CHAPTER ONE: GENERAL INTRODUCTION

The aim of this chapter is to provide an overview of the main themes, including the current knowledge and the importance (as we know it) of wrack to sandy beach and nearshore ecosystems. Thus, it aims to provide an introduction to wrack and its role in the sandy beach ecosystem, background to the study and the rationale for this research. I also identify the key research questions to be addressed, give a brief description of the approach taken and outline the thesis structure.

Exposed sandy shores consist of a coupled surf-zone, beach and dune system (Short & Hesp 1982). Sandy beach sediments are unconsolidated and are frequently disturbed by waves making them unsuitable for the attachment of macrophytes (macroalgae and seagrasses). *In situ* primary productivity (through benthic microalgae) is thus low (Brown & McLachlan 2002). On dissipative beaches (with fine sands, flat beach-face slopes and low wave energy reaching the beach), the import of phytoplankton, DOM and POM from offshore is believed to be the most important source of nutrients and energy for the beach ecosystem (McLachlan 1981). On reflective beaches (with coarse sands, steep beach-face slopes and high energy reaching the beach), however, the import of marine macrophyte (seagrass and macroalgae) detritus may be the more important (Alongi 1998).

What is wrack?

Many marine shores accumulate piles of seagrass, macroalgae and other marine, terrestrial or anthropogenic matter that is collectively known as ‘wrack’, ‘beach cast’, ‘beach wrack’ and ‘drift’. Wrack is composed primarily of macroalgal and seagrass material ranging in size from fragments of leaves and blades to whole plants. Other components of wrack generally make up a small proportion of the volume/cover deposited and include epiphytic plants and animals (i.e. attached to wrack plants), sponges, dead marine animals and birds (Colombini & Chelazzi 2003), terrestrial and dune vegetation and anthropogenic debris (Van der Merwe & McLachlan 1987; Maccarone *et al.* 1993). The species composition of wrack at a given beach is largely determined by the offshore marine environment, prevailing wind and/or current directions, and the physical characteristics of the macrophyte detritus (e.g. buoyancy)

(Ochieng & Erftemeijer 1999; Orr *et al.* 2005). Wrack material may originate from a range of intertidal and subtidal marine habitats (e.g. seagrass from soft substrata, algae from reefs). Thus, as it is deposited onto sandy beaches, it provides an example of organic material crossing habitat boundaries (i.e. seascape ecology, sensu Fairweather & Quinn 1992).

Wrack deposits may range in size from fragments of individual plants to accumulations that cover the whole beach and may reach depths of up to several metres (Kendrick *et al.* 1995; Kirkman & Kendrick 1997). Wave exposure (Orr *et al.* 2005), beach aspect, tidal regime (McLachlan 1985; Ochieng & Erftemeijer 1999) and substrate characteristics (Orr *et al.* 2005) are known to affect the amount of wrack deposited on the beach. The rate of arrival, amount and composition of wrack deposited onto beaches are ultimately determined by environmental conditions both at the source(s) of the macrophytes (Ochieng & Erftemeijer 1999) and at the beach (McLachlan 1985; Ochieng & Erftemeijer 1999; Orr *et al.* 2005). Storms can detach large quantities of macrophytes in sporadic bursts (Hobday 2000; Yatsuya *et al.* 2007), or natural senescence of algae and/or seagrass may result in seasonality in the supply of detritus (ZoBell 1971; Yatsuya *et al.* 2007), and the exposure and tidal regimes both at the source and receiving beach may also affect the amount (Orr *et al.* 2005) and distribution (McLachlan 1985; Ochieng & Erftemeijer 1999) of wrack on the beach. The combination of these factors can result in considerable spatial and temporal variability in the cover, volume and composition of wrack on beaches.

The role of wrack in the sandy beach ecosystem

Wrack deposits can play an important role in coastal and nearshore ecosystems by modifying sediment characteristics and beach profiles, acting as a site of nutrient regeneration via its decomposition, and providing habitat and food for meiofauna, marine and terrestrial macrofauna, birds and fish (Table 1.1). Wrack ultimately provides an important source of nutrients and energy for the beach ecosystem (McLachlan 1981; Alongi 1998).

