and characteristics of sandy beaches as a habitat. However, this thesis aims to include as much data as possible to increase the reliability of the findings, thus the west, north, east and southeast coasts are included as well as Flinders Island (located on Tasmania´s northeast

coast). Due to data processing complications and time constraints, it was not possible to incorporate Kind Island (located on Tasmania´s northwest coast) in the analyses.

1.5 Structure of thesis

The structure of this thesis leads the reader from the general to the more specific. Starting off with the necessary background knowledge by introducing ecosystems and their complexity (2.1 Sandy beaches as ecosystems), the thesis continues with sandy beaches as a habitat for flora and fauna and some basic definitions (2.2 Sandy beaches as a habitat). After these two chapters, the literature review provides an introduction to the core of the study and introduces the current state of knowledge on shorebird habitat use and habitat requirements (e.g. for foraging, roosting and breeding), particularly of resident species, and the potential effects of beach or habitat attributes and environmental factors (2.3 Literature review on shorebird habitat use). Some studies specifically on beach types and categories are outlined. Chapter 3 provides information on the biology and habits of the three Tasmanian study species, the Hooded Plover, Pied Oystercatcher and the Red-capped Plover, to gain a better understanding of their species-specific habitat use (3.1 The study species). The sandy beaches and their characteristics are also introduced in this chapter (3.2 Sandy beaches), followed by the specific conditions on Tasmanian beaches as the study sites (3.3 Sandy beaches in Tasmania). The following chapters reflect a classical IMRAD thesis structure: Chapter 4 introduces the methodology, data sets and investigated variables, and the data preparation and analyses. Chapter 5 presents the results, Chapter 6 the discussion and Chapter 7 the conclusions of the study.

2 Background and context

2.1 Sandy beaches as ecosystems

2.1.1 Introduction to ecosystems

"Beaches are not just piles of sand,

they support a range of (under-appreciated) biodiversity"

(Schlacher et al., 2007, pp. 556)

Sandy beaches present prime examples for complex and dynamic ecosystems (Brown & McLachlan, 2002). Generally, ecosystems may be small and simple, like an isolated pond, or large and complex, like a tropical rainforest or coral reef (IUCN glossary definitions). A detailed and encompassing description has been provided by the IUCN List of Threatened Ecosystems (Keith et al., 2013) comprising of four main components that define an ecosystem (pp. 3):

(1) a biotic complex or assemblage of species,

(2) an associated abiotic environment or complex,

(3) the interactions within and between those complexes, and

(4) a physical space in which these operate.

2.1.2 Sandy beaches as complex systems

Sandy beaches represent one of the most dynamic and lively ecosystems on Earth, consisting only of a small strip of sand being located between the terrestrial and the marine environment (Feagin, Sherman, & Grant, 2005). Accordingly, sandy beaches can be referred to as 'ecotones', a narrow transition zone with steep environmental gradients located between extensive systems with more consistent environmental conditions (Berry et al., 2013; Ray, 1991; Schlacher & Thompson, 2013b; Wasson, Woolfolk, & Fresquez, 2013). With such characteristics, a range of studies have described sandy beaches as 'being

trapped in a coastal squeeze' between erosion and sea level rise on the wet, marine side, and encroaching development from expanding human populations and fortifications on the terrestrial side (Berry et al., 2013; Defeo et al., 2009; Hardiman & Burgin, 2010). Sandy beach species are particularly at risk of suffering from habitat loss (Defeo et al., 2009; Fish et al., 2008) if retreating landwards as a response to sea level rise is not possible anymore due to fixed shoreline-adaption options such as revetments and groynes. These reduce the 'ecological resilience' of the beach and thus its adaptive capacity to retreat (Berry et al., 2013).

However, sandy beach biodiversity has been argued to be mostly physically controlled, due to the dynamic conditions resulting from its coastal squeeze location between the terrestrial and marine environment and the effects resulting from both systems (Covazzi Harriague & Albertelli, 2007; Defeo, Brazeiro, de Alava, & Riestra, 1997; Dugan, Jaramillo, Hubbard, Contreras, & Duarte, 2004; Harris, Nel, Smale, & Schoeman, 2011; McLachlan & Dorvlo, 2007; Ray, 1991; Rodil et al., 2007). Here, the smallest organisms in the system, such as the invertebrates (filter feeders) in the sediment and primary producers in the water, are believed to be the most affected. However, the physical conditions and environmental factors will create the base in sandy beach ecosystems for fauna and flora to settle on, and according to the present conditions (and species adaptions), species diversity may vary locally along beaches and among beach types (Lercari et al., 2010).

Energy flow and the food webs of sandy beaches

Foraging represents an essential part of every organism´s life cycle (Doremus, 2004) to enable the survival, reproduction, and fitness of the individual (Clark et al., 1993; Davidson & Rothwell, 1993). However, the structure of 'food chains' or 'food webs' within an ecosystem can become very complex due to the endless number of relationships, interactions, and dependencies among organisms in the system (Kuwae et al., 2012). As an example, Lercari et al. (2010) modelled the food web relationships and 'trophic levels' (every organism occupies 'a level' in the food chain according to what it eats) in sandy beach ecosystems (Figure 2.1.1). This food web starts with the primary producers (Level 1) on the base (biomass 'B') and at the bottom of the food chain, representing the prey for the next higher level to feed on (consume 'C'). The second level organisms consist of herbivores like filter feeders, which will then provide the prey for the primary consumers

or carnivores on the next level (Level 3) such as crabs and fish. Finally, the top predators, or secondary consumers, such as shorebirds, are located at the top of the food chain (Level 3.3). Following the energy flow from the bottom to the top, biomass (B) will be consumed (Q) on every level and partially be used for the individuals´ own metabolic processes (production 'P') such as respiration, but also new biomass will be produced through growth and reproduction.

As every organism occupies a trophic level in the food chain, the direction flows (flow chart) from the bottom to the top, illustrating potential 'predator-prey relationships' (biological interaction between the predator and its prey, both affecting each other), with regards to 'who is feeding on who'. As shorebirds are located on the top of the food chain and feed on herbivores like invertebrates, they will likely be affected if changes on the lower levels of the chain occur ('bottom-up processes'). These may include changes in invertebrate assemblages and composition or a reduction in abundance, resulting in a potential overall decrease in prey availability for the shorebirds (Dugan, Hubbard, McCrary, & Pierson, 2003; Erwin, 1996). Such interactions may work in both directions, as shorebirds may also actively affect the lower levels ('top-down processes') due to their predation on them, thus they may affect invertebrate density, causing an overall decline in their population size and a reduction in biomass (Boer & Prins, 2002; Evans, 1987).
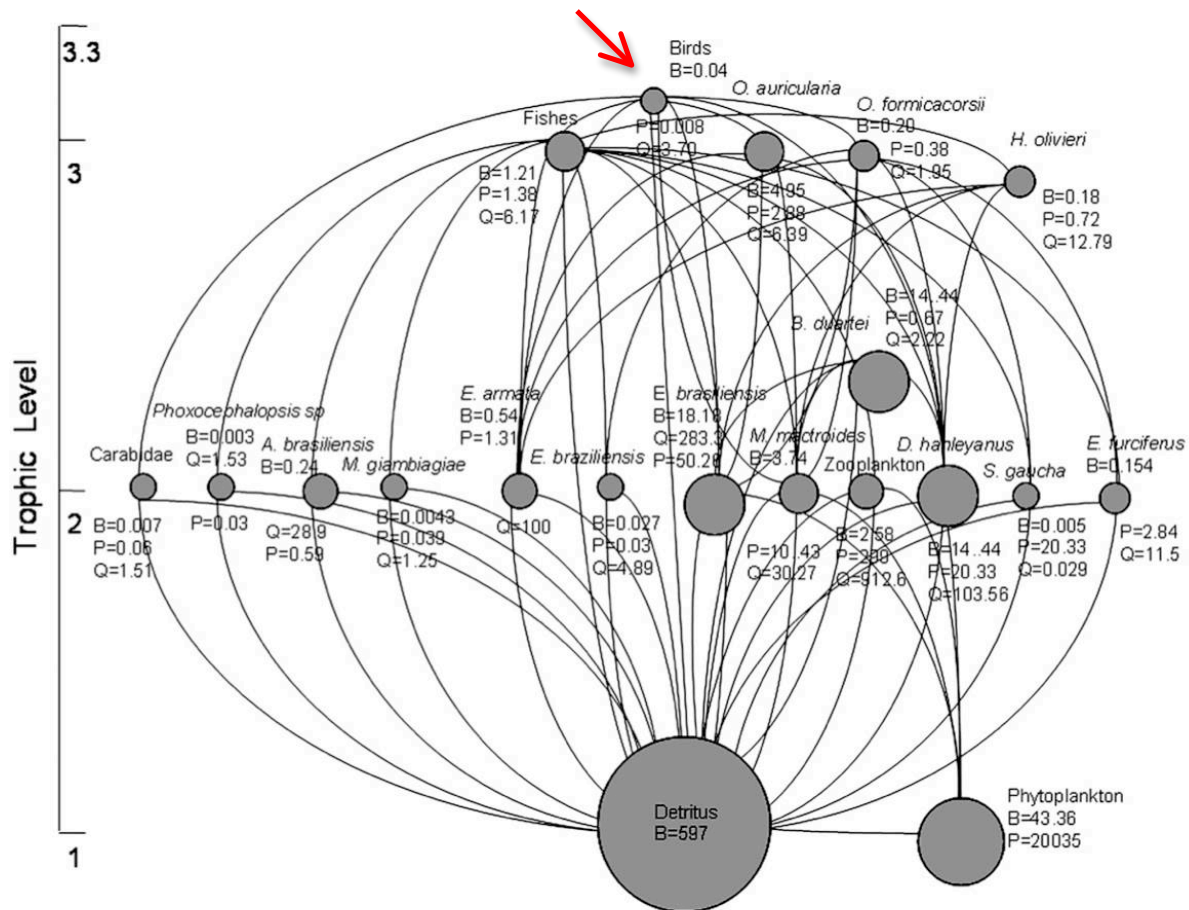
Figure 2.1.1: Flow chart illustrating the major trophic levels, interactions (whom is feeding on who) and energy transfer (fraction of input) in sandy beach ecosystems from one level to another. Primary producers (biomass production via photosynthesis) and detritus represent the lowest level (1) in the food chain, providing the largest amount of biomass (B) that will be consumed (Q) by herbivores such as filter-feeders on level 2 in the food web. Next, the level 2 organisms will provide the prey (with their biomass 'B') for the next level (3), the carnivores or (top) predators, including the resident shorebirds of this study. However, some of the energy taken up (consumption 'Q') by level 2, 3 (first consumers) and 3.3 (secondary consumers) will be used for own metabolic processes (production/processes 'P') such as respiration and growth resulting in the increase of the organism´s own biomass (amount of organism´s biomass represented by the size of the circles, Source: Lercari et al., 2010).

In summary, Lercari et al. (2010) revealed that dissipative beaches inherited a more complex food web structure compared to reflective beaches, with an overall increased energy flow across the trophic levels, more trophic connections and higher species diversity. Moreover, the number of predators, including shorebirds, was higher on dissipative beaches compared to reflective beaches. A likely result of higher primary productivity rates by phytoplankton and thus increased biomass production via

photosynthesis at the lowest level. This could facilitate an increase in filter-feeder biomass, providing overall more prey for shorebirds.

Compared to Lercari et al. (2010), most studies investigated a certain part of sandy beach ecosystems and food webs, such as Odebrecht et al. (2013) and Kuwae et al. (2012). Accordingly, a study undertaken by Odebrecht, Preez, Abreu, & Campbell (2013) focused on the diatoms in the surf zone that are highly influenced by the prevalent chemical and physical factors and by the attributes of the beaches. Similarly Kuwae et al. (2012) investigated the biofilm in sand beach ecosystems that may provide a food source for invertebrates, but also for shorebirds. The presence of biofilm may be beneficial for shorebirds in two ways. First, it provides a direct and additional food source to the birds. Second, it also supports invertebrate populations, which are prey for the birds (Figure 2.1.2).
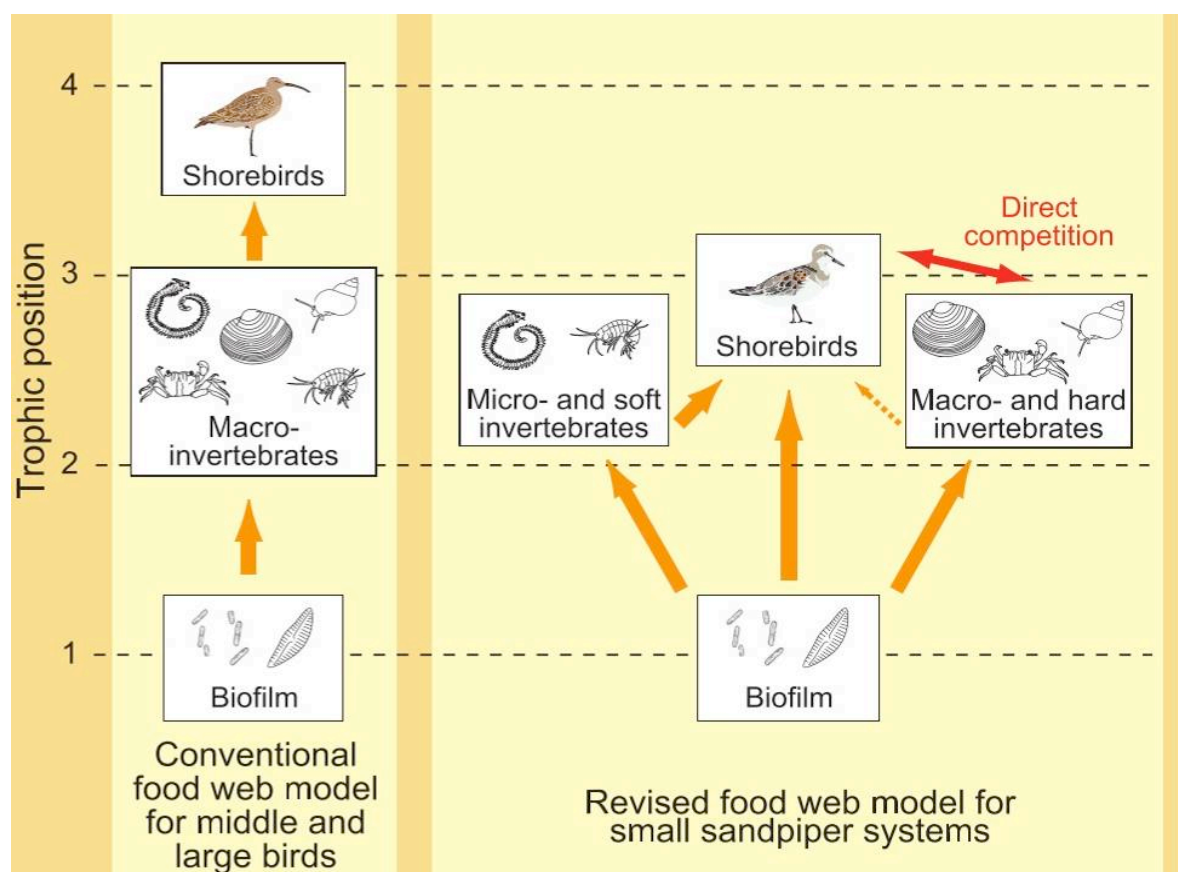
Figure 2.1.2: A simplified food web model compared to Lercari et al. (2010), developed by Kuwae et al. (2012), illustrating the position of biofilm in sandy beach ecosystem and potential importance for shorebirds.

However, food webs only represent one factor that could potentially influence the habitat use, and thus the distributions and abundances of shorebirds (Martin, 1995), as two further important shorebird activities are roosting and breeding (Block & Brennan, 1993; Mysterud & Ims, 1998; Schlacher, Nielsen, et al., 2013).

2.1.3 **Values of sandy beaches**

According to Klein, Osleeb, & Viola (2004), beaches are prime sites for recreation and underpin many coastal economies all around the world. This is particularly of Australia, where about 85% of the population live within 100km of the coastline. Here, beaches are highly valued and a 'national icon' of the country (Jones et al., 2007; Maguire et al., 2011). However, the values of sandy beaches as ecosystems and from an ecological perspective have not been very well recognised (Glavovic, 2006; Lucrezi et al., 2009). Especially in Australia, the ecology of sandy beaches has received little attention and there remains much to be learned about the biology of sandy beach organisms (Robertson, 1996, cited in James, 2000, Ray, 1991; Zaitsev, 2012). The ecology of some groups of beach organisms has been nearly neglected in Australia (James, 2000). As such, despite some studies (Godet et al., 2011; Gratto-Trevor et al., 2012; Placyk & Harrington, 2004; Wilson, Kendall, Fuller, Milton, & Possingham, 2011) investigating the importance of beaches for migratory shorebirds in specific areas of Australia and elsewhere, resident shorebirds have not received much attention (Rohweder & Baverstock, 1996, cited in James, 2000, Brown & McLachlan, 2002).

In summary, sandy beaches harbour a range of distinctive biodiversity (Dahl, 1952), represent unique ecosystems (Bessa et al., 2013), provide critical habitats for nesting and foraging for endangered species (Barbier et al., 2011; Burger & Niles, 2013; Dugan et al., 2003), and are irreplaceable ecosystems for shorebirds (Convertino et al., 2011; Dowling & Weston, 1999; Maslo, Handel, & Pover, 2011; Schlacher, Nielsen, et al., 2013). Moreover, beaches provide a variety of important ecological services such as the filtration of large volumes of seawater and the recycling of nutrients (Hardiman & Burgin, 2010; Zaitsev, 2012) and have therefore also been referred to as "the greatest natural absorbing filter on the planet" (Zaitsev, 2012, pp. 119). With regards to such a lively environment, sandy beach animals display a range of unique adaptations such as mobility and burrowing abilities, rhythmicity in their behaviour (Evans, 1987), and advanced sensory mechanisms

and orientation, which applies especially to the small invertebrate fauna in the sediment (Mclachlan, 1991; McLachlan et al., 1995; Rossano et al., 2009).

2.1.4 Recognition of natural sandy beach values

Overall, sandy beaches have always been seen as "natural places of sun, sea, surf and sand" (Dutton, 1985, cited in James, 2000, pp. 496), thus mainly used for recreational purposes, especially in Australia. Such a statement may provide an indication of how well recognised the natural values of beaches have been. A study conducted by Maguire et al. (2011) was undertaken in order to get a more detailed impression on on how people, particularly local residents, perceive and value Australian beaches. The results revealed that respondents valued "clean, uncrowded beaches with opportunities to view wildlife, but also the access to desired facilities" (Maguire et al., 2011, pp. 781). – rather conflicting perceptions, attitudes and values. In monetary terms, the recreational value of e.g. the beaches of the 1400km coastline of Queensland was extrapolated to an overall annual sum of 587.3 million Australian dollars, which, broken down, reflects an amount of 35.09$ per person for a day´s beach visit (Rolfe & Gregg, 2012). Moreover, the extrapolation indicated a total number of about 16.7 million beach visits annually made by a believed total of about 838,000 local residents (travel time not included). Accordingly, one adult is expected to make about 20 beach visits per year. Aside from these monetary values, Rolfe and Gregg (2012) pointed out that the recreational experience is dependent on the beach condition and characteristics, thus if beach conditions, such as water quality, would change, it is likely to result in a decrease of visits on that particular beach, but the visitor may simply switch to the next neighbouring beach. However, beaches of recreational importance require maintenance (Rolfe & Gregg, 2012), and are already visited with increasing frequency (Maguire et al., 2011), a trend that is likely to continue in the future. This will increase pressure on beach biodiversity and challenge coastal managers to coordinate the conflicting interests as revealed by Maguire et al. (2011).

2.1.5 Recognition of species conservation

The study by Maguire, Rimmer, and Weston (2013) also revealed that the awareness of threatened species present on a beach, such as the Hooded Plover, influenced the respondents rating considerably, with the result of human-induced impacts being scored

much higher compared to responses where no or poor awareness was present. Overall, according to this study, respondents were supportive of bird conservation and of beach-nesting birds. However, it may be an important aspect to keep inconvenience levels low and to promote 'coexistence' between people and wildlife with measures such as putting a dog on a leash during the breeding season rather than closing an entire beach (rather limiting than prohibiting measures). Such a compromise may also inherit more potential to facilitate collaboration and cooperation, and to avoid conflicts (Maguire et al., 2013).

However, human disturbance (the behavioural and/or physiological response of an animal to anthropogenic stimuli such as people, dogs, vehicles, etc.) is viewed as a key threat to sandy beach-dependent shorebirds (Brown & McLachlan, 2002; Burger, Carlucci, Jeitner, & Niles, 2007; Lafferty, 2001; Schlacher, Weston, et al., 2013; Weston & Elgar, 2005a). One of the most widely used approaches to reduce encounters between people and shorebirds (Whitfield, Ruddock, & Bullmann, 2008) is the initiation of 'set-backs' or 'buffers' (Glover, Weston, Maguire, Miller, & Christie, 2011), where the beach user will keep a certain distance from the birds. However, for this conservation practise it is necessary to have knowledge about the biology of the species and to know which distance is 'too close' (Burger, Gochfeld, Jenkins, & Lesser, 2010; Whitfield et al., 2008). In addition to the need for acquiring this knowledge. Glover et al. (2010) have suggested taking into consideration social acceptability, i.e, people's opinions, in order to be able to set 'ecologically most efficient and meaningful buffer distances' for people and birds. However, even if complete compliance among humans exists, initiated buffer widths may be unlikely to eliminate disturbance to shorebirds (Glover et al., 2011). By contrast, Brown and McLachlan (2002) suggested the introduction of stricter controls and the creation of additional reserves, especially for the protection of threatened species.

A study undertaken by Petel and Bunce (2012) supports the importance of raised awareness and education, as human disturbance represents a major threat for shorebirds, in addition to habitat loss and predation. According to Miller and Weston (2009), Australian ornithologists considered education as the fourth most important conservation action for Australian birds. Here, the most efficient information channels are conservation organisations (34%), friends and family (20%) and newspapers (14%, Antos, Weston, & Priest, 2006, cited in Petel & Bunce, 2012). A study by Corre, Peuziat, Brigand, Gélinaud, and Meur-Férec (2013) showed that awareness represents an important aspect, and

moreover, revealed to be dependent on socioeconomic characteristics of the user group. Also, the vast majority of the respondents (77%) did not believe that their activities would negatively affect shorebirds along a beach. Overall, there was no difference in awareness between local residents and tourists, and the older the user group, the less aware the respondents (Corre et al., 2013).

2.2 Sandy beaches as a habitat

2.2.1 Introduction to the habitat concept

Habitats – "The addresses of organisms"

(Odum, 1971)

As Krausman (1999) stated "most biologists would have difficulties visualising organisms without their habitat" (pp. 85). Accordingly, the habitat presents an essential component of understanding a species' life history (Dusen et al., 2012) and has therefore had a long tradition in biological sciences, especially in ecology. Ornithology has played a key role in the development of the 'habitat concept' (Block & Brennan, 1993), as indicated by a range of studies dealing with various terms such as habitat use (Bolster & Robinson, 1990; Colwell & Oring, 1988; Elix & Lambert, 2007; Spruzen et al., 2008; Withers & Chapman, 1993), habitat selection (Battin & Lawler, 2006; Lack, 1933; Lunardi et al., 2012; Morris, 1987, 1992), habitat preferences (Summers, Underhill, & Simpson, 2002; Warnock & Takekawa, 1995), habitat suitability (Avissar, 2006; Tian, Zhou, Zhang, & Yuan, 2008; Toor, Jaberg, & Safi, 2011) or habitat quality (Gunnarsson, Gill, Newton, Potts, & Sutherland, 2005; Johnson, 2007; Norris & Marra, 2007). Overall, the habitat concept relates the presence of a particular species to the attributes of its surrounding physical and biological environment (Block, With, & Morrison, 1987). However, it presents an artificial human construct that aims to describe the place where an animal occurs (MacMahon, Schimpf, Andersen, Smith, & Bayn, 1981) as a description through the eye of the observer. Features of the environment will be correlated to the presence or relative abundance of the organism and may have some relevance to those factors that the species actually uses and requires for its persistence (Brown, 1984).

Due to the complexity of ecosystems, the use of a habitat may be driven by a range of factors that might not derive directly from the habitat itself (Sutherland et al., 2012), but rather due to competition (Osnas, 2003), predators (Angelstam, 1986), diseases (Mendes, Piersma, Lecoq, Spaans, & Ricklefs, 2005) or parasites (Piersma, 1997). Moreover, habitat use is also influenced by the adaption of each species over time to certain features of the

habitat (Grippo, Cooper, & Massey, 2007; Peters & Otis, 2007; Wiens, Rotenberry, & Horne, 1987). For example every shorebird species has developed a fixed set of morphological and behavioural characteristics that enables but also constrains the species to use specific parts of its environment and thus occupy a 'niche' (Cody, 1981; Jing, Ma, Li, Li, & Chen, 2007; Kuwae et al., 2012; Prakash, Quéré, & Bush, 2008; Thrush, 1999). However, there is no guarantee that the presence of individuals in a given habitat is related to the quality of a habitat, and the absence from a particular habitat does not mean that it is being avoided. It could simply be that not all habitat sites are equally available and accessible for a species (Caughley, 1994; Horne, 1983). It has been widely accepted that habitats are species- specific (Hatfield, Reynolds, Seavy, & Krause, 2012; Wiens et al., 1987) and scale dependent (Kerr, Southwood, & Cihlar, 2001; Thompson & McGarigal, 2002), and the outcome of the study will depend on the questions being asked (Battin & Lawler, 2006; Krausman, 1999).

2.2.2 Important terminology

A review of Jones (2001) stated that nearly one quarter of 85 surveyed ornithological papers "misused or misinterpreted" (pp. 559) terms such as habitat use, selection and others. Hall et al. (1997) declared that even 82% of the reviewed articles used terminology vaguely and imprecisely. Such a degree of semantic inconsistency and vagueness might be a result of the assumption that readers are familiar with the habitat terminologies (Jones, 2001). However, in order to avoid misunderstandings, a few definitions are provided by Block and Brennan (1993, p. 38):

Habitat Use - *The manner in which a species uses a collection of environmental components to meet life requisites. It can be regarded in a general sense, or broken into specific acts or needs such as foraging, nesting, or roosting.*

Habitat Selection and Preferences – *Innate and learned behavioural responses of birds that allow them to distinguish among various components of the environment resulting in the disproportional use of environmental conditions to influence survival and ultimate fitness of individuals.*

__Habitat Suitability and Quality__ – The ability of the environment to provide conditions suitable for survival, reproduction, and population persistence. Suitability is a continuous variable measured by the intrinsic rate of population increase.

Overall, the 'selection of a habitat' implies a (conscious) decision-making process or a behavioural response over time of a species (Burger, 1987; Hutto, 1985; Orians & Wittenberger, 1991), while 'habitat use' presents the end-result of this process, how the species uses the resources available within its habitat (Jones, 2001).

2.2.3 Habitat scales and shorebird habitat selection

Depending on the questions being asked, a habitat can be approached from different angles and have different scales such as a 'spatial' and 'temporal scale' (Hutto, 1985). With regards to avian studies, Block and Brennan (1993) provided a visual example (Figure 2.2.1), where a spatial scale can range from the use of a specific perch or foraging substrate to listing biomes within the geographic range of a species, whereas a temporal scale can include environments that are used on a seasonal (e.g. breeding, wintering, migratory), yearly, or historical basis. Within the spatial scales, one may differentiate between a 'macro-habitat' that operates on a landscape-scale and a 'micro-habitat' that aims to describe "specific, recognizable features of the environment that act as proximal cues to elicit a settling response from an individual bird" (Block & Brennan, 1993, pp. 38).

Moreover, the selection of a habitat can be viewed as a 'hierarchical process', where the individual must choose, first, a general location. Subsequently, decisions about the use of different patches within its new habitat will follow (Charnov & Orians, 1982, unpubl., cited in Orians & Wittenberger, 1991, Battin & Lawler, 2006). Certainly, the latter is highly dependent on the type of habitat chosen, and the point at which to make a decision will be a trade-off, as the individual will only have a certain amount of time available to explore the area and assess its suitability. At the same time, there is the risk that another individual might be faster and occupy the area, which it will defend (territory selection). Accordingly, a habitat might be good enough to trigger exploration, but not good enough for settling (Orians & Wittenberger, 1991). Furthermore, a habitat must be vacant, which might only be the case following death or illness. Generally, it should be expected that a suitable habitat or habitat of higher quality needs to contain a mixture of patches, providing

opportunities for all activities that are required for successful reproduction (Orians & Wittenberger, 1991).
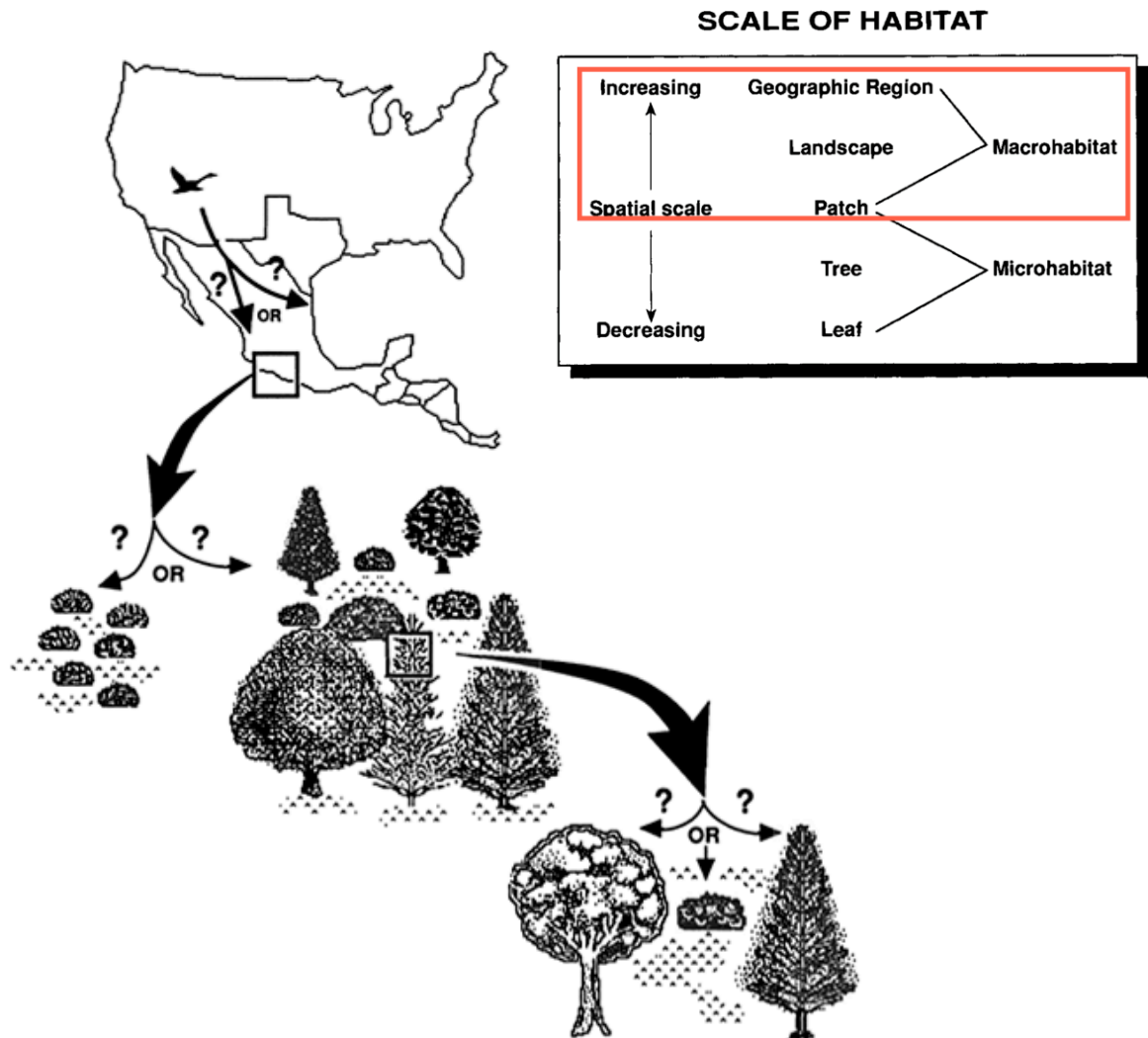
Figure 2.2.1: Spatial scaling of habitats and hierarchical decision-making process of habitat selection of migratory species (Source: Block & Brennan, 1993).

2.2.4 Territoriality and connectivity

Overall, it is believed that an individual would select a habitat with the best and highest number of available resources that are necessary to maximise its own fitness and lifetime reproductive success (Gunnarsson et al., 2005; Johnson, 2007). With regards to resident shorebirds, it would therefore be expected that an individual will select an area that suits its life history needs the best with regards to (1) foraging, (2) roosting, and (3) breeding (Mysterud & Ims, 1998; Schlacher, Nielsen, et al., 2013), and moreover, that may also hold a lowered risk of predation, a reduced number of competitors and overall low degree

of human disturbance (Ens & Goss-Custard, 1984; Meager, Schlacher, & Nielsen, 2012; Page, Stenzel, & Ribic, 1985; Powell, 2001; Warnock & Takekawa, 1995). Therefore, a distinction should be possible between habitats of 'lower' and 'higher' quality, according to the amount and types of resources available (Burger, 1987; Dias, 1996). One strategy to obtain as many necessary resources as possible would be to 'occupy a territory', which most resident shorebirds do (Colwell, 2000; Myers, 1980). Thus a region that is defended against conspecifics, where the young are raised and where its resources are exclusively used by the occupying breeding pair (Pitelka, 1959; Weston et al., 2009). Overall, the size of the territory may depend on the species, its life history, body size, and weight (Colwell, 2000).

Within the selected territory, the bird will use different patches for different purposes (Mysterud & Ims, 1998; Wiens, Stenseth, Horne, & Ims, 1993), as the intertidal zone will be used for foraging, whereas other dry and sheltered regions will be used for roosting and breeding (Rehfisch, Clark, Langston, & Jeremy, 1996; Rogers, Battley, et al., 2006). Accordingly, there will be regional differences within the territory, and the individual will perform many smaller scale movements between the different compartments or 'patches', such as feeding migrations (Sheaves, 2009; Wiens et al., 1993). This pattern can be referred to using the term 'connectivity' and can link habitats in space and time, such as with regards to migrations on a country scale (Gratto-Trevor et al., 2012; Norris & Marra, 2007) or an ecosystem (Barbier et al., 2011), or as in this case, on a territory or habitat-scale (Sheaves, 2009; Thorne, Takekawa, & Elliott-Fisk, 2012). Also 'natal dispersal', the point when the juveniles leave the parental territory in order to look for their own territory and to secure a partner (Zimmerman, Lahaye, & Gutie, 2003), can be considered as connecting habitats (Sheaves, 2009). Sheaves (2009) stated that "organisms, populations, assemblages and communities all depend on a range of often disparate habitats and ecosystems, and link those habitat and ecosystem units into a complex mosaic" (pp. 112), and referred therefore to connectivity as a key process facilitating many life-history functions.

Here, the principle of 'central place foraging', which was introduced by Orians and Pearson (1979) to describe situations where the individual will leave a central place such as a nest to search for prey and return to it, can be applied (Houston, 1985a). During the breeding season, this is also the case for certain shorebird species such as the Pied

Oystercatcher, where the chicks stay close to the dunes and the adults search in the intertidal zone for prey and will return to the chicks (Baudains & Lloyd, 2007; Emlen & Wrege, 2004; Groves, 1984; Weston & Elgar, 2005a). Here, commuting distances might be crucial, as not only would the parents use energy (Rehfisch et al., 1996) and perhaps also draw the attention of predators (Weston & Elgar, 2007), but also the chicks will not get as much prey in a given timeframe and would be unattended for longer. However, the parents' decision on the size of the habitat may be very important (Anderson, 1981; Gunnarsson et al., 2005) with regards to the abundance of prey or resources available to feed to the chicks. If not enough resources are available, competition will be higher for the amount of prey available and additionally there might not be enough food available for every chick to reach maturity (Lack, 1954). Furthermore, the parents may have to decide on a trade-off between the number of offspring raised and the energy expenditure invested in to the care for each of the chicks (Lloyd, 1987). Therefore, according to Anderson (1981) and Cairns (1982), if more prey is available and the breeding pair has got good control over its resources by defending its territory, a smaller territory could be sufficient. Additionally, if the territory is rich in resources and thus prey, long commuting distances and search-time for prey might not be necessary anymore (Anderson, 1981).

It has been pointed out that the fitness of a breeding pair or individual could be measured by the number of offspring reaching maturity (Lloyd, 1987). This might not only reflect the ability of the parents to defend a territory and manage to care for its young (Groves, 1984), but also the ability to choose the best trade-off in selecting a territory (Mysterud & Ims, 1998).

2.2.5 Shorebird distribution, abundance, and habitat use

It has been argued that the distribution and abundance of a species is determined by the combination of many abiotic and biotic factors that are required for survival and reproduction of its individuals (Brown, 1984; Danufsky & Colwell, 2003; Duong & Fairweather, 2011; McConkey & Bell, 2005; Ribeiro et al., 2004). Accordingly, the distributions and abundances of species should be limited by the combination of physical and biotic factors. Moreover, there should be a site or patch for each species, where conditions are most favourable (and where population density might be greatest), because the combination of environmental variables (Figure 2.2.2) corresponds most closely to the

requirements of the species (Brown, 1984; Goss-Custard, Stillman, Caldow, West, & Guillemain, 2003). If this is the case, species abundances should be highest in the centre and decrease towards the boundaries.

Such an aggregation of species (Veech, 2005), with disproportional habitat use (Hall, Krausman, & Morrison, 1997), and clumped or patchy distribution (Colwell & Landrum, 1993) may vary across space and time and may reflect the suitability of the local environment (Brown et al., 1995). Accordingly, shorebirds could either be randomly and evenly distributed across a habitat and not obviously be affected by certain environmental factors, or non-randomly distributed, as is usually the case (Buenrostro et al., 1999; Colwell & Landrum, 1993; Spruzen et al., 2008), where irregular distribution and abundance patterns indicate that the individual has certain requirements that its environment needs to fulfil (Brown et al., 1995). A 'patchy' or 'non-random distribution' represents a common pattern on sandy beaches (Burger, 1987; Schlacher & Thompson, 2013a), indicating that certain segments along a beach offer a better trade-off and potentially higher quality resources (Santos, Saraiva, Palmeirim, & Granadeiro, 2009). The identification of the most important variables driving the birds' distribution and abundance will help to understand the needs of the species, and, accordingly, the identification of species-dependent 'hot-spots' would indicate where the establishment of a protected area would be most useful (Schoener, 1987).
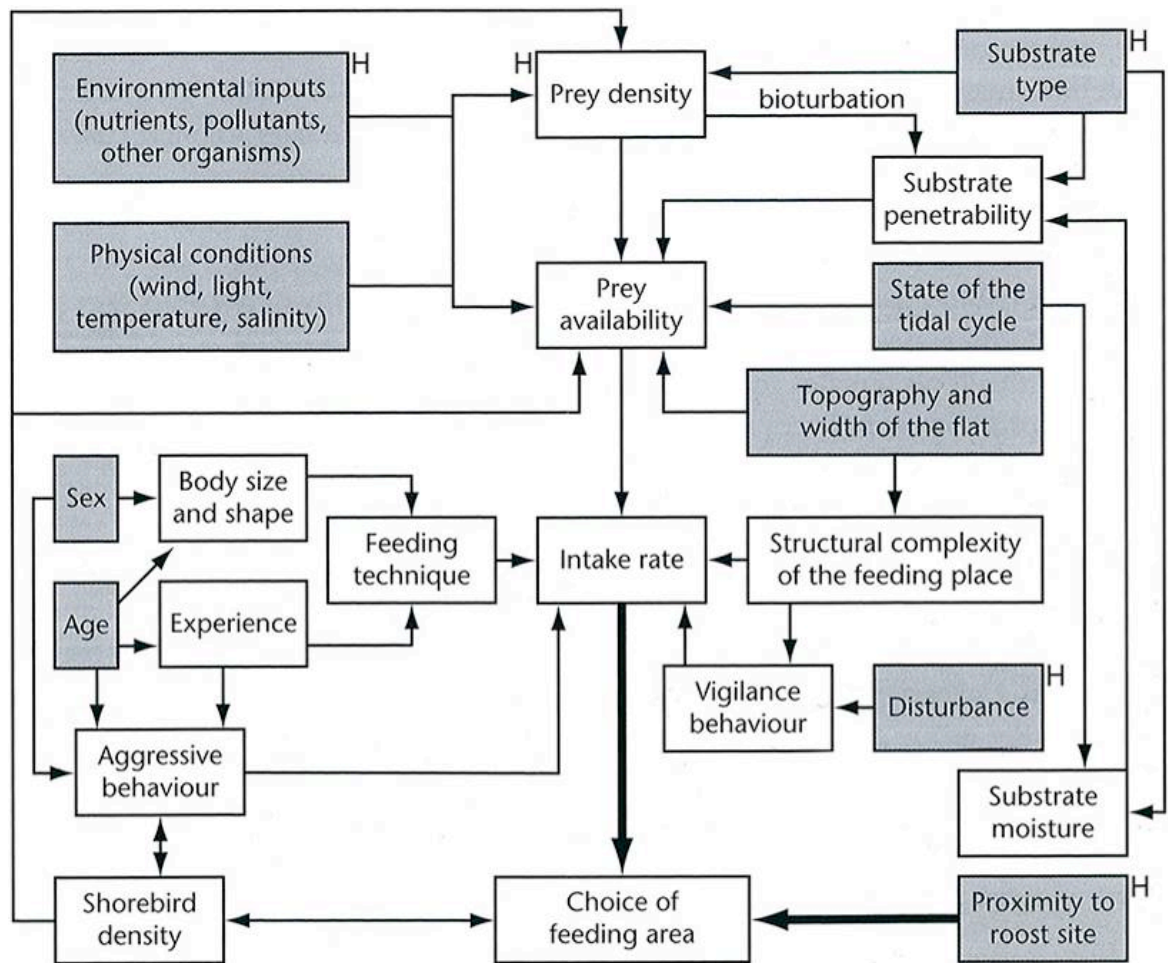
Figure 2.2.2: A shematic flow chart illustrating factors that may influence the habitat selection and use of resident and migratory feeding shorebirds. Shaded boxed indicate base inputs, where no other factor leads to (Source: Geering, Agnew, & Harding, 2008).