Beach morphodynamics

Wrack deposits may trap sediments on the beach by catching wind-blown sand

(Nordstrom *et al.* 2006), and by compressing surface sands and keeping them moist, thus reducing erosion by winds during low tide. In addition, wrack deposits may attenuate wave energy and thus reduce loss of sand due to water movements at high tide (McLachlan 1985). As a result, beach profiles (i.e. width and slope) may be modified depending on the cover and volume of wrack on the beach, with the amount of sand on a beach increasing during periods when wrack inputs are high. Sediment particle size may also shift, as finer particles may be retained due to lower water velocities on the beach and filtration is augmented by wrack deposits (Ochieng & Erftemeijer 1999).

Wrack accumulations can also assist in the formation of coastal sand dunes. Hemminga & Niuwenhuize (1990) described the formation of dunes through the interacting processes of deposition of wrack on the shore and the wind-blown transport of sands in a shoreward direction. More conventional formation of dunes may also result as wrack is deposited on the beach and traps wind-blown sand of marine origin and sand moved by waves, in a similar manner to dune vegetation (Short & Hesp 1982; Nordstrom *et al.* 2000; 2006). Gradual accretion of sand and wrack at the back of the beach may result in the formation of a new frontal dune (Nordstrom *et al.* 2000).

Decomposition of wrack

Wrack is an important site for nutrient regeneration via its decomposition (Ochieng & Erftemeijer 1999). Decomposition is a combination of 3 major processes, saprophytic decay, fragmentation and leaching (Robertson & Mann 1980; Harrison 1982; Jedrzejczak 2002a). Saprophytic decay involves the breakdown of the structural components of detritus by bacteria and fungi (Harrison 1982; Rieper-Kirchner 1990), typically characterised by a rapid rise in microbial activity initially until the easily utilized components are consumed (Robertson & Hansen 1982). Mechanical fragmentation is achieved by abiotic (e.g. grinding and abrasion by sand) and biotic (e.g. maceration by shredding macrofauna) means (Robertson & Mann 1980; Alongi 1998). Amphipods are particularly important as shredders, causing a significant reduction in the size of particles (Harrison 1982). Leaching of cellular components occurs through cell lysis (Ochieng & Erftemeijer 1999) and wetting through rain or tidal inundation. The processes involved in decomposition may act concurrently and synergistically. The rate at which these processes occur depends on the type of detritus (Hansen 1984; Walker & McComb 1985), the location and rate of input (Jedrzejczak 2002b), and the local physical and biotic environment (Alongi 1998).

The nutrients released from wrack during the decomposition process are either retained within the beach sands, where they become available to bacteria, diatoms and meiofauna, or they are washed from the beach into the surf-zone and nearshore waters, where they may be taken up by phytoplankton, filter-feeding macrofauna (Bustamante & Branch 1996) and meiofauna. Elevated dissolved nutrient concentrations (e.g. nitrate NO_3, phosphate PO_4, silicate SO_4) have been recorded among surf-zone accumulations of macrophytes and in water associated with beach wrack compared with offshore waters or water from beaches without seaweed accumulations (Robertson & Hansen 1982). The nutrients released by decomposing algae and seagrass may also be important for the nutrient budgets of the living macrophytes themselves (Walker & McComb 1985).

Provision of habitat and incorporation into trophic webs

Wrack provides both a physical structure (which can be used as shelter and breeding sites) and a source of nutrients and energy to beach and nearshore fauna. Fungi, bacteria, meio- and macrofauna, shorebirds and fish utilise wrack deposits and interact in a variety of ways with the wrack itself and other components of the wrack community. Wrack provides the basis of a complex trophic system that provides pathways for the transfer of nutrients and energy from allochthonous macrophyte inputs into primary and secondary consumers, and then further up the food chain. Macrophyte wrack subsidies have been reported to increase the production of primary and secondary consumers and higher trophic levels of the food web in other marine communities including rocky reefs (Duggins *et al.* 1989; Bustamante & Branch 1996; Rodriguez 2003), mud flats, mangroves, estuaries (Lavery *et al.* 1999) and submarine canyons (Harrold *et al.* 1998). Wrack inputs also provide a pathway for the transfer of nutrients and energy between marine habitats (e.g. reefs, seagrass beds, mudflats and sandy beaches) and into terrestrial ecosystems (Polis & Hurd 1996). On sandy shores, where *in situ* primary productivity is very low because of disturbance of sand by waves, the importance of wrack subsidies is potentially greater than in any other marine environment.