However, territoriality results in a more even distribution of individuals across a habitat than expected from the 'ideal free distribution', resulting in lower densities in the most suitable sites and more individuals distributed among relatively low-quality sites (Brown et al., 1995). According to the ideal free distribution, it is assumed that animals distribute themselves among habitats and that they will aggregate proportionally to the amount of resources available. As such, the term 'ideal' implies that animals are aware of the quality of each patch, whereas the term 'free' implies that animals can move freely from one patch to another (thus no competition is assumed), (Abrahams, 1986). As the ideal free distribution does not take intra-specific (between individuals of one species) and inter-specific (between individuals of different species) competition into consideration, Fretwell (1972) expanded its notion and developed the 'ideal despotic distribution', which assumes

that dominant individuals will occupy the sites of best quality first, forcing other individuals to swerve to sites of lower quality (Dias, 1996; Zimmerman et al., 2003). Territorial species would be assumed to follow this distribution, but as with all hypotheses in ecology based on critical assumptions, it is assumed that individuals have perfect knowledge of the area and its resources (Zimmerman et al., 2003).

2.2.6 **Habitat heterogeneity, fragmentation and loss**

Habitat suitability can be referred to as a mosaic of suitable habitat patches (Brown et al., 1995; Wiens et al., 1993), which can occur as a consequence of 'habitat fragmentation'. Habitat fragmentation is a state and process that often leads to population declines (Brown et al., 1995; Stephens, 2003; Dusen et al., 2012), as it results in the alteration, potential degradation, and in the worst case, the loss of habitat. The latter two represent the greatest threats to wild bird species (Brittain & Craft, 2012; Caughley, 1994; Hay, 2013; Johnson, 2007), as habitat fragmentation reduces the total habitat area in its size (Stephens, 2003) and will disrupt its continuity. This means that the area will be broken or divided into smaller parcels, and therefore presents a primary concern for conservation biology (Franklin, Noon, & George, 2002). Habitat fragmentation is often a result of human actions such as after the conversion of landscapes into agricultural lands or the construction of roads (Tilman & Lehman, 2001). However, there has been confusion about the difference between habitat fragmentation and 'habitat heterogeneity' (Franklin et al., 2002). According to Franklin et al. (2002), habitat fragmentation is habitat heterogeneity in its simplest form and a division into habitats and non-habitats. Generally, habitat heterogeneity refers to a composition of dissimilar components in one system and to an uneven or non-random distribution of objects. According to Bazzaz (1975), it assumes that such structurally more complex habitats may provide more niches and diverse ways of exploiting the environmental resources and thus increase species diversity (considered as a measure of the number of component species and their abundance at a defined point in space and time), (Rosenzweig, 1995, cited in Tews et al., 2004). A review undertaken by Tews et al. (2004) revealed that about 85% of all studies found a positive correlation between species diversity and the structural variables measured (Danufsky & Colwell, 2003), but, some studies proved the opposite, that species diversity decreased with habitat heterogeneity (Ralph, 1985; Wiens, 1974).

2.3 Review of shorebird habitat use

2.3.1 Introduction

"Birds,

so visible, audible and ubiquitous, so variable yet structurally uniform,

so inspiring in numbers and behaviour and so inviting to study ..."

(Piersma, 2007, pp. S46)

Certain sandy beach species such as birds have received little attention, particularly in Australia (Rohweder & Baverstock, 1996, cited in James, 2000), except for a few studies that focused on migratory shorebirds (Godet et al., 2011; Gratto-Trevor et al., 2012; Placyk & Harrington, 2004; Wilson et al., 2011). Accordingly, Colwell and Sundeen (2000) stated that:

„the use of coastal beaches by non-breeding shorebirds along the Pacific coast of North America is poorly understood because survey efforts have targeted large bays and wetlands where birds concentrate... the variation in shorebird use and species abundance varied greatly among sites from highly aggregated to randomly dispersed along beaches, suggesting that some areas are more important to wintering and migrating shorebirds than others" (pp. 1)

This indicates that there is a need for further investigations, particularly along sandy beaches. Moreover, due to the complexity of ecosystems, particularly of dynamic sandy beaches, there may be a range of factors affecting resident shorebird habitat use, and thus their distributions and abundances (Brown, 1984; Danufsky & Colwell, 2003; Duong & Fairweather, 2011; McConkey & Bell, 2005; Ribeiro et al., 2004).

2.3.2 **Habitat requirements of resident shorebirds**

1. With regards to foraging

The availability of prey presents a vital aspect for a suitable shorebird habitat and many studies have investigated prey availability and foraging behaviour in shorebirds resulting most of the time in the patchy distribution of the birds, following the patchy distribution of their prey (Colwell, 2000; Ribeiro et al., 2004; Santos et al., 2009; Schlacher, Meager, & Nielsen, 2014; Spruzen et al., 2008). Accordingly, a study by Ribeiro et al. (2004) showed that the spatial distribution of shorebirds varied with the distribution of their prey, such that birds that prefer polychaete worms were more abundant where the polychaete worms were located, while species that are more crab-oriented where more abundant in regions with higher crab densities. As shorebirds usually feed during low tide (Lafferty et al., 2013; McConkey & Bell, 2005; Schlacher et al., 2014; Dusen et al., 2012), this segregation was particularly visible during these periods, as crabs and polychaetes have a well-defined and patchy distribution (Burger, 1987; Santos et al., 2009; Schlacher & Thompson, 2013a; Spruzen et al., 2008). In summary, Lercari et al. (2010) stated that "shorebird occurrences on sandy beaches are often positively correlated with prey and habitat availability" (pp. 2757) and as top predators, shorebirds may be absent from certain types of beaches because of a reduced availability of prey (Colwell & Landrum, 1993; Finn, Catterall, & Driscoll, 2008; Houston, 1985b; Kvitek & Bretz, 2005; Placyk & Harrington, 2004).

Altogether, it is not only vital to gain an overall understanding of the biology of a species, but also of the interactions in the ecosystem, especially of the trophic food chain relationships (Kuwae et al., 2012; Lercari et al., 2010). Particularly, less-studied organisms need to be investigated. As Kuwae et al. (2012) revealed, biofilm contributes substantially to the food intake of shorebirds, and as it is located on the sediment surface and not underneath, it represents prey that is easy to access, particularly for visual foragers such as plovers. In this context, Butler et al. (2001) suggested that shorebird density (migratory and residents) would be higher in coastal regions with high primary productivity (providing the base for sandy beach food webs - see Lercari et al., 2010), which might be facilitated by upwelling systems. In summary, there are a range of factors that may limit the 'detectability, accessibility, and harvest-ability' of prey for shorebirds (Figure 2.3.1), (Boer & Prins, 2002; Zwarts & Wanink, 1993). Moreover, it is not only about the abundance, but

also about the behaviour of the prey (Baker & Baker, 1973), as both, the birds and their prey, may be affected by abiotic factors. This is particularly the case in such dynamic and productive ecosystems as sandy beaches, which are exposed to a range of environmental forces including waves and tides (Coverdale, Bertness, & Altieri, 2013; Maguire et al., 2011; Saunders, Mcminn, Roberts, Hodgson, & Heijnis, 2007).
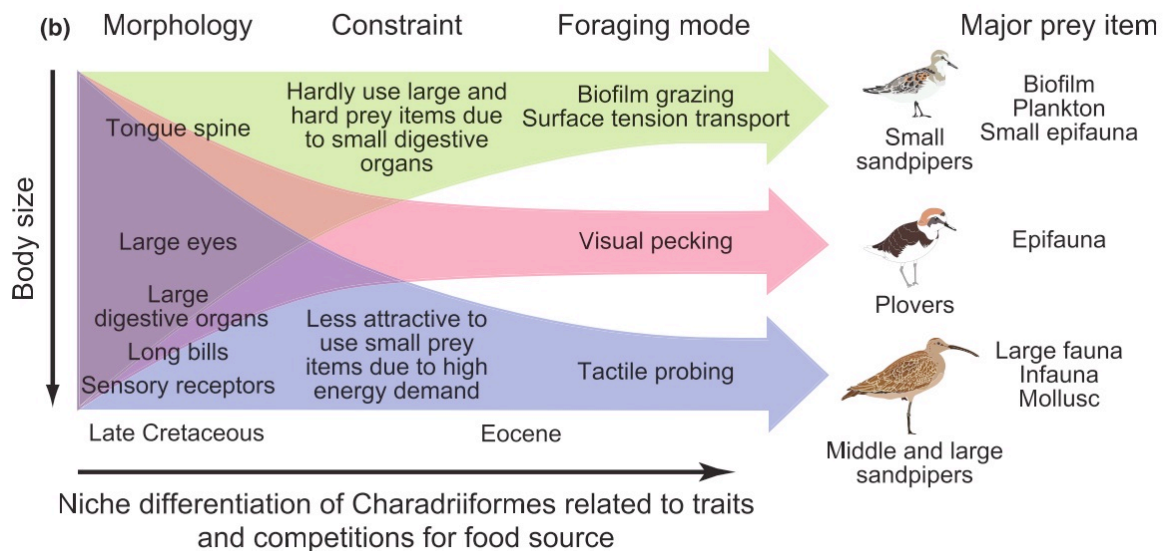
Figure 2.3.1: Groups of closely related species share some traits by common ancestry, but still have evolved with different morphology and foraging behaviours enabling the species to exploit a specific part of their environment and a specific type of prey (Source: Kuwae et al., 2012).

2.   With regards to roosting

Another important aspect of a resident shorebird's daily life is roosting (Schlacher & Thompson, 2013b), as the birds need to rest and save energy, only using the feeding areas for part of the day and having to rely on alternative areas for the remaining hours (Colwell, Danufsky, Fox-Fernandez, Roth, & Conklin, 2003; Rogers, Battley, et al., 2006; Rogers, Piersma, & Hassell, 2006). Therefore, roosting sites often comprise of areas where shorebirds congregate when the intertidal feeding zone is inundated (Colwell & Sundeen, 2000; Rogers, Piersma, et al., 2006). Overall, roosting sites should provide protection from prevailing weather conditions, human disturbance (Navedo & Herrera, 2012; Peters & Otis, 2007), and predators (Rehfisch et al., 1996), and thus can be viewed as features in the landscape that possess particular attributes 'attractive to shorebirds' (Zharikov & Milton, 2009). Accordingly, a study by Colwell et al. (2003) revealed that different shorebird

species used a range of roosting sites to which they returned frequently, indicating that a suitable habitat should contain a range of roosting sites that are likely to be used during different conditions. It has also been suggested that roosting sites should be in close proximity to the foraging area, e.g. in order to save energy with short commuting distances (Rehfisch et al., 1996; Rogers, Battley, et al., 2006; Spruzen et al., 2008). Extensive movements between roosting and feeding locations could also draw attention from predators (Rehfisch et al. 1996, Peters & Otis, 2007). However, local and micro-climatic differences may play a large role for roosting sites, as areas with dense vegetation are likely to be less preferred due to restricted visibility of the surrounding area posing an increased risk of predation for the shorebirds (Zharikov & Milton, 2009).

3.   With regards to breeding

Smith et al. (2012) revealed a higher chance of nest predation the longer the nest was unattended. Therefore, nest-sites should not be too far away from foraging and roosting sites. However, the critical aspect will be the selection of a habitat or territory with suitable and available nest sites, as visibility is important in order to overlook the area for approaching predators (Amat & Masero, 2004; Barbosa, 1996; Lauro & Nol, 1993). Overall, shorebirds would have to face a trade-off between nesting closer to the dunes and vegetation, but farther away from the foraging area and potentially at greater risk of ground-predation, but potentially also better protected from sun and wind. also more protected from sun and wind (Burger, 1987). Proximity to other seabirds such as terns, which spend more time in the air.might be very beneficial for shorebirds to receive early warning-calls when predators are approaching (Burger, 1987; Nguyen, Abraham, & Nol, 2006; Powell, 2001).

2.3.3 **Morphological and behavioural constraints**

Being smaller birds with smaller organs, food intake and digestion might be more restricted for the species investigated in the present study, by comparison with larger species (Piersma & Gill, 1998; Gils, Piersma, Dekinga, & Dietz, 2003). Overall, larger shorebird species tend to have a larger food intake need (Baker, 1977; Both, Edelaar, & Renema, 2003; Rogers, Piersma, et al., 2006) and may also have larger beaks enabling them to handle larger prey (Durell, 2000; Kuwae et al., 2012; Thrush, 1999). Generally,

compared to migratory species, resident shorebirds may have smaller fat reserves, as with the occupation of territories and resources, there is no longer a need to store energy for long periods of time, or for specific physically demanding activities such as long distance migrations (Morrier & McNeil, 1991). However, an overall adaption strategy of smaller species to satisfy their energy-time budgets could be to increase the food-intake speed, but this will also be finite due to the digestive capacity of the species (Rogers, Piersma, et al., 2006; Gils et al., 2003). A second strategy could be to switch to richer prey containing a larger energy content per individual. This has been investigated by Santos et al. (2009), revealing that the detection of richer prey patches (prey density, and patch size) such as rag worms *(Hediste diversicolor)* for dunlins *(Calidris alpina),* could increase the energy intake by 2.9 times, which would be particularly beneficial for small species like plovers. Such a strategy has also been observed when conditions change, such as towards winter and decreasing temperatures, for example among knots *(Calidris canutus)* in the Wadden Sea that started to feed more frequently on a small gastropod Hydrobia when their preferred prey Macoma became less abundant (Piersma, 1994). Interestingly, certain prey species may even be ignored by the birds due to low profitability, depending on prey size and energy content (Baker, 1977; Gils et al., 2003; Zwarts & Wanink, 1993). Overall, it has been pointed out that larger species seem to be more selective in their prey selection (Baker, 1977).

Moreover, as smaller species are also more likely to have shorter legs, this might be a disadvantage when water levels are too high, and may become a limiting factor during feeding, as has been the case for plovers in Rosa, Palmeirim, & Moreira (2003). This was summarised by Cody (1981) as: "Birds have a fixed morphology within which they are able to operate" (pp. 107), and others (Kuwae et al., 2012; Prakash et al., 2008; Thrush, 1999). With regards to the feeding strategy applied, it has been pointed out that tactile foragers may be able to exploit a wider variety of prey in comparison to visual foragers, as these species can more easily prey on buried organisms, but also feed on the surface, such as on wrack- and seaweed-associated prey (Dugan et al., 2003).

Competition

Factors such as inter- and intra-specific competition and predation may also affect habitat use significantly, as pointed out by Thrush (1999): "Eating and being eaten are

fundamental processes that affect the success of individuals, populations and thus communities" (pp. 344). The occurrence of conspecifics competing for the same prey could drive habitat use and foraging efficiency, or stealing the already caught prey could have severe impacts with regards to energy-time budgets, as the individual spend time and energy searching and harvesting its prey. Such 'kleptoparasitic behaviours' have been observed (Both et al., 2003) by several gull species (Martínez-Abraín et al., 2003; Taylor & Taylor, 2005; Thompson, 1986), in skuas (*Catharacta* spp. and *Stercorarius* spp., Andersson, 1976; Arnason & Grant, 1978; Jones, 2002) and frigatebirds (*Fregata* spp., Congdon & Preker, 2004; Gilardi, 1994; Osorno, Torres, & Garcia, 1992).

2.3.4 Potential effects of beach attributes and environmental factors

Effect of tides and beach width

It is widely accepted that the tidal range represents the most important abiotic driver for many species of shorebirds, dictating the daily feeding schedule (Evans, 1987; Johnson & Baldassarre, 1988; Rosa, Granadeiro, Cruz, & Palmeirim, 2007). As tides, in interaction with waves and the type of sediment, shape the intertidal and swash zone of the beaches (Schlacher & Thompson, 2013a; Zaitsev, 2012), the foraging area might differ in width and thus provide more or less room for foraging (Danufsky & Colwell, 2003; Dugan, Hubbard, Rodil, Revell, & Schroeter, 2008; Elias, Fraser, & Buckley, 2000; Mclachlan & Dorvlo, 2007). Accordingly, Rosa et al. (2003) found a higher number of species (richness) on wider mudflats offering a larger foraging area. Associated with tides, the type of sediment and underlying morphology of a beach may facilitate the development of channels that may create a larger (beach width) and wetter foraging area (longer flooded), supporting an increased number of prey and shorebirds, and potentially more sheltered feeding areas (Danufsky & Colwell, 2003; Rosa et al., 2007). Due to elevation and local differences in beach morphology, certain areas may dry out faster when the tide recedes and may therefore provide more favourable conditions for shorebirds to swerve to such patches (Rosa et al., 2007). However, sites of lower elevation may be sooner available for shorebirds to feed on and therefore create more favourable conditions. (Danufsky & Colwell, 2003; Dusen et al., 2012).
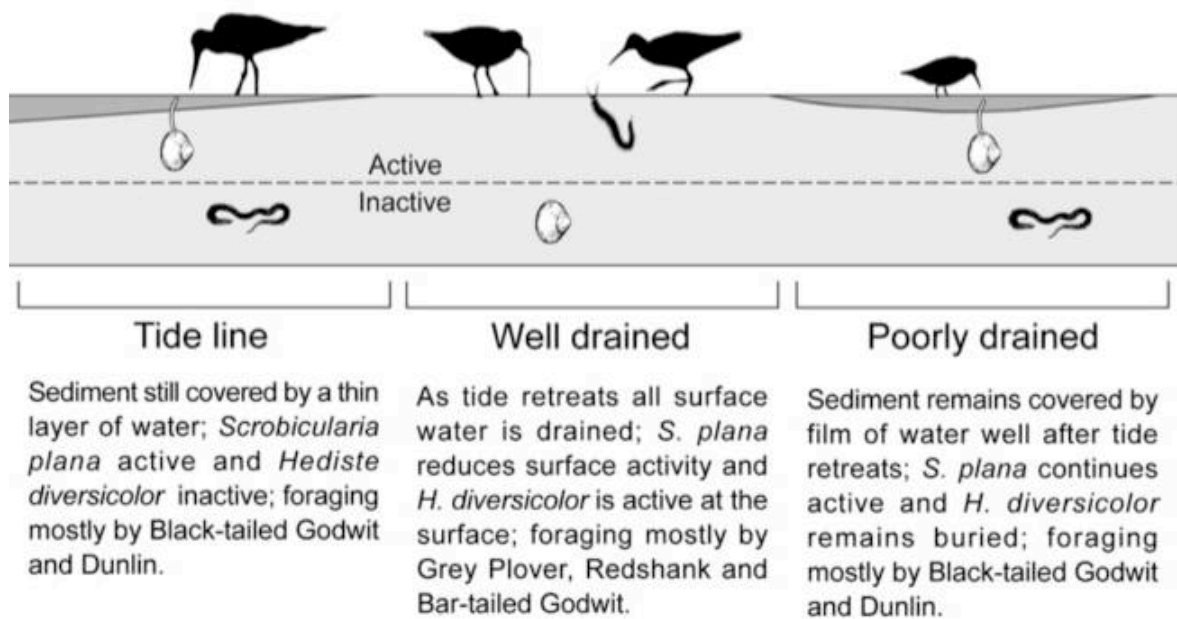
Figure 2.3.2: The relationship between sediment drainage, invertebrate and shorebird activity: More well-drained areas come along with an increased invertebrate activity (left and middle), that is often followed by the shorebirds (Source: Rosa et al., 2007).

Effect of wind speed and decreasing temperatures

Overall, the smallest birds have got the highest relative conductance, the narrowest temperature range (Wiersma & Piersma, 1994), and the highest relative heat loss to body size (Visser & Ricklefs, 1993), which needs to be compensated to stay warm. Additionally, conductance will increase with wind speed, thus under windier conditions smaller birds may need more energy for their own body maintenance (Wiersma & Piersma, 1994). The chicks of the smaller species are especially at risk (Visser & Ricklefs, 1993). This is the point where micro-habitat may become more important and the availability of sheltered roosting sites can potentially be life-saving. A study by Wiersma and Piersma (1994) investigated the reduction in wind speed expressed in the relative heat loss of Red Knots *(Calidris canutus islandica)* with regards to sheltered locations in a habitat, and found that the best locations were in dense vegetation, in a flock, or behind an obstacle along the beach (Figure 2.3.3). Accordingly, a study by Bergström (1985, cited in Page, 1985) found that the Wilson´s Plover in Texas placed its nests close to vegetation patches on the leeward side of the normal wind direction. This had the additional positive effect that nests were placed in the shade in the afternoon, when temperatures were high. However, Snowy

Plovers have been found to breed in rather sparsely vegetated areas, a likely result to believed improved visibility over the area (Colwell et al., 2005; Lafferty, 2001)
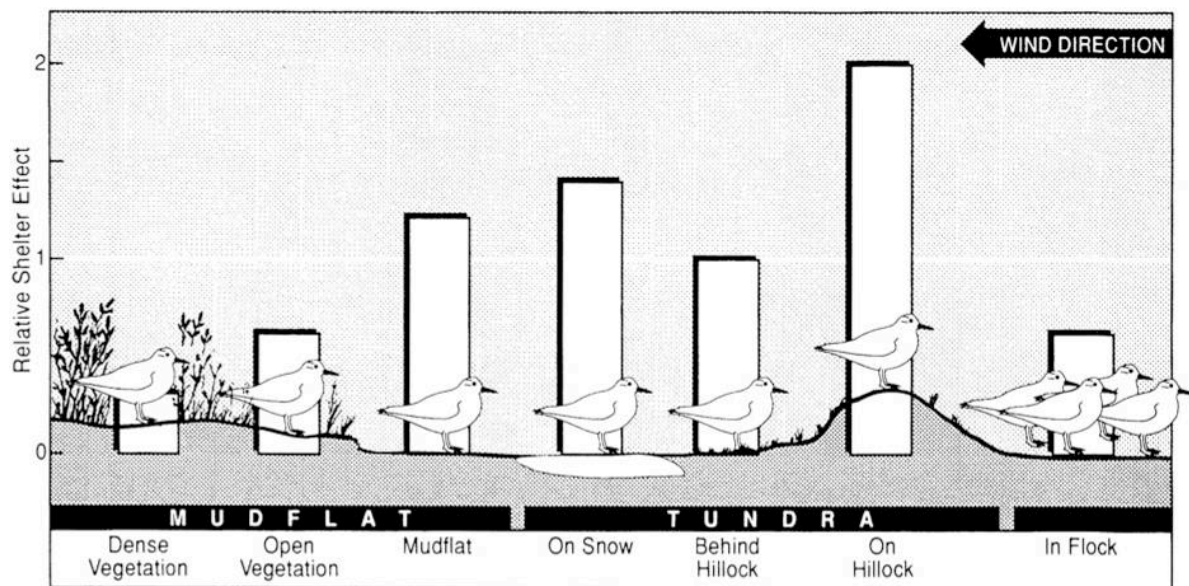
Figure 2.3.3: The reduction in wind speed for Red Knots (Calidris canutus islandica) expressed in relative heat loss at different locations within a sandy beach or tidal flat habitat (Wiersma & Piersma, 1994).

If temperatures decrease, every species' metabolic rate will increase (Piersma, 1994; Rogers, Piersma, et al., 2006; Visser & Ricklefs, 1993), which is often accompanied by higher mortality rates due to starvation (Zwarts & Wanink, 1993). However, not only the birds will be affected by decreasing temperatures, but also their prey, which may indirectly affect the birds further. As such, the activity of invertebrates in the sediment may decrease and they would stay more deeply buried in the sediment (Davidson, 1981; Evans, 1987; Pienkowski, 1983). This would have multiple consequences. First, there will be less cues for the birds to detect their prey, making it more difficult for visual foragers such as plovers (Pienkowski, 1983). Second, bill length is likely to be a limiting factor, as the invertebrates may not be accessible due to the depth (Nebel, Jackson, & Elner, 2005; Pienkowski, 1983). Third, cold wind and lower temperatures dry out the sediment, which may affect the penetrability of the sediment and will take the bird more effort to stab into the ground (Danufsky & Colwell, 2003; Finn et al., 2008; Grant, 1984). Consequently, handling time and effort may increase with depth (Zwarts & Wanink, 1993).

Moreover, a study by Botton et al. (1994) revealed that strong onshore-winds could create a delay in crab spawning (shift from May to June) resulting in a mismatch, as egg density will be reduced and not be available for migratory birds to feed on at arrival at the site. Here, low-wave energy beaches seem to be preferred by the crabs, where they can retain eggs in surface sediments more easily (Botton, Loveland, & Jacobsen, 1994).

Waves and swash regime

Waves are a product of prevailing wind forces over space and time, and have a considerable role in shaping sandy beaches as well as the conditions present in the intertidal zone, which is the main foraging area for resident shorebirds. Accordingly, few studies detected higher shorebird numbers associated with wider swash zones and relatively low swash zone gradients (Neuman, Henkel, & Page, 2008), conditions that have been accompanied with higher invertebrate abundance and diversity (McLachlan & Dorvlo, 2005). However, Neumann et al. (2008) found a significant negative relationship between swash zone slope and the distribution of four out of six investigated shorebird species, indicating that steeper slopes harbour less favourable conditions. However, the Snowy Plover was not affected by swash zone slope that was explained by its foraging strategy and type of prey, as Snowy Plovers feed mainly on wrack-associated invertebrates (Page et al. 1985) and are therefore not as dependent on intertidal zones (Neuman et al., 2008). In addition to its nutritional value for plover species, beach wrack may also be important for shelter or orientation, e.g. to find a nest again (Page et al., 1985; Powell, 2001), or for hiding, e.g. from predators (Powell, 2001). However, other obstacles such as driftwood or rocks may serve similar purposes (Page et al. 1985). Additionally, the resulting swash regime could facilitate the accumulation of wrack along a beach, providing a variety of macro- and micro-fauna for shorebirds and other predators to feed on (Dugan et al., 2003). Overall, McLachlan (1985) reported that biomass of invertebrate fauna would be one to three times higher on wrack-covered beaches, which would most likely be the case on exposed ocean sandy beaches.

Feeding conditions provided by different beach types

As every beach type can be described by different conditions, different species such as shorebirds may also have adapted to or favour a specific type of beach. Accordingly, it has been suggested that dissipative beaches or generally lower wave energy beaches may offer

more favourable conditions for a variety of organisms (Figure 2.3.4c), (Lercari et al., 2010; McLachlan & Dorvlo, 2005; McLachlan, 1990). This is explained by the fact that maintenance costs, particularly for invertebrates species in the sediment, are not as high. As such, the physical stress in the swash zone would not be as high and thus it would not as important to stay attached to the sediment (McLachlan & Dorvlo, 2005). This has led to the 'swash exclusion hypothesis', which suggests that within the conditions of the dynamic and turbulent swash zone with constantly breaking waves, certain species could be excluded from this part of the beach by being washed away (McArdle & McLachlan, 1992; McLachlan & Turner, 1994; McLachlan et al., 1995).

However, McLachlan et al. (1993) underlined that more than one environmental factor will be important for a sandy beach species, and that the combination and interaction of different factors are critical (Figure 2.3.4). As pointed out, according to Lercari et al. (2010), dissipative beaches represent the 'more complex system' compared to reflective beaches, with more species diversity and increased productivity. Dissipative beaches also own higher trophic levels, and may support higher numbers of top predators such as shorebirds.
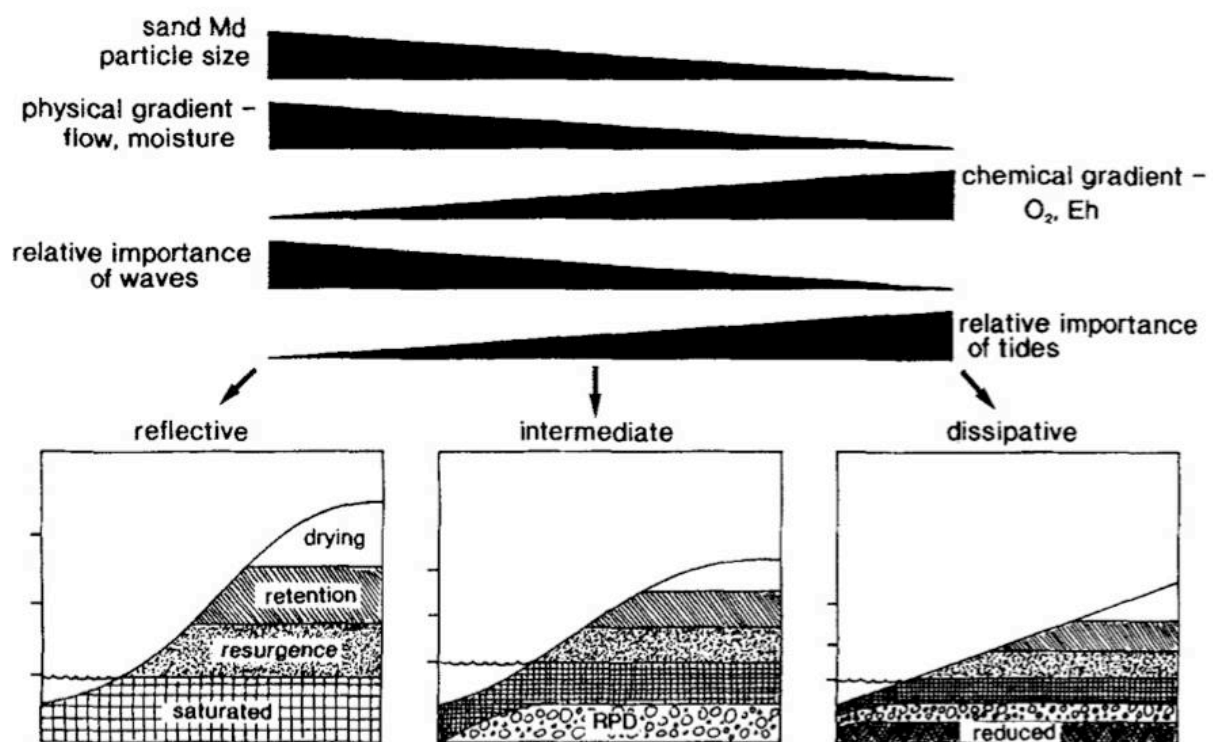
Figure 2.3.4a-c: Within the wave-dominated beaches, reflective beaches represent one extreme (a, left), with the coarsest sediment acting as a large water filter and may

therefore harbour the harshest conditions to live and settle, as this sediment is well drained by tides and waves (as indicated by a, left) and highly oxygenated. The dissipative beaches (c, right) on the other extreme consist of much finer sediment, containing less oxygen and are more affected by tides than by waves. McLachlan and Turner (1994) defined the dissipative beach type as 'chemically' controlled, whereas the reflective type was described as more 'physically' controlled. Hereby, the terms 'saturated, resurgence, retention and drying' (a, left) define the moisture content in every sediment layer. Accordingly, also on a vertical axis, reflective beaches may range from rather dry to saturated conditions, whereas dissipative beaches filter smaller, therefore 'reduced' volumes of seawater (Source: McLachlan & Turner, 1994; Schlacher & Thompson, 2013).

3 Tasmania´s shorebirds and beaches

3.1 Introduction to shorebirds

Shorebirds (order Charadriiformes), also known as waders, are often grouped into a homogeneous category of birds (Maclean, 1972; Piersma, 2007) that occupy wetland and coastal habitats (Piersma, de Goeij, & Tulp, 1993; Piersma, 2003), where they wade through shallow water probing the sediment for prey (Both et al., 2003; Jing et al., 2007; Kuwae et al., 2012). Often they are referred to as long-legged and –billed birds, but in fact, there are distinct differences among the species groups (see species descriptions below).

Overall, shorebirds are long-lived (Goede, 1993, cited in Piersma, 1997) and monogamous species, thus a couple will pair up for life (Sandercock, 2001). The reproductive rate is rather low with 2-4 eggs in one clutch, which is laid in one season (Piersma, 2003). The young are considered to be 'precocial', meaning that the chicks hatch with open eyes, down feathers (Visser & Ricklefs, 1993), and are mobile in order to leave the nest immediately, but will still be guided by the parents (Schekkerman, Tulp, Piersma, & Visser, 2003). The nest consists of a scrape in the sand ('open nests', Piersma, 2003). When chicks are present, most shorebird species exhibit a variety of anti-predator behaviours, including distraction displays and aggressive nest defence (Gochfeld, 1984).

3.1.1 Morphological adaptions

Many shorebird species exhibit pronounced inter- and intra-specific variation in bill length and shape (Figure 3.1.1), particularly with regards to curvature and slenderness (Nebel et al., 2005), enabling the birds to exploit a specific niche (referring to a location and a function within an ecosystem that is exhibited by an organism) of their habitat (Clayton et al., 2005; Lauro & Nol, 1995; Prakash et al., 2008). The niche concept represents a specialisation process to utilise different parts of an environment (Toor et al., 2011). It is a mechanism to partition resources, enable the coexistence of individuals (Baker & Baker, 1973; Pianka, 1974), and reduce competition (Duffy, 1981; Lauro & Nol, 1995). However,

shorebirds are top-level consumers (Erwin, 1996; Lercari et al., 2010) and feed on a variety of invertebrates including worms, crustaceans, molluscs and small insects (Jing et al., 2007; Kuwae et al., 2012; Piersma et al., 1993).

Figure 3.1.1: Morphological beak adaptions enable different shorebird species to exploit a specific niche in their habitat (Source: Department of Primary Industries, Parks, Water and Environment (2010). Shorebirds in Tasmania [Brochure]. State of Tasmania.).

3.1.2 **Feeding behaviours**

Compliant with the morphological beak and leg adaptions, different species developed a range of distinct feeding behaviours based on visual and tactile mechanisms, including several feeding styles such as pecking, probing, stabbing, sweeping, and ploughing (Jing et al., 2007; Nebel et al., 2005). Overall, three styles have been established in the literature:

(1) 'pause-travel' where birds alternate between short stationary periods and short runs, either attempting to peck according to visual cues or stop at the end of each run,

(2) 'tactile-continuous' birds move steadily and sense prey by touch by either probing prey from or beneath the surface and,

(3) 'visual-continuous' detect prey with their eyes by visual cues (Jing et al., 2007).

The tactile species have mechanoreceptors at the tips of their beaks and are therefore referred to as 'tactile-foragers', as they sense pressure gradients deriving from the presence and the movements of buried invertebrate species (Jing et al., 2007; Nebel et al., 2005).

3.1.3 **Migratory and resident species**

On ocean sandy beaches, shorebirds can often be observed feeding in the intertidal or swash zone during low tide and roosting above the high water line at high tide (Thomas, 1968; Zharikov & Milton, 2009). Accordingly, the daily pattern of a shorebird is driven by the tides, regulating roosting and foraging behaviours (Burger, Howe, Hahn, & Chase, 1977; Johnson & Baldassarre, 1988; McConkey & Bell, 2005; Rogers, Battley, et al., 2006). Overall, the main activities of a shorebird can be divided into (1) foraging, (2) roosting, and (3) breeding (Schlacher, Nielsen, et al., 2013). There are two distinct life-styles that can be identified: migratory and resident species (Piersma, 2003, 2007). The latter are year-round residents in the same area where they occupy a territory (either throughtout the entire year or seasonally), thus an area that is used exclusively by the breeding pair for breeding, feeding, and roosting, and will be defended by the pair (Pitelka, 1959). By contrast, migratory shorebird species fly long distances to winter in an area different from their breeding range. Migratory species are defined by an entire population or any geographically separate part of a population that cyclically and predictably crosses one or more national jurisdictional boundar(ies), (Bamford et al., 2008).

3.1.4 **Evolutionary relationships**

Overall, the traditional order 'Charadriiformes' represents one of the largest and most specious of the nonpasserine (songbirds) groupings and used to represent its own order, but has just recently been assigned with a new position (Dyke & Tuinen, 2004). According to recent molecular analyses (Sibley & Ahlquist, 1990, cited in Dyke & Tuinen, 2004), the order Charadriiformes comprises now of 14 families and about 217 shorebird species worldwide (Figure 3.1.2.) including the jacanas, oystercatchers, avocets and stilts, stone-curlews and thick-knees, coursers and pratincoles, sandpipers and snipes, button-quails, plovers, sheathbills, gulls, terns, skimmers and auks, that are now placed as suborders into the much larger Ciconiiformes or Charadrii order (Dyke & Tuinen, 2004; Maclean, 1972; Piersma, 2007).
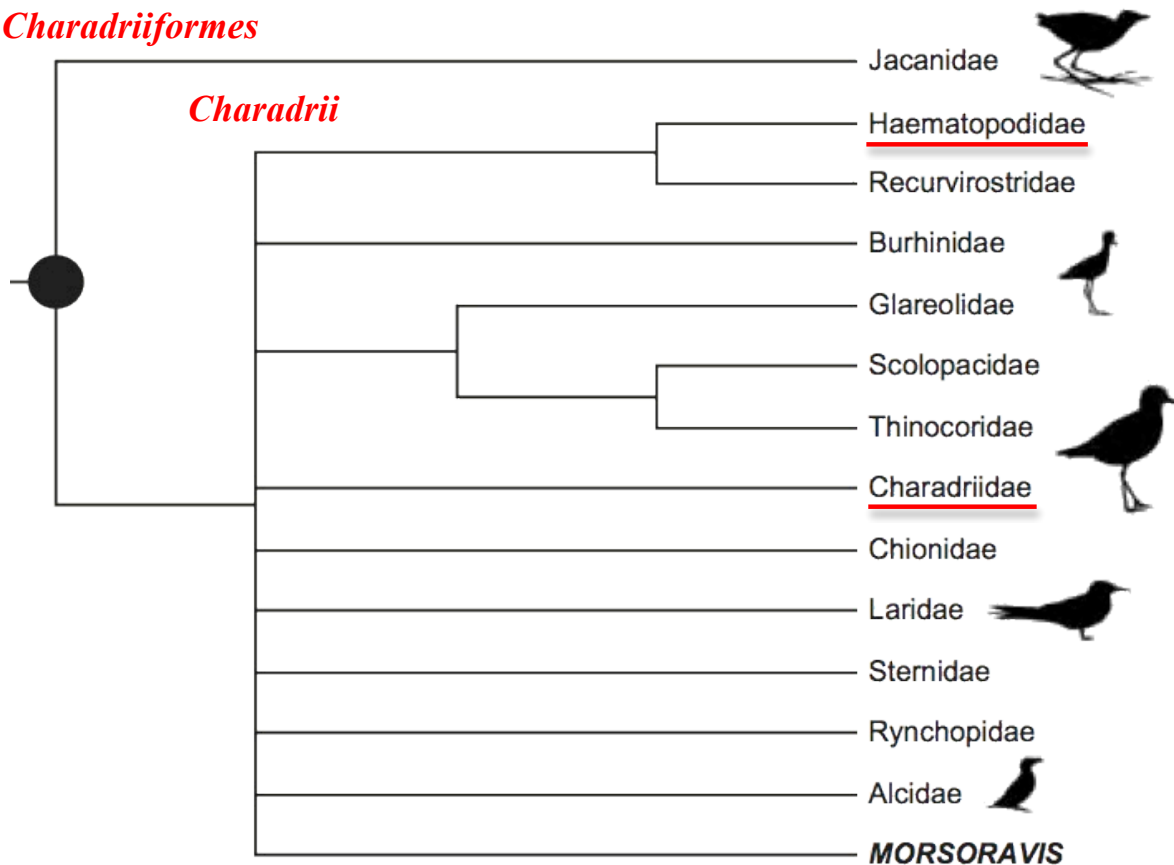
Figure 3.1.2: Phylogenetic relationships of the order Charadriiformes from the top to the bottom: The first branch are the jacanas (Jacanidae), whereas the following branches are suborders from the order Ciconiiformes or Charadrii starting with the oystercatchers on top (Haematopodidae, red underlined), further below the avocets and stilts (Recurvirostridae), stone-curlews and thick-knees (Burhinidae), coursers and pratincoles (Glareolidae), sandpipers and snipes (Scolopacidae), button-quails (Thinocoridae), plovers (Charadriidae, red underlined), sheathbills (Chionidae), gulls (Laridae), terns (Sternidae), skimmers (Rynchopidae), auks (Alcidae) and the recently discovered fossils of Morsoravis sedile (Morsoravis), a primitive member of Charadrii from the Palaeocene-Lower Eocene deposits in Jutland, Denmark (Source: Dyke & Tuinen, 2004).