Wrack deposits provide food, shelter and breeding sites for macrofauna on the beach and in the surf-zone, and the species richness and abundance of macrofauna have been positively correlated with wrack cover (Ochieng & Erftemeijer 1999; Dugan *et al.* 2003). Comparisons of beach sections that are covered with wrack and those that are bare sand have found significantly greater numbers of invertebrates associated with wrack (Ochieng & Erftemeijer 1999; Jaramillo *et al.* 2006), and that the highest macrofaunal biomass often occurs at the level of the current driftline (Koop & Griffiths 1982). The diversity of macrofauna associated with wrack is also high. Lavoie (1985) found 53 species of macroinvertebrates associated with wrack deposits, including members of 5 classes, 12 orders and 32 families, and Griffiths and Stenton-Dozey (1981) identified 27 species associated with wrack. Coleoptera (beetles) appear to be the most diverse group; 27 (including adult, larval, egg and pupal stages) and 22 of the species identified in these respective studies were coleopterans. Amphipods (Robertson & Lucas 1983; Van der Merwe & McLachlan 1987; Colombini *et al.* 2000) and seaweed flies (coleopids) (Egglishaw 1965; McAlpine 1991; Blanche 1992) were among the most abundant macrofauna inhabiting wrack deposits. Other taxa encountered in wrack deposits include members of the Arachnida (mites, spiders and pseudoscorpions), Chilopoda (centipedes), Crustacea (e.g. isopods) and Insecta (bees and wasps) (Lavoie 1985). Macrofaunal communities associated with wrack deposits thus include a mix of truly marine and terrestrial taxa.

The macrofauna that colonise wrack deposits include members of multiple trophic levels. Herbivorous and/or detritivorous species directly consume the wrack and associated meiofaunal, fungal and bacterial communities. These macrofauna have the potential to consume large quantities of macrophytic detritus. The majority of studies indicated that consumption of seagrass wrack by macrofauna is minimal (Robertson & Mann 1980; Jedrzejczak 2002a; Coupland & McDonald 2008; Urban-Malinga *et al.* 2008) but the consumption of algal wrack, in particular kelp, by macrofauna can cause a significant reduction in the amount of material remaining on the beach (Griffiths & Stenton-Dozey 1981; Lastra *et al.* 2008). A recent study conducted in Western Australia by Ince *et al.* (2007) used stable isotopes to assess whether wrack acts as a direct food source for beach macroinvertebrates. The authors found that algal, seagrass and terrestrial vegetation contributed to the diets of beach macrofauna (Ince *et al.* 2007). Predatory taxa such as staphylinoid beetles, spiders and isopods colonise wrack deposits in response to the availability of their prey (Colombini *et al.* 2000), and may arrive at a later stage than herbivorous species.

Detached macrophytes suspended in nearshore waters play an important role as habitat for fish (Kingsford & Choat 1985; Lenanton & Caputi 1989). Wrack accumulations in the surf-zone provide shelter from predators (Lenanton & Caputi 1989) and food resources, both directly for herbivorous fishes and indirectly as they provide habitat and food for prey species such as amphipods (Lenanton *et al.* 1982). The importance of beach-wrack-associated fauna to fish is, as yet, unclear. In their study on New England beaches, Behbehani and Croker (1982) did not find the dominant, beach-inhabiting amphipod *Orchestia platensis* in the gut contents of any of the fish found in that study. Amphipods and other mobile fauna that inhabit wrack deposits may be able to burrow into the underlying sand and hence avoid being washed out to sea by the tide; however, observations suggest that at least some fauna are washed off the beach and may become prey for fish in the nearshore zone (Griffiths & Stenton-Dozey 1981; pers. obs.).

Wrack removal: Beach cleaning and wrack harvesting

Wrack is removed from sandy beaches for two main purposes. Wrack is often perceived by beach-goers as an unpleasant and inconvenient disturbance, which should be ‘cleaned’ away to improve the aesthetics, amenity and safety of beaches (Llewellyn & Shackley 1996; Engelhard & Withers 1998; Fairweather & Henry 2003; Malm *et al.* 2004). Beach cleaning occurs on sandy shores around the world, particularly in urban areas and beaches with high value as recreational and tourist destinations (Gheskiere *et al*. 2006; de Falco *et al.* 2008; Williams *et al.* 2008). Given that the majority of the world’s population is centred in coastal zones, it seems likely that beach cleaning for amenity purposes will continue. Another viewpoint is that wrack is a natural resource that can be harvested for economic gain (Kirkman & Kendrick 1997; Piriz *et al.* 2003). In Australia small operations harvest kelp and seagrass to be processed into alginates, fertilizers and other agricultural products (Kendrick *et al.* 1995; Kirkman & Kendrick 1997).