3.2 The study species

3.2.1 Shorebirds in Australia and Tasmania

Approximately 55 shorebird species can be found across Australia throughout the year, where the majority are migratory species that come via the East Asian - Australasian Flyway (EAAF) from the Northern Hemisphere to over-winter in and around the coastal zones of Australia. Of these 55 species, 18 are resident species that are present throughout the year in Australia (Milton, 2003). With regards to the migratory species, Australia is of particular importance as these species need to feed throughout the southern summer and prepare for the return flight northwards to the breeding grounds (Canaris & Kinsella, 1998). The EAAF is one of nine major recognised waterbird flyways (light green in Figure 3.2.1), defined as "a geographic region that supports a group of populations of waterbirds throughout their annual cycle" (Bamford et al., 2008, pp. V). It is believed to be one of the largest, with an extent from the Russian Far East and Alaska to Australia and New Zealand totalling up to about 23 countries.

According to Wetlands International (Delany & Scott, 2006), out of 237 populations of migratory species worldwide (where data on abundance trends were available), 52% are decreasing and only 8% have been increasing. This has been supported by Wilson et al. (2011), who detected a decrease of 43-79% over the past 15 years in migratory shorebird species. Also, species using the EAAF seem to be decreasing, such as the Spoon-billed Sandpiper (*Eurynorhynchus pygmeus*), already listed as Vulnerable, Curlew Sandpiper (*Calidris ferruginea*) and the Red-neck Stint (*Calidris ruficollis),* Bamford et al., 2008). However, not only are migratory species affected, but resident species are also decreasing in numbers. One example is the Hooded Plover, which is listed as vulnerable on the IUCN Red List of Threatened Species (Milton, 2003) with local extirpations on certain beaches. From 1982-2002, its population decreased in Tasmania by 20% (Woehler & Park, 1997). However, Tasmania is still believed to be a stronghold for several resident shorebird species (E. Woehler, personal communication, March 15, 2014).
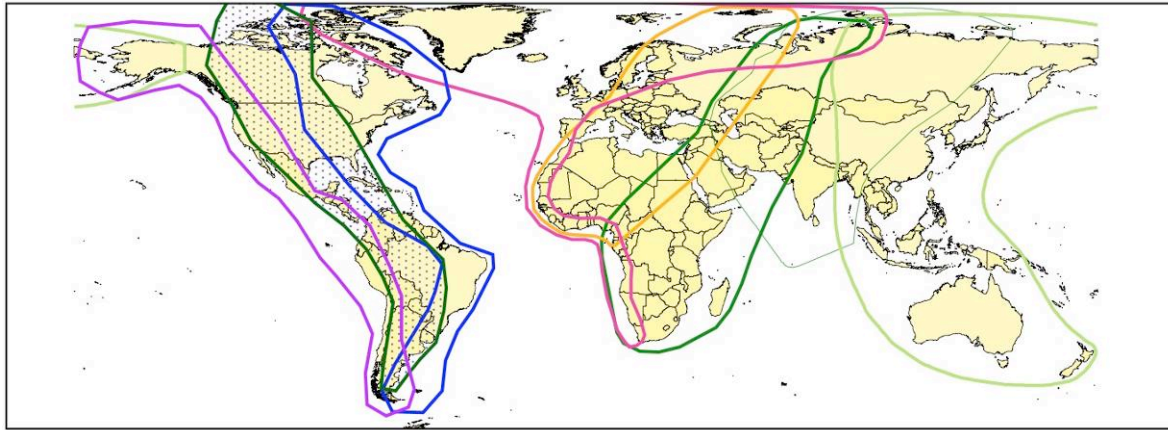
Figure 3.2.1: Nine major flyways are recognised worldwide. These are names and divided according to the continent. The EAAF (light green) extends from Northern Russia to Australia and New Zealand (Source: Bamford at al., 2008).

3.2.2 **Oystercatchers - *Haematopodidae***

Oystercatchers (*Haematopodidae*) are a cosmopolitan shorebird family comprising of 10 different species worldwide (Table 3.2.1), (Piersma, 2003). One of these, the Canary Island Species, is believed to be extinct, as it has not been recorded since 1913 (Hayman et al., 1986). Oystercatchers can be described as bulky waders with black/brown or black/brown-and-white plumage, a long orange bill and fairly short legs. All species are chiefly coastal with some exceptions that breed inland (Heppleston, 1973; Lauro & Nol, 1995). Rocky-shore oystercatchers tend to be blacker in plumage, thicker-billed, and stouter-legged. All species are remarkably similar with just slight variations in size, shape of bill and legs, iris and eye-ring colour, and distribution of black, brown and white in the plumage (Lauro & Nol, 1995). Species can be migratory or resident, more sedentary or gregarious. The Eurasian Oystercatcher is the most widespread and a migratory species (Maclean, 1972). Two species are endemic to Australia, the Sooty and the Pied Oystercatchers (*Haematopus fuliginosu* and *longirostris)*, where the former is a typical inhabitant of rocky shores. Both are easily distinguishable, as Sooty Oystercatchers are entirely black and Pied Oystercatcher black and white (Figure 3.2.2), (Condon & McGill, 1960, Rutgers, 1967, cited in Hepleston, 1973).

Table 3.2.1: Oystercatcher species worldwide according to Hayman et al. (1986).

Common Name	Scientific Name	Continent/Country
Eurasian Oystercatcher	*Haematopus ostralegus*	Europe/Asia
African Black Oystercatcher	*Haematopus moquini*	Southern Africa (West)
American Oystercatcher	*Haematopus palliatus*	Central and South America
American Black Oystercatcher	*Haematopus bachmani*	North America (West)
Blackish Oystercatcher	*Haematopus ater*	South America (West)
Magellanic Oystercatcher	*Haematopus leucopodus*	South America (West)
Variable Oystercatcher	*Haematopus unicolor*	New Zealand
Chatham Islands Oystercatcher	*Heamatopus chathamensis*	New Zealand/Chatham Is.
Pied Oystercatcher	***Haematopus longirostris***	**Australia**
Sooty Oystercatcher	*Haematopus fuliginosus*	Australia

1.   Australian Pied Oystercatcher - *Haematopus longirostris*

Measurements:

Length: 480-510mm

Wing: 263-295mm

Bill: 69-89mm

Tarsus: 53-60mm

Identification:

Compared to other oystercatcher species, the Australian form differs by having a shorter white wingbar, less white on the back, a black leading edge to the underwing and black coming slightly farther down the breast (Hayman et al., 1986). Furthermore, it has glossy black upper parts and adults have a red iris, like the Eurasian type, unlike the four American species. Compared to the two species from New Zealand, Pied Oystercatchers have less black on the breast and a sharper division between the black and white, but more white on the rump and lower back.

20 Pied Oystercatcher *Haematopus longirostris*
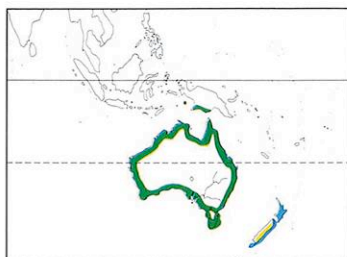
There are two, well-differentiated races.
a ADULT Australian *longirostris*: Has red eye-ring and iris, and black-and-white plumage with white shoulder-patch.
b ADULT South Island Pied Oystercatcher (SIPO) of New Zealand, race *finschi*: Superficially like Australian form, but rather smaller.
c Race *longirostris*: Short wingbar, not meeting trailing edge. White rump extends onto the lower back.
d Race *longirostris*: Flight feathers and median under primary coverts dark. Wing fairly broad.
e Race *finschi*: All-white greater coverts form a longer bar than in *longirostris*. Some show white also on inner primaries. White rump extends well up the back to end in a point.
f Race *finschi*: Underwing is similar to *longirostris*, but slightly more white shows on bases of flight feathers.
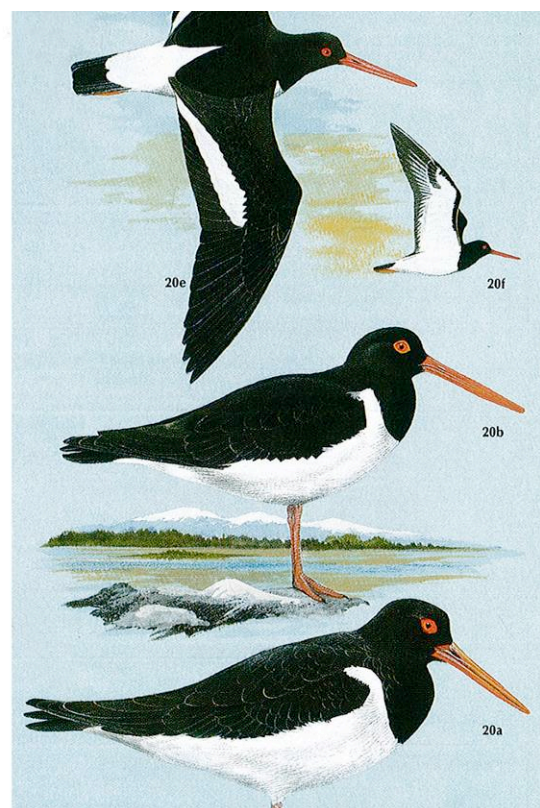
Figure 3.2.2: Field guide to adult Pied Oystercatcher males and females, and juvenile plumage (Source: Hayman et al., 1986).

Habitat and habits:

Pied Oystercatchers have been well studied in Tasmania with first banding surveys in 1968 by David Thomas around Hobart (Thomas, 1968), but the largest contribution to the understanding of Pied Oystercatcher habits and life-history was made by Newman, who has published a range of studies since 1977 from his long-term surveys. Overall, Pied Oystercatchers have been described as long-lived, sedentary, and territorial birds (Fletcher & Newman, 2010) that frequently return to the same sites (Newman, 1982b; Sharland, 1930). Throughout the literature, Pied Oystercatchers are described as a coastal species (Schlacher et al., 2014) occupying, preferably, intertidal mudflats, sandy beaches, and sandbanks in large marine embayments (Lauro & Nol, 1995; Newman, 1984). They have, however, also been observed farther inland on pastures, saline wetlands, or brackish swamps. According to Newman (1992), Pied Oystercatchers seem to differ in their habits from other oystercatcher species by having a relatively small clutch size, a long incubation period, and a long interval between hatching and flying at a very high age at first breeding.

Foraging:

As is the case with other oystercatcher species (Ens & Goss-Custard, 1984; Schlacher et al., 2014; Sutherland, 1982; Weber & Haig, 2014, Zwarts & Wanink, 1993), Pied Oystercatchers feed to a large proportion on molluscs, bivalves and small crustaceans (Dare & Mercer, 1973; McConkey & Bell, 2005; Rehfisch et al., 1996; Spruzen et al., 2008; Taylor & Taylor, 2005; Thomas, 1968) such as cockles *(Cerastoderma edule L.)* and mussels *(Mytilus edulis L.)*. However, polychaete worms also represent an important part of the Pied Oystercatcher´s diet (Boates & Goss-Custard, 1992; Lauro & Nol, 1995), that are the easiest to access in the shallow water of the intertidal zone during low tide at ocean sandy beaches or other types of intertidal flats or wetlands (Newman, 1982b).

Breeding:

Pied Oystercatchers are monogamous, thus will pair up for life with one partner (Fletcher & Newman, 2010). During the breeding season from September to February (Newman, 1992; Newman & Park, 1992), both parents share the breeding, which includes the incubation of the eggs, the defense of the territory, and the feeding and guidance of the chicks. The nest is placed as a depression in the sand above the high water mark, where

excellent visibility is provided to spot any predators approaching (Fletcher & Newman, 2010; Lauro & Nol, 1993; Newman, 1992). The nest site selection seems to vary with the experience of the pair, since there have also been cases recorded where the nest was placed on shell-grit (Newman, 1992). After hatching, the young can run immediately ('runners'), but will be fed by the parents until they can fly (Newman & Park, 1992). If the parents are looking for food or the young are disturbed, they will hide and crouch on the upper part of the beach close to the dunes, wrack, or other obstacles (Newman, 1992; Yasue & Dearden, 2009). As in other oystercatcher species and as territory holders, Pied Oystercatchers will exhibit a distinctive display when an intruder enters the territory, where it runs sideways with its wing carpels raised and the beak held nearly vertically, while emitting a series of load calls (Newman & Park, 1992; Vines, 1979). If still on eggs, it will run away in order to avoid indicating the nest location. In the case of nest loss and if breeding started early in the season, Pied Oystercatchers have been observed to lay replacement clutches (Newman, 1992). As a territorial species, the juveniles will leave the parental territory in order to establish their own (Newman, 1982b).

Roosting:

As in other shorebird species, Pied Oystercatchers roost above the high water mark during high tide and will wait for the next low tide and thus feeding period.

Population status and threats:

Current population numbers have been estimated to range between 11.000 and 14.000 birds for all of Australia and southern Papua New Guinea (Delaney & Scott, 2006). Overall, it is believed that Australian mainland populations are decreasing due to low breeding success, while population numbers have been announced as increasing on the southeast coast of Tasmania (Fletcher & Newman, 2010). Main threats that were identified included human recreational use, particularly during the breeding season, and a combination of rising sea levels, storm-driven tides, and the loss of seagrass beds (Fletcher & Newman, 2010). Accordingly, some clutches were lost due to inundation, but the birds responded by using alternative nest sites behind the beachfront such as paddocks with short grass, or even beside roads.

3.2.3 Lapwings and Plovers - *Charadriidae*

The lapwings and plovers comprise about 66 species with 105 distinct populations or subspecies worldwide, and represent with the sandpipers *Scolopacidae* (with 86 species and 134 subspecies units) the most diverse shorebird-family with regards to migration propensity and migration distance (Piersma, 2003, 2007). There are 37 species belonging to the small plovers, which also contains the two study species - Hooded and Red-capped Plovers (*Charadrius rubricollis* and *ruficapillus*), while lapwings comprise 24 species and four species of Golden and Grey Plovers *(Pluvialis apricaria* and *squatarola),* (Hayman et al., 1986). Overall, lapwings and plovers are described as a cosmopolitan group of birds that have distinctive short bills and are chiefly visual feeders (Evans, 1987; Zaitsev, 2012). The actual feeding behaviour can be described as a run-pause-dip or run-pause sequences, where during pauses the bird is actively searching for signs of possible prey (Jing et al., 2007). The small plovers are a varied group with a number of single-species genera that show similarities and are probably closely related (Maclean, 1972). As a cosmopolitan suborder, Charadrii occupy a wide variety of habitats from the edges of snowfields at high altitudes or in the Arctic, to areas of tropical sand, where eggs have to be cooled rather than warmed (Fuller, 1986; Goutner, Kazantzidis, & Charalambidou, 2005; Gudmundsson & Gardarsson, 2006; Summers et al., 2002; Underhill, 1987). Therefore almost all patterns of distribution and migration are represented within this group. From its 37 species, six are found in Australia including Double-banded (*Charadrius bicinctus),* (Dann, 1991) and Black-fronted Plovers (*Charadrius melanops),* (MacLean, 1977), Inland *(Peltohyas austvalis*), (MacLean, 1973) and Red-kneed Dotterels (*Peltohyas cinctus)*, (McGill, 1944), and the two study species Hooded and Red-capped Plovers (*Charadrius rubricollis* and *ruficapillus*).

2.   Hooded Plover – *Charadrius rubricollis*

Measurements:

Length: 190-205mm

Wing: 139-145mm

Bill: 16-18mm

Tarsus: 25-27mm

Identification:

The Hooded Plover has been described as stocky and endemic to the southern half of Australia, and is especially common on Tasmanian beaches (Hayman et al., 1986). It appears rather neckless with a horizontal stance and protruding breast (Figure 3.2.3), which separates it from most other plovers in Australia. It is distinguishable by its short pale legs and conspicuous white band across the hind neck. Adults are recognisable by a black head, white nape and pale sandy-grey upper parts that provide a unique pattern, while juveniles have a rather pale brown head and white neck collar.
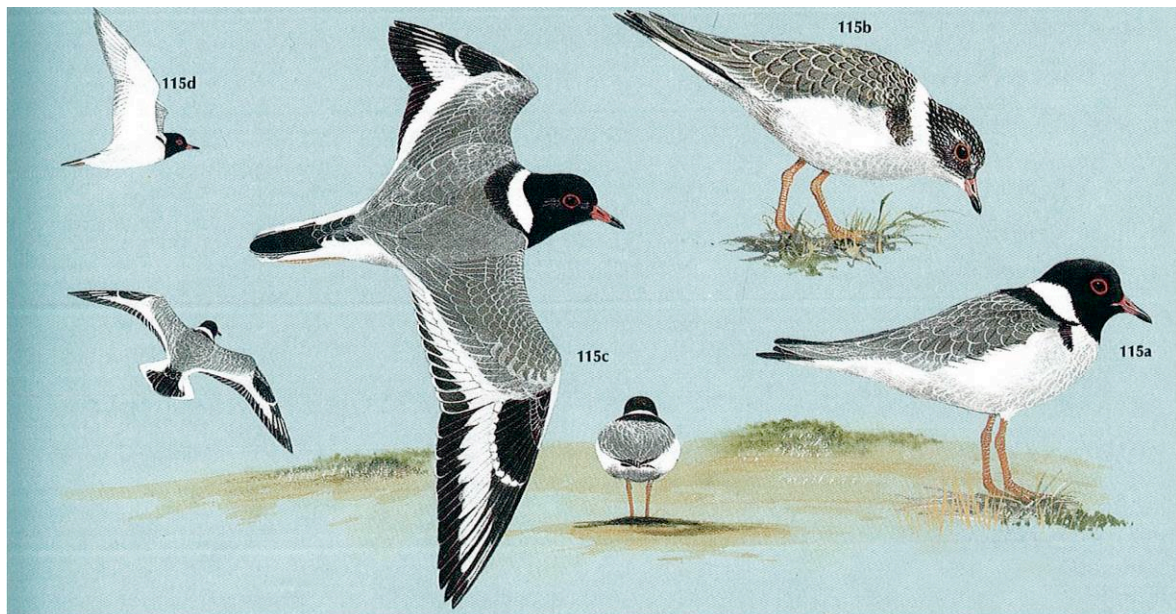
115 Hooded Plover *Charadrius rubricollis*

Text page 305
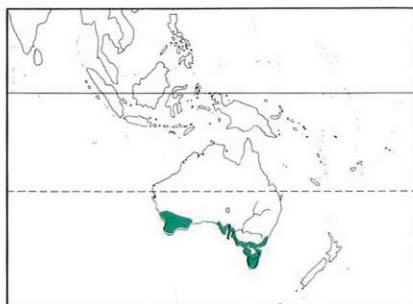
A stocky, pale plover found mainly on sandy beaches. Disruptive patterning makes very good camouflage. Has a broad white hindneck collar and short orangey legs.

a ADULT: Entire head is black. Black lower hindneck collar extends into small lateral breast-patches. Bill pink, tipped black. Legs orange-brown to yellowish-pink.

b JUVENILE: Black on hindneck and cap is replaced by pale grey-brown, tipped buff-white; chin and throat whitish, washed pale grey. Upperpart feathers have distinct dark submarginal lines and buffish-white fringes; looks pale and scaly.

c In flight, shows broad and long white wingbar contrasting with blackish trailing edge and primary coverts. Sides of uppertail and base of tail broadly white, contrasting with blackish tail centre and subterminal tail-band.

d Entire underwing is very white.

Figure 3.2.3: Field guide to adult Hooded Plover, and juvenile plumage (Source: Hayman et al., 1986).

Habitat and habits:

The Hooded Plover is probably one of the most investigated shorebirds in Australia and has received significant amount of attention due to is population decline (Baird & Dann, 2003; Dowling & Weston, 1999; Weston & Elgar, 2005a, 2007; Weston, 2005; Woehler & Park, 1997). The Australian populations have been divided into an eastern sub-species occurring in the southeast of the Australian mainland and in Tasmania (Garnett, Szabo, & Dutson, 2011), and into a western sub-species in Western Australia (Garnett et al., 2011). The Hooded Plover is a species typically found on ocean sandy beaches, especially wide-

flat beaches (Baird & Dann, 2003; Thomas, 1968; Weston & Elgar, 2005b) with a lot of seaweed (Schulz, 1993; Weston, 1992). As territory holders, Hooded Plover juveniles disperse from the parental territory when reaching maturity in order to establish their own territory, find a partner, and start to breed (Dowling & Weston, 1999; Weston et al., 2009; Whitelaw, Whitelaw, & Weston, 2005).

Foraging:

According to Marchant and Higgins (1993, cited in Garnett et al., 2011), Hooded Plovers feed mostly on polychaetes, molluscs, turions, crustaceans, and seeds. Given the recorded value of seaweed and wrack on a beach for Hooded Plover breeding and roosting, and the importance of wrack-associated insects for other plover species such as Piping and Snowy Plovers (Dugan et al., 2003; Elias et al., 2000; Kuwae et al., 2012; Lafferty et al., 2013), it is likely that these are of similar importance for the Hooded Plover´s food intake.

Breeding:

As with other shorebird species, also Hooded Plovers are monogamous and breed in widely spaced territories (Weston & Elgar, 2005b). The breeding period has been described as rather lengthy, ranging from August to February in Victoria (Baird & Dann, 2003; Weston, 2005). Nests are simple scrapes in the substrate in which the clutch of one to four cryptically coloured eggs is laid (Buick & Paton, 1988; Weston & Elgar, 2005b). Most nest sites were recorded on flat ocean sandy beaches (52%). Only few breeding attempts were recorded on stony terraces (25%) and in dunes (23%), according to a study undertaken by Baird and Dann (2003). According to Weston et al. (2005), substrate was a dominant factor in nest site selection with birds preferring to nest in wrack, but no difference in Hooded Plover densities was observed among different beach types (unpubl., cited in Weston et al., 2005). Both parents share the breeding, including the egg incubation and guidance of the chicks (Weston & Elgar, 2005b). Also Hooded Plover chicks are precocial and can therefore run and feed immediately after hatching. However, Hooded Plover chicks stay mostly on the upper part of the beach, where they can crouch, freeze, and hide in the dunes or next to seaweed, when being disturbed (Weston & Elgar, 2005a; Weston, 2005). According to Weston and Elgar (2005), chicks are not fed by the parents after hatching, as is the case e.g. for Pied Oystercatchers. Hooded Plover defence strategies rely heavily on camouflage and leaving the nest, when an intruder enters the territory

(Schulz, 1993; Weston & Elgar, 2005b). If chicks are present, Hooded Plovers may also perform distraction displays, such as pretending to be injured, or show aggressive responses (Weston & Elgar, 2005b). Hooded Plovers have also been observed to lay replacement clutches.

Roosting:

Hooded Plovers have been observed to move onto recently exposed tidal reef platforms when the tide recedes (Schulz, 1993). In a survey on Victorian beaches, about 70% of roosting Hooded Plovers were observed on upper beach parts between seaweed and wrack (Weston, 1992). Birds were also observed in the dunes and on rocks, but altogether found almost exclusively on sandy beaches. Only 11% were found in other habitats, illustrating the dependency of Hooded Plovers on ocean sandy beaches (Weston, 1992).

Population status and threats:

In an Action Plan for Australian Birds 2010 published by Birds Australia in 2011, the eastern Hooded Plover was listed on the IUCN List of Threatened Species as Vulnerable and its population was stated to be lower than 10.000 individuals in a single subpopulation with an estimated ongoing decline of 10–20% in 3 generations (39 years, Garnett et al., 2011). The last estimates for Australia were around 5500 birds, while Tasmania sustains about 2000 Hooded Plovers (BirdLife Tasmania unpubl. data).

The largest threats derive from human disturbance (any event having the potential to cause a response among breeding Hooded Plovers), (Weston & Elgar, 2005a) and recreational activities on beaches, which result in nest failures and low reproductive success (Dowling & Weston, 1999). These activities comprise of walkers/joggers with and without dogs, recreationists on horses, or other activities such as dune-boarding (Dowling & Weston, 1999), off-road vehicles such as bikes or quads (Buick & Paton, 1988), and also wandering livestock (Figure 3.2.4). Altogether such activities result in either crushing the eggs/chicks by trampling (Dowling & Weston, 1999) or separating the parents from the nests/chicks. Additionally, natural predation plays a role. Predators include foxes on the Australian mainland (*Vulpes vulpes*), ravens and currawongs (*Corvus spp.* and *Strepera spp.*), gulls such as Silver Gulls (*Larus novaehollandiae*), birds of prey or Australian Magpies

(Cracticus tibicen), (Baird & Dann, 2003; Garnett et al., 2011; Weston & Elgar, 2005a, 2005b, 2007).

However, it has been pointed out that disturbance may be more critical during certain stages within the breeding cycle, as Hooded Plovers only start to breed after the clutch has been completed with all eggs in the nest (Weston & Elgar, 2005b). Other consequences that have been pointed out are thermal stress (disturbance may prevent plover chicks from being effectively brooded), failure of defence (spatial separation or attraction of predators due to alarm calls), and energetic stress (reduction in foraging time or increase of energy expenditure), (Weston & Elgar 2005a).
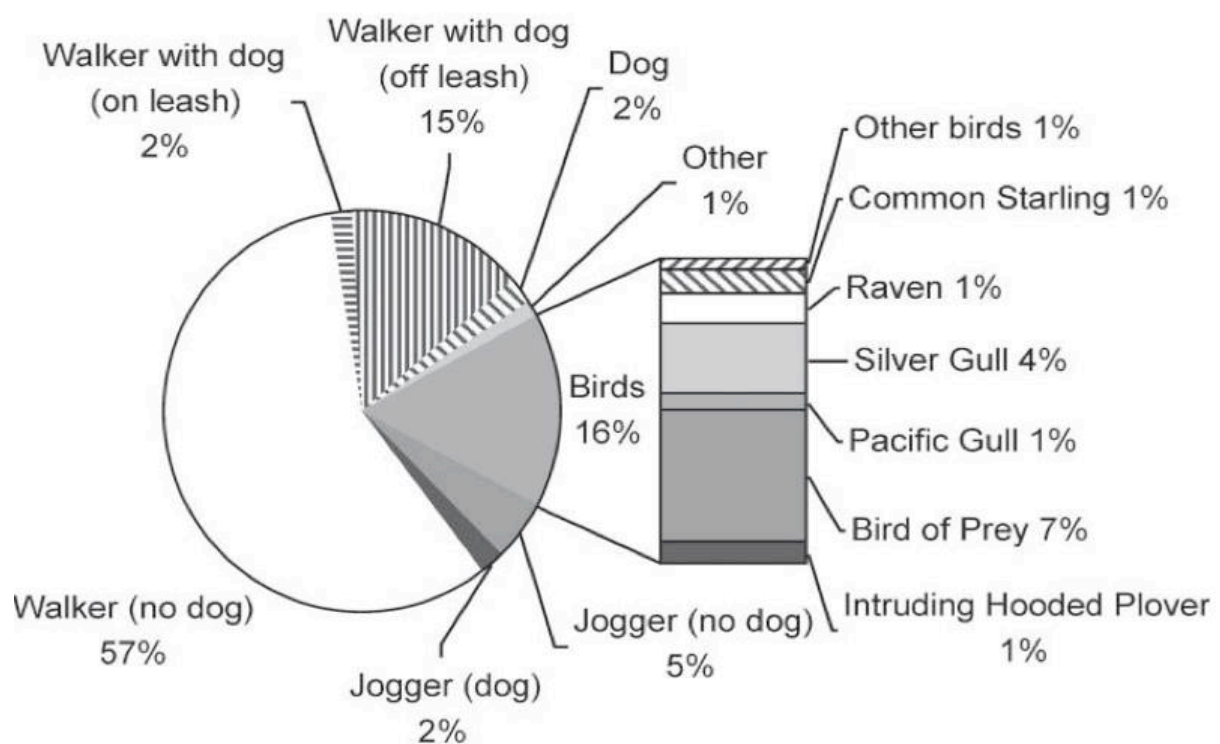
Figure 3.2.4: The contribution of different disturbance stimuli with Hooded Plover brood encounters (n=1.510, definition encounters= any event where a stimulus passed within a 100m of a brood), (Source: Weston & Elgar 2005a).

3.   Red-capped Plover – *Charadrius ruficapillus*

Measurements:

Length: 140-160mm

Wing: 98-107mm

Bill: 12-14mm

Tarsus: 24-28mm

Identification:

The Red-capped Plover is a small plover endemic to Australasia (smaller than the Hooded Plover) with a rather leggy appearance (Figure 3.2.5) that separates it from all other resident and migratory plovers throughout its range (Hayman et al., 1986). In flight it shows a strong white wing-bar and broad-conspicuous white sides to the rump, upper tail and tail. Male adults have a chestnut-reddish cap.
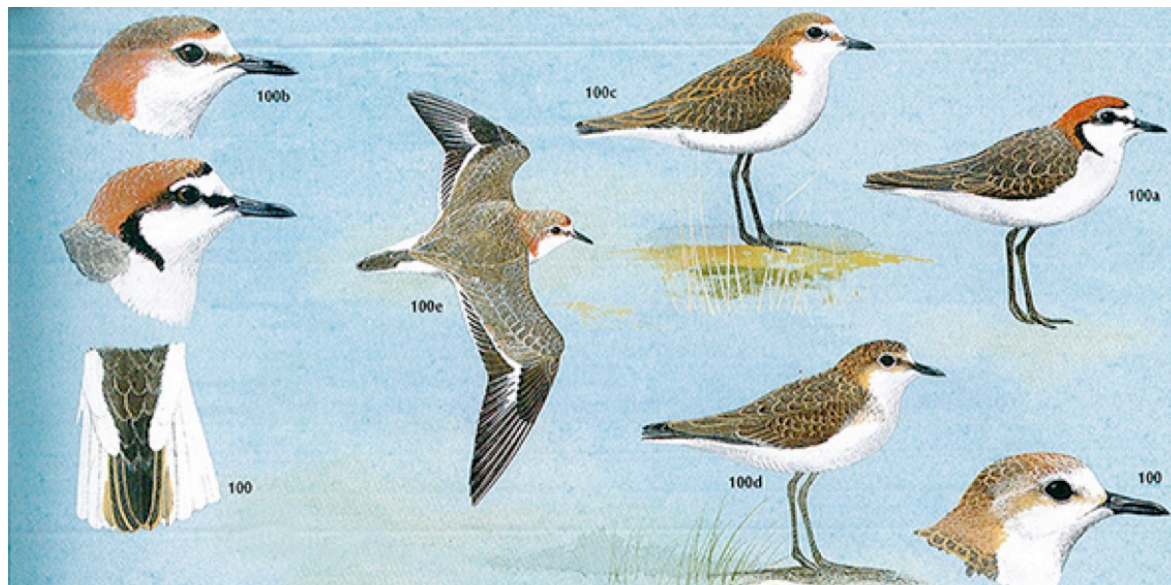
100 Red-capped Plover *Charadrius ruficapillus*

Text page 293

A small, dark-legged plover recalling Kentish (98), but always lacking a white hindneck collar and with tiny lateral breast-patches and a short supercilium.

a ADULT: Frontal bar, lores, eye-stripe and breast-patches black or blackish; extensive chestnut on crown and nape. On male, black areas lack brown tips, crown and nape often entirely chestnut.

b ADULT FEMALE: Sometimes duller than male, with centre of crown grey-brown.

c NON-BREEDING: Adult non-breeding and first-winter individuals may show only traces of adult head pattern. Breast white in centre. Supercilium extends only a little behind eye.

d JUVENILE: Chestnut and black of adults is replaced by brown. Lores and ear-coverts brown. Upperpart feathers show obscure dark submarginal lines and buff fringes.

e In flight, has distinct white wingbar and white sides to uppertail and tail, as on 98. Underwing-coverts and axillaries are white.

Figure 3.2.5: Field guide to adult male and female Red-capped Plovers, and juvenile plumage (Source: Hayman et al., 1986).

Habitat and habits:

Overall, Red-capped Plovers have not received as much attention as the other species of this study. Most sightings were recorded on brackish inland lakes and saline habitats (Abensperg-Traun & Dickman, 1989; Green, 1956; Newman, 1982a; Watkins, 1993), providing the impression that Red-capped Plovers do not seem to rely as heavily on sandy beaches or coastal habitats as Hooded Plovers or Pied Oystercatchers. A summer count in 1983 in Victoria revealed that about 72% of the birds were distributed around saline habitats, whereas only 28% were found at or near a coastal site (Lane & Jessop, 1983, cited in the RAOU Report, 1993), and, moreover, numbers at coastal sites seem to increase

during summer and decrease during autumn and winter (Alcorn, 1990, cited in the RAOU Report, 1993). In another example, Green was looking in 1956 at a salt-pan lagoon in Tasmania for Black-fronted Dotterels, but to his surprise he found a large colony of Red-capped Dotterels, the former name of Red-capped Plovers (Green, 1956). He described this lake as relatively salty, drying out in the summer and leaving coarse, white salt behind, and being fed by rain runoff and freshwater springs. Hobbs (1972) described the Red-capped Plover as common along the Australian coast, but more abundant further inland (Abensperg-Traun & Dickman, 1989). Due to observed agonistic behaviour among neighbouring breeding pairs, it was suggested that territoriality exists in Red-capped Plover breeding pairs (Abensperg-Traun & Dickman, 1989).

Foraging:

As with the Hooded Plover, Abensperg-Traun & Dickman (1989) described the Red-capped Plover as a chiefly visual forager that catches its prey by cues such as surface activity or food procurement. Overall, Red-capped Plovers have been described as mainly insectivorous (Poore, Corrick & Norman, 1979, cited in Abensperg-Traun & Dickman 1989), with individuals recorded feeding on beetles, ants, and polychaete worms *(Capitella capitata)*. This suggests that foraging occurs mainly on the littoral fringe of the salt lake, when water recedes. In summary, it has been suggested that prey abundance was the main driver for Red-capped Plover abundance around the salt lake (Abensperg-Traun & Dickman, 1989), and that a wider and more gentle lake shore may offer a larger foraging area and access to terrestrial insects such as ants (Corrick & Cowling, 1975, cited in Abensperg-Traun & Dickman, 1989). When the water recedes due to evaporation in summer, fresh sediments will be exposed with prey in high abundance (Abensperg-Traun & Dickman, 1989).

Breeding:

According to Green´s (1956) and Hobb´s (1972) descriptions, Red-capped Plovers show typical plover family characteristics like the Hooded Plover, such as that both parents share the breeding consisting mainly of egg incubation and guidance of the chicks. Nests were scrapes or small depressions on the ground close the water's edge of the salt lakes, with no nest being further than 40m away. The nests were supported and protected by some kind of nesting material such as dried grass or grass roots in and around the nest. Overall, Hobbs

(1972) described the nest locations as 'damp places with substantial nesting material', as almost every nest was located at a muddy location (e.g. in the centre of a mud-pancake, on drying mud, or on thin weed mats on dry mud) with the result that the eggs were covered in mud. Moreover, Red-capped Plovers have been described as 'group-nesters' (Gannon, 1953, cited in Hobbs, 1972), as Hobbs found about 43 nests on an 800m long stripe. Accordingly, territories seem to be rather small. The clutch size consisted usually of two eggs, that were laid in the breeding season between June and September (Green, 1956; Hobbs, 1972). As in the case of the Hooded Plover, when the chicks hatch, they can leave the nest immediately and forage by themselves while still being guided by the parents. Also, when disturbed, Red-capped Plovers leave the nest to lead the intruder away, or may perform distraction displays by pretending to be injured, or even attack the intruder with loud squeaking noises (Green, 1956; Hobbs, 1972). Chicks may also rely on their camouflage, crouch and freeze.

Roosting:

Hobbs (1972) described the roosting behaviour around a salt lake, where the Red-capped Plovers were first feeding in a dispersed manner in the shallow and receding water of the lake. During the extreme heat of the day, they flocked away from the water and the nests into the shade. According to his description, as though they were driven by tides like on sandy beaches, Red-capped Plovers would return to the lake to feed again.

Population status and threats:

In terms of threats, foxes *(Vulpes vulpes)*, ravens and crows *(Corvus spp.)*, kestrels *(Falco spp.)* and cats *(Felis catus)* have been observed, as well as trampling by livestock (Abensperg-Traun & Dickman, 1989; Hobbs, 1972). By contrast with Green's study (1956), the birds in Abensperg-Traun & Dickman's (1989) study did not show signs of being disturbed by the observers. However, as in the case of other shorebirds, Red-capped Plover populations are also declining (E. Woehler, personal communication, April 10, 2014).

3.3 Sandy beaches

3.3.1 **Introduction to sandy beach characteristics**

Often a beach is considered as the dry part to sit on, but precisely it is a "by waves deposited sediment system, that extends from the base of wave-activity to the limit of wave run-up" (Short, 2006b, pp.1). Geologically, according to Zaitsev (2012), a beach represents an "unconsolidated aggregation of grains of different sizes and mineralogical nature (mainly quartz)" (pp.114), and consists of the (1) dry subaerial beach, the (2) swash and intertidal zone, the (3) surf zone and, beyond the breakers (4), the nearshore zone (Figure 3.3.1), (Masselink, 1993). The extent of each zone will vary considerably depending on prevailing environmental conditions such as the types of waves and tide range (Nordstrom & Jackson, 1990; Short & Hesp, 1982). The interaction of waves, tides, and sediment type results in a specific type of 'beach morphology' (Davies, 1969; Gourlay, 1980; Sanderson & Eliot, 1999; Short, 2010).

(1) Subaerial beach

The subaerial beach contains the part of the beach above sea level, which is shaped by wave run-up or swash. It starts at the shoreline, thus at the intersection of the land and sea, and extends up the relatively steep swash zone or beach face, and may be backed by a flatter berm or cusps. Often the dry beach varies in width from tens of metres to just a few, depending on the arriving wave energy eroding the sediment (Farris & List, 2007; McLachlan, Defeo, Jaramillo, & Short, 2013; Short & Hesp, 1982).

(2) Swash or intertidal zone

The swash or intertidal zone represents the zone in which the waves run up and down. This zone may vary with tides, as the shoreline moves up and down the beach. As wave height decreases and tide range increases, this zone tends to become flatter and considerably wider and is termed the intertidal zone on tide-modified to tide-dominated beaches. In areas of higher tide range, it may be several hundred metres in width (Elfrink & Baldock, 2002; Hughes, Masselink, & Brander, 1997; Masselink & Puleo, 2006; Nordstrom & Jackson, 1990; Saini, Jackson, & Nordstrom, 2012).

(3) Surf zone

The third zone extending seaward from shore is called 'surf zone' and is considered the 'wave breaker zone'. In this zone, waves are continuously expending their energy. The wave breaking zone is often underlined with a bar, while the wave bore (white water) moves towards the shoreline, transforming along the way into surf zone currents and, at the shoreline, into swash (Masselink & Pattiaratchi, 1998; Wright, Guza, & Short, 1982; Wright & Short, 1984)

(4) Nearshore zone

The 'nearshore zone' extends seaward from the outer breakers to the maximum depth, at which average waves can mobilise beach sediment and move it shoreward. This point is called the wave base, referring to the base of wave activity, which decreases in depth and width according to wave height (Masselink & Short, 1993; Short, 2006b).
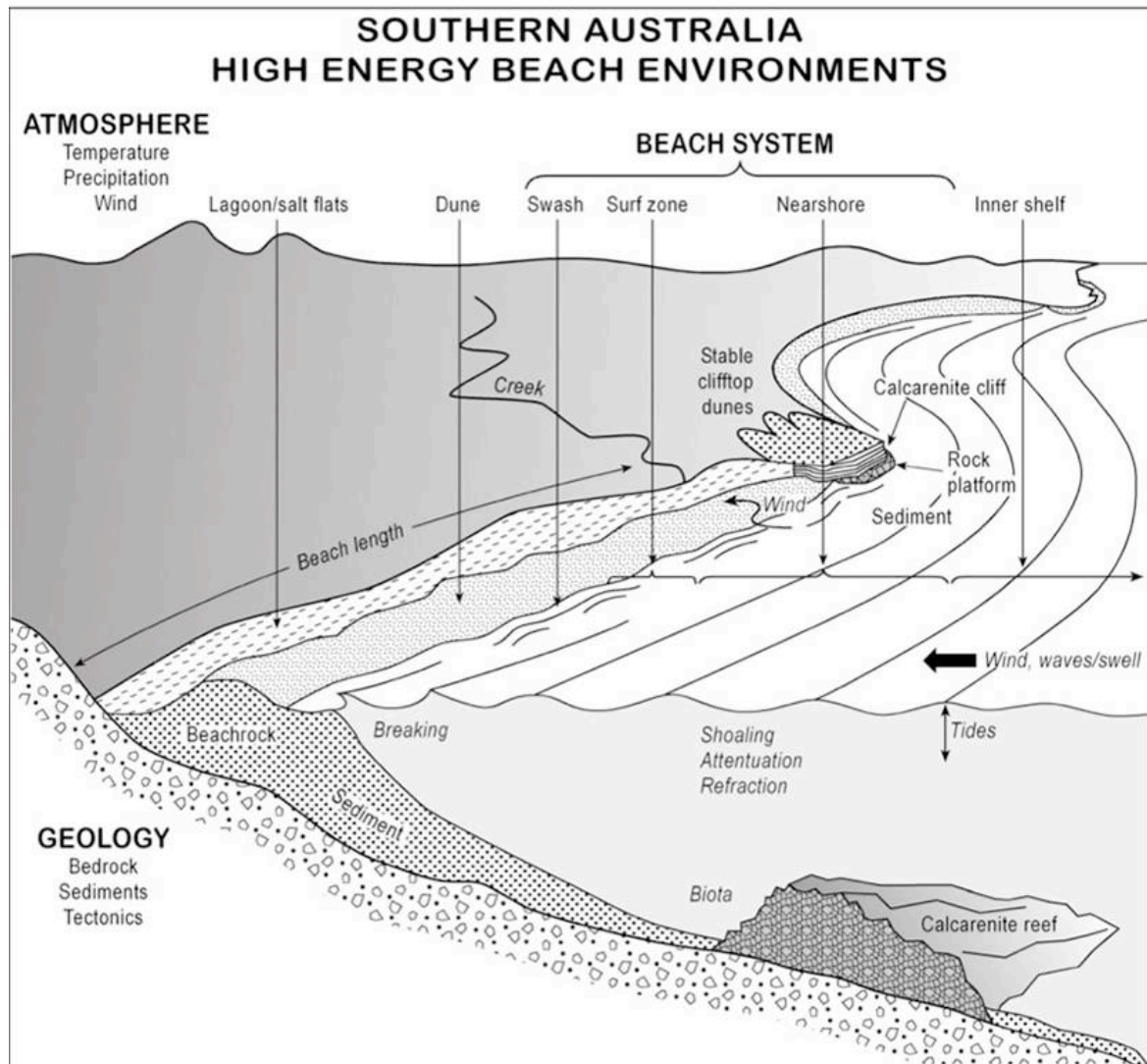
Figure 3.3.1: A structural overview on the beach zones expanding from shore out seawards of a high wave energy beach, while restricted to geological features and shaped by atmospheric forces (Source: Short, 2006b).

3.3.2 **Shaping of beach morphology**

Beach morphology reflects the sum of many factors comprising of atmospheric forces and ocean processes including different types of waves, tides and their interactions (Gourlay, 1980; Jackson, Cooper, & del Rio, 2005; Large & Pond, 1980; Sanderson & Eliot, 1999). Also, the underlying geology, as the base of every beach, will determine the beache´s response to these external forces, and moreover, restrict the beach in its length by setting the boundaries on its edges (Jackson & Nordstrom, 1992; Jackson, 1995; Short, 2006a, 2010). Other geological features such as rock outcroppings or headlands in front of a beach provide protection and cause the arriving waves to refract (Gallop, Bosserelle, Pattiaratchi,

& Eliot, 2011; McKenzie, 1958; Munk & Traylor, 1947; Silvester, Tschuiya, & Shibano, 1980; Yasso, 1965). Additionally, atmospheric forces play a vital role for the shaping of beaches, as climate-driven winds interact with the ocean surface resulting in a range of oceanic processes (Chen, Zhao, Donelan, Price, & Walsh, 2007; Hasselmann, Ross, Müller, & Sell, 1976; Jeffreys, 1925; Kumar, Voulgaris, Warner, & Olabarrieta, 2012). Also, from the landside, the climate will interact with different terrestrial geological features resulting in the possible weathering of sediments (Bradley, 1954; French & Burningham, 2013; Nott, Young, & Idnurm, 1991). The consequences may be that sediment is transported to the coast through runoff and erosion, providing surface material for ocean sandy beaches (Davies, 1969, 1973; McLachlan & Turner, 1994)

The term 'ocean processes' refers mainly to different kinds of waves that arrive with different intensities at the beaches (Chen et al., 2007; Large & Pond, 1980; Muetze & Vining, 2006). About half of the energy arriving at the beaches around the world derive from waves (Muetze & Vining, 2006), while another large proportion is transmitted via tides (McLachlan & Turner, 1994). Accordingly, a wave starts off usually as a (1) wind wave, which will transform into (2) swell, (3) wave shoaling, and finally result in the energy release by (4) wave breaking at the coast (Hasselmann et al., 1973; Melville & Matusov, 2002; Short, 2006b; Sullivan & McWilliams, 2010). Overall, the strength of a wave or its height is dependent on wind velocity, duration, direction, the fetch, and the water depth (Hasselmann et al., 1973, 1976; Jackson, 1995). However, the longer the wind blows with a constant velocity and direction, and the larger the area of fetch (the area of ocean surface available to the wind to blow over), the larger the waves will become (Carter, 1982; Hasselmann et al., 1973; Komen, Hasselmann, & Hasselmann, 1984). Such air- sea gas transfer relationships, where the wind is acting upon the ocean surface, are complex, as illustrated in a simplified example of the physical processes involved under short wind waves in Figure 3.3.2 (Bock et al., 1999).
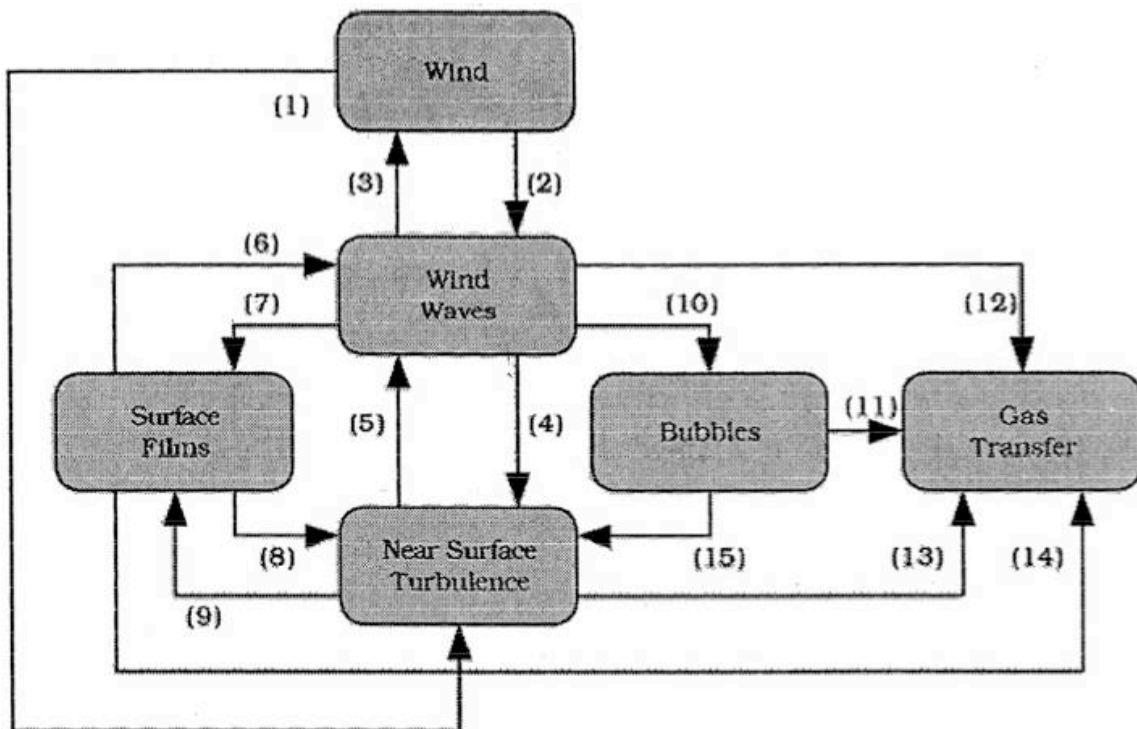
Figure 3.3.2: The physical processes that influence the air-sea gas exchange on the ocean surface comprise of the following steps: (1) generation of near-surface turbulence through direct wind shear, (2) generation of wind-waves, (3) increase in surface drag (wind stress), (4) turbulence generation by wind waves, (5) enhanced dissipation of wind waves by near subsurface turbulence, (6) enhanced viscous dissipation of wind waves, (7) break up and surface films by waves, (8) suppression of near surface turbulence by modified surface boundary conditions, (9) break up and accumulation of surface films by near surface turbulence, (10) generation of bubbles by wave breaking, (11) gas exchange due to bubbles, (12) gas exchange due to wave motion, (13) gas exchange due to near surface turbulence, (14) suppression of gas exchange by surface films, and (15) enhancement of turbulence by bubbles (Source: Bock, Hara, Frew, & McGillis, 1999).

3.3.3 **Different wave types**

A range of different waves can be distinguished (Figure 3.3.3):

(1) 'Wind waves' occur in the area of wave generation, are certainly driven by the wind, and often referred to by the common term 'sea' (Bock et al., 1999; Jeffreys, 1925).

(2) 'Swell' can be considered a second transformation stage on the waves' way to the coast (Hasselmann et al., 1973; Sullivan & McWilliams, 2010). Generally, swell waves will decrease in height (vertical distance between crest and trough), when approaching the coast, but increase in length (horizontal distance between adjacent crests) and become

more unidirectional (Munk & Traylor, 1947; Sullivan, Edson, Hristov, & McWilliams, 2008). As the speed of a wave is proportional to its length, swell waves will also increase in speed (Munk & Traylor, 1947; Short, 2006a)

(3) 'Shoaling waves' are waves entering shallower waters, where they start to interact with the seabed and start to move faster. This results usually in the refraction of the wave, thus the bending over of the wave crests (Grilli, Subramanya, Svendsen, & Veeramony, 1994; Hsiao & Shemdin, 1980; Munk & Traylor, 1947).

(4) Finally, 'wave breakers' are waves that approach the coast close enough to break, as the wave trough and crest do not reach the shallower water at the same time. Here, the trough slows down first, while the crest in deeper water is still travelling a little faster. Depending on the slope of the bar, the speed and distance over which this occurs, the crest will attempt to overtake the trough by spilling or even plunging forward and thereby breaking. These conditions are often referred to as plunging (occurs at steep slopes, the wave brakes immediately), surging, or spilling (slow moving wave) breakers (Melville & Matusov, 2002; Sullivan & McWilliams, 2010; Svendsen, 1984; Wang, Smith, & Ebersole, 2002)
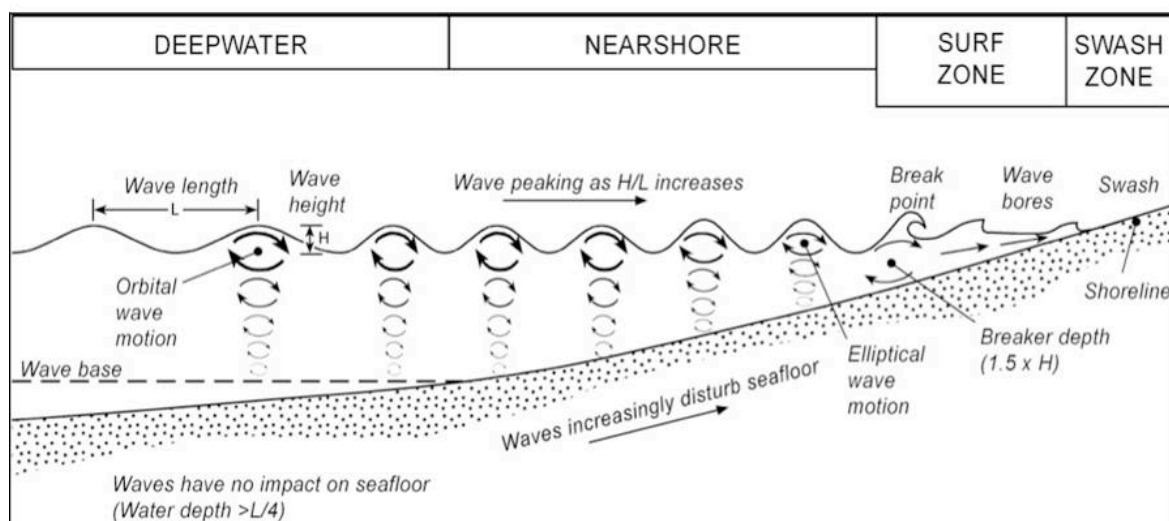
Figure 3.3.3: Wave transformations on their way to the coast by entering different wave stages (Source: Short, 2006b).

3.3.4 **Other oceanic processes**

Another very important aspect with regards to the shaping of beaches are the tides, which describe the periodic rise and fall of the ocean surface due to the gravitational force of the

moon and sun with the additional rotation of the Earth (Lacheur, 1924; Short, 2006b). As described in Short (2006b), the "amount of force is a function of the size of each, the sun and the moon, and their distance from the Earth" (pp. 18). While the gravitational field of the sun is about 177 times stronger than that of the moon, the moon is still the dominant force in regards to tides by a factor of about two (Baker, 1991). According to Baker (1991), this is due to the fact that the ratio of the earth's diameter to the distance of the moon is much greater than the ratio for the sun. Therefore, approximately two-thirds of the tidal force is due to the moon (lunar tides), whereas the other one-third is due to the sun (solar tides), (Avsyuk & Maslov, 2011; Forbes & Vial, 1994; Forbes, 1995). According to the tidal range, tides can be classified into micro-tidal, when their range is less than 2m, meso-tidal between 2 and 4m, macro-tidal 4-8m, and eventually into mega-tidal, when greater than 8m (Levoy, Anthony, Monfort, & Larsonneur, 2000; Masselink & Short, 1993; Short, 1991)

Also, ocean currents (Price, Weller, & Schudlich, 1987; Stommel, 1957; Tynan, 1998), sea surface temperature, and salinity are important oceanic processes (Brasseur, Beckers, Brankart, & Schoenauen, 1996; Hall & Manabe, 1997; Muetze & Vining, 2006). 'Ocean currents' refer to the wind-driven movement of the upper 100 to 200m of the ocean, where the major wind systems blow over the ocean surface and drive currents moving in large ocean gyres, spanning millions of square kilometres (Berloff, Hogg, & Dewar, 2007; Munk, 1950; Short, 2006b). Closer to the coast, the currents become increasingly dependent on local winds (Nordstrom, 1977). All oceans and seas contain dissolved salts derived from the erosion of land surfaces from over hundreds of millions of years (Herczeg, Dogramaci, & Leaney, 2001; Milliman & Meade, 1983). Chlorine and sodium dominate and, together with several other minerals, account for the dissolved salt. The salts are well-mixed and range globally between 33.0 and 35.0 parts per thousand (ppt), increasing slightly in the subtropical evaporation-dominated regions (Boyer, 2005; Durack & Wijffels, 2010; Lagerloef, Swift, & Vine, 1995).

3.3.5 **The beach sediment**

When the wave and tidal forces arrive at the beach, they will first encounter and therefore mostly interact with the sediment (Nordstrom & Jackson, 1990; Sanderson & Eliot, 1999). The response of the sediment may depend on its type, grain size, and composition (Short,

2006b). Accordingly, depending on its size and the strength of the waves, it may take more or less time for the sediment to be eroded (Wright, Nielsen, Short, & Green, 1982).

Five sizes are most commonly used, which comprise from the finest to the coarsest: (1) clay (0.001-0.008mm), (2) silt (0.008-0.063mm), (3) sand (0.063-2mm), (4) cobble (2mm-6.4cm), and (5) boulder (> 6.4cm), (Blair & McPherson, 1999; Wentworth, 1922). Overall, sand is the most common grain size on beaches, as it is fine enough to be put into suspension, but also coarse enough to settle quickly to the seabed when the waves stop breaking (Short, 2006b). Sand grains can fall into two categories, into quartz with other particles originating from the weathering of rocks (most common in granites), and calcium carbonate, thus fragments of biogenic origin. (Davies, 1969, 1973; McLachlan & Turner, 1994). However, the reason for which beaches never consist of silt or mud is that in the wave-breaking environment, anything finer than sand stays in continual suspension and is flushed out from the beach into deeper, quieter water (Wright, Nielsen, et al., 1982).

The sediment type does not necessarily determine the mineralogy of the beach, but its dynamics due to the interactions with waves and tides (Davies, 1969, 1973; Elfrink & Baldock, 2002; Wiberg & Harris, 1994). Due to different characteristics, fine sand will produce a low gradient of the swash zone (1-3°) and wide surf zone, while medium to coarser sands will result in a steeper gradient (4-10°), a narrower surf zone, and less mobile sands. Eventually, cobble and boulder beaches become not only very steep (>8°), but they have no surf zone and are usually immobile. Therefore, it is not just the sand or waves, but the interaction of both (Short, 2006b).

3.3.6 Beach types

All environmental factors, the underlying morphology and the type of sediment, shape a beach and produce a range of different conditions (Figure 3.3.4), (Hughes et al., 1997; Sanderson & Eliot, 1999; Schlacher & Thompson, 2013a). Accordingly, different kinds of beaches summarizing all prevailing conditions may be distinguished. (Sanderson & Eliot, 1999). Three main categories have been established, including 'wave-dominated', 'tide-modified', and 'tide-dominated' beaches (Davis & Hayes, 1984; Heward, 1981; Masselink, Kroon, & Davidson-Arnott, 2006; Masselink & Short, 1993; Short, 2007). These can be further subdivided into 14 beach types, comprising of six wave-dominated, three tide-

modified, and four tide-dominated (Short, 2003). The identification of a beach refers to the following two equations:

(1) The dimensionless 'fall velocity model' (Ω, based on Gourlay, 1980) was the first model being mainly used for the identification of wave-dominated beaches:

$$\Omega = H_b/w_S*T$$

where H_b= breaking wave height, w_S=sediment fall velocity and T=wave period.

(2) The 'relative tide range model' (RTR, based on Masselink & Short, 1993) has been developed for the increased influence of tides and thus takes both, tides and waves into consideration. It represents a more recent approach:

$$RTR=TR/H_b$$

where TR= mean spring tide range and H_b is derived from the fall velocity model.

As an example, if RTR< 3m a beach can be identified as micro-tidal which goes along with being a wave-dominated type of beach; if RTR>7m the beach is of a macro-tidal nature, while in between is referred to a meso-tidal range of 3-7m tidal range meaning that the tide is 3 to 7 times the wave height (Short, 2003).
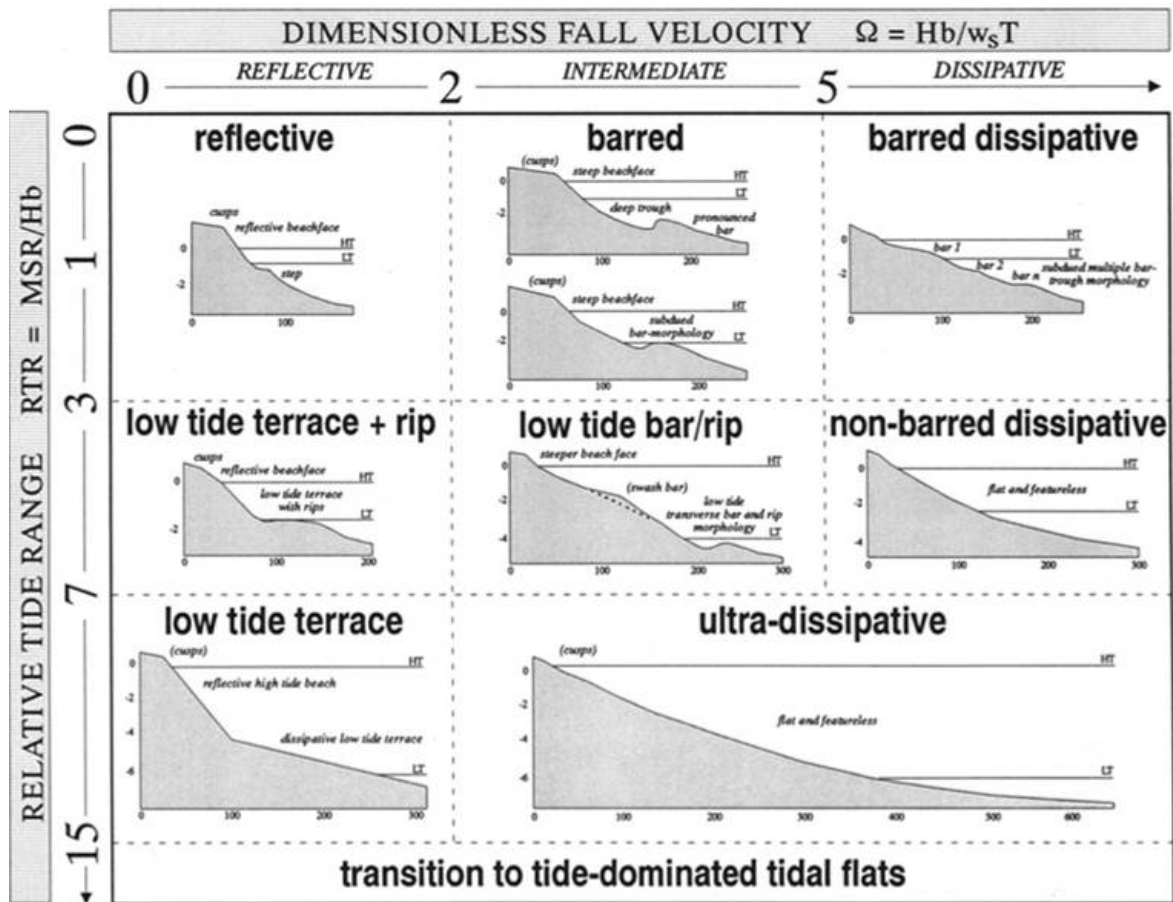
Figure 3.3.4: A conceptual beach model incorporating the roles of waves and tides according to the fall velocity and the relative tide model. From top to bottom (0 to 15), the tidal influence on sandy beaches increases as reflected in different beach morphologies. Same with the influence of waves, from the left to the right, the impact of waves on sandy beaches decreases, as reflected in shallower, more gentle sloping beaches due to less eroded sediment and a decrease in wave energy/height (Source: Masselink & Short, 1993).

(1) Wave-dominated beaches

Wave-dominated beaches are considered to be the most investigated beach category of the three just introduced (Davis & Hayes, 1984; Heward, 1981; Masselink & Short, 1993). According to the degree from low to high wave-energy, wave-dominated beaches are further divided into 'reflective', 'intermediate' and 'dissipative' beaches, whereas intermediate beaches include a few different beach types (Numbers 2-5), (Wright, Chappell, Thom, Bradshaw, & Cowell, 1979; Wright, Guza, et al., 1982; Wright & Short, 1983). In total, the following six have been defined:

(1) Reflective (R),
(2) Low tide terrace (LTT),
(3) Transverse bar and rip (TBR),
(4) Rhythmic bar and beach (RBB),
(5) Longshore bar and trough (LBT), and
(6) Dissipative (D) beaches.

In summary, (1) reflective beaches (R) represent the least energetic beach type, that is, characterised by coarser sediments and a steep, relatively narrow beach and swash zone (Heward, 1981; Wright et al., 1979). According to the fall velocity and relative tide range model, reflective beaches would be $\Omega<2$ and RTR<3 (Masselink & Short, 1993). As implied by its terminology, intermediate beaches are located between the higher energy dissipative and lower energy reflective beaches. Therefore, wave energy will increase throughout the intermediate beaches (Short & Hesp, 1982; Wright, Guza, et al., 1982). This results in the development of bars and rips to different extents and numbers. Furthermore, more energy is available to sort the sediment, including larger particles, resulting in medium to fine sediments (Masselink et al., 2006; Wiberg & Harris, 1994)

The (2) low tide terrace beach (LTT) is the first of the intermediate beaches and the second after the reflective beaches, and therefore receives the lowest amount of wave energy compared to the other intermediate stages (Miles & Russell, 2004; Short, 2003). It consists of a continuous bar attached to the beach that will be exposed at low tide. It may be crossed by small transverse rips, fed by narrow feeder channels at the base of the beach (Short 1996). The (3) transverse bar and rip (TBR) beach differs from the low tide terrace, as it consists of bars and a highly rhythmic beach face, which is attached to the mega crisps

horns, thereby fully segregating the rip feeder and rip channels, particularly at low tide when rip currents will also intensify (Masselink & Short, 1993; Short, 2006a).

The (4) rhythmic bar and beach (RBB) is characterised by a well-developed rip topography with highly rhythmic or crescent bars, separated by deep rip channels that are fed by rip feeder channels, which are part of a continuous rhythmic longshore trough. Located at the other end of the four intermediate categories, the (5) longshore bar and trough (LBT) receives the highest amount of wave energy, inheriting therefore the most pronounced bar and rip system, and a deeper trough. Waves break heavily at the outer bar and reform the trough. By doing so, the waves decrease in height and reach the shore as lower waves (Masselink & Short, 1993; Short, 1996, 2006a).

According to Short (1996), (6) dissipative (D) beaches are characterised by a wide, low gradient swash zone, a wide surf zone expanding up to hundreds of metres seaward. Their dynamics are driven by spilling breakers, which dissipate their energy across the wide surf zone (Wright et al., 1979; Wright, Guza, et al., 1982).

(2) Tide-modified beaches

Tide-modified beaches are located between wave-dominated and tide-dominated and represent a mix of wave and tidal forces. According to Short (2006a), tide-modified beaches occur in "areas of higher tide range exposed to persistent waves" (pp. 21). Therefore, this beach type may be sheltered from ocean swell receiving low to moderate and short-period wind-waves. Tide-modified beaches also consist of sub-beach-types:

(7) Reflective plus low tide terrace (R+LTT),
(8) Reflective plus bar and rips (R+LTR), and
(9) Ultra dissipative (UD).

The (7) reflective plus low tide terrace (R+LTT) inherits the lowest energy with the coarsest sand. As a consequence, these beaches tend to be steep, cusped high-tide beaches, which usually grade into an abrupt break in slope. (8) Reflective plus bar and rips (R+LTR) beaches only differ to ultra dissipative beaches by the fact that they consist of fine to medium coarse sands, instead of very fine. Otherwise these beaches receive the highest energy of the tide-modified beaches and like all tide-influenced beaches, they lack the shoreline rhythmicity of wave-dominated intermediate beaches. (9) Ultra dissipative

(UD) beaches have a relatively low to moderate gradient and a very wide intertidal zone at high tide and a very low gradient (<1°) at low tide. Due to a generally low gradient across the beach, a wide shallow surf zone exists of more than 100m width, where the waves dissipate to the full extent (Masselink & Short, 1993; Short, 2006a, 2007).

(3) Tide-dominated beaches

Compared to wave-dominated beaches, tide-dominated beaches are located on the other end, where the tide range exceeds the wave height by at least 10 to 12 times (Masselink & Short, 1993). Generally, these beaches receive sufficient wave energy to both build the sandy, and often shelly, high tide beach, while wide low gradient tidal sand flats extend seaward of the base of the high tide beach and are exposed at low tide (Short, 1996). Furthermore, all tide-dominated beaches are characterised by a steeper and wider, low gradient intertidal zone. Also, tide-dominated beaches can be subdivided into:

(10) Reflective plus sand ridges (R+SR),
(11) Reflective plus sand flats (R+SF),
(12) Reflective plus tidal sand flats (R+TSF), and
(13) Reflective plus mud flats.

The (10) reflective plus sand ridges (R+SR*)* has been described as "a steeper, reflective, low energy high tide beach, which is only active during spring tide. It is fronted by low gradient sand flats containing multiple, sinuous, shore-parallel, equally spaced, low amplitude sand ridges" (pp. 16). (11) Reflective plus sand flats (R+SF) consist of very low energy periodically active high tide reflective beach, that is fronted by a wide, flat, featureless intertidal flat. The (12) reflective plus tidal sand flats (R+TSF) often represents a muddy tidal flat. As a high tide beach, it is fronted by tidal flats with a very low gradient (<1°) and is featureless apart from drainage channels. These beaches consist of fine sediment and possibly of discontinuous shelly high tide deposits (Masselink & Short, 1993; Short, 2003, 2006a). The next stage with increasing tidal influence is the (13) reflective plus mud flats beach type, a beach type that is not present in Tasmania.

(14) Beaches plus rock flats (R+rock flats)

Another beach type is the (14) beaches plus rock flats (R+ rock flats), where waves start to break over rocks located in front of the beach lowering wave height on their way approaching the shoreline.

3.4 Sandy beaches in Tasmania

3.4.1 Introduction to Tasmania

As Australia´s only island and southernmost state (Figure 3.4.1), Tasmania is located at about 39.5° and 43.5° south separated by the Bass Strait from the Australian mainland (Macphail, 1979). Due to its location in the Southern Hemisphere with no other countries on the same latitude until Chile and Argentina, its west coast is highly exposed to the Roaring Forties, a very strong circumpolar wind blowing from west to east (Hemer, Church, & Hunter, 2009; Pickrill & Mitchell, 1979). In total, Tasmania has 1269 recognised sandy beaches that make up about 40% of the coastline, while the other 60% is represented by bedrock (Short, 2006b). The total length of the Tasmanian coastline is 2237km, excluding its 330 offshore islands (Short, 2006a).

Figure 3.4.1: Tasmania is located south of Australia (Source: Screenshot from an ESRI ArcGIS image)

Initially attached to the Australian mainland during ice-ages, Tasmania shares much of its geological history with the southern part of Australia such as Victoria (Coney, 1990; Powell, Preiss, Gatehouse, Krapez, & Li, 1994; Stump, White, & Borg, 1986). Altogether, for an island of a small size, Tasmania holds a varied geology with ancient Precambrian (>4500-600Ma years = in geological terms >4500-600 million years before present), (Aubry et al., 2009) and Cambrian (600-500Ma years) sedimentary and volcanic rocks in the west, middle Palaeozoic dolerite and granite in the east (Banks, 1972; Bradley, 1954; Coney, 1990). Tasmania´s geological history dates back to the breakup of Gondwana about 205-55Ma years ago, where Australia (heading northeast) separated from Antarctica (heading south) during the Jurassic-Cretaceous (205-135Ma) with Tasmania in between (Powell et al., 1994; Stump et al., 1986). Overall, Tasmania´s coast was formed as a result of continental drifting and buckling during the Cretaceous. Due to periodic floodings and exposures, winds and waves caused the sediment to erode from the shelves towards and onto the shore, with rising and falling sea levels moving the sediments (Bradley, 1954; Macphail, 1979). However, there are regional differences across Tasmania with granite, and some Tertiary limestone, basalt and Cambrian volcanic on the east coast, Jurassic dolerite and Triassic sandstone in the east, and Cambrian and Precambrian partially meta- and non-metamorphosed geology on the west coast and northwest (Banks, 1972; Bradley, 1954; Davies, 1969, 1973; Powell et al., 1994; Stump et al., 1986).

Tasmania´s climate can be described as Mediterranean, with winds bringing humid maritime air, particularly during the winter months (Macphail, 1979). While during autumn and spring, east coast lows can form and bring rainfall to the northeast resulting in a temperate climate with no dry season (Scott, 1956). Overall, rainfall is highest in the west, where the mountains rise to between 500 and 1600m, while the central region is in a rain shadow in lee of the mountains with rainfall decreasing to less than 600mm in the midlands (Risbey, Pook, McIntosh, Wheeler, & Hendon, 2009; Scott, 1956). Temperatures are moderate throughout the year, due to the surrounding maritime environment. Summer mean maximum temperatures range from 18-23°C, whereas during winter the mean maximum rages between 9° and 14°C (Macphail, 1979).

3.4.2 **Tasmania´s wind and wave climates**

Tasmania has three distinct wave climates: (1) The high energy west coast, (2) the more sheltered low to moderate swell along the east coast, and (3) the north coast which ranges from sheltered in the west to more exposed in the east (Davies, 1969). The west coast receives the highest wave energies parallel to the most persistent winds, travelling across the Atlantic and Indian Oceans from South America (Figure 3.4.2a), (Hegge et al., 1996, cited in Sanderson, 1999, Hemer & Griffin, 2010; Hughes & Heap, 2010). Here, winds can blow with unidirectional velocity, and wave energy can build up due to the large fetch of the wind (Hemer et al., 2009). In contrast, the north of Tasmania and the Bass Strait are rather sheltered, due to a high number of islands including King and Flinders Island (northwest and northeast), and the shallow depth of the Bass Strait (typically 30-90m) that precludes the development of large waves (Davies, 1969; Malikides, Harris, & Tate, 1989; Sandery & Kämpf, 2007). The wave energy that arrives at the east coast varies considerably, as a response of refracted westerly swell waves that arrive all year-round, but are reduced in height as they travel along the southern part of the coast, which consists of a vast variety of rocks, reefs, islets and headlands (Cresswell, 2000; Short, 2006b). Overall, Tasmania is surrounded by more than 300 small islands (Terauds, 2005).
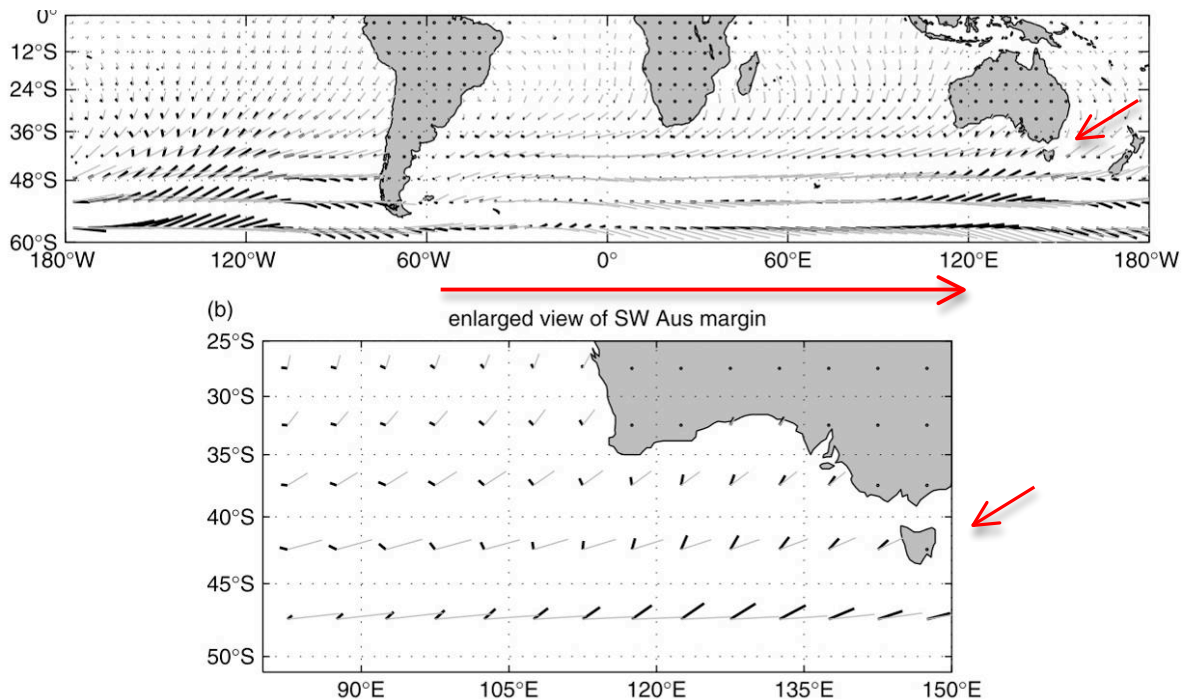
Figure 3.4.2a+b: Wave energy flux vectors indicate the direction (red arrow) and height/wave energy (angle and length of vector) of the waves in the Southern Ocean travelling with an overall direction from South America to Australia (a, global view in

upper map, mean autumn values deriving from a 22-year data set). Due to this long distance without distracting landmarks, wind speed has the potential to increase considerably, creating very high and powerful waves that arrive on the southwest coast of Australia and the west coast of Tasmania (red arrow), thus on the high wave energy coasts (b, zoomed in view in lower map showing Australia´s southwest margin), (Source: Hemer et al. 2009).

3.4.3 Other oceanic processes around Tasmania

With regards to tides, Tasmania experiences a substantial variation in both the tide range and the time of its arrival (Edgar, 1984). Micro-tidal conditions exist around the east and southeast, and on the west coast, with a mean spring tide ranging between 0.6 and 1.4m. Meso-tides are most recorded along the north coast, where they generally exceed 3m (Edgar, Barrett, Graddon, & Last, 2000; Edgar, 1984). The tidal wave arrives in the east and moves clockwise around the southeast coast and up the west coast, arriving approximately 1.5 hour laters (Baines, Edwards, & Fandry, 1983). All the open ocean coast tides are low (<1.3m spring range), such as on the west coast, reflecting the relatively narrow, steep continental shelf. In the Bass Strait, the tides undergo considerable modification as the wave enters from the east, slows down and amplifies due to the shallow depth of the strait with possible maxima of 4.4m resulting in meso-tide conditions (Baines & Fandry, 1983; Malikides et al., 1989; McIntosh & Bennett, 1984).