Despite the widespread and increasingly common practice of wrack removal from sandy beaches, there is a lack of information regarding the ecological effects of wrack removal on sandy beaches (Kirkman & Kendrick 1997; McKechnie & Fairweather 2003). This dearth of knowledge is compounded by the lack of published information on the spatial extent of clearing, its frequency, the methods used, and the amount and type of material removed, all of which can vary between 'amenity' and 'harvest' operations, and among locations and times. In addition, the few published studies appear to be severely limited in spatial extent and replication, and details of the exact nature of the beach-cleaning operations are rarely given. Such patchy information makes interpretation of studies on the effects of wrack removal difficult, and extrapolation of these results to other locations and situations is questionable.

Potential effects of wrack removal

Beach morphodynamics

To date, few studies have investigated the effects of wrack removal on beach morphology and sediment characteristics. Wrack is known to trap wind-blown sediments (Short & Hesp 1982; Nordstrom *et al.* 2000; 2006), and its removal almost certainly increases the erosion of sand from the beach. Whilst many authors have suggested that removal of wrack may alter beach slope and width (Ochieng & Erftemeijer 1999; Piriz *et al.* 2003; de Falco *et al.* 2008; Williams *et al.* 2008) there has only been one study investigating this (Williams *et al.* 2008). Contrary to most opinion, in their recent study on Galveston Island, Texas, Williams *et al.* (2008) found that wrack removal activities had no effect on beach elevation over a single year. This study proposed that effects on beach elevation may manifest over longer periods of time but had studied only 4 sites during a relatively calm year.

The removal of wrack may also prevent the formation and seaward extension of dunes, which can form during periods of high wrack input to the beach (Hemminga & Nieuwenhuize 1990; Nordstrom *et al.* 2000). This may result in increased erosion and loss of the frontal dune and subsequent degradation of the remaining dunes. On beaches bounded by artificial structures such as rock walls, increased erosion of sand may result in narrowing of the beach width and a shift from sandy beaches to rocky intertidal areas. Potential also exists for changes in sediment characteristics (e.g. organic matter content, grain size and distribution, depth of anoxic layer) (Malm *et al.* 2004; Gheskiere *et al.* 2006).

The physical processes of wrack clearing can also affect beach morphodynamics. Sand adheres to wrack and is removed along with the wrack when it is cleared from the beach (Ochieng & Erftemeijer 1999; Piriz *et al.* 2003; de Falco *et al.* 2008). Estimates of the amount of sand removed during beach cleaning range from approximately 50% (Piriz *et al.* 2003) to 84% (Ochieng & Erftemeijer 1999) of the total dry weight removed. Raking and digging cause the hard pan of the beach surface to break and also loosens surface sand, enhancing erosion (Ochieng & Erftemeijer 1999), whilst at the same time vehicles and raking machinery cause compaction of the deeper layers of sand and crush fauna (Llewellyn & Shackley 1996).

Loss of wrack as a habitat and source of energy and nutrients

As discussed above, a diverse and abundant macrofaunal community inhabits wrack deposits. The removal of wrack from beaches therefore constitutes the loss of habitat for macrofauna on the beach and in the surf zone. The effects of wrack removal on these communities have been investigated in several studies; however, results are conflicting. Several studies have reported that macrofaunal species richness, abundance or community structure is greatly altered by wrack removal. In California, Dugan *et al*. (2003) recorded significant differences in the macrofaunal community structure between cleaned and uncleaned beaches, including depressed species richness, abundance and biomass of wrack-associated fauna. Llewellyn and Shackley (1996, in Britain) and Fanini *et al*. (2005, in Italy) also reported reduced abundances of amphipods (the dominant macrofauna) on raked beaches compared to unraked beaches. Evidence also suggests that the effects of wrack removal may occur in the short term but that macrofaunal communities may return to their pre-raked state following a period of recovery (Engelhard & Withers 1998, on Padre Island, Texas, USA). In contrast, Malm *et al*. (2004) concluded that there were no significant differences in the macrofaunal community structure between cleaned and uncleaned beaches in Sweden. This study was poorly designed and analysed with the multivariate statistics having little power due to the small number of sites (4) used.