With regards to salinity, Tasmania's oceans are well mixed and therefore relatively constant thoughout the year with values ranging from 35.1 and 35.4 ppt (Edgar, 1984; Herraiz-Borreguero & Rintoul, 2011). A southward current, sometimes called the Zeehan Current, flows along the outer continental shelf of Tasmania with peak speeds in winter, whereas during summer, the East Australian Current is stronger and overshoots southwards past Tasmania by about 200km (Figure 3.4.3b), (Cresswell, 2000; Herraiz-Borreguero & Rintoul, 2011). Accordingly, sea surface temperatures range from 12° in August (winter) and 17° in February (summer) with usually about 2° warmer water temperatures in the Bass Strait (Edgar, 1984; Herraiz-Borreguero & Rintoul, 2011).
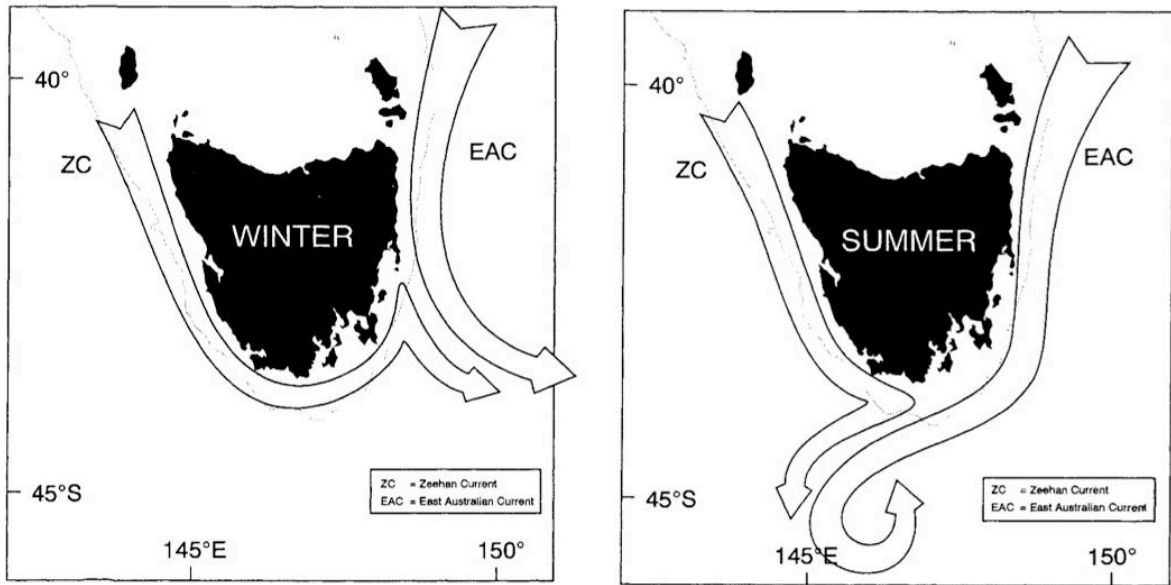
Figure 3.4.3a+b: Illustrated interaction between the Zeehan Current off western Tasmania and the East Australian Current in winter (a, left) and summer (b, right, Source: Cresswell 2000).

3.4.4 Beach types in Tasmania

From a total number of 1270 beaches in Tasmania, about 1156 (91.4%) are wave-dominated beaches and thus represent the most common beach category (Figure 3.4.4). The reflective sub-category is present with almost 62% (n=786), particularly in the sheltered bays of the southeast (Figure 3.4.5a-c), in the southwest, and the west part of the north coast (Davies, 1969, 1973). Tide-modified and tide-dominated beaches exist mostly along the meso-tide range on the Bass Strait coastline in the north of Tasmania and in some of the southeastern coast bays. Here, tide-modified (prevailing seas and higher tide range) beaches make up about 3.7% (n=37) of the Tasmanian coast, while tide-dominated account for 4.9% (n=70), protected from high waves and dominated by tides, resulting in a mix of beach and tidal flats (Short, 2006b).

Overall, only 9 beach types are found in Tasmania, comprising of the wave-dominated (1) reflective (R), (2) low tide terrace (LTT), (3) transverse bar and rip (TBR), (4) rhythmic bar and beach (RBB); of the entire three tide-modified (7) reflective plus low tide terrace (R+LTT), (8) reflective plus bar and rips (R+LTR) and (9) ultra dissipative (UD) beaches; and as tide-dominated, the (10) reflective plus sand ridges (R+SR), (11) reflective plus sand flats (R+SF). However, the latter tide-modified and tide-dominated are only present in very low numbers (Short, 2006b).

	Beach Type	Number	Number %	Mean length (km)	Ω (km)	Total length (km)	Length (%)	Beach type (%)
	Wave-dominated							91.4
1	Reflective	786	61.9	0.52	1.18	406.6	46.3	
2	Low tide terrace	174	13.7	0.78	1.54	134.7	15.3	
3	Transverse bar & rip	193	15.2	1.34	2.46	258.5	29.4	
4	Rhythmic bar & beach	2	0.2	0.2		0.4	-	
5	Longshore bar & trough							
6	Dissipative	1	-			0.2	-	
	Tide-modified							3.7
7	R+LTT	28	2.2	0.6	0.9	16.91	1.9	
8	R+LT rips	1	0.1	0.25	-	0.25	0.0	
9	Ultra dissipative	8	0.6	1.98	1.97	15.85	1.8	
	Tide-dominated							4.9
10	R+sand ridges	33	2.6	0.53	0.74	17.6	2.0	
11	R+sand flats	35	2.8	0.64	0.78	22.3	2.5	
12	Retial flats	2	0.2	1.7	-	3.4	0.4	
13	R+mud flats							
	Beach+rock flats							
14	R+rock flats	7	0.6	0.18	0.05	1.25	0.1	0.1
		1269	100.0			877.9	100	100

Figure 3.4.4: The beach types that are present across Tasmania by number and length (Source: Short, 2006b).

Figure 3.4.5a-c: Three beach types occur in Tasmania: A high-energy rip-dominated beach (a, left), a moderate wave-energy beach (b, middle) and a low wave-energy beach with ridged sand flats (c, right). These beaches are located on the southeast of Tasmania, where beaches range from exposed to sheltered conditions in bays and where wave heights are increasingly reduced from metre-high wind-waves to sandy tidal flat conditions (Source: Short 2006a).

4 Methods and data

4.1 Study sites and beach segments

The study sites of this thesis are Tasmania´s sandy ocean beaches. As there may be differences among beaches, there may also be differences along just one single beach. Conditions may change from one end to the other, such as the mean width of the aerial sandy part, or the gradient of the intertidal zone. Also, beaches differ in length, and in order to achieve the most precise results, this study used 'beach segments' as investigated sites, rather than 'entire' beaches, as named and shown in regular maps. Accordingly, one entire beach as shown in a map, has been divided into different parts or 'segments' according to the prevailing conditions across this beach. If conditions changed considerably, a new segment was established (Figure 4.1.1). Moreover, these segments differ in length and were assigned with ID codes, such as tas0993.
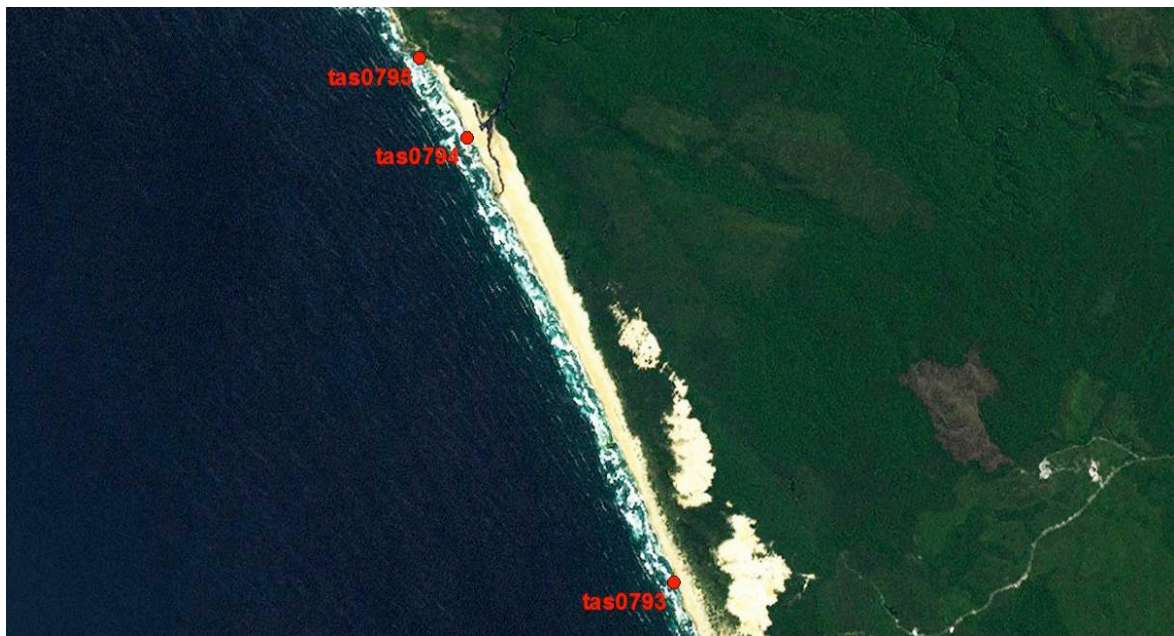
Figure 4.1.1: A relatively long beach has been divided into (three) different segments according to its present conditions with regards to beach attributes and environmental factors. Moreover, each segment was assigned with an ID code e.g. tas0793 and a centre point, containing the abiotic information to describe this part of the beach. As these beach segments vary in length, e.g. segment tas0793 is considerably longer than the other two.

Overall, the beach segments were part of one of the five data sets used in this study, the ABSMP data set from the Australian Surf Life Saving Association. All beach segments, where breeding pairs and thus territory locations were available (collected by Dr Eric Woehler over the past 12 years, unpubl.), were included in this study. A total of 322 sites, or beach segments, were selected and used in the analyses for this study. As sandy beach conditions vary geographically and regionally across Tasmania (see background section on Tasmania´s sandy beaches), it became one aspect of the analysis (separate analysis), besides the general investigation of the biotic and abiotic variables on shorebird habitat use, to look for regional differences or preferences of the birds among Tasmania´s sandy beaches with regards to the distributions and abundances of the species. From a regional point of view, 84 beach segments were located on the west coast, 34 in the north, 147 on the east coast and 20 in the southeast, as well as 37 on Flinders Island (Figure 4.1.2). Due to data handling complications, Kind Island had to be excluded from the analysis of this study.
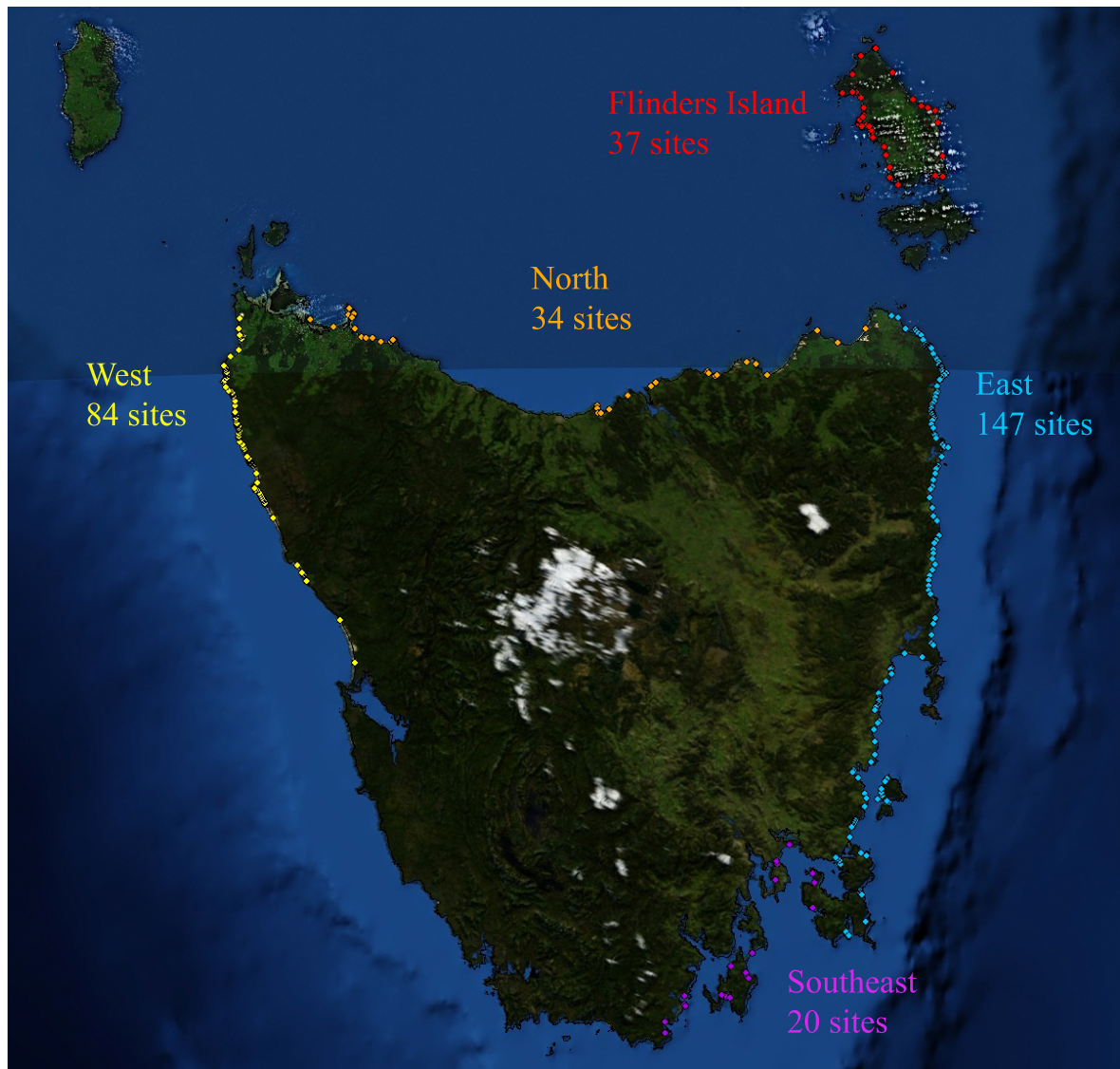
Figure 4.1.2: A total of 322 sites, thus beach segments (centre points of the segments from the ABSMP data set), were selected and used (all sites where bird data were available) in the analysis of this study across Tasmania´s coastline. With regards to regional differences, with 147 beach segments most were located on the east coast (blue), followed by the west coast with 84 segments (yellow), the north with 34 segments (orange), Flinders Island with 37 segments (red) and last, the southeast with 20 segments (purple).

4.2 Shorebird surveys

More than 200 beaches (according to the beaches on maps) have been surveyed since 1999/00 (Eric Woehler, BirdLife Tasmania unpubl. data). It has been the aim to survey the beaches every 3-4 years. During the visits, every beach has been walked from one end to the other, mapping nesting pairs of shorebirds en route - as soon as the first individual has been spotted, the location has been mapped (Figure 4.2.1). To achieve a relatively precise location, it is not necessary to spend a lot of time at site or to look for the nests, as the behaviours of the shorebirds provides information on breeding phenology (E. Woehler, personal communication, November 22, 2013). For example the Pied Oystercatcher elicits very distinct calls that indicate if chicks or eggs are already present. There is high certainty that every breeding pair present on the beaches has been recorded due to the surveying and ornithological experience of the researcher. If a breeding pair has been spotted, GPS data and some notes on the weather (cloud cover, wave swell) and on the behaviour have been recorded.
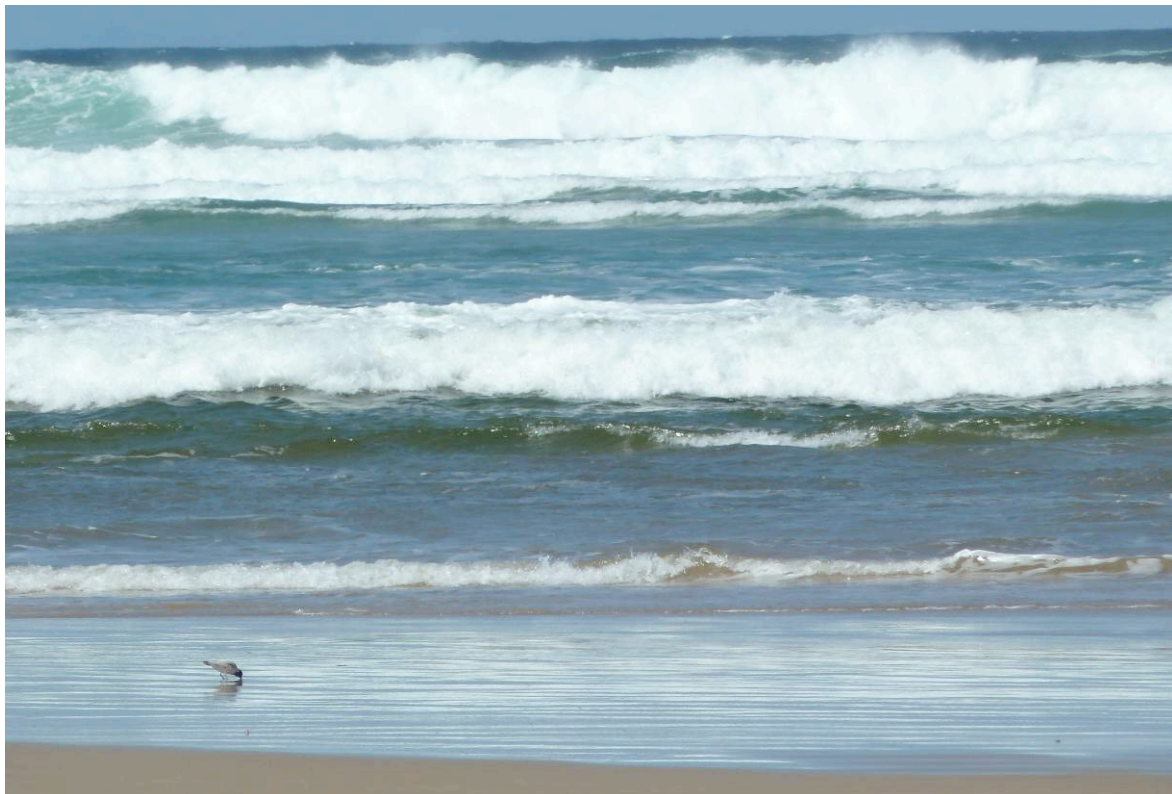
Figure 4.2.1: A spotted Hooded Plover feeding in the intertidal/swash zone of a high wave energy beach on invertebrates in the sediment on the exposed west coast of Tasmania, indicating the location of its territory. A well camouflaged, small plover that is easy to oversee in its native habitat, ocean sandy beaches (Source: Anja Bock).

4.3 Investigated variables

A range of possible predictors to investigate for shorebird habitat use have been obtained from four different sources. The data sets used in the analyses were the following:

(1) the physical beach attribute data (ABSMP data set) were obtained from the Surf Life Saving Association Australia,

(2) the wave data were received from the Centre for Australian Weather and Climate Research (Dr Mark Hemer and Claire Trenham),

(3) mean annual wind speed was received from the Climate Futures Tasmania Project (Dr Stuart Corney and Dr Ben Raymond),

(4) the invertebrate data were obtained from the University of Tasmania (Prof Alastair Richardson) and last,

(5) the shorebird data from Dr Eric Woehler (BirdLife Tasmania).

4.3.1 Physical beach attributes

In collaboration with the Surf Life Saving Association Australia and Prof Andrew Short from the Coastal Studies Unit Sydney, a database on the surf processes that impose hazards for swimmers has been compiled under the name 'Australian Beach Safety and Management Programme' (ABSMP, Short, 2006a), with a range of different methods such as satellite imagery or data collection on the beaches. Deriving from this data set, four main physical variables on beach characteristics have been selected to investigate for this study (Table 4.3.1).

Table 4.3.1: Overview of investigated beach attributes.

Physical beach attributes			
Variables	*Description*	*Unit*	*Abbreviation in analyses*
Mean width	The average width of each beach segment has been measured at high tide	metres	Mean_width_1
Embayment	The degree of embayment has been calculated as the chord of the beach divided by the arc	exposed-sheltered 0-1	Embaymen_1
Swash gradient	The vertical gradient indicates the steepness of the swash/intertidal zone	degrees	Swash_Gr_1
Surf zone width	The width of the surf zone	metres	Surf_Zon_1

Beach categories and types

As all prevailing conditions are summarised in the 'type of beach' or 'category', these two variables have also been taken into consideration in a separate analysis, where the beach category comprises 'wave-dominated', 'tide-modified', and 'tide-dominated'. In total, 14 beach types have been described by Short (2006b), but as not every type is present in Tasmania, only the following were used in the analysis:

(1) Reflective (R),

(2) Low tide terrace (LTT),

(3) Transverse bar and rip (TBR),

(4) Rhythmic bar and beach (RBB),

(7) Reflective plus low tide terrace (R+LTT),

(8) Reflective plus bar and rips (R+LTR),

(9) Ultra dissipative (UD),

(10) Reflective plus sand ridges (R+SR), and

(11) Reflective plus sand flats (R+SF).

4.3.2 Environmental factors

Three wave variables were investigated in this study deriving from a larger data set, the ocean wave hind cast project, which was obtained from the Centre for Australian Weather and Climate Research (Dr Mark Hemer and Claire Trenham, Table 4.3.2). This data set contains spectral wave output at 3683 points, and gridded outputs on a global 0.4° (24 arc minute) grid, with nested Australian and western Pacific sub grids of 10 and 4 arc minutes resolution. These grid rasters contain annual cycles of wave fields generated from a 31-year (1979-2009) data set using the Wave Watch III model version 4.08 with hourly winds.

The mean annual wind speed variable has been provided as monthly averages of the daily maximum wind speed from 1980-1999 by Dr Stuart Corney from the Climate Futures Tasmania Project. He passed this datum on to Dr Ben Raymond, who down sampled the datum to a 10km grid with values given in m/s. The down sampled mean annual wind speed from Dr Ben Raymond has been used for this study (Table 4.3.3).

Table 4.3.2: Overview of investigated environmental variables, waves and wind.

Waves

Variables	Description	Unit	Abbreviation in analyses
Mean annual wave period	The wave period is usually considered as the time that elapses between the passing of successive crests or troughs.	seconds	tm_an_av_1
Mean annual significant wave height	Wave height is considered the distance measured from the trough to the crest of the wave, whereas the significant wave height refers to the average height of the highest one-third waves in a wave spectrum	metres	hs_an_av_1
Maximum significant wave height	The maximum significant wave height is often referred to a size twice as high as the significant wave height.	metres	hs_max_a_1

Wind

Mean annual wind speed	The mean wind speed has been calculated as the vector sum of the zonal and meridional components.	metres per seconds	wind_speed_ annual

4.3.3 Biotic factors

Invertebrate data were provided by Prof Alastair Richardson from the University of Tasmania (UTas) for the west and north coasts of Tasmania, and for Flinders Island (Figure 4.3.1), deriving from a survey that was undertaken over two seasons in 1996 and 1998. Surface invertebrates were collected with pitfall traps, the species were identified and individuals per taxa, family or species were recorded. Afterwards, the data were compiled and grouped into the subphyla Crustacea and Myriapoda, and into the classes Arachnida and Insecta (Table 4.3.3).

As no digitised data were available for the east and southeast coasts of Tasmania, these regions had to be excluded from the analyses and, consequently, from this study. A second and smaller data set was created specifically for the investigation of the invertebrate variables on the distribution and abundance of the shorebirds.

Table 4.3.3: Overview of investigated invertebrate taxa.

Biotic factors			
Invertebrate taxa	*Description*	*Unit*	*Abbreviation in analyses*
Crustaceans	Total number of crustacean individuals	number	Crustacea
Myriapods	Total number of myriapod individuals	number	Myriapoda
Arachnids	Total number of arachnid individuals	number	Arachnida
Insects	Total number of insect individuals	number	Insecta

All invertebrate data in a digital format provided by Prof Alastair Richardson were selected and used in the analyses, comprising of a total number of 140 sites, thus beach segments, across Tasmania. Regionally, 69 sites were located on the west coast, 34 in the north and 37 beach segments on Flinders Island.
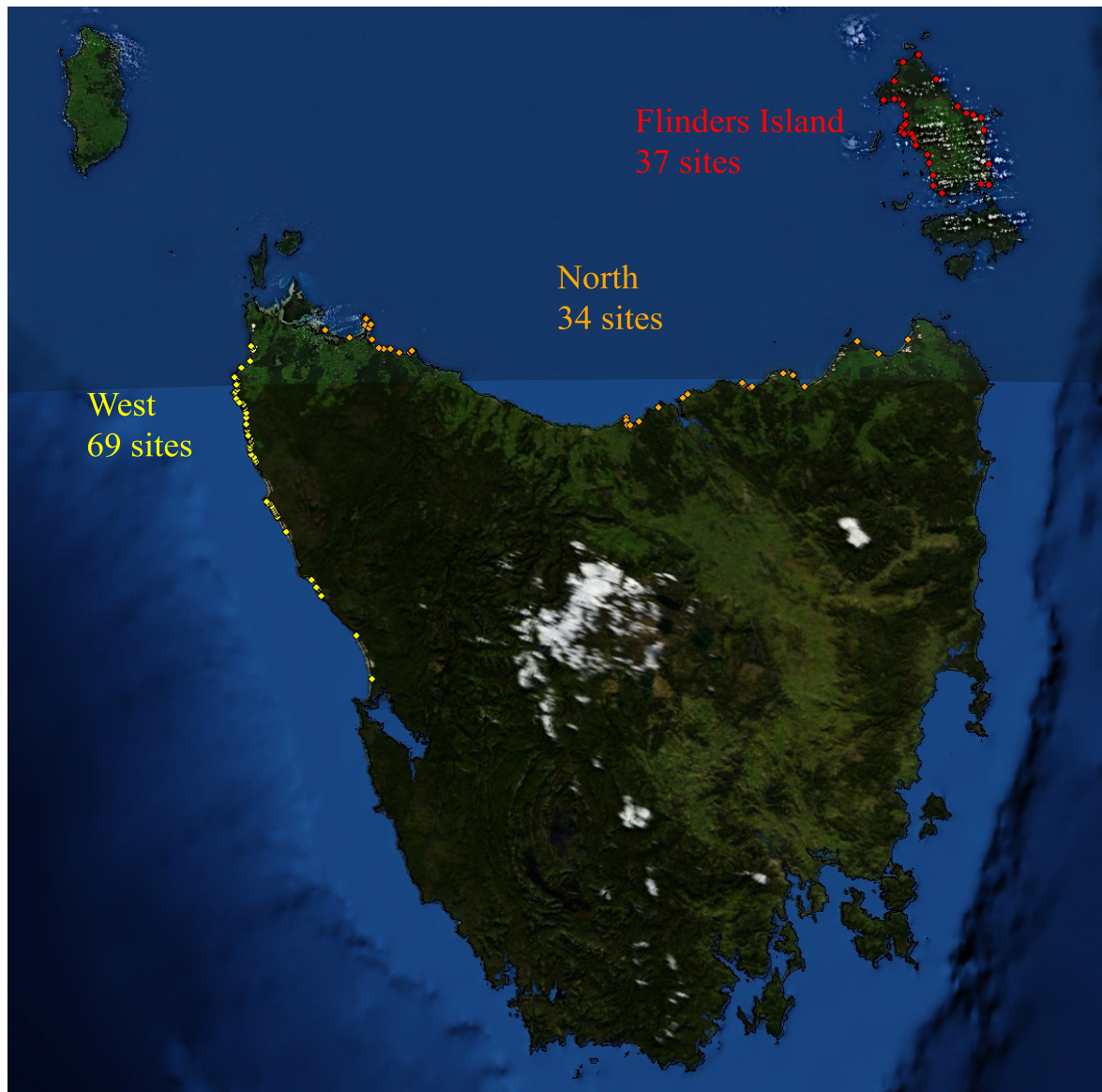
Figure 4.3.1: Due to non-available data for the other regions, a smaller data set was created containing the invertebrate data with the total number of crustacean, Myriapoda, arachnid and insect species at each of the sites. A total of 140 sites, thus beach segments (centre points of the ABSMP data set), were used in the analysis with the majority of 69 beach segments being located on the west coast (yellow). Another 34 beach segments were used from the north coast and 37 from Flinders Island.

4.4 Data preparation for analyses

First, the different formats of the main data sets, (1) shorebirds, (2) beach attributes, and (3) wave data, had to be made compatible and linked to each other. This was achieved via its spatial information in ESRI ArcGIS. Here, coordinate systems were converted to geographic GCS_GDA_1994 and projected GDA_1994_MGA_Zone_55. The shorebird

and the habitat attribute data (ABSMP) had to be merged first. This was achieved by the creation of buffers around each beach centre point of the ABSMP data set, where the diameter represents the entire length of the beach segment (Figure 4.3.2a). By laying the shorebird locations layer on top of the beach attribute data with the help of a spatial selection function (Selection>Select by Location), all shorebird locations within or bordering a buffer were merged with the beach attribute data of the buffer; more precisely the data from the bordering shorebird locations were added to the buffers and thus centre points of the ABSMP data set (Figure 4.3.2b). Therefore, the units of interest became the beach segments from the ABSMP data set, and only the data of interest, thus the beach segments with bird data, were kept.
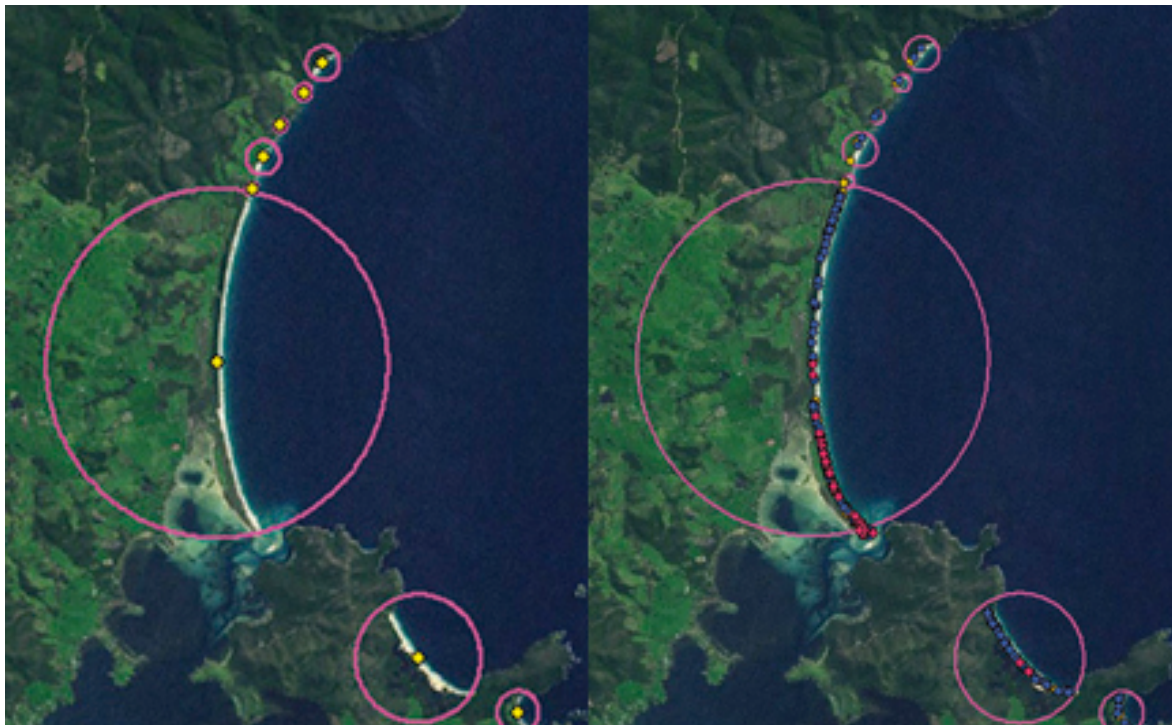
Figure 4.4.1a+b: Centre points were created by Surf Life Saving Association Australia for each segment along a beach. Around them, buffers were constructed representing the length of each particular segment (a, left) and every bird location within its range has been assigned with the segment attributes and the prevailing environmental conditions of that particular segment (b, right).

In a further step, the wave data were added by extracting the information from the raster data sets (Grid cells-ASCII format, Figure 4.3.3a+b). This was achieved with the spatial analyst tool (>Extraction>Extract Multi-Values to Points) by extracting the pixel values bordering on the shorebird locations and adding them to these locations. In a former step,

the wave rasters had to be extended by focal statistics in order to achieve the bordering of the grid to the shorebird locations (Spatial Analyst Tool> Neighbourhood> Focal Stats, Figure 4.3.3a).

The same procedure was repeated with the smaller invertebrate data set.
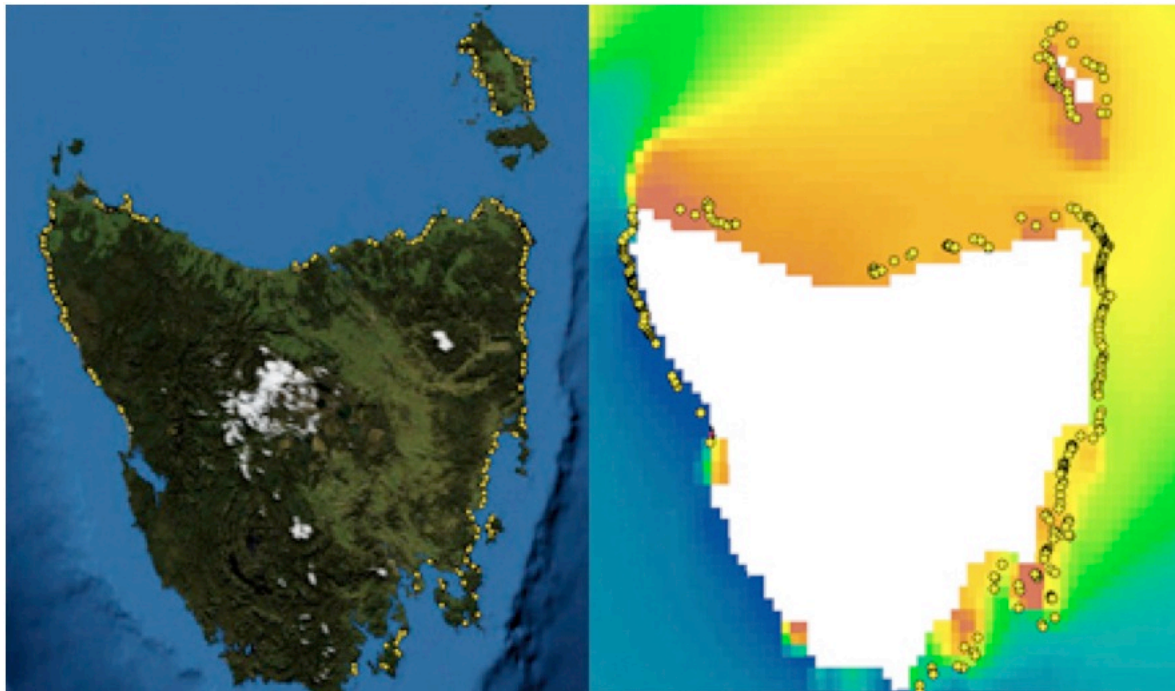
Figure 4.4.2a+b: All selected beach segments with its centre points around Tasmania´s coastline (a, left) and an example of a wave grid raster (b, right), that has been extended in its extent to reach the centre points in order to extract their beach attribute information.

4.5 Data analysis

All available abiotic and biotic variables as potential predictors for shorebird habitat use, such as mean annual wind speed (metres per second), mean annual significant wave height (metres), maximum significant wave height (metres), wave period (metres per second), mean beach width (metres), embayment (0-1), surf zone width (metres), and swash zone gradient (degrees), were plotted in a series of scatterplots against the abundances for every beach segment for all three species (see Appendix). The purpose of the scatterplots was to get a preliminary impression, such as with regards to the type of distribution. Therefore a line of best fit was added according to the Pearson's correlation coefficient (r), as well as the specific r-values and significance levels.

As mentioned, two data sets were used, a smaller one comprised of the biotic predictors or components of sandy beaches such as the invertebrate fauna, and the large data set comprising of all other abiotic variables including the beach attributes and the environmental factors affecting those beaches. The smaller biotic data set is restricted geographically to the west and north coasts, and Flinders Island, whereas the large data set also includes data on the east and southeast of Tasmania. All analyses, aside from the data preparation in ArcGIS, were undertaken with the statistical programming language R (Ihaka & Gentleman, 1996), and partially with Microsoft Excel.

Generally, in order to explore the contribution of each predictor on the dependent variables, thus the shorebird species, a range of Generalised Linear Models (GLMs) were performed for each species within the large and the small data set (biotic variables). As the shorebird data set consists of count data (integers), a poisson distribution has been applied. In total, nine GLMs were undertaken, six for the large data set and three to investigate the importance of invertebrate species of the small data set. For each species, one GLM was undertaken, whereas within the large data set, two for each species were performed. This decision was made due to the fact that there may be interactions among the different predictors, especially since the categorical variables represent summaries of a range of prevailing factors and conditions such as the regions and the beach types. Therefore, to investigate the importance of individual variables, one GLM was performed with the categorical variables, the beach type, and the region (data set called 'total'), and one has been performed with only the numeric variables (data set called 'plain'). As interactions may play a role, particularly among the beach types, regions, and the abiotic variables, a further correlation matrix was calculated using the Pearson´s correlation coefficient (r). In order to find the most suitable predictors and the lowest number of variables, a step function was chosen for the GLMs to test a range of variable combinations.

5 Results

5.1 Shorebird distribution and abundance

Among the selected number of 322 surveyed beach segments or sites (equalling up to about 150 entire beaches as printed in maps), a total number of 1454 breeding pairs and thus territories have been recorded. The majority of breeding pairs were Pied Oystercatchers with 748 pairs, accounting for about 51% (half of the total number recorded). The other half consisted of 30% of Hooded Plovers (n=436 breeding pairs) and 19% of Red-capped Plovers (n=270 breeding pairs, Figure 5.1.1a+b).

About 64% (n=207) of the total 322 beach segments were occupied by at least one Hooded Plover breeding pair, almost 80% (n=253) by one or more Pied Oystercatcher breeding pairs, thus 2/3 of the beaches, and just 25% (n=80) by one or more Red-capped Plover pairs.
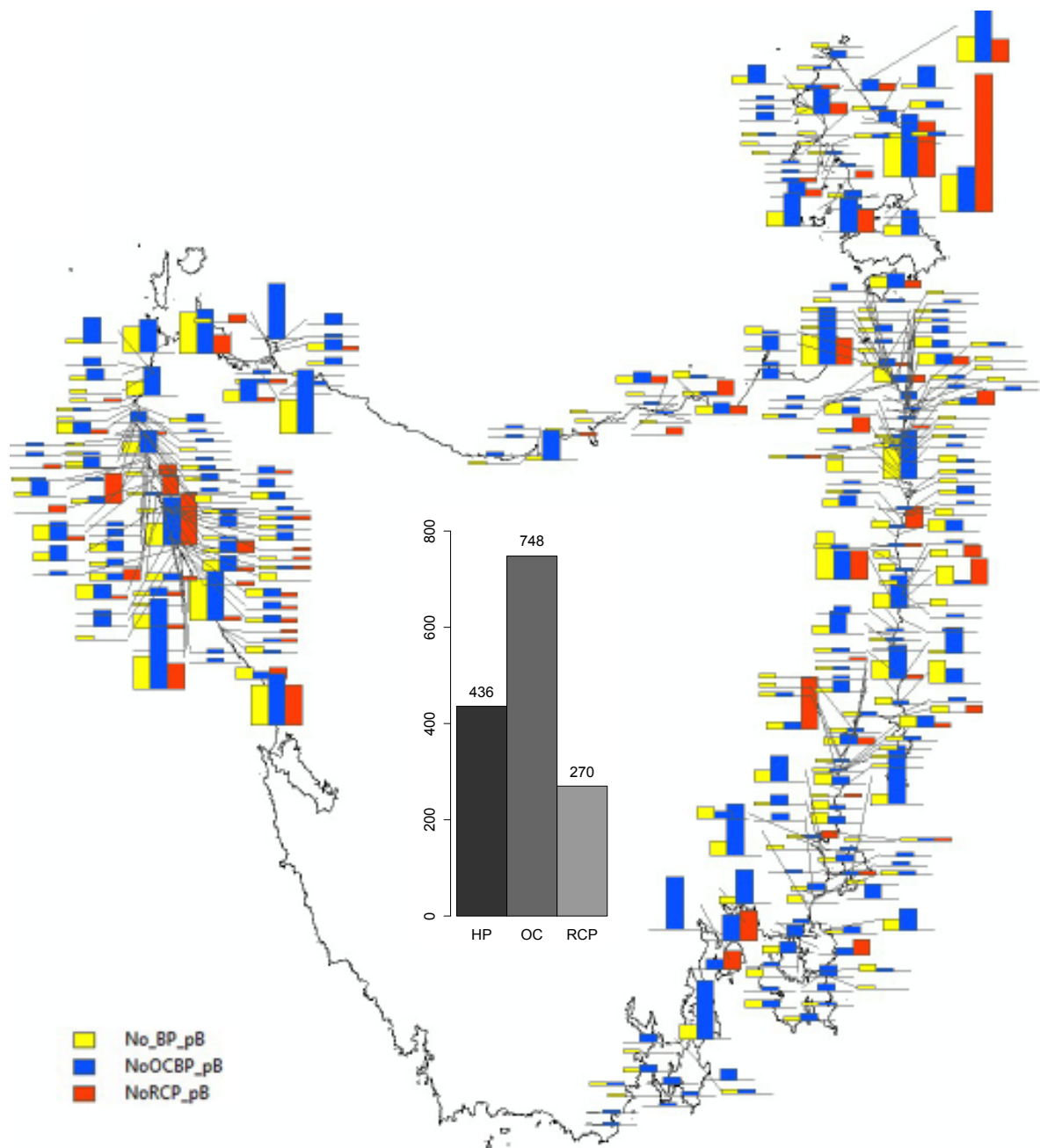
Figure 5.1.1a+b: Total number of Hooded Plover (HP), Pied Oystercatcher (OC) and Red-capped Plover (RCP) breeding pairs (a, middle image), with Pied Oystercatchers being the most abundant (a, OC, middle bar in middle image.) As indicated by the lower bar for Red-capped Plovers (RCP in a, middle image) and by the lower number of red bars (b, larger image, NoRCP_pB), Red-capped Plovers were not as abundant on Tasmania´s ocean sandy beaches, compared to Hooded Plovers (yellow in b, No_BP_pB) and Pied Oystercatchers (blue in b, NoOCBP_pB)

5.1.1 **Beach categories and types**

Among the 322 selected beach segments and sites, the majority with 302 or almost 94% were wave-dominated beaches (Table 5.1.1) comprising of reflective (36%, n=115), low tide terrace (29%, n=94) and transverse bar and rip (29%, n=93) beaches (Table 5.1.1). The remaining 20 beaches (6%) were distributed amongst six other beach types (7-11), thus the tide-modified and tide-dominated category beaches.

Table 5.1.1: Overview of the beach types contained in the data set.

	Beach Type	Beach Category	Total
1	Reflective	Wave-dominated	115 (36%)
2	Low tide terrace	Wave-dominated	94 (29%)
3	Transverse bar and rips	Wave-dominated	93 (29%)
4	Rhythmic bar and beach	Wave-dominated	1 (<1%)
7	Reflective plus low tide terrace	Tide-modified	4 (1%)
8	Reflective plus bar and rips	Tide-modified	1 (<1%)
9	Ultra dissipative	Tide-modified	4 (1%)
10	Reflective plus sand ridges	Tide-dominated	5 (2%)
11	Reflective plus sand flats	Tide-dominated	5 (2%)
			322

With regards to the total number of breeding pairs occupying these beach categories, most sightings occurred on wave-dominated beaches (Table 5.1.2), where Hooded Plovers comprising 98% (n=426) were particularly abundant. Red-capped Plovers, with their low numbers of 270 breeding pairs, occupied 6% tide-dominated beaches (n=17), whereas Pied Oystercatchers were 4% and the most abundant on tide-modified beaches (n=30).

Table 5.1.2: Total number of occupied beach segments (No. occ. bs) by the three focal species and their distribution, abundance among beach categories.

	No occ. bs	wave-dominated	tide-modified	tide-dominated
Hooded Plover	206	426 (98%)	8 (2%)	2 (<1%)
Pied Oystercatcher	252	682 (91%)	30 (4%)	36 (5%)
Red-capped Plover	79	250 (92%)	3 (1%)	17 (6%)
Total	537	1358	41	55

Further divided into the specific beach types, the reflective, low tide terrace, and transverse bar and rip beaches were the most occupied, whereas transverse bar and rip seemed to be most constantly occupied towards larger breeding pair numbers (Figure 5.1.2).
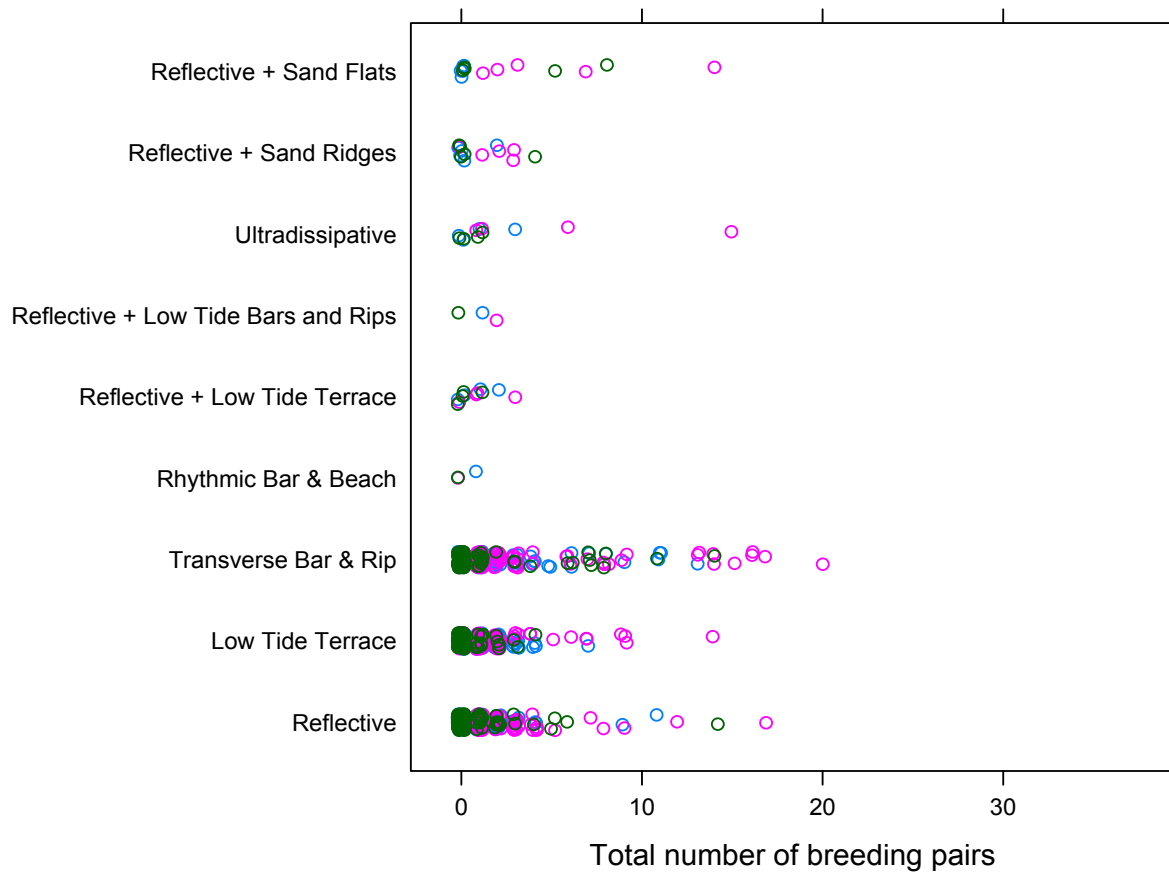
Figure 5.1.2: Most species´ breeding pairs (indicated by the three colours) were recorded on reflective, low tide terrace and transverse bar and rip beaches, thus on the wave dominated beaches.

5.1.2 **Geographic differences**

As indicated by Figure 5.1.3, wave dominated beaches (blue in Figure 5.1.3b) are the most common beach category that are evenly distributed across Tasmania´s coasts and regions (Figure 5.1.3a).
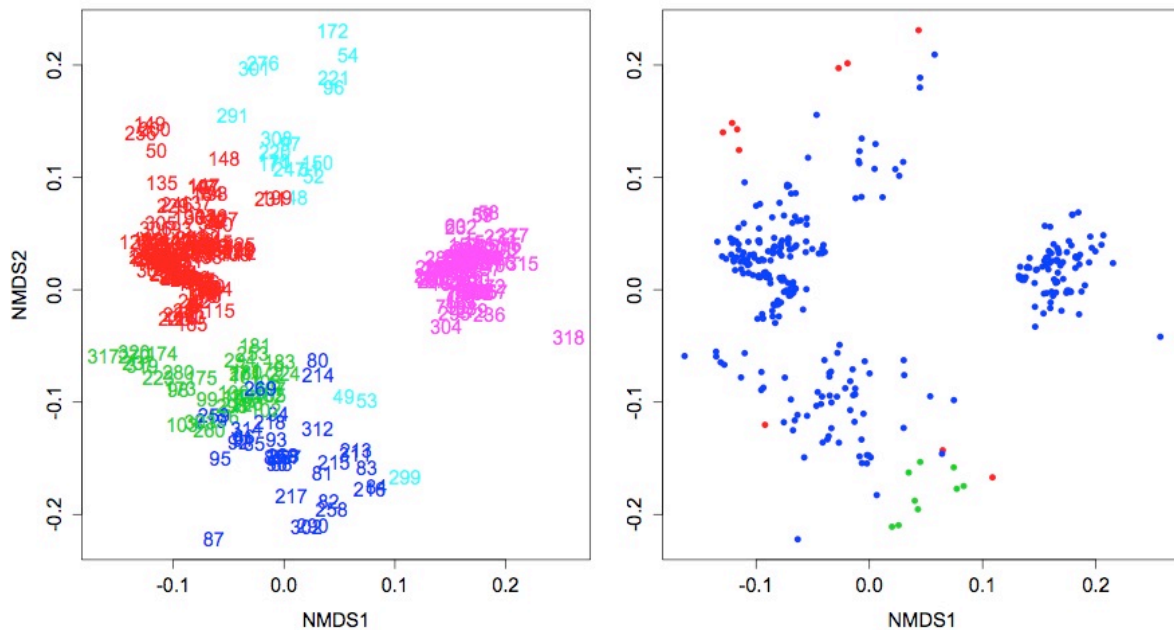
Figure 5.1.3a+b: A cluster matrix shows the division of the beaches (each coloured number represents a segment) according to regions, thus five distinct separated patches are visible representing the west, north, east and southeast coasts and Flinders Island (a, left). As indicated by the blue dots (b, right), these regions are dominated by wave-dominated beaches, just a few green and red dots indicate tide-modified and tide-dominated beaches.

Overall, the largest proportion among the selected beaches were located on the east coast with 46% and 147 beaches (39+60+43 in Table 5.1.3), followed by the west coast with 84 beaches (26%). Therefore most wave-dominated beaches were either located on the west or east coast. Apart from the low tide terrace (that was with 60 beaches more common in the east than with 15 beaches on the west coast), the 20 remaining beaches were mostly located along the north coast, and only a few on the east or southeast coast, and none are on the west coast.

Table 5.1.3: Overview of beach types and categories (wave-dominated, tide-modified, tide-dominated) among regions.

	Beach Type	Beach Category	West	North	East	South -east	Flinders Island	Total
1	Reflective	Wave-dominated	30	21	39	7	18	115 (36%)
2	Low tide terrace	Wave-dominated	15	2	60	3	14	94 (29%)
3	Transverse bar and rips	Wave-dominated	39	1	43	6	4	93 (29%)
4	Rhythmic bar and beach	Wave-dominated	0	0	1	0	0	1 (<1%)
7	Reflective plus low tide terrace	Tide-modified	0	4	0	0	0	4 (1%)
8	Reflective plus bar and rips	Tide-modified	0	1	0	0	0	1 (<1%)
9	Ultra dissipative	Tide-modified	0	4	0	0	0	4 (1%)
10	Reflective plus sand ridges	Tide-dominated	0	1	4	0	0	5 (2%)
11	Reflective plus sand flats	Tide-dominated	0	0	0	4	1	5 (2%)
			84 (26%)	34 (11%)	147 (46%)	20 (6%)	37 (11%)	322

The greatest number of individuals 514 sightings recorded for the east and 407 in total for the west coast (Table 5.1.4). The highest numbers of Hooded Plover breeding pairs were also found on the east coast (44%, n=192), thereby making them the most abundant species in the region. Whereas Pied Oystercatchers were the most abundant in the southeast (9%, n=69), and Red-capped Plovers were the most abundant on the west coast (30%, n=82) and on Flinders Island (28%, n=75).

Table 5.1.4: Total number of occupied beach segments (No. occ. bs) by Hooded Plovers, Pied Oystercatchers and Red-capped Plovers, and their distributions, abundances among regions.

	No occ. bs	West	North	East	South-east	Flinders Island
Hooded Plover	206	123 (28%)	52 (12%)	192 (44%)	13 (3%)	56 (13%)
Pied Oystercatcher	252	202 (27%)	103 (14%)	250 (33%)	69 (9%)	124 (17%)
Red-capped Plover	79	82 (30%)	28 (10%)	72 (27%)	13 (5%)	75 (28%)
	537	407	183	514	95	255

5.1.3 **Significances**

The three Generalised Linear Models (GLMs) that were performed for each of the three species (including the categorical variables 'regions' and 'beach categories') indicated three highly significant and two significant relationships for Pied Oystercatchers and Red-capped Plovers. Accordingly, reflective beaches appeared to be highly significant for Red-capped Plovers (Estimate=1.126, z-score=4.832, P<0.001), and it was the only significant association with a wave-dominated beach type (Table 5.1.5). All other beach type associations were either with tide-modified or –dominated beaches. Of significant influence for the Pied Oystercatcher were the reflective plus bar and rips, and the reflective plus sand flat beach types (Estimate=1.806, z-score=2.514, P=0.012 and estimate=1.650, z-score=7.444, P<0.001), which comprised of five beaches in total, present in the southeast and on Flinders Island and one beach on the north coast. The reflective plus sand ridges beaches, five beaches in total along the north and east coast, and the sand flat beaches seem to be of further significant importance for the Red- capped Plover. (Estimate=3.358, z-score=9.481, P<0.001 and estimate=1.303, z-score=2.386, P=0.017).

Table 5.1.5: A GLM was performed with all possible predictor variables including categorical and continuous variables ('total' data set). The table contains only the categorical variables, thus the beach types.

Hooded Plover - total	**Estimate**	**Std. Error**	**z-score**	**Pr(>lzl)**
Flinders Island	-0.754	0.204	-3.703	<0.001
Pied Oystercatcher - total	**Estimate**	**Std. Error**	**z-score**	**Pr(>lzl)**
Reflective plus bar and rips	1.806	0.719	2.514	0.012
Reflective plus sand flats	1.650	0.222	7.444	<0.001
Red-capped Plover - total	**Estimate**	**Std. Error**	**z-score**	**Pr(>lzl)**
Reflective	1.126	0.233	4.832	<0.001
Reflective plus sand flats	3.358	0.354	9.481	<0.001
Reflective plus sand ridges	1.303	0.546	2.386	0.017

Estimate= *The estimated coefficient is the value of slope calculated by the regression.*
Std. Error= *The Standard Error of the coefficient estimate is a measure of the variability in the estimate for the coefficient. However, the value is relative to the value of the coefficient.*
z-score= *The z-score indicates, where in the distribution the value is located and how far away it is from the mean, if e.g. 2 or 3 standard deviations above or below the mean.*
Pr(>lzl) = *The Pr(>lzl) represents the p-value and indicates the type of analysis that has been performed. Accordingly, this value indicates the calculated probability that the variation of the dependent variable is caused by the investigated predictor variable. If its value is significant (<0.05) or highly significant (<0.001) the null hypothesis can be*

rejected. In summary, it provides the likelihood of an incident to occur according to this impact ('P=' or 'P<' were used in the text).

The only significant association with a region appeared for Flinders Island and Hooded Plovers (Estimate=-0.754, z-score=-3.703, P<0.001). However with regards to interactions between predictor variables, no significant correlation appeared between beach categories and regions (r=-0.013, p=0.822, see Pearson´s correlation matrix in Appendix), but a significant correlation was revealed for beach types and regions (r=0.181, p=0.001).

5.2 Role of beach attributes and environmental factors

5.2.1 Beach categories and types

The beaches with the widest subaerial beach zone (mean beach width) and the largest variance belong to the tide-modified beach category (mean=230.0, sd=+/-177.4). These also contain the gentlest slope (mean=2.1, sd=+/-0.8), whereas surf zone width was most expanded at wave-dominated beaches (mean=96.6, sd=+/-141.6) and shortest at tide-dominated beaches (mean=3.5, sd=+/-3.0, Table 5.2.1, see also boxplots in Appendix).

Table 5.2.1: Overview of beach attributes and their variations among beach categories

	Average (+/-sd) mean beach width (m)	Average (+/-sd) mean degree of embayment (0-1)	Average (+/-sd) mean swash gradient (degrees)	Average (+/-sd) mean surf zone width (m)
Wave-dominated	45.0 (+/-83.0)	0.8 (+/-0.2)	5.3 (+/-1.3)	96.6 (+/-141.6)
Tide-modified	230.0 (+/-177.4)	0.9 (+/-0.2)	2.1 (+/-0.8)	78.3 (+/-50.7)
Tide-dominated	23.0 (+/-44.9)	0.8 (+/-0.3)	5.0 (+/- 0.0)	3.5 (+/-3.0)
Total average	49.4 (+/-91.1)	0.8 (+/-0.2)	5.2 (+/-1.4)	93.2 (+/-138.5)

With regards to the environmental factors, the newly calculated average of the mean annual wind speed stayed fairly constant among all three beach types, except the variations are largest at wave-dominated beaches (mean= 2.4, sd=+/-1.4, Table 5.2.2). Mean annual significant wave height was highest at wave-dominated beaches (mean=1.3, sd=+/-0.9), whereas mean annual wave period was longest at wave dominated beaches (mean=5.6, sd=+/-1.9, see also boxplots in Appendix).

Table 5.2.2: Overview of environmental variables and their variations among beach categories.

	Average (+/-sd) mean annual wind speed (m/s)	Average (+/-sd) mean annual wave period (s)	Average (+/-sd) mean annual sign. wave height (m)	Average (+/-sd) max. sign. wave height (m)
Wave-dominated	2.4 (+/-1.4)	5.6 (+/-1.9)	1.3 (+/-0.9)	2.9 (+/-1.8)
Tide-modified	2.4 (+/-0.2)	3.3 (+/-0.1)	0.6 (+/-0.0)	2.2 (+/-0.1)
Tide-dominated	2.5 (+/-0.6)	3.4 (+/-2.2)	0.4 (+/-0.4)	2.9 (+/-1.8)
Total average	2.4 (+/-1.1)	5.5 (+/-1.9)	1.2 (+/-0.9)	2.8 (+/-1.8)

5.2.2 Geographic differences

Overall, the widest beach segments, but also the ones with the largest variation, are located on the north coast (mean=189.4, sd=+/-203.0), while the shortest segments are located in the southeast of Tasmania (mean=23.0, sd=+/-10.6, Table 5.2.3). The beach segments with the steepest intertidal slope are located on the west coast (mean=5.7, sd=+/-0.8), as are the beaches with the widest.surf zone owning a high degree of variance (mean=221.4, sd=+/-212.5). However, the beach segments with the shortest surf zone were located on Flinders Island (mean=34.9, sd=+/-33.8, see boxplots in Appendix).

Table 5.2.3: Overview of beach attributes and their variations among regions

	Average (+/-sd) mean beach width (m)	Average (+/-sd) mean degree of embayment (0-1)	Average (+/-sd) mean swash gradient (degrees)	Average (+/-sd) mean surf zone width (m)
West	27.5 (+/-8.3)	0.8 (+/-0.2)	5.7 (+/-0.8)	221.4 (+/-212.5)
North	189.4 (+/-203.0)	0.8 (+/-0.2)	4.6 (+/-2.1)	55.4 (+/-50.0)
East	26.6 (+/-7.8)	0.9 (+/-0.2)	5.1 (+/-1.3)	46.7 (+/-32.7)
Southeast	23.0 (+/-10.6)	0.7 (+/-0.2)	4.9 (+/-0.9)	63.5 (+/-104.9)
Flinders Island	73.5 (+/-112)	0.9 (+/-0.1)	5.1 (+/-2.1)	34.9 (+/-33.8)
Total average	49.4 (+/-91.1)	0.8 (+/-0.2)	5.2 (+/-1.4)	93.2 (+/-138.5)

With regards to environmental conditions, the highest waves (mean=2.7, sd=+/-0.2 and mean=5.2, sd=+/-1.5) and longest wave periods (mean=8.4, sd=+/-0.4) were found on the west coast, whereas lowest wave periods were recorded for Flinders Island (mean=3.5, sd=+/-0.5, Table 5.2.2). Lowest wind speeds were indicated for the east (mean=1.6, sd=+/-0.7), and highest for the north coast (mean=3.7, sd=+/-1.1, Table 5.2.4, see boxplots in Appendix).

Table 5.2.4: Overview of environmental variables and their variations among regions.

	Average (+/-sd) mean annual wind speed (m/s)	Average (+/-sd) mean annual wave period (s)	Average (+/-sd) mean annual sign. wave height (m)	Average (+/-sd) max. sign. wave height (m)
West	2.4 (+/-0.3)	8.4 (+/-0.4)	2.7 (+/-0.2)	5.2 (+/-1.5)
North	3.7 (+/-1.1)	3.6 (+/-0.4)	0.6 (+/-0.1)	2.3 (+/-0.3)
East	1.6 (+/-0.7)	4.9 (+/-0.8)	0.8 (+/-0.3)	1.8 (+/-0.9)
Southeast	3.4 (+/-1.1)	5.5 (+/-1.3)	0.8 (+/-0.5)	1.5 (+/-0.8)
Flinders Island	3.5 (+/-0.9)	3.5 (+/-0.5)	0.7 (+/-0.2)	2.3 (+/-0.7)
Total average	2.4 (+/-1.1)	5.5 (+/-1.9)	1.2 (+/-0.9)	2.8 (+/-1.8)

5.2.3 **Significances**

When taking the categorical variables into consideration, the width of the surf zone was the only beach attribute that appeared to be significant for Hooded Plovers (Estimate=-0.001, z-score=-2.119, P=0.034) and Pied Oystercatchers (Estimate=-0.001, z-score=-2.012, P<0.044). With regards to environmental factors, mean annual wind speed appeared to be highly significant for Hooded and Red-capped Plovers (Estimate=-0.192, z-score=-2.826, P<0.005 and estimate=-0.548, z-score=0.085, P<0.001). Also, maximum significant wave height revealed a significant association for Hooded and Red-capped Plovers (Estimate=0.020, z-score=3.200, P=0.001 and estimate=0.288, z-score=5.765, P<0.001), whereas mean annual significant wave height was significant for Pied Oystercatchers (Estimate=0.486, z-score=-8.088, P<0.001, Table: 5.2.5).

However, as surf zone width was significantly correlated with all three wave variables (r=0.525, p<0.001; r=0.561, p<0.001 and r=0.379, p<0.001), these values might not be as representative. Mean annual wind speed did not reveal a significant correlation with surf zone width (r=-0.044, p=0.436), but region was significantly correlated with all four environmental variables (r=0.723, p<0.001; r=0.788, p<0.001 and r=0.716, p<0.001), as well as with surf zone width (r=0.489, p<0.001), swash zone gradient (r=0.140, p=0.012), and degree of embayment (r=-0.151, p=0.007). Also, the beach categories appeared to be highly significantly correlated with all three wave variables (r=0.269, p<0.001; r=0.223, p<0.001 and r=0.205, p<0.001), swash zone gradient (r=0.182, p=0.001) and surf zone width (r=0.114, p=0.041), but not with mean annual wind speed (r=-0.02, p=0.728) or degree of embayment (r=0.021, p=0.704, Table 5.2.3).

Table 5.2.5: A GLM was performed with all possible predictor variables including categorical and continuous variables ('total' data set). The table contains only the beach attributes and environmental variables.

Hooded Plover - total	Estimate	Std. Error	z-score	Pr(>|z|)
Surf zone width	-0.001	0.001	-2.119	0.034
Maximum significant wave height	0.020	0.006	3.200	0.001
Mean annual wind speed	-0.192	0.068	-2.826	0.005
Pied Oystercatcher - total	**Estimate**	**Std. Error**	**z-score**	**Pr(>|z|)**
Surf zone width	-0.001	<0.000	-2.012	0.044
Mean annual significant wave height	0.486	0.060	8.088	<0.001
Red-capped Plover - total	**Estimate**	**Std. Error**	**z-score**	**Pr(>|z|)**
Maximum significant wave height	0.288	0.050	5.765	<0.001
Mean annual wind speed	-0.548	0.085	-6.441	<0.001

Estimate*= The estimated coefficient is the value of slope calculated by the regression.*
Std. Error*= The Standard Error of the coefficient estimate is a measure of the variability in the estimate for the coefficient. However, the value is relative to the value of the coefficient.*
z-score*= The z-score indicates, where in the distribution the value is located and how far away it is from the mean, if e.g. 2 or 3 standard deviations above or below the mean.*
Pr(>|z|) = *The Pr(>|z|) represents the p-value and indicates the type of analysis that has been performed. Accordingly, this value indicates the calculated probability that the variation of the dependent variable is caused by the investigated predictor variable. If its value is significant (<0.05) or highly significant (<0.001) the null hypothesis can be rejected. In summary, it provides the likelihood of an incident to occur according to this impact ('P=' or 'P<' were used in the text).*

When excluding the regions and beach types, most significance values revealed before either increased or new significant variables appeared, such as mean beach width for Pied Oystercatchers (Estimate=0.001, z-score=2.400, P=0.016) and swash zone gradient for Red-capped Plovers (Estimate=-0.092, z-score=-2.204, P<0.028, Table: 5.2.4). Moreover, mean annual significant wave height was no longer significant for Pied Oystercatchers and was exchanged to a positive mean annual wave period value (Estimate=0.223, z-score=7.676, P<0.001). Maximum significant wave height was exchanged to mean annual significant wave height for Red-capped Plovers (Table 5.2.6, Estimate=0.459, z-score=6.091, P<0.001).

However, the GLMs without the categorical variables (data set 'plain') revealed highly significant values for mean annual wind speed and Hooded Plovers (Estimate=-0.259, z-score=-4.787, P<0.001), surf zone width and wave period for Pied Oystercatchers (Estimate=-0.001, z-score=-3.291, P<0.001 and estimate=0.223, z-score=7.676, P<0.001), and mean annual significant wave height and mean annual wind speed for Red-capped Plovers (Estimate=0.459, z-score=6.091, P<0.001 and estimate=-0.253, z-score=-3.680, P<0.001). Overall surf zone width was significant for both Hooded Plovers (Estimate=-0.001, z-score=-2.920, P<0.004) and Pied Oystercatchers (Estimate=-0.001, z-score=-3.291, P<0.001).

Table 5.2.6: All predictor variables were tested in a GLM without the categorical variables being included ('plain' data set).

Hooded Plover - plain	Estimate	Std. Error	z-score	Pr(>|z|)
Surf zone width	-0.001	<0.000	-2.920	0.004
Maximum significant wave height	0.157	0.065	2.397	0.017
Mean annual wind speed	-0.259	0.054	-4.787	<0.001
Pied Oystercatcher - plain	**Estimate**	**Std. Error**	**z-score**	**Pr(>|z|)**
Mean beach width	0.001	<0.000	2.400	0.016
Surf zone width	-0.001	<0.000	-3.291	<0.001
Mean annual wave period	0.223	0.029	7.676	<0.001
Red-capped Plover - plain	**Estimate**	**Std. Error**	**z-score**	**Pr(>|z|)**
Swash gradient	-0.092	0.042	-2.204	0.028
Mean annual significant wave height	0.459	0.075	6.091	<0.001
Mean annual wind speed	-0.253	0.069	-3.680	<0.001

Estimate*= The estimated coefficient is the value of slope calculated by the regression.*

Std. Error*= The Standard Error of the coefficient estimate is a measure of the variability in the estimate for the coefficient. However, the value is relative to the value of the coefficient.*

z-score*= The z-score indicates, where in the distribution the value is located and how far away it is from the mean, if e.g. 2 or 3 standard deviations above or below the mean.*

Pr(>|z|) = *The Pr(>|z|) represents the p-value and indicates the type of analysis that has been performed. Accordingly, this value indicates the calculated probability that the variation of the dependent variable is caused by the investigated predictor variable. If its value is significant (<0.05) or highly significant (<0.001) the null hypothesis can be rejected. In summary, it provides the likelihood of an incident to occur according to this impact ('P=' or 'P<' were used in the text).*

5.3 Invertebrate abundance

5.3.1 Beach categories and types

The most abundant invertebrate subphylum were the crustaceans (mean=448.7, sd=+/-408.7), followed by insects (mean=67.2, sd=+/-115.6), whereas myriapods and arachnids were not very frequently abundant (mean=0.6, sd=+/-4.7 and mean=1.4, sd=+/-4.7, Table. 5.3.1). However, most crustaceans and insects were found on wave-dominated beaches (mean=478.0, sd=+/-410.2 and mean=69.5, sd=+/-120.1).

Table 5.3.1: Overview of invertebrate taxa among beach categories.

	Average (+/-sd) no. of crustaceans	Average (+/-sd) no. of myriapods	Average (+/-sd) no. of arachnids	Average (+/-sd) no. of insects
Wave-dominated	478.0 (+/-410.2)	0.6 (+/-1.8)	1.5 (+/-4.9)	69.5 (+/-120.1)
Tide-modified	119.7 (+/-196.6)	0.2 (+/-0.4)	0.5 (+/-0.7)	42.4 (+/-19.0)
Tide-dominated	70.0 (+/-51.0)	0.0 (+/-0.0)	4.0 (+/-5.7)	34.0 (+/-21.2)
Total average	448.7 (+/-408.7)	0.6 (+/-4.7)	1.4 (+/-4.7)	67.2 (+/-115.6)

5.3.2 Geographic differences

Most crustaceans were recorded on the west coast (mean=659.6, sd=+/-333.5), whereas most insects were present in the north (mean=101.6, sd=+/-137.4, Table 5.3.2).

Table 5.3.2: Overview of invertebrate taxa among regions.

	Average (+/-sd) no. of crustaceans	Average (+/-sd) no. of myriapods	Average (+/-sd) no. of arachnids	Average (+/-sd) no. of insects
West	659.6 (+/-333.5)	0.1 (+/-0.3)	0.1 (+/-0.3)	52.2 (+/-122.8)
North	231.5 (+/-317.6)	1.1 (+/-2.4)	1.5 (+/-1.8)	101.6 (+/-137.4)
Flinders Island	255.6 (+/-418.4)	1.1 (+/-2.4)	3.9 (+/-8.7)	63.1 (+/-63.6)
Total average	448.7 (+/-408.7)	0.6 (+/-4.7)	1.4 (+/-4.7)	67.2 (+/-115.6)

5.3.3 **Significances**

With regards to the importance of certain invertebrate taxa to the birds, insects and crustaceans revealed to be significant for Hooded (Estimate=0.007, z-score=4.095, P<0.001 and estimate=0.001, z-score=2.356, P<0.020) and Red-capped Plovers (Estimate=0.006, z-score=2.370, P<0.020 and estimate= 0.003, z-score=-2.949, P<0.004). However, only crustaceans appeared to be significant for Pied Oystercatchers (Estimate=0.003, z-score=2.953, P=0.004, Table 5.3.3).

Table 5.3.3: All predictor variables were tested in a GLM without the categorical variables being included of the small data set with the invertebrates (Inv.)

Hooded Plover – Inv.	**Estimate**	**Std. Error**	**z-score**	**Pr(>|z|)**
Insects	0.007	0.002	4.095	<0.001
Crustaceans	0.001	<0.000	2.356	0.020
Pied Oystercatcher – Inv.	**Estimate**	**Std. Error**	**z-score**	**Pr(>|z|)**
Crustaceans	0.003	0.001	2.953	0.004
Red-capped Plover – Inv.	**Estimate**	**Std. Error**	**z-score**	**Pr(>|z|)**
Insects	0.006	0.003	2.370	0.020
Crustaceans	0.003	0.001	2.949	0.004

***Estimate**= The estimated coefficient is the value of slope calculated by the regression.*
***Std. Error**= The Standard Error of the coefficient estimate is a measure of the variability in the estimate for the coefficient. However, the value is relative to the value of the coefficient.*
***z-score**= The z-score indicates, where in the distribution the value is located and how far away it is from the mean, if e.g. 2 or 3 standard deviations above or below the mean.*
***Pr(>|z|) =** The Pr(>|z|) represents the p-value and indicates the type of analysis that has been performed. Accordingly, this value indicates the calculated probability that the variation of the dependent variable is caused by the investigated predictor variable. If its value is significant (<0.05) or highly significant (<0.001) the null hypothesis can be rejected. In summary, it provides the likelihood of an incident to occur according to this impact ('P=' or 'P<' were used in the text).*

The Pearson correlation matrix revealed interactions between crustaceans and arachnids (r=-0.284, p<0.001), and between arachnids and insects (r=0.314, p<0.001). Furthermore, most variables showed correlations among the invertebrates such as between crustaceans, arachnids and all environmental variables. These include correlations between crustaceans and all three wave variables (r=0.505, p<0.001; r=0.544, p<0.001 and r=0.326, p<0.001), mean annual wind speed (r=0.475, p<0.001), but also surf zone width (r=0.015, p=0.021) and mean beach width (r=-0.265, p=0.002)

5.4 Principal Component Analysis

When investigating all independent and dependent variables of the large data set (excluding the categorical variables 'region' and 'beach types') together within a Principal Component Analysis (PCA), the first component explains 28% of the variation in the data (proportion of variance, Table 5.4.1). Whereas with the second component combined, already 49% of the variation in the data is explained (cumulative proportion).

Table 5.4.1: The first component (Comp. 1) explains most of the variation in the data with 28%, whereas the following components will contribute increasingly less, thus the second component accounts only for 21%, which, combined, add up to almost half of the variation (cumulative proportion).

Importance of components:

	Comp.1	Comp.2	Comp.3	Comp.4	Comp.5
Standard deviation	1.781	1.502	1.134	1.061	0.909
Proportion of variance	0.288	0.205	0.117	0.102	0.075
Cumulative proportion	0.288	0.493	0.610	0.713	0.788

As all wave variables, surf zone width, the swash gradient, and mean beach width contribute to the first component (Table 5.4.2 and Figure 5.4.1), they also account for most of the variation of the 28%. Whereas the shorebird species and the degree of embayment contribute to the second component, only mean annual wind speed contributes to the third component.

Table 5.4.2: The loadings indicate the extent to which the original variables contribute to the components (Comp. 1-5), thus all wave variables and the surf and swash zone contribute to the first component, whereas the second component contains the study species.

Loadings:

	Comp.1	Comp.2	Comp.3	Comp.4	Comp.5
Hooded Plover		0.581			0.185
Pied Oystercatcher		0.566	0.113		
Red-capped Plover		0.467			0.383
Mean beach width	-0.152	0.143	0.568		-0.537
Degree of embayment		0.137	-0.326	-0.708	-0.442
Swash gradient	0.173	-0.194		-0.638	0.354
Surf zone width	0.362	0.194			-0.413
Mean annual wave period	0.531			0.15	
Mean annual significant wave height	0.546				
Maximum significant wave height	0.483		0.187		
Mean annual wind speed			0.713	-0.209	0.195
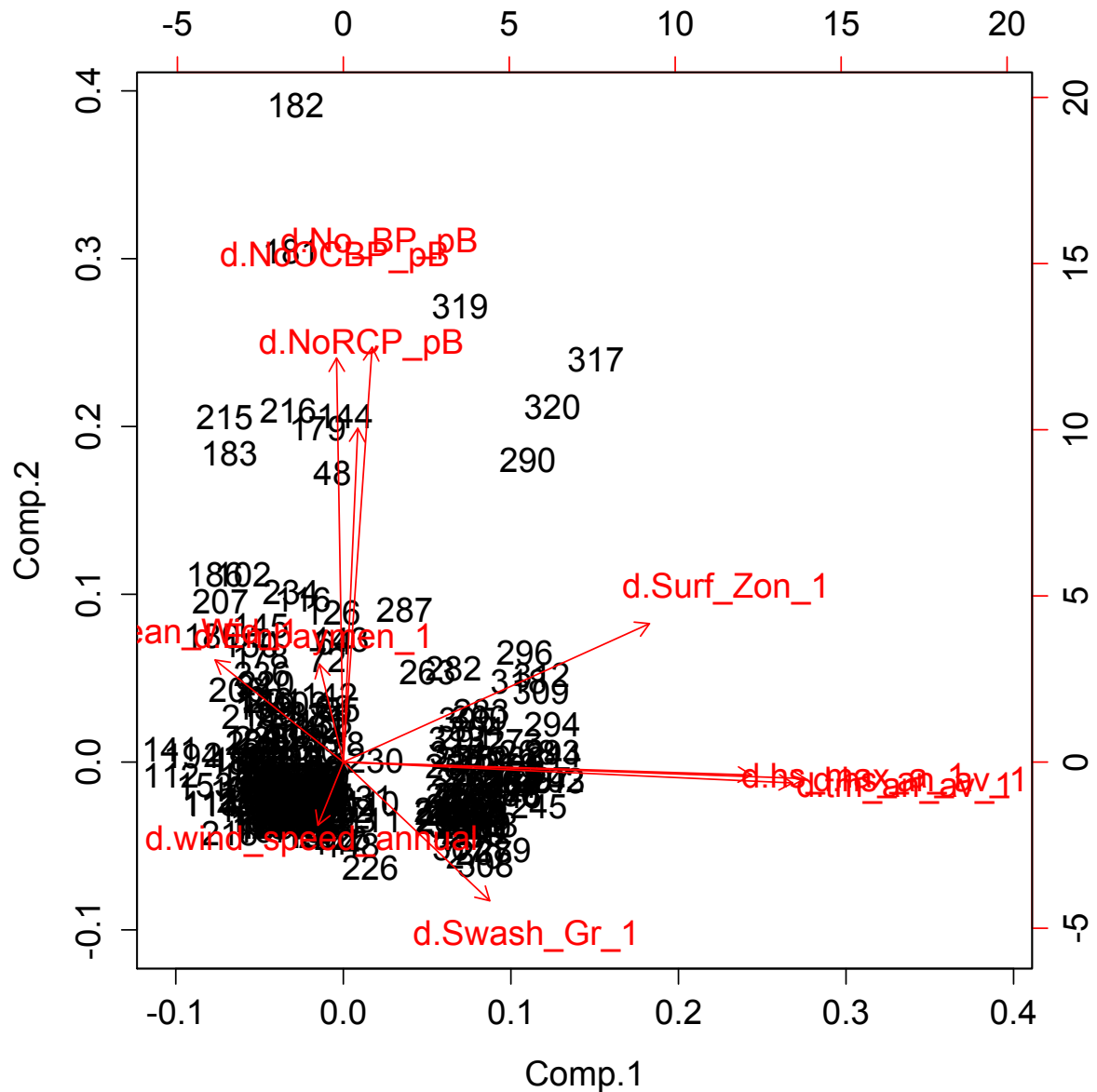
Figure 5.4.1: The contribution of every original component is illustrated in this biplot. Accordingly, it is indicated that the mean annual wind speed is located in the middle of both first and second component, whereas the shorebirds are more strongly associated with component 2 and the wave variables strongly associated with component 1 (difficult to read).