Exchange of wrack between the beach and surf-zone occurs as tidal movements move wrack on and off the beach. The removal of wrack from the beach can thus also reduce the amount of wrack in the surf-zone, resulting in a loss of habitat and food for invertebrates and herbivorous fish in the nearshore zone. For example, in their study in Western Australia, Lavery *et al.* (1999) recorded relatively lower abundance and species richness of fish and decapod crustaceans one week after clearing wrack from a beach, compared with an uncleared beach. Wrack removal also has the potential for decreasing the amount of prey (e.g. amphipods) available to juvenile fish in the surf-zone (Lenanton & Caputi 1989).

Removal of large quantities of wrack may constitute the loss of significant amounts of carbon and nutrients from the nearshore ecosystem, potentially resulting in a decrease in the productivity of the system and shifts in the character of the region. This may be of particular concern in nutrient-poor environments where the remineralisation of nutrients via the decomposition of wrack may be important for the nutrient budgets of the growing macrophytes themselves (Walker & McComb 1985). Any such long-term and widespread effects have not been assessed; however, this has been identified as a priority for researchers (Kirkman & Kendrick 1997).

Thus, research is needed to establish what role wrack deposits play in the sandy beach ecosystem, as a basis for furthering our understanding of the ecological implications of removing wrack from the beach.

Background to this project

Perhaps because of the dynamic nature of wrack, the processes involved in its deposition, decomposition and incorporation into trophic webs are poorly understood globally. Possibly because of this, the management of wrack deposits has largely been overlooked by beach managers. It is clear, however, that wrack deposits vary considerably between locations, and so local research is required to adequately describe its role in the beach ecosystem. In South Australia, wrack deposits are a feature of many sandy beaches but there has, to my knowledge, been only one study

(McKechnie & Fairweather 2003) of the wrack deposits occurring here. McKechnie and Fairweather (2003) provides an excellent foundation and developed some useful methods for a longer-term study of local wrack deposits. This research is critical as a basis for furthering our understanding of wrack's role in the local coastal and nearshore ecosystem. The findings have the potential to greatly increase our knowledge of the importance of wrack to sandy-beach systems throughout Australia and in other regions of the world.

In South Australia, removal of wrack from sandy beaches occurs to increase the public amenity of some beaches and for the commercial harvest of wrack. The Coast Protection Board of South Australia (CPB), a branch of the Department for Environment and Heritage (DEH) is the statutory authority responsible for managing South Australia's coastline and is responsible for assessing the environmental effects of coastal activities and protection of coastal habitats. Primary Industries and Resources South Australia (PIRSA), in their role as managers of wrack harvesting activities in South Australia, are responsible for developing and implementing a management plan for harvesting seagrass and algal wrack (PIRSA 2006). PIRSA are responsible for assessing whether current harvest practices are sustainable, could be improved, or if further opportunities for commercial development exist.

Both DEH and PIRSA, which are government organisations, have expressed concern over the lack of research on wrack and any effects of its removal. This research thus aims to address the lack of knowledge of wrack in general and of the effects of its removal from the local beach ecosystem. This research thus addresses the critical need to understand the effects of wrack removal on beach-sediment processes, nutrient remineralisation, and beach and nearshore trophodynamics. It also aims to better inform DEH and PIRSA on any such effects, and provide recommendations to these organisations for the management of wrack removal activities.

In South Australia, harvesting of wrack from sandy beaches currently occurs in the South East region only. Licensed harvesting occurs at Kingston and Beachport (Figure 1.1). Kingston receives large inputs of wrack on the beach and deposits can cover the entire beach to a depth of up to 4m (McKechnie & Fairweather 2003). For the convenience of beach users, the Kingston District Council contracts the removal of large quantities of wrack from the beach (Figure 1.2). The contractor is a licenced harvestor of wrack and removes 10s of tonnes of wrack each year (anecdotal report from bulldozer operator at Kingston, December 2007) using bulldozers, front-end loaders and tractors. Clearing of the beach at Kingston occurs only once or twice per year (V. Neverauskas, PIRSA, pers. comm.). Another licence holder occasionally removes relatively small quantities of wrack from Beachport. Harvesting occurs infrequently and targets fresh algal wrack via collection by hand and the use of small vehicles (Susan Mills, pers. comm.). Harvested wrack from both sites is used in the production of fertilisers and soil improvers.