6 Discussion

6.1 Shorebird distribution and abundance

Overall the distributions and abundances of Hooded Plovers, Pied Oystercatcher, and Red-capped Plovers seem to vary among beaches and regions, as differences in shorebird breeding pair numbers were revealed. Red-capped Plovers, with 270 breeding pairs in total, were less abundant on sandy beaches, as compared to Hooded Plovers with 436 and Pied Oystercatchers with 748 breeding pairs. As former studies have observed, flocks of Red-capped Plovers were highly abundant farther inland, such as around salt lakes (Abensperg-Traun & Dickman, 1989; Green, 1956). Accordingly, it might not be as surprising that Red-capped Plover breeding pair numbers were lower on ocean sandy beaches compared to Hooded Plovers and Pied Oystercatchers.

6.1.1 **Among regions**

Although only Flinders Island appeared to be significant for Hooded Plovers (Estimate=-0.754, z-score=-3.703, P<0.001), the distribution and abundance values still indicate further slight differences among regions. However, Hooded Plovers were highly abundant on the east coast representing 44% (n=192), whereas Pied Oystercatchers represented 9% (n=69) in the southeast and Red-capped Plovers represented 28% (n=75) and were highly abundant on Flinders Island.

6.1.2 **Among beach types**

With regards to distributions and abundances among beach categories and beach types, significance values appeared for tide-modified and tide-dominated beaches for Pied Oystercatchers (Estimate=1.806, z-score=2.514, P=0.012 and estimate=1.650, z-score=7.444, P<0.001) and Red-capped Plovers (Estimate=3.358, z-score=9.481, P<0.001 and estimate=1.303, z-score=2.386, P=0.017). However, with only 20 beaches in total, these two beach categories represent a very low proportion of the total 322 beach segments. Accordingly, these significance values might not be very representative or

reliable (Table 5.1.5), and further research would be beneficial. However, only one wave-dominated beach appeared to be significant for Red-capped Plovers (Estimate=1.126, z-score=4.832, P<0.001), which would comply with increased Red-capped Plover numbers on the west coast (n=82, 30%) and a large proportion of present reflective beaches (30 beaches from 84 in total). The most common beach type in this data set were reflective beaches with a total number of 115 representing 36% of the total 322 investigated beach segments. Moreover, Hooded Plovers were also highly abundant on wave-dominated beaches representing 98% (n=426), Pied Oystercatchers represented 4% (n=30) on tide-modified beaches, and Red-capped Plovers represented 6% (n=17) on tide-dominated beaches.

6.2 Role of beach attributes and environmental factors

6.2.1 Differences in beach characteristics

Overall, the revealed differences among regions and beach types comply with (Short, 2006b) descriptions about Tasmania´s sandy beaches. Accordingly, mean annual significant and maximum wave height were highest on the exposed west coast (mean=2.7, sd=+/-0.2 and mean=5.2, sd=+/-1.5), where the wave energy arrives that travels from South America across the Southern Ocean. These values are consistent with the longest mean annual wave period (mean=8.4, sd=+/-0.4) and the longest surf zone (mean=96.6, sd=+/-141.6), the area of wave generation (Masselink & Pattiaratchi, 1998; Wright & Short, 1984). Furthermore, the beaches with the most extensive subaerial beaches (mean beach width) were present on the north coast (mean=189.4, sd=+/-203.0), consistent with the most tide-modified and –dominated beaches. The lowest mean annual wind speed has been revealed for the east coast (mean=1.6, sd=+/-0.7), which has been described as more 'sheltered' due to the many offshore islands and reduced wave energy due to its location in lee to the wind direction (Short, 2006).

6.2.2 **Influence on shorebird habitat use**

Surf zone width, wave energy, and wind forces

When investigating the influence of abiotic habitat characteristics on Tasmanian resident shorebirds, a few variables appeared to be of significant importance. As such, surf zone width appeared to be significant for Hooded Plovers and Pied Oystercatchers, indicating that breeding pair numbers decrease with an increase in surf zone width (Estimate=-0.001, z-score=-2.920, P=0.004 and estimate=-0.001, z-score=-3.291, P<0.001). This would be expected, as the surf zone is also known as the 'area of wave generation' (Masselink & Pattiaratchi, 1998; Wright & Short, 1984). Accordingly, if the wave energy arriving at the beach is high, it might create less favourable conditions for the shorebirds, particularly with regards to feeding due to constant wave run up. As such, highly significant positive correlations were revealed between surf zone width and mean annual significant wave height and maximum significant wave height (r=0.171, p<0.001 and r=0.092, p<0.001), and with mean annual wave period (r=0.169, p<0.001).

As wind drives wave generation and propagation (Jackson, 1995; Young, Zieger, & Babanin, 2011), mean annual wind speed was also significantly but negatively correlated with mean annual wave period (r=-0.160, p=0.004). This indicates that with increasing wind speeds the period between wave crests will become shorter and waves will propagate at a higher frequency. Moreover, maximum significant wave height was positively correlated with mean annual wind speed (r=0.134, p=0.016), indicating that maximum wave height increases with increasing wind speed. However, no significant correlation was detected between mean annual significant wave height and mean annual wind speed (r=-0.035, p=0.533).

However, as wind was also highly negatively associated with Hooded and Red-capped Plovers (Estimate=-0.259, z-score=-4.787, P<0.001 and estimate=-0.253, z-score=-3.680, P<0.001), this might also be an indication that less preferable conditions are created. These could include thermal disadvantages for individuals and eggs due to increased heat loss, requiring more effort to maintain energy budgets (McConkey & Bell, 2005; Visser & Ricklefs, 1993).

Wave energy and beach types

As expected, wave heights appeared to be significant for resident shorebird breeding pairs, such as maximum significant wave height for Hooded (Estimate=0.157, z-score=2.397, P=0.017) and mean annual significant wave height for Red-capped Plovers (Estimate=0.459, z-score=6.091, P<0.001). As these two significant associations are of a positive nature, it would indicate that breeding pair numbers increase with increasing wave height. This could possibly be due to the fact that wave dominated beaches are the most common beach category around Tasmania (Short, 2006b) and that most territories were found on these beaches, or due to the previously indicated correlations with surf zone width. Beach categories were also significantly and positively correlated with all three wave variables (r=0.269, p<0.001; r=0.223, p<0.001 and r=0.205, p<0.001). This finding would be supported by the significant associations revealed among the different beach types and the shorebirds, such as between reflective beaches and Red-capped Plovers (Estimate=1.126, z-score=4.832, P<0.001).

However, the other beach types that appeared to be significantly relevant, would also support the significance values of the wave variables. According to the findings of other studies, dissipative or tide-dominated beaches would harbour more favourable living conditions, particularly for sediment burrowing organisms (Lercari et al., 2010; McLachlan & Dorvlo, 2005; McLachlan, 1990). As shorebirds are predators at the top of the food chain, it would be expected that if a territory on a beach containing larger numbers of prey becomes vacant, it would be selected immediately (Orians & Wittenberger, 1991). Therefore, it would be expected that tide-modified and –dominated beaches would also host larger numbers of shorebird breeding pairs. As no wave-dominated beach types appeared to be significant for Hooded Plovers, the significant wave height values might be a result from a different factor, such as increased wrack or biofilm accumulation. These appeared to be an important food source for other plover species due to the associated insects living in the wrack (Kuwae et al., 2012; Neuman et al., 2008).

Wave energy and swash zone gradient

The Pied Oystercatcher seems to be significantly and positively affected by mean annual wave period (Estimate=0.223, z-score=7.676, P<0.001). As previously indicated, feeding conditions might be less preferable, for example due to wave run up on the beach face

occurring more frequently. However, another important aspect for feeding shorebirds might also be the fact that under certain conditions such as increased wave period and wave height, the beach sediment would be eroded, resulting in a steeper intertidal zone (Davidson-Arnott, 2005; Lucrezi, Schlacher, & Robinson, 2010; Malikides et al., 1989). This would leave a smaller strip of sand in the intertidal zone for the birds to forage, and would be supported by significant positive correlations between swash zone gradient and all three wave variables (r=0.206, p<0.001, r=0.254, p<0.001 and r=0.244, p<0.001). This indicates that if wave period and wave heights increase, the steeper the intertidal zone will become. However, only swash gradient was revealed to be negatively significant for Red-capped Plovers (Estimate=-0.092, z-score=-2.204, P<0.028), also indicating that Red-capped Plover breeding pairs would decrease with a steeper intertidal slope.

Beach width

The last variable, and only other beach attribute besides surf zone width, appeared to be mean beach width for Pied Oystercatchers with a positive association (Estimate=0.001, z-score=2.400, P=0.016), indicating that Pied Oystercatchers prefer beaches with a wider subaerial zone. This would make sense, as it is the largest species of the three investigated and might require larger territories, which might be a consequence of higher energy requirements (Piersma & Gill, 1998; Gils et al., 2003). Accordingly, Pied Oystercatchers might just need larger amounts of prey and require therefore a larger territory to occupy these resources. Also, commuting distances might not be as crucial for such larger species, as more energy can be stored (Rehfisch et al., 2014). Also, if the quality of prey is not very high in the area (low energetic value per prey individual, Santos et al., 2009), it might also result in the need to occupy a larger territory.

6.3 Role of invertebrate abundance

As shorebirds feed and may therefore be affected in their habitat use by the availability and abundance of certain invertebrate species, four invertebrate taxa (crustaceans, myriapods, arachnids and insects) available to this study were incorporated in the analyses. Unfortunetaly these data included only species living on the surface of the beach sediment, thus polychaete abundance could not be integrated in the analyses of this study. Overall, invertebrate abundance appeared to be significant for all three shorebird species,

particularly the availability of crustaceans and insects. Accordingly, crustaceans appeared with a positive association for Pied Oystercatchers (Estimate=0.003, z-score=2.953, P=0.004), indicating that Pied Oystercatcher numbers would increase with the availability of crustaceans. Moreover, crustaceans appeared to be positively significant for Hooded and Red-capped Plovers (Estimate=0.001, z-score=2.356, P=0.020 and estimate=0.003, z-score=2.949, P=0.004).

However, due to morphological adaptions, shorebird species are only able to handle certain types of prey, and thus may only be able to handle smaller crustacean species. Due to its body size and beak shape, Pied Oystercatchers are likely more able to handle a larger range of crustacean species (Baker, 1977; Nebel et al., 2005; Prakash et al., 2008) compared to plovers. However, altogether, aside from molluscs and polychaetes, crustaceans only represent one fraction of the diet of these three resident shorebird species (Hobbs, 1972; Lauro & Nol, 1995; Schlacher et al., 2014; Spruzen et al., 2008; Taylor & Taylor, 2005). As no buried invertebrate species were investigated in this study, further reserach is recommended in order to investigate the role and influence of buried and surface prey organisms on the habitat use of resident Tasmanian shorebirds, particularly in light of the importance of buried invertebrate species for migratory and resident shorebirds worldwide. (Alves, Sutherland, & Gill, 2012; Duffy, 1981; Estelle & Grosholz, 2012; Jing et al., 2007; Pienkowski, 1983; Placyk & Harrington, 2004; Santos et al., 2009; Zwarts & Wanink, 1993).

Aside from crustaceans, insects also appeared to be positively associated as surface organisms with Hooded and Red-capped Plovers (Estimate=0.007, z-score=4.095, P<0.001 and estimate=0.007, z-score=2.370, P=0.020). This finding is consistent with the observations of other studies where plovers fed on a variety of surface organisms such as wrack- and seaweed-associated insects (Jing et al., 2007; Piersma et al., 1993; Scarton, Cecconi, & Valle, 2012), which represent easily accessible prey (Dugan et al., 2008; Kuwae et al., 2012; Neuman et al., 2008) for these on visual cues-dependent feeders (Burger, Caldwell Hahn, & Chase, 1979; Colwell, 2000; Jing et al., 2007).

However, crustaceans were also significantly correlated with all environmental variables, positively with all wave variables (r=0.484, p<0.001; r=0.463, p<0.001 and r=0.459, p<0.001) and negatively with mean annual wind speed (r=-0.268, p<0.001). These findings

suggest that crustacean abundance would increase with wave energy, but decrease with wind speed. This might either reflect the data due to the majority of wave-dominated beaches, or might be a consequence due to the many interactions as shown in the correlation matrix (see Appendix) or last, that more preferable conditions are created, such as that primary production is facilitated or more diatoms are transported to the beach (Odebrecht et al., 2013) that may provide more food for the crustaceans. However, a few studies suggested that wave-dominated beaches and increased wave heights would create less preferable conditions (McLachlan & Dorvlo, 2005; McLachlan, 1990), particularly for sediment-burrowing species due to the 'harshness of the environment'. Also, the negative association with wind speed could be an indicator that conditions are not as desirable, which could be a result of an increased loss of heat and thermal energy (Helmuth, 1998) and the overall reduction in metabolic activity (Pienkowski, 1983). With regards to sediment-burrowing organisms, it has been pointed out that increasing wind speed dries out the sediment and cools it down (Danufsky & Colwell, 2003; Finn et al., 2008; Grant, 1984). Therefore it may take more effort for burrowing, which may result in decreased activity and the invertebrates may stay further down in the sediment (Davidson, 1981; Evans, 1987; Pienkowski, 1983). However, such wind-affected-activity-patterns of sediment burrowing and surface organisms may as one example also drive the daily activity of the shorebirds, but as sediment burrowing organisms were not investigated in this study no conclusions can be drawn on the influence on the habitat use of the birds. Accordingly, resident Tasmanian shorebirds may not only be directly affected by abiotic sandy beach characteristics and environmental factors, but also indirectly, by the effects that environmental factors have on their prey, which will also respond to these forces.

6.4 Principal Component Analysis

The PCA confirmed the findings, that surf zone width and the wave variables seem to be important to the shorebirds. Figure 5.4.1 illustrates the correlations and relationships among the predictor variables and which component they are most affiliated with. The figure indicates that surf zone width falls between the shorebird species and the wave variables.

7 Conclusions

According to the findings of this study, the biotic and abiotic sandy beach characteristics do seem to influence and play a role for the habitat use of resident Tasmanian shorebird species, such as the Hooded Plover, Pied Oystercatcher, and the Red-capped Plover. Accordingly, abiotic and biotic sandy beach characteristics seem to be important to resident shorebirds, and are therefore also likely to affect the distributions and abundances of the birds. Moreover, the two plover species and the one oystercatcher species differ in their morphology and in their adaptions to their environment and thus their habitat. As the findings of this study revealed, predictor variables seem to vary in the extent of their influence, thus not all variables seem to be equally important and affect the habitat use of the shorebirds. For example, mean beach width appeared to be only highly significant for Pied Oystercatchers, whereas surf zone width appeared to be highly significant for Pied Oystercatchers and Hooded Plovers, and swash gradient only for Red-capped Plovers. At least one wave variable appeared to be significant for each of the three species, but caution needs to be taken for drawing conclusions, as the wave variables shape the beaches and were significantly correlated with many other predictor variables, including surf zone width and with the invertebrate taxa. However, species-specific differences were also detected, such as in the preferences for certain prey and invertebrates species. Significant associations appeared for Pied Oystercatchers and crustaceans, and for insects, crustaceans, and the two plover species, indicating that breeding pair numbers may increase with increasing abundance of these invertebrate taxa as potential prey species.

However, many factors may be responsible for differences in shorebird distributions and abundances, which have been supported by the numerous revealed correlations, and may also be consistent with the knowledge of sandy beaches representing complex and dynamic ecosystems. Additionally, there may be many other factors that could affect the habitat use of resident shorebirds such as human disturbance, predation, competition or unsuitable micro-scale differences among sites and along a beach. These factors may already affect the initial 'habitat selection process' of the juveniles, when leaving the parental territory to establish an own territory, and this selection may also be affected by the vacancy of

territories. Accordingly, there is a range of factors that may be important and limiting to resident shorebirds, and that have not been investigated in this study.

The findings of this study suggest that abiotic and biotic habitat characteristics are important to resident shorebirds and should therefore also be taken into consideration with regards to species protection and habitat management. Certainly, this also includes the management of ocean sandy beaches, where shorebirds collide with recreationists, resulting also in clashing interests from an economic and nature conservation perspective. As indicated, natural values have not been recognised as they should, and many shorebird species, such as the Hooded Plover, which is highly dependent on Australian ocean sandy beaches, are already decreasing in numbers. Accordingly, incorporating the existing knowledge of the species' biology, of their habitat (such as the interactions within sandy beach ecosystems), and of the importance of biotic and abiotic sandy beach characteristics for the species in the establishment of future management strategies is recommended. This would also help to raise awareness for ecosystem-based-management approaches. Overall, as it has been pointed out by other studies, it is very important to raise public awareness in order to generate a will to cooperate and achieve the compromises that natural resource managers aim for. Moreover, beach users may not always be aware of their impact on local fauna and flora.

This study is believed to contribute to the improvement of species protection and habitat management, but additional research would be beneficial to investigate the habitat requirements of resident shorebird species further. This is particularly important, as habitat loss and fragmentation represent major threats to all animal species and are major reasons for species extinctions. Particularly in light of human use of the coastal zone, climate change and increasing sea-levels, further knowledge on habitat requirements and characteristics would help to identify the beaches that are most in need of protection due to their shorebird numbers and species assemblages, and due to their habitat characteristics that might be the most suitable for the birds.

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Appendix

Pearson´s correlation matrix

Significance values are located underneath the *****, whereas the Pearson´s correlation coefficient (r) is shown above.

Large data set (beach attributes and environmental variables)

	d.B_cat	d.Primary_	d.Region_1	d.Zone_Typ	d.Length_	d.Mean_Wi	d.Embaym	d.Swash_G	d.Surf_Zon	d.tm_an_av	d.hs_an_av	d.hs_max_	d.wind_spe	d.No_BP_	d.NoOCBP	d.NoRCP_
d.B_cat	*****	-0.165	-0.013	0.215	0.029	-0.099	0.021	0.182	0.114	0.269	0.223	0.205	-0.02	0.11	-0.081	-0.036
d.Primary__1	0.003	*****	0.181	0.014	0.127	0.024	0.174	-0.182	0.464	0.206	0.2	0.15	-0.164	0.153	0.19	0.055
d.Region_1	0.822	0.001	*****	-0.017	-0.027	0.029	-0.151	0.14	0.489	0.723	0.788	0.716	0.334	0.008	0.093	0.049
d.Zone_Typ_1	<0.001	0.801	0.76	*****	-0.071	-0.054	-0.014	-0.002	0.065	0.169	0.171	0.092	-0.095	-0.062	-0.054	-0.112
d.Length__m1	0.605	0.023	0.634	0.207	*****	0.2	0.137	-0.182	0.12	-0.176	-0.16	-0.123	0.023	0.664	0.769	0.451
d.Mean_Wid_1	0.077	0.675	0.606	0.34	<0.001	*****	-0.045	-0.091	-0.051	-0.273	-0.188	-0.093	0.205	0.081	0.192	0.057
d.Embaymen_1	0.704	0.002	0.007	0.799	0.014	0.421	*****	0.122	0.075	-0.143	-0.103	0.012	-0.124	0.14	0.079	0.094
d.Swash_Gr_1	0.001	0.001	0.012	0.967	0.001	0.106	0.029	*****	0.022	0.206	0.254	0.244	0.127	-0.103	-0.203	-0.106
d.Surf_Zon_1	0.041	<0.001	<0.001	0.245	0.032	0.36	0.179	0.7	*****	0.525	0.561	0.379	-0.044	0.196	0.182	0.126
d.tm_an_av_1	<0.001	<0.001	<0.001	0.002	0.002	<0.001	0.011	<0.001	<0.001	*****	0.943	0.751	-0.16	0.008	-0.036	-0.006
d.hs_an_av_1	<0.001	<0.001	<0.001	0.002	0.004	0.001	0.067	<0.001	<0.001	<0.001	*****	0.839	-0.035	0.013	-0.03	0.004
d.hs_max_a_1	<0.001	0.007	<0.001	0.099	0.028	0.096	0.833	<0.001	<0.001	<0.001	<0.001	*****	0.134	0.04	-0.025	0.014
d.wind_speed_annua	0.728	0.003	<0.001	0.089	0.677	<0.001	0.026	0.023	0.436	0.004	0.533	0.016	*****	-0.11	-0.013	-0.046
d.No_BP_pB	0.049	0.006	0.893	0.266	<0.001	0.15	0.012	0.066	<0.001	0.887	0.814	0.473	0.049	*****	0.702	0.502
d.NoOCBP_pB	0.148	0.001	0.097	0.34	<0.001	0.001	0.157	<0.001	0.001	0.516	0.587	0.657	0.815	<0.001	*****	0.398
d.NoRCP_pB	0.521	0.327	0.385	0.045	<0.001	0.31	0.093	0.059	0.024	0.916	0.947	0.801	0.412	<0.001	<0.001	*****

Small data set (invertebrates)

|	inv.Mean_	inv.Embay	inv.Swash_	inv.Surf_Z	inv.tm_an_	inv.hs_an_	inv.hs_ma	inv.wind_s	inv.Crustac	inv.Myriap	inv.Arachn	inv.Insecta	inv.Beach_	inv.Region	inv.No_BP	inv.NoOCl	inv.NoRCF
inv.Mean_Wid_1	*****	-0.126	-0.149	-0.185	-0.412	-0.416	-0.357	0.114	-0.117	-0.103	0.059	0.181	-0.222	-0.219	0.08	0.222	0.034
inv.Embaymen_1	0.139	*****	-0.01	0.078	-0.1	-0.111	0.009	0.061	-0.057	0.047	-0.022	-0.077	-0.055	-0.111	0.174	0.216	0.133
inv.Swash_Gr_1	0.081	0.905	*****	0.05	0.244	0.252	0.183	0.075	-0.034	0.036	-0.131	-0.104	0.379	0.179	-0.183	-0.278	-0.181
inv.Surf_Zon_1	0.03	0.366	0.559	*****	0.552	0.575	0.305	-0.376	0.053	-0.198	-0.151	-0.094	0.133	0.511	0.191	0.138	0.062
inv.tm_an_avgf	<0.001	0.244	0.004	<0.001	*****	0.99	0.757	-0.603	0.484	-0.253	-0.26	-0.144	0.288	0.902	-0.029	-0.126	-0.051
inv.hs_an_avgf	<0.001	0.194	0.003	<0.001	<0.001	*****	0.757	-0.626	0.463	-0.273	-0.252	-0.188	0.27	0.875	-0.044	-0.134	-0.066
inv.hs_max_avg	<0.001	0.913	0.032	<0.001	<0.001	<0.001	*****	-0.338	0.459	-0.193	-0.189	-0.075	0.218	0.698	-0.029	-0.139	-0.063
inv.wind_speed_annual	0.182	0.479	0.383	<0.001	<0.001	<0.001	<0.001	*****	-0.268	0.449	0.245	0.166	0.111	-0.513	-0.156	-0.18	-0.145
inv.Crustacea	0.173	0.507	0.691	0.534	<0.001	<0.001	<0.001	0.001	*****	-0.263	-0.157	-0.026	0.236	0.453	0.082	0.055	0.148
inv.Myriapoda	0.229	0.582	0.679	0.02	0.003	0.001	0.024	<0.001	0.002	*****	0.018	0.069	0.07	-0.241	-0.086	-0.109	-0.062
inv.Arachnida	0.49	0.794	0.125	0.077	0.002	0.003	0.026	0.004	0.066	0.837	*****	0.102	-0.006	-0.321	0.04	0.112	-0.051
inv.Insecta	0.034	0.372	0.224	0.274	0.092	0.027	0.379	0.051	0.765	0.422	0.232	*****	0.066	-0.066	0.298	0.133	0.191
inv.Beach_category	0.009	0.52	<0.001	0.12	0.001	0.001	0.01	0.195	0.005	0.418	0.943	0.44	*****	0.128	0.097	-0.013	0.071
inv.Region_1	0.01	0.194	0.036	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	<0.001	0.443	0.133	*****	-0.034	-0.126	-0.118
inv.No_BP_pB	0.351	0.041	0.032	0.025	0.732	0.611	0.735	0.068	0.339	0.318	0.645	<0.001	0.259	0.689	*****	0.803	0.595
inv.NoOCBP_pB	0.009	0.011	0.001	0.106	0.14	0.119	0.104	0.035	0.519	0.203	0.192	0.12	0.882	0.14	<0.001	*****	0.486
inv.NoRCP_pB	0.69	0.119	0.033	0.468	0.549	0.44	0.459	0.089	0.084	0.474	0.554	0.025	0.408	0.168	<0.001	<0.001	*****

Boxplots

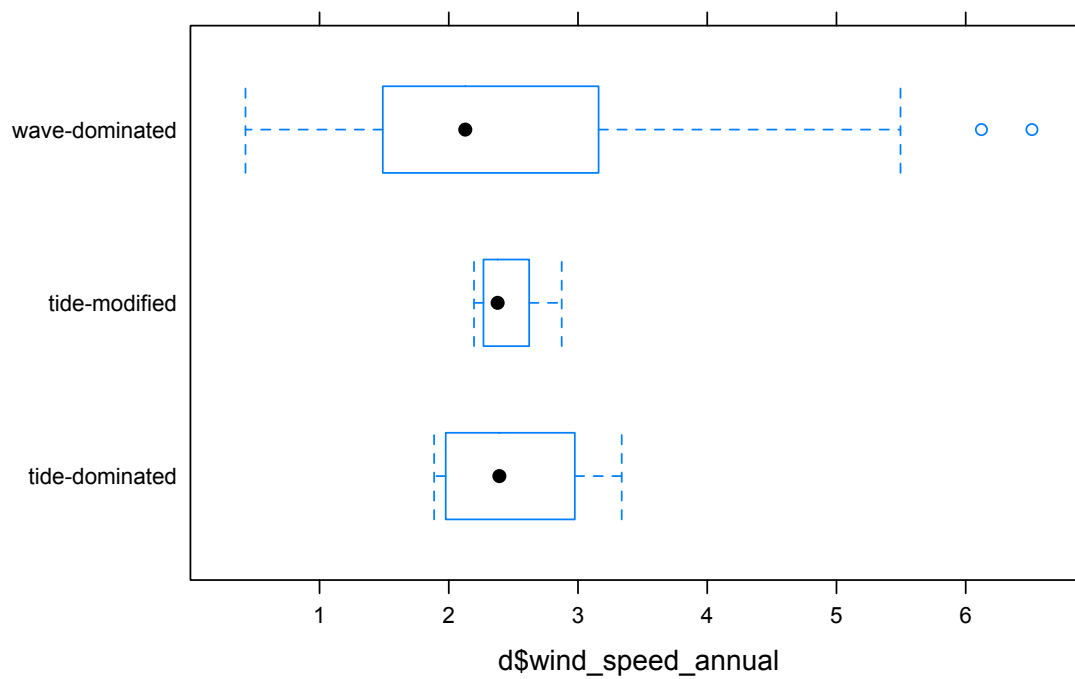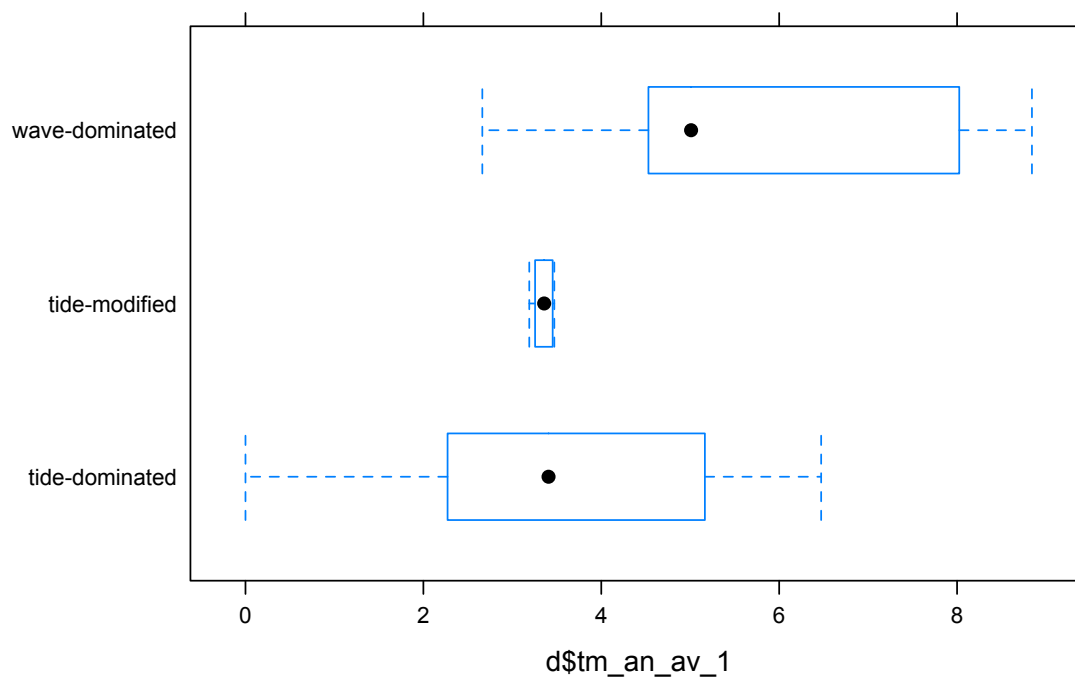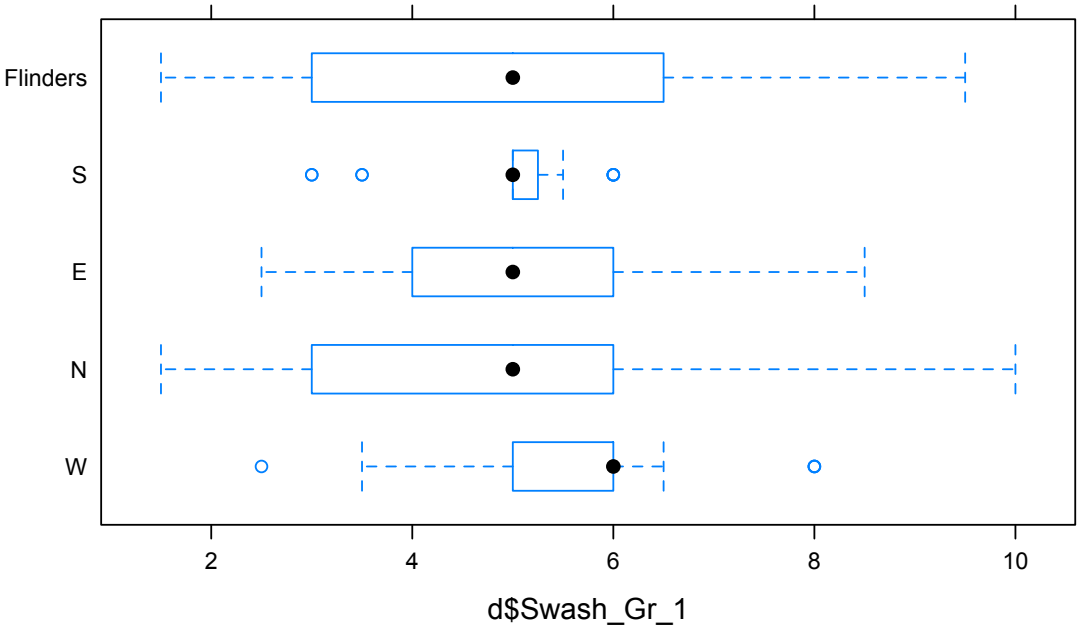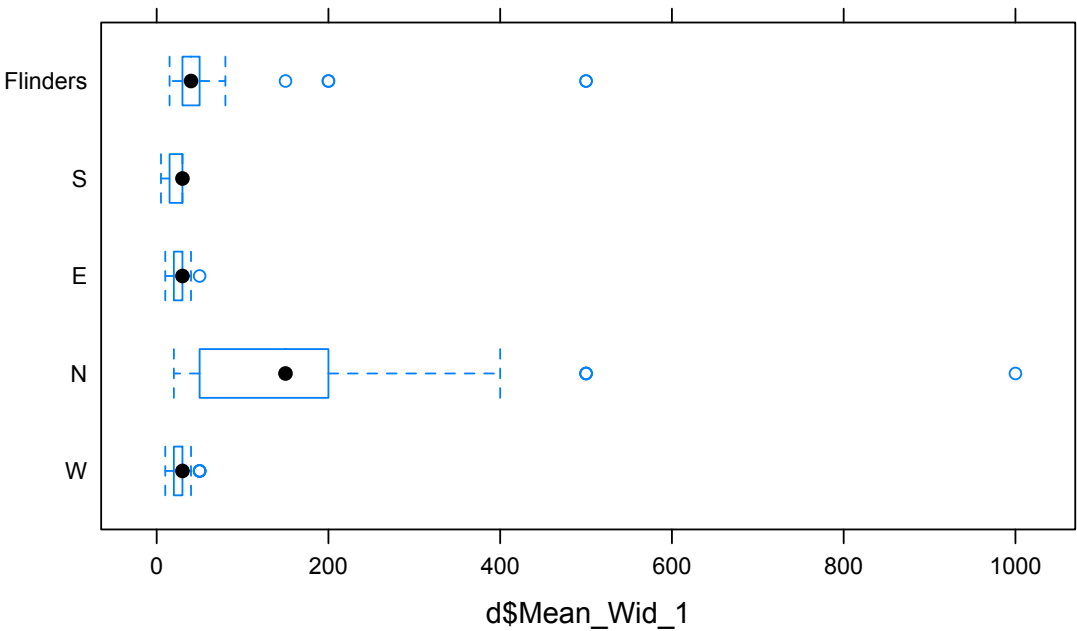**Differences among beach categories**

Beach attributes among beach categories
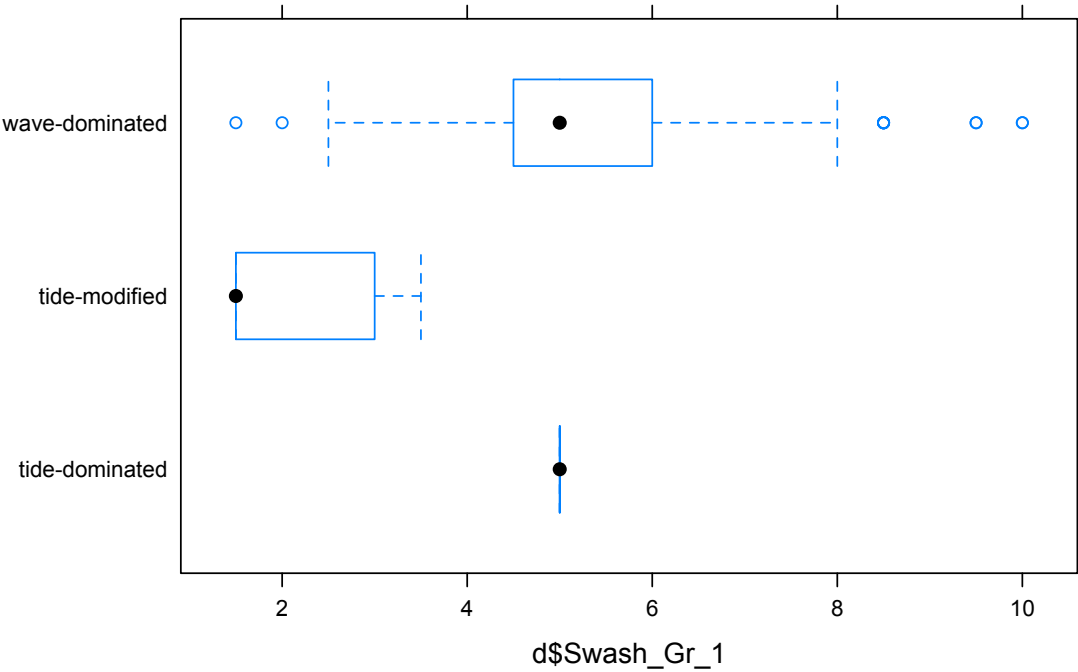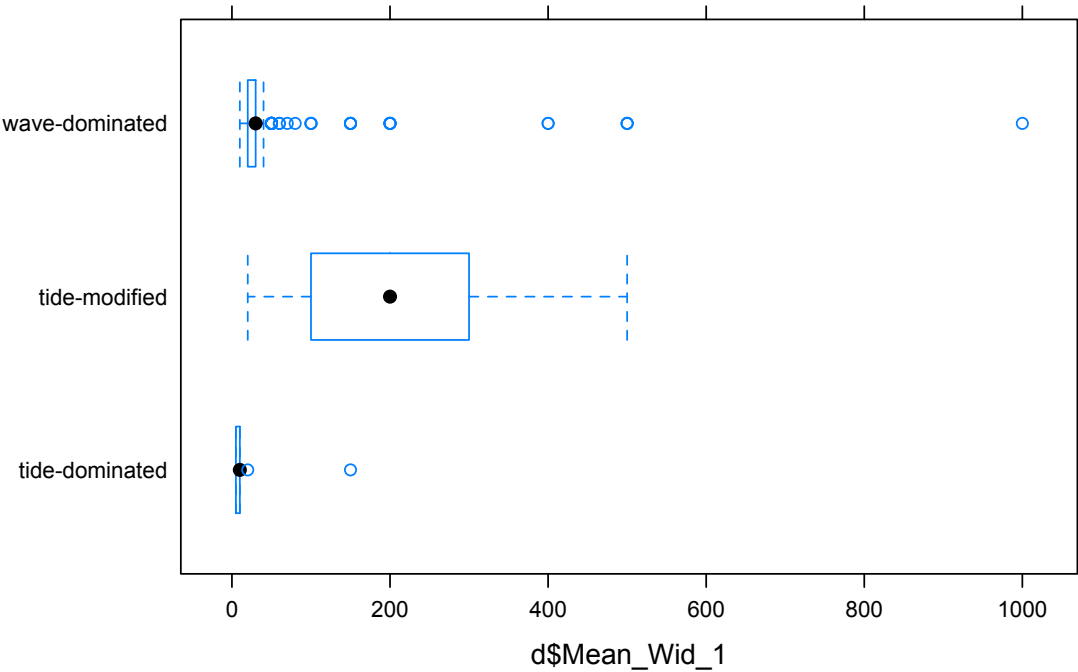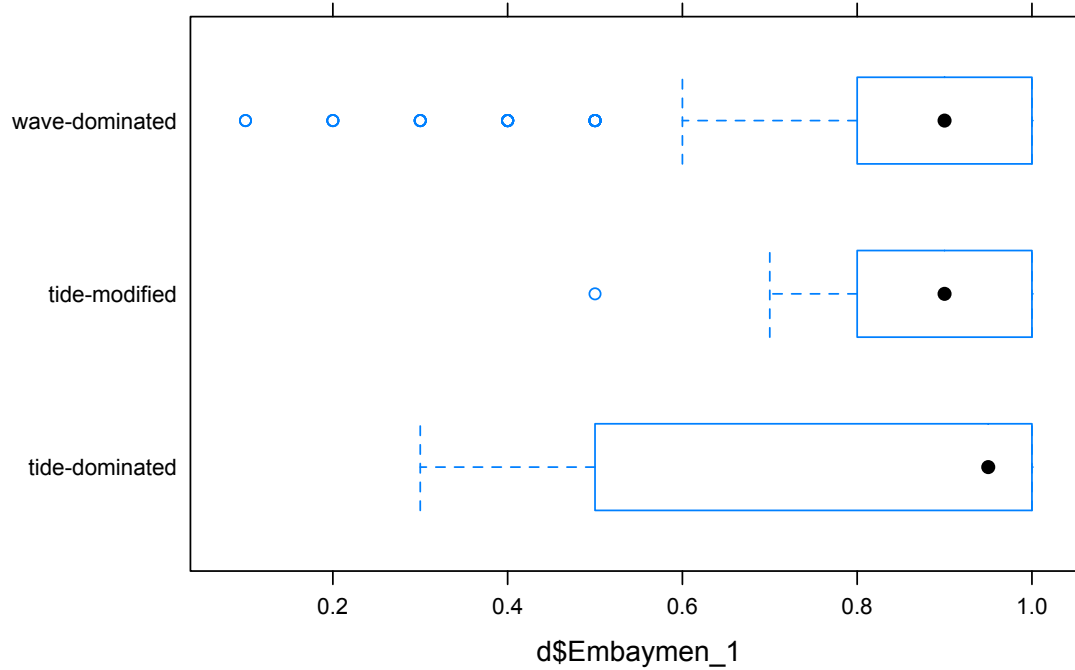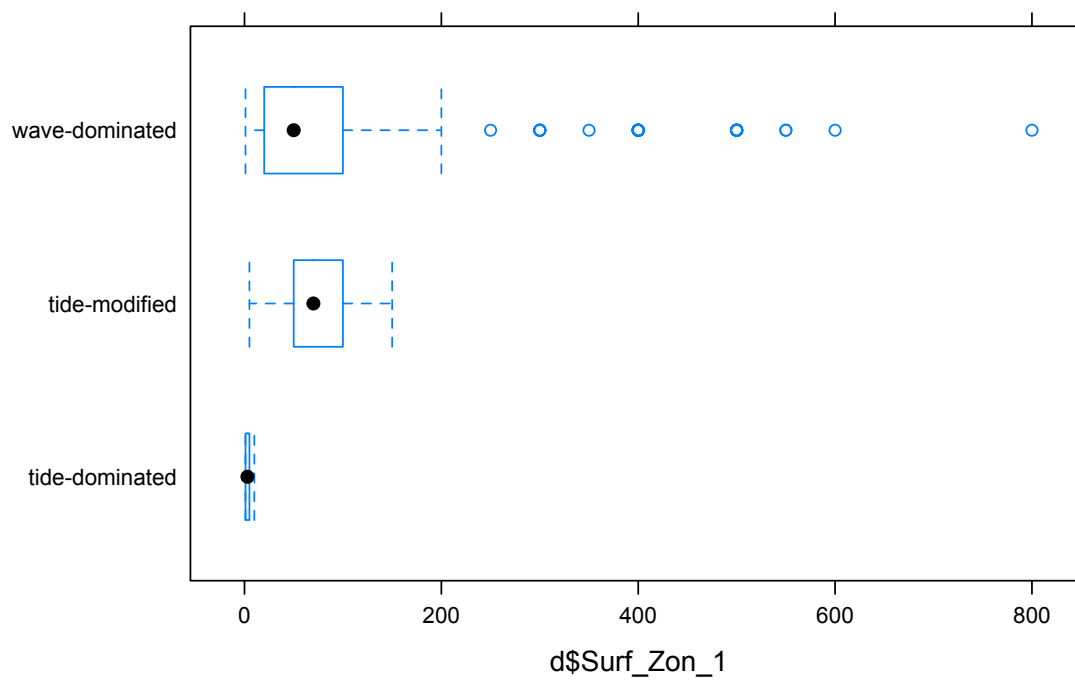
Environmental factors among beach categories
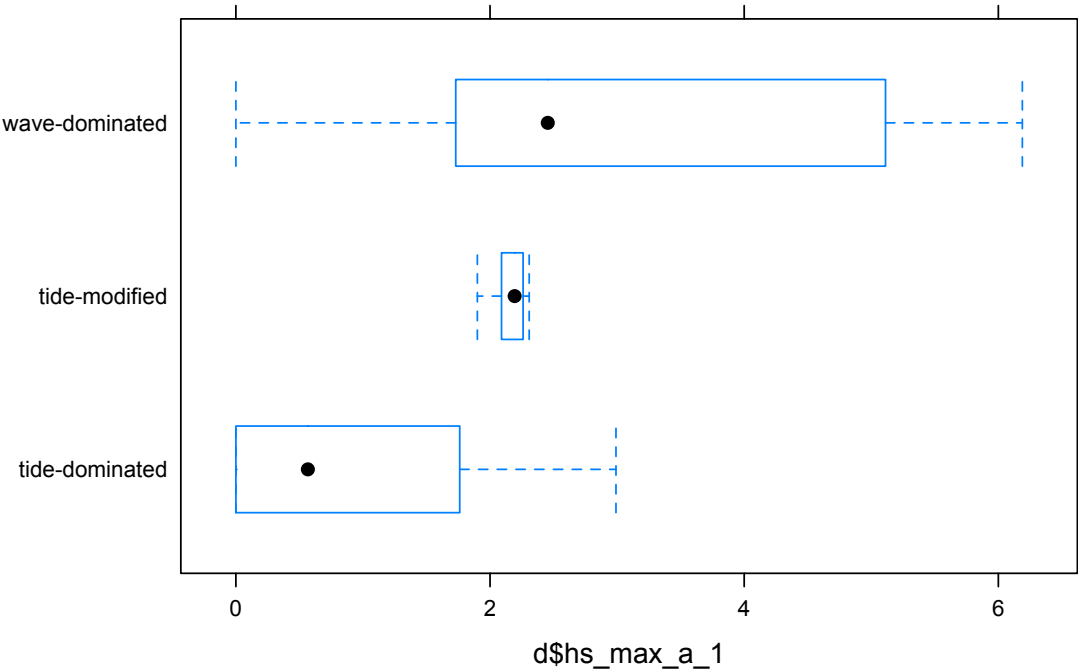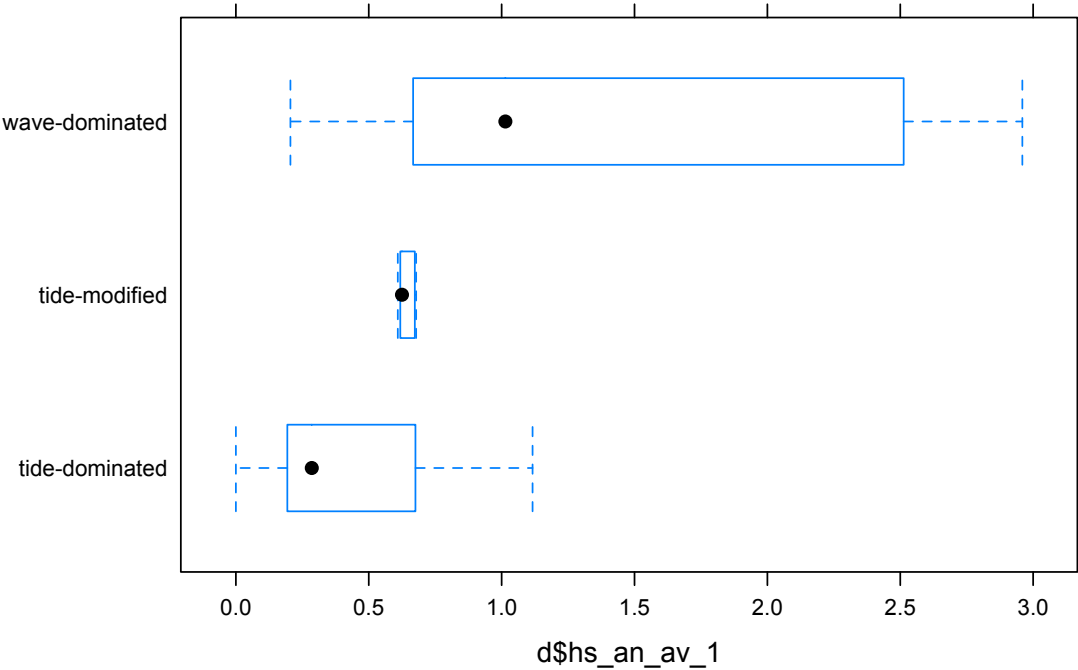
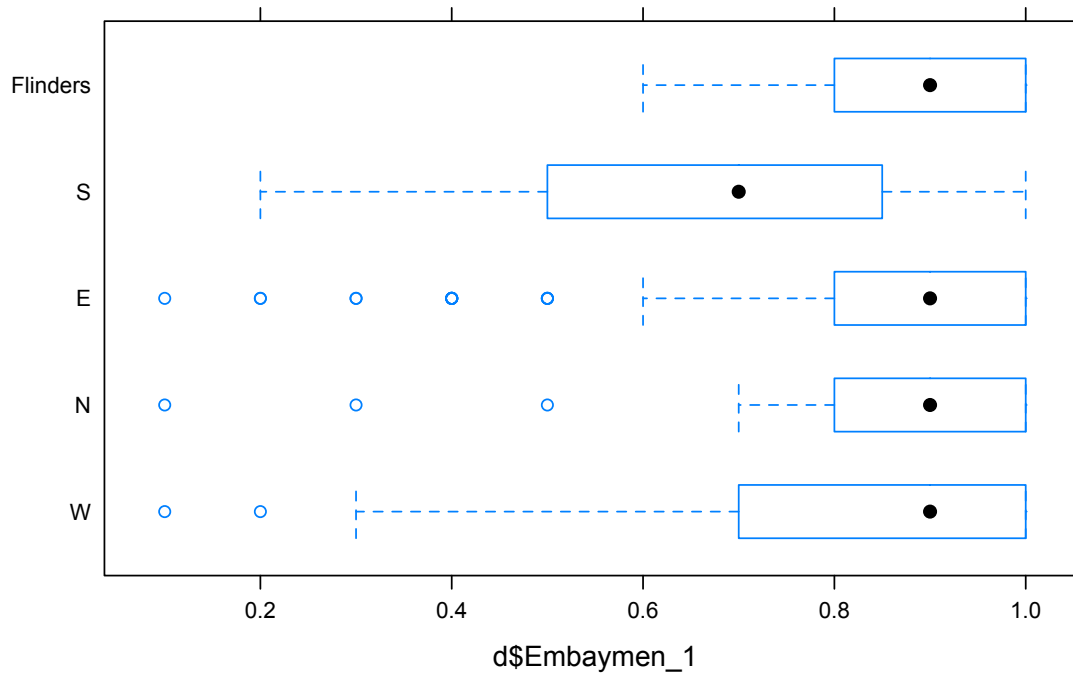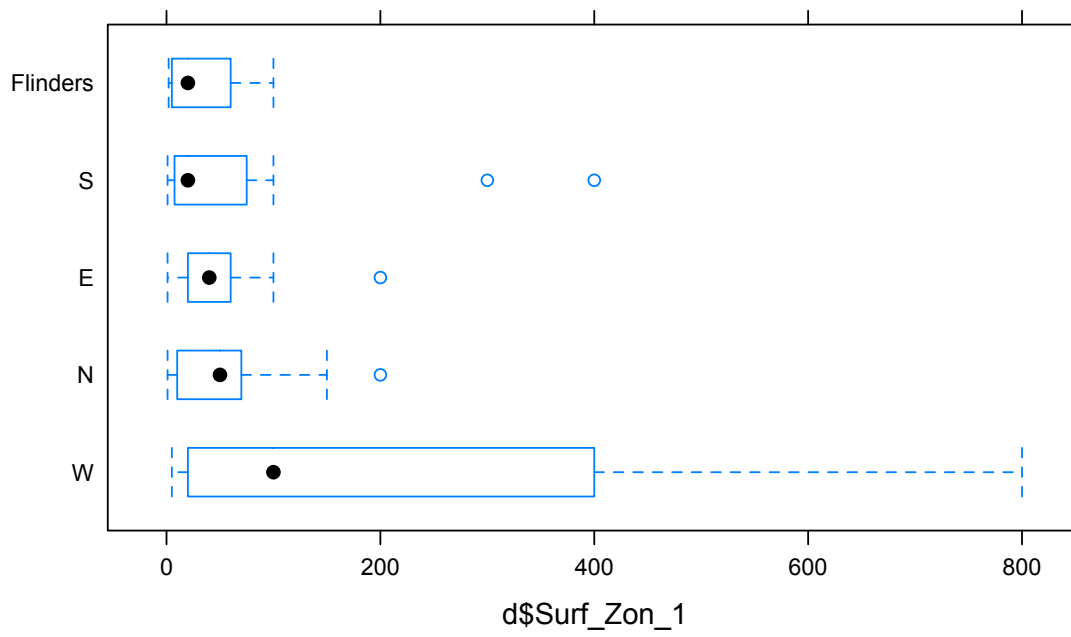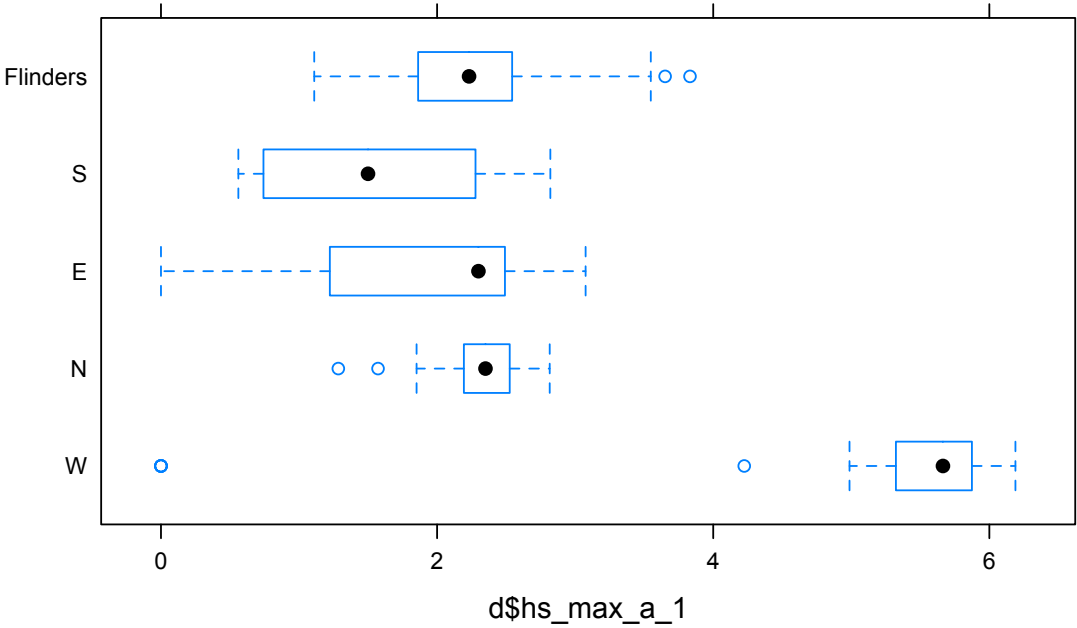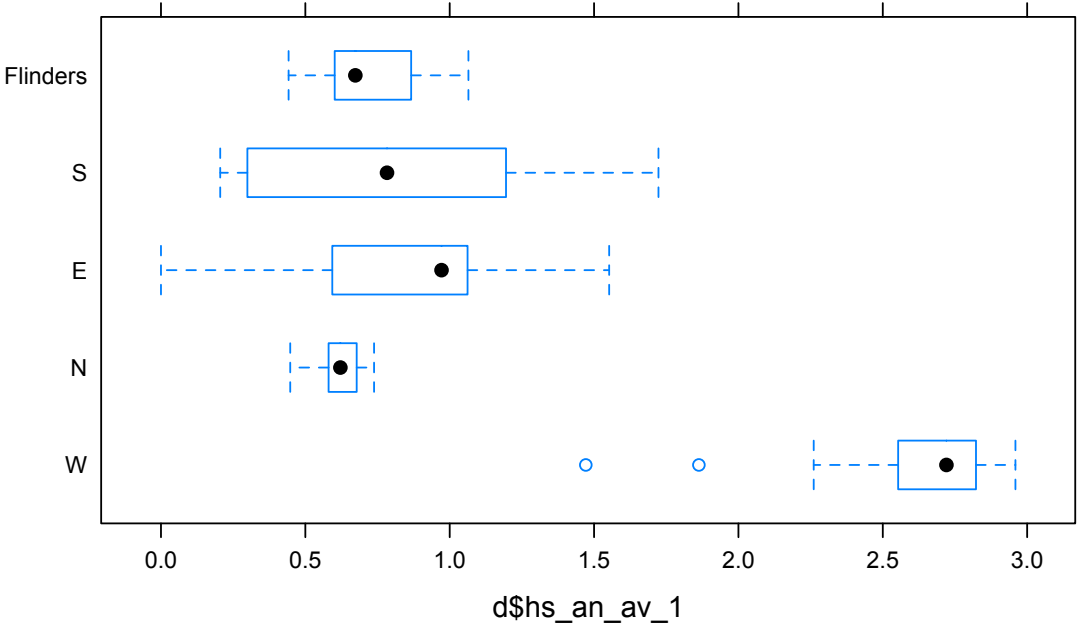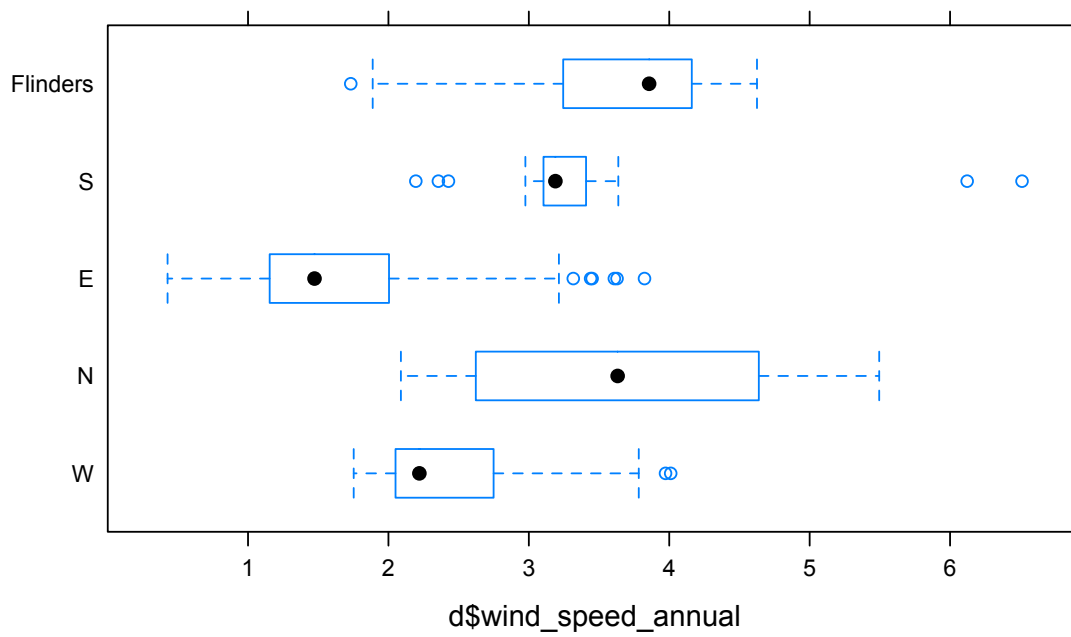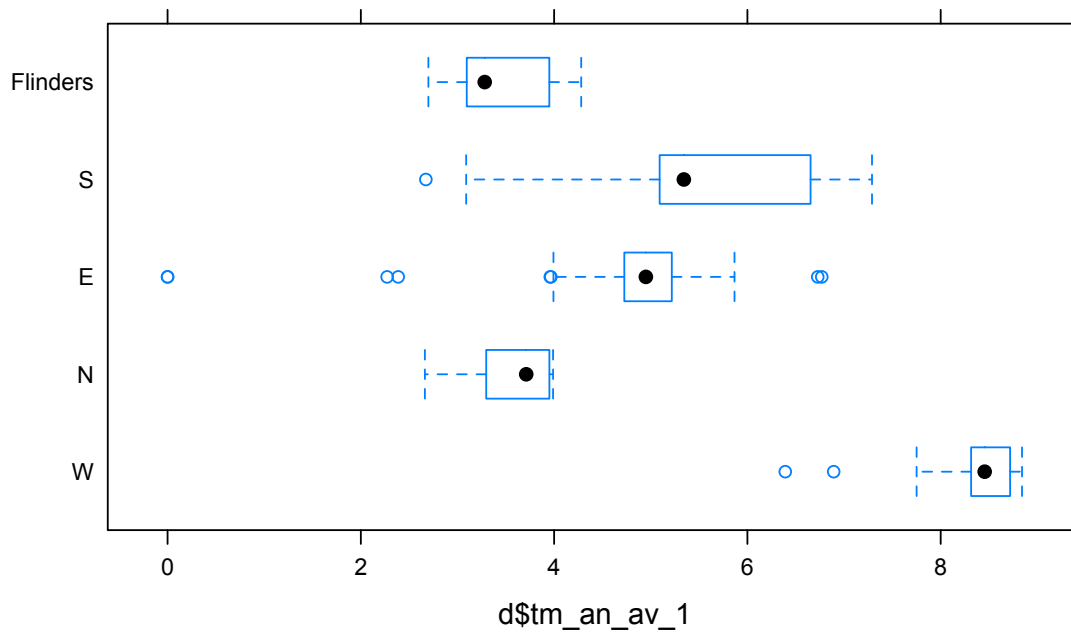# Regional differences

Beach attributes among regions

Environmental factors among regions

Scatterplots

Every investigated variable has been plotted with a Pearsons´ correlation coefficient against each of the dependent variables, thus the three shorebird species: Hooded Plovers (No_BP_pB), Pied Oystercatchers (NoOCBP_pB) and Red-capped Plovers (NoRCP_pB). Also a line of best fit has been added. Moreover, the R coefficient (not R-sqaure) is shown with the overall nature of the relationship (if positive or negative), and significance values are indicated by *** highly significant (<0.001), ** significant (<0.05) and *trends (<0.1).

Large data set (beach attributes and environmental variables)
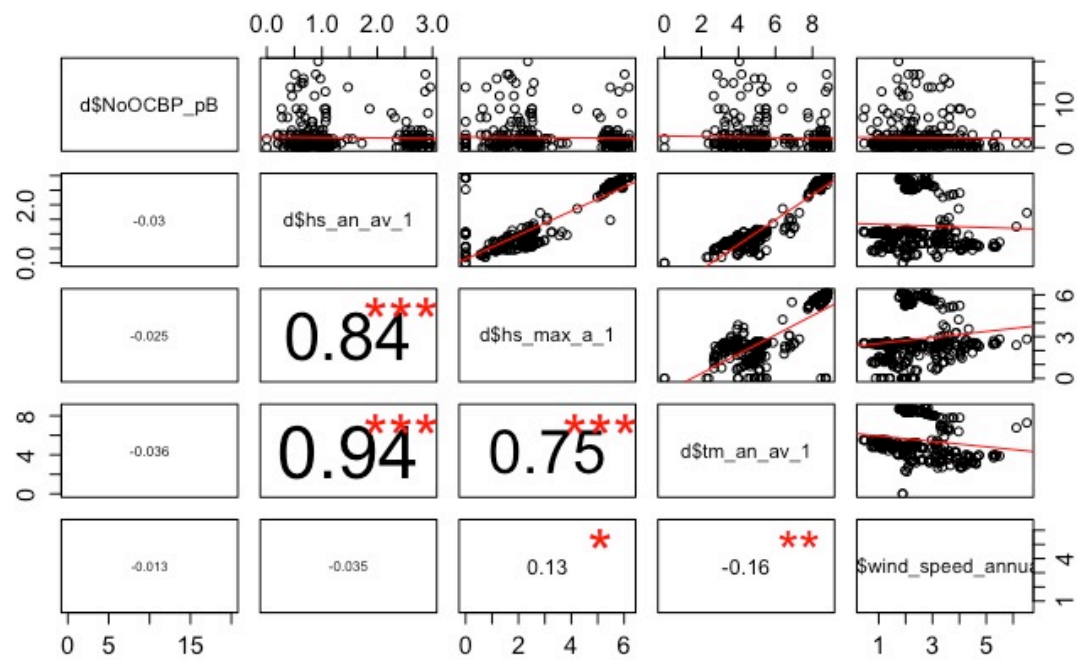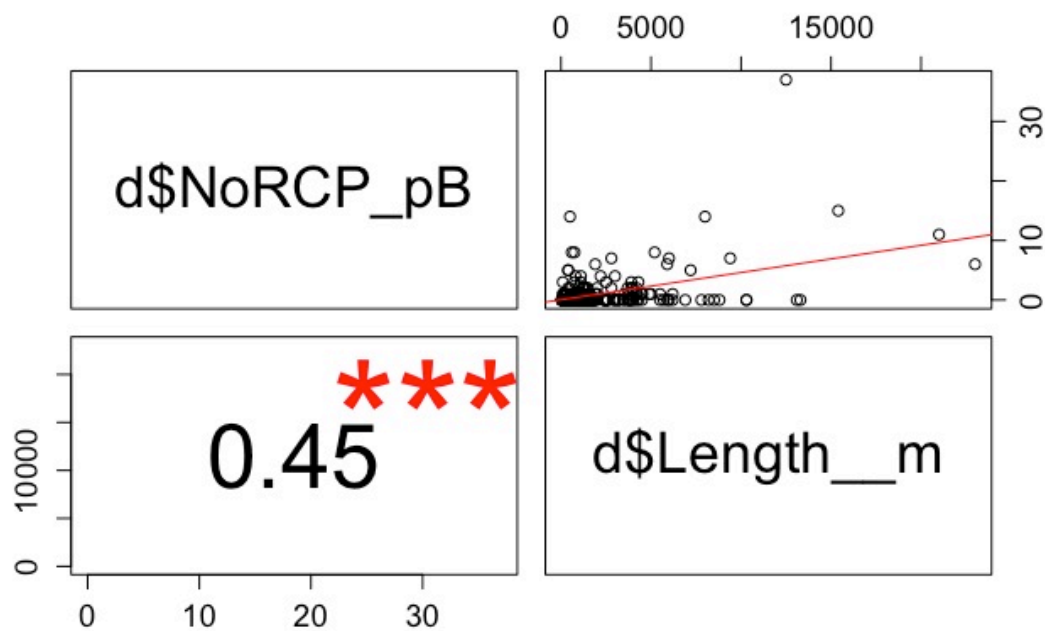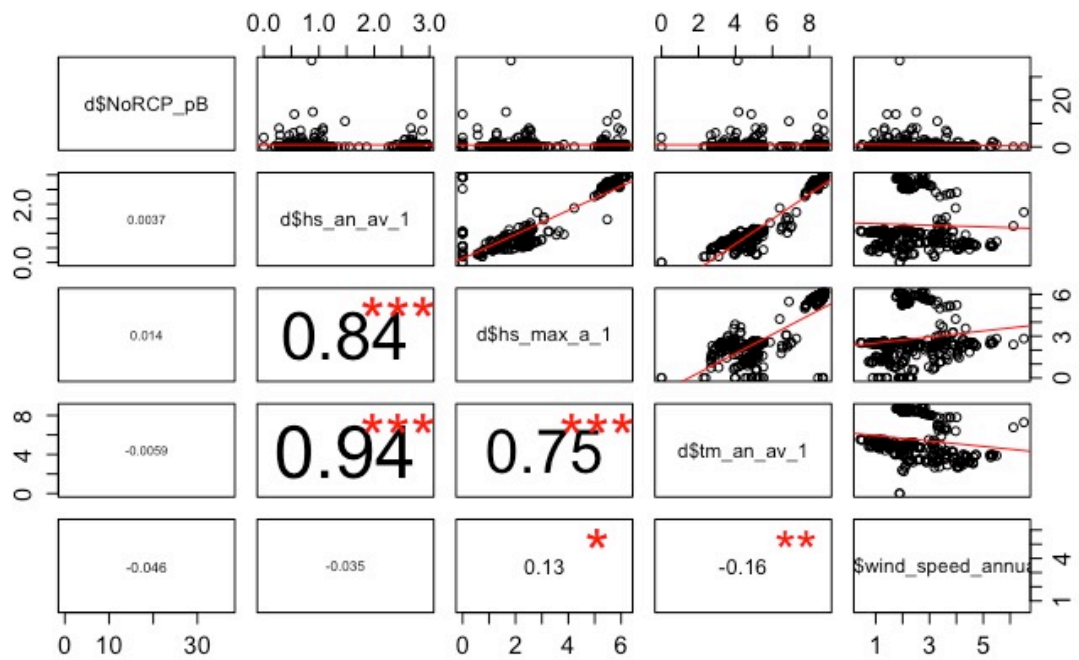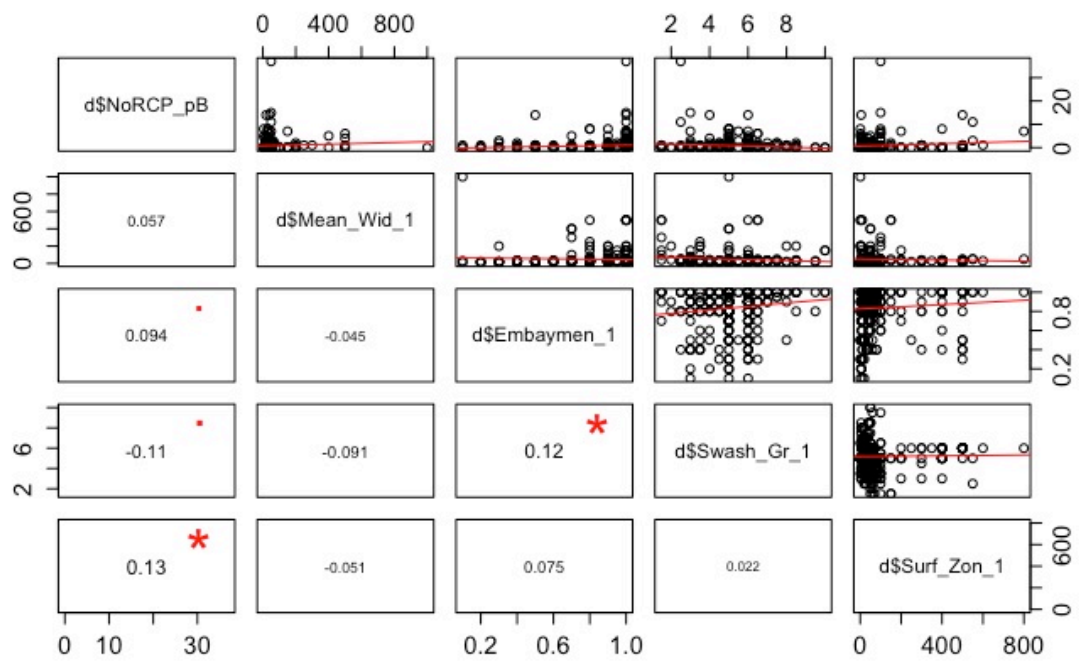
Hooded Plover

164
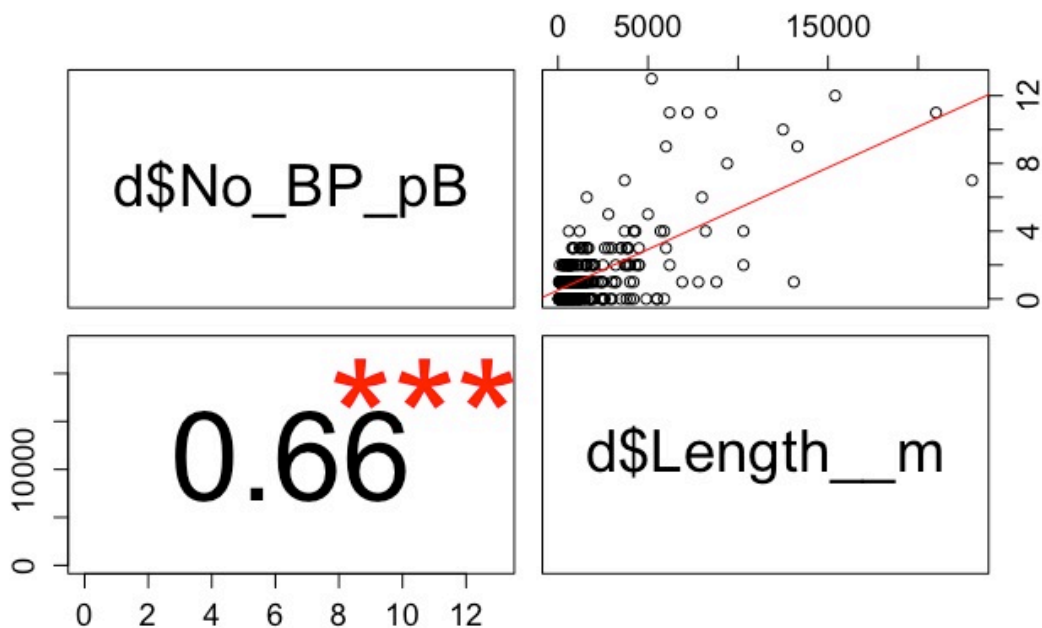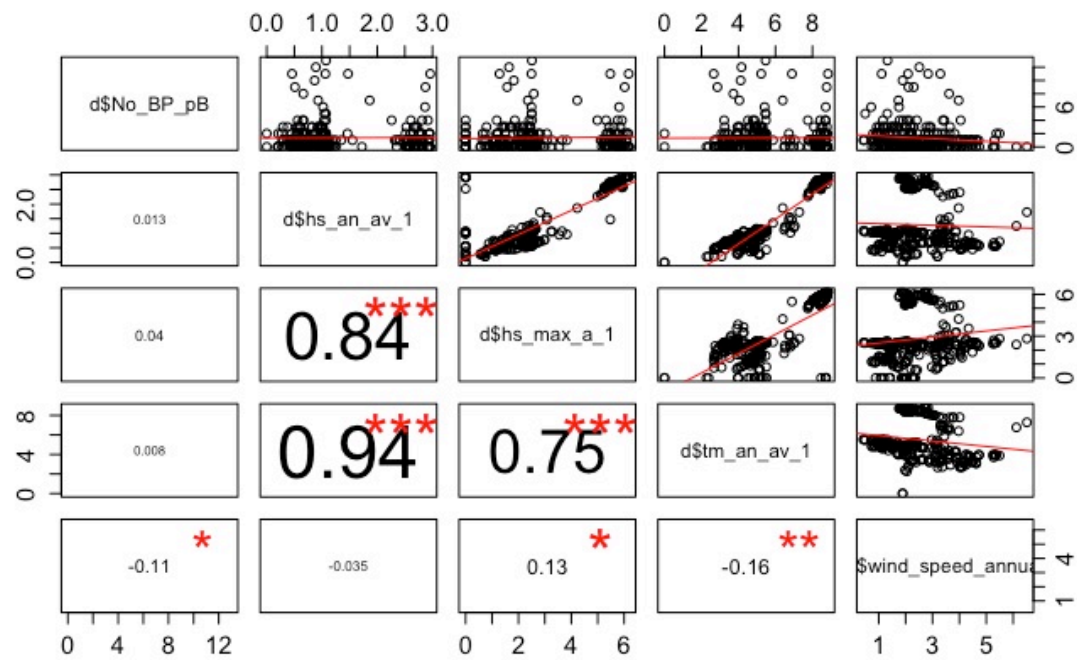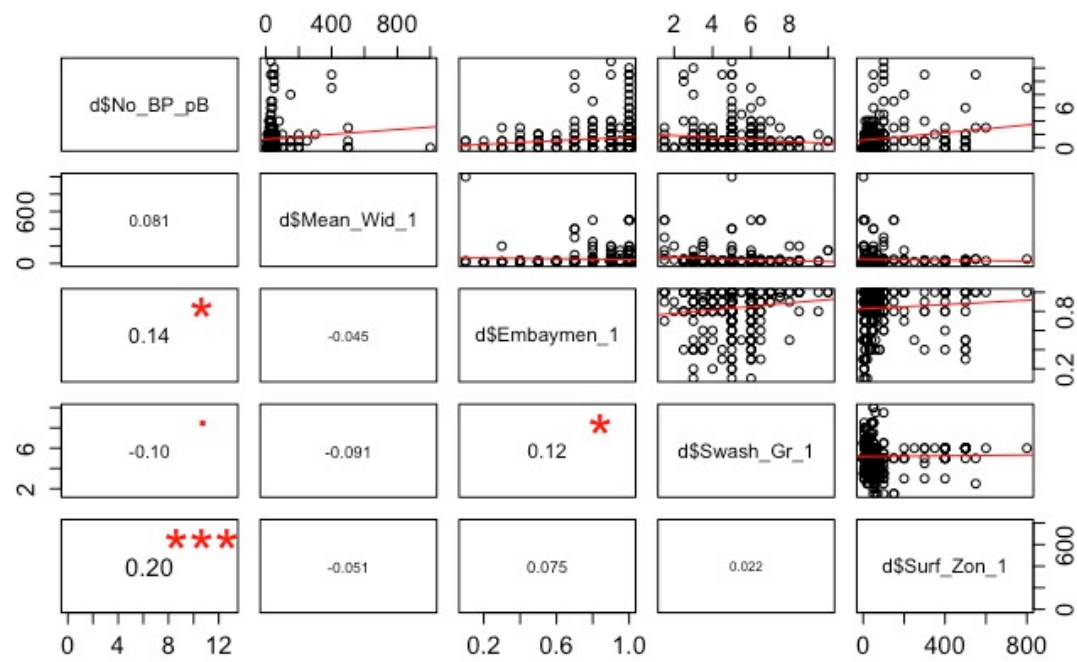
Pied Oystercatcher
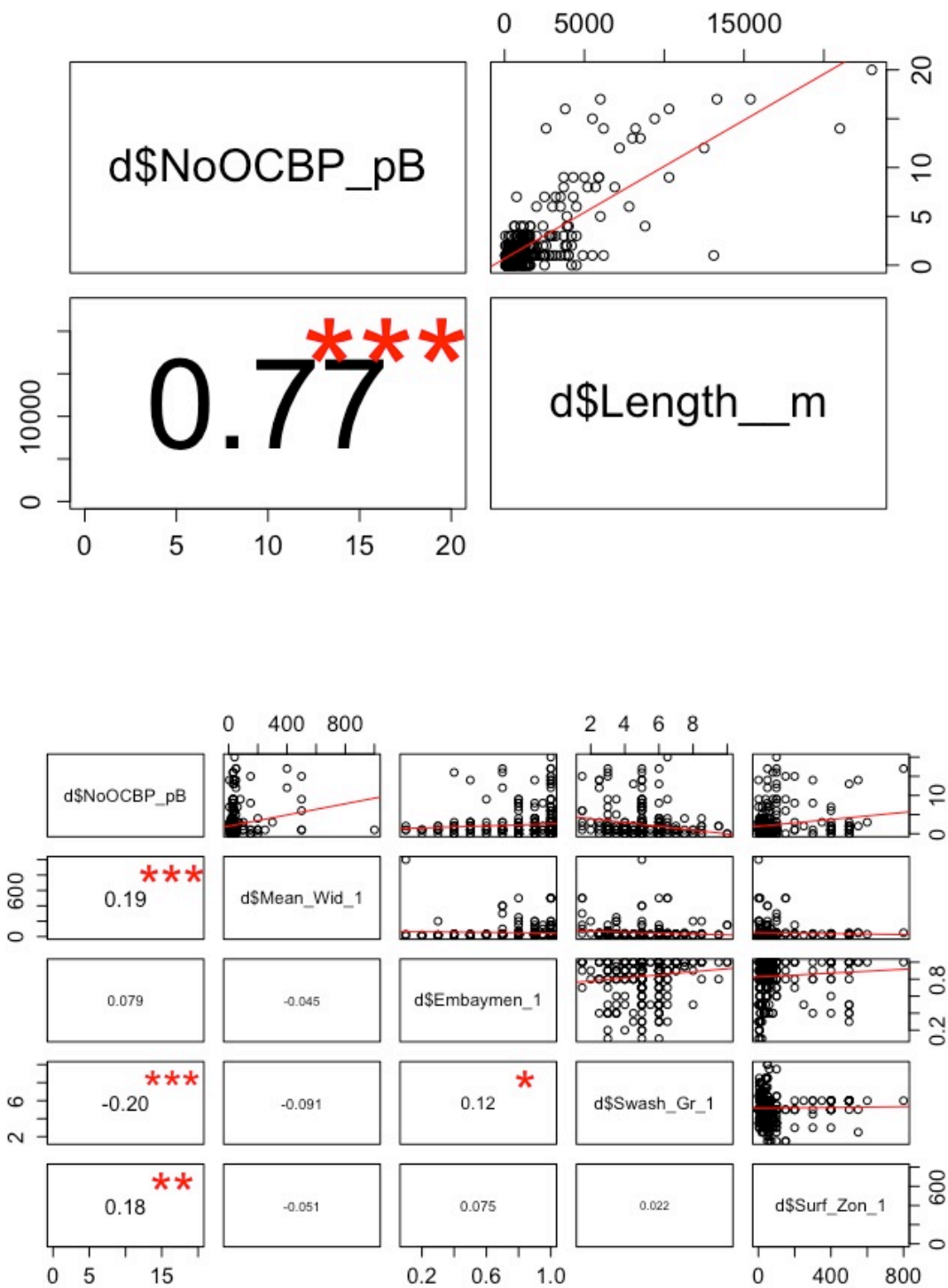
Red-capped Plover

Small data set (invertebrates)