Cleaning of beaches for public amenity is carried out at selected beaches along the Metropolitan Adelaide coastline (Figure 1.1). Glenelg is a popular beach located 11 km from the Adelaide central business district. It is raked by a small tractor towing a mechanical raking machine (pers. obs., Figure 1.3) to remove wrack and anthropogenic litter (especially syringes and glass), with raking activities occurring more frequently in summer (pers. obs.) when the majority of beach users visit. Seacliff Beach is not raked; however, a sand replenishment program occurs at this beach. Large quantities of cleaned sand are brought from beaches further north by semi-trailers and are dumped on the beach to be re-distributed by waves and currents. The effect of vehicles and the sand dumping may be considerable but the effects are currently unknown. The actions of the trucks and the additional sand bury any wrack naturally deposited on the beach and thus reduce the wrack present at the sand surface. Seacliff is thus classed as a Cleaned beach for the purposes of this study.

Approach taken in this thesis

In the context of this thesis, wrack is considered to be beach-cast material of marine, terrestrial and anthropogenic origin and includes all components of the deposits (marine algae and seagrass, as well as epiphytic plants and animals, sponges, dead marine animals and birds, terrestrial and dune vegetation, and anthropogenic debris). Surf-zone wrack deposits are not considered except in Chapter 6, where I also include surf-zone wrack as a source of nutrition for fish. Care has been taken to distinguish between beach-cast and surf-zone wrack in Chapter 6.

This thesis incorporates both field-based surveys and experimental manipulations. Surveys were conducted over a broad spatial scale and included temporal replication at relevant time scales. Experimental manipulations were carried out at a sub-set of beaches and over shorter times. Method development and pilot studies were carried out as required and included extensive sampling and analysis of data.

The spatial range of this study will extend to three main biogeographical regions of South Australia; the Metropolitan coast within Gulf St Vincent (hereafter "Metro"), the Fleurieu Peninsula ("Fleurieu"), and the South East ("SE") (Figure 1.1). The previous study by McKechnie and Fairweather (2003) in these three Regions indicated that, in their one year of study, there was considerable variation in wrack cover and the composition of wrack deposits. In addition, wrack-cleaning activities (for amenity purposes) occur in both the Metropolitan region and the SE, whilst harvest activities are restricted to the SE region. Stakeholder interest also lies in the three regions studied by McKechnie and Fairweather (2003) and thus the same three regions were further studied here with sampling conducted over an extended time frame. Within each Region, study beaches were chosen to give a reasonable geographical spread throughout each region (Figure 1.1), and to represent a variety of beach morphologies and a range of wrack percent covers.

Previous studies suggest that there is a considerable temporal variation in the amount and type of wrack, and the processes it undergoes on the beach. Where possible, this research thus incorporates multiple sampling events to capture some of this variability.

The aim of this thesis was to establish the ecological importance of wrack in local sandy beach ecosystems. As a first step in furthering our understanding of the effects of wrack removal I aimed to assess the importance of wrack, independent of the effects of wrack removal (Figure 1.4). The second over-riding aim of this thesis was to determine the environmental effects of wrack removal. The study thus contrasts harvested versus cleaned beaches and compares these types of wrack removal to uncleared beaches. Due to the limited number of harvested and cleaned beaches within SA and despite attempts to identify additional impacted beaches, the design must be unbalanced. Thus the number of potential comparisons is limited and formal analyses were not conducted.

Aims of this thesis

The general aims of this thesis were to increase our understanding of the role of wrack in the beach and nearshore ecosystem and to assess the effects of wrack removal on aspects of these systems (Figure 1.4). Specifically, I aimed to:

- Characterise the wrack deposits on South Australian sandy beaches in terms of the amount and type of wrack present, where and when wrack deposits occur;
- Investigate the role of wrack as a habitat for beach macrofauna;
- Assess the effects of wrack deposits on beach sediments and morphodynamics;
- Assess the input of nutrients and energy from wrack deposits into the sandy beach ecosystem via the decomposition and incorporation of wrack into trophic webs;
- Investigate the effects of wrack removal on the ecosystem by comparing cleared and uncleared beaches with reference to key performance indicators;
- Perform experimental manipulations on wrack deposits to further investigate effects of wrack removal on macrofaunal communities (which will aid in assessing effects on higher trophic levels such as birds and fish); and
- Recommend strategies to avoid, remedy or mitigate any adverse impacts of wrack removal including guidelines for regulators, councils and license holders regarding policies and operational procedures.

Thesis structure

This thesis consists of eight chapters. Chapters 2 to 7 contain the results of field investigations. Chapter 8 provides a synthesis of the findings, recommendations and conclusions.

Chapter 2 aims to increase our knowledge of the nature (amount and type) of wrack on South Australian sandy beaches. Wrack deposits in three main biogeographical regions of South Australia were repeatedly surveyed to assess spatial (between and within regions) and temporal (seasonal and inter-annual) variation. A rapid method for estimating the percentage cover of wrack on sandy beaches (“photopoint” method) was also further developed and tested.

Chapter 3 aims to assess the role of wrack accumulations as habitat for beach macrofauna. The role of the driftline (the line on the beach, parallel to the dune, with the greatest amount of wrack) as a habitat is studied and I attempt to determine whether macrofaunal communities associated with the driftline differ between beaches and/or seasonally.

Chapter 4 focuses on interactions between wrack and physical components of the beach habitat. First, I aim to determine whether wrack accumulations (cover and composition) differ between beaches of varying morphodynamic types (beach-face profile width and slope, grain size). Second, I examine whether wrack deposits affected the sediment characteristics (particle size distribution, organic matter content, bulk density and compaction) of underlying and nearby sediments.

Whilst conducting research on local sandy beaches, I noted that, on beach cusps (a morphological feature of some sandy beaches which manifest as rhythmic undulations in the sand), wrack deposits appeared to be concentrated in their bays. The research presented in Chapter 5 thus stems from those observations and investigates the effects of beach cusps on wrack accumulations, sediments and macrofaunal communities. It aims to determine whether wrack accumulations, sediment characteristics (grain size and organic matter content) and macrofaunal communities differ between positions within cusps (i.e. bays and horns). I also assessed whether cusp morphology or wrack accumulations drive any differences in sediments and macrofaunal communities between bays and horns. This research thus incorporates concepts presented in Chapters 2 (wrack cover), 3 (macrofauna) and 4 (beach morphology and sediments).

Chapter 6 assesses the incorporation of wrack into beach and nearshore ecosystems via two pathways: decomposition and incorporation into trophic webs. Decomposition of algal and seagrass wrack was assessed using litterbag experiments to determine the rate of mass loss, and whether any changes in C and N content and/or C and N stable isotope ratios occur over time. Stable isotopes of C and N were used to assess whether beach macrofauna and nearshore macro-invertebrates and fish rely on wrack as a source of nutrition, either directly as a food source or through the provision of invertebrate prey. I also investigated whether the species richness and abundance of fish in the nearshore zone was related to the amount of wrack present on the beach or in the nearshore. Due to considerable delays beyond my control in receiving back stable isotope analysis data, this chapter contains preliminary results and discussion of stable isotope data only. Here, I attempt only to determine whether there is any flow of nutrients from wrack into higher trophic levels at a range of beaches. At this stage I have not attempted to assign individual food sources to consumers. Further analysis of this data will be carried out later and manuscripts will be submitted to suitable journals.

Chapter 7 investigates the effects of wrack removal on macrofaunal communities. This chapter involved two components: a single sampling event conducted opportunistically following a commercial harvest of wrack from Kingston, SE; and experimental manipulations of wrack deposits, in an attempt to simulate the wrack-removal activities of mechanical rakes (used for amenity purposes). Sampling at Kingston compared the macrofaunal communities present in 'Cleared' and 'Natural' sections of beach. Manipulations of wrack deposits involved raking and removing wrack from the driftline of beaches. I sampled the macrofaunal communities in raked (experimental) and natural (control) plots to assess the short-term effects of this small-scale wrack removal. I also quantified the volume of wrack and associated sand removed by raking, to provide estimates of the amount of material that may be removed by beach cleaning operations. Experiments were carried out at four beaches on two occasions to determine whether any effects vary between locations or seasons, and therefore could be lessened or mitigated through flexible management of wrack removal activities.

Chapter 8 provides a general discussion with a synthesis of the findings of this thesis. I summarise the implications for the management of wrack deposits and make recommendations for management, including with regard to the techniques used in this thesis and their applicability in managing wrack deposits. I attempt to identify the shortcomings of this research (also discussed in each chapter) and directions for further research.

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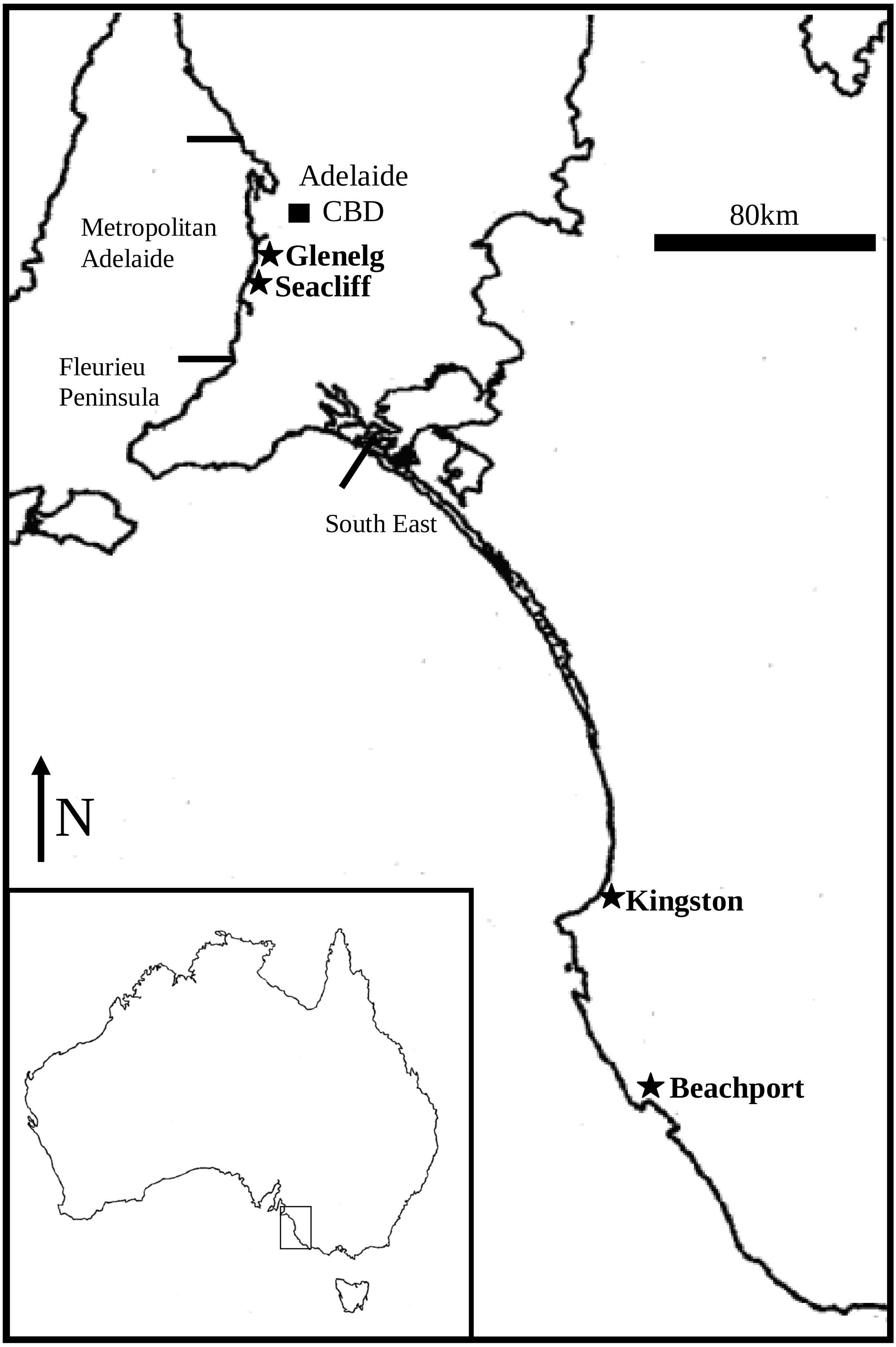
Adelaide
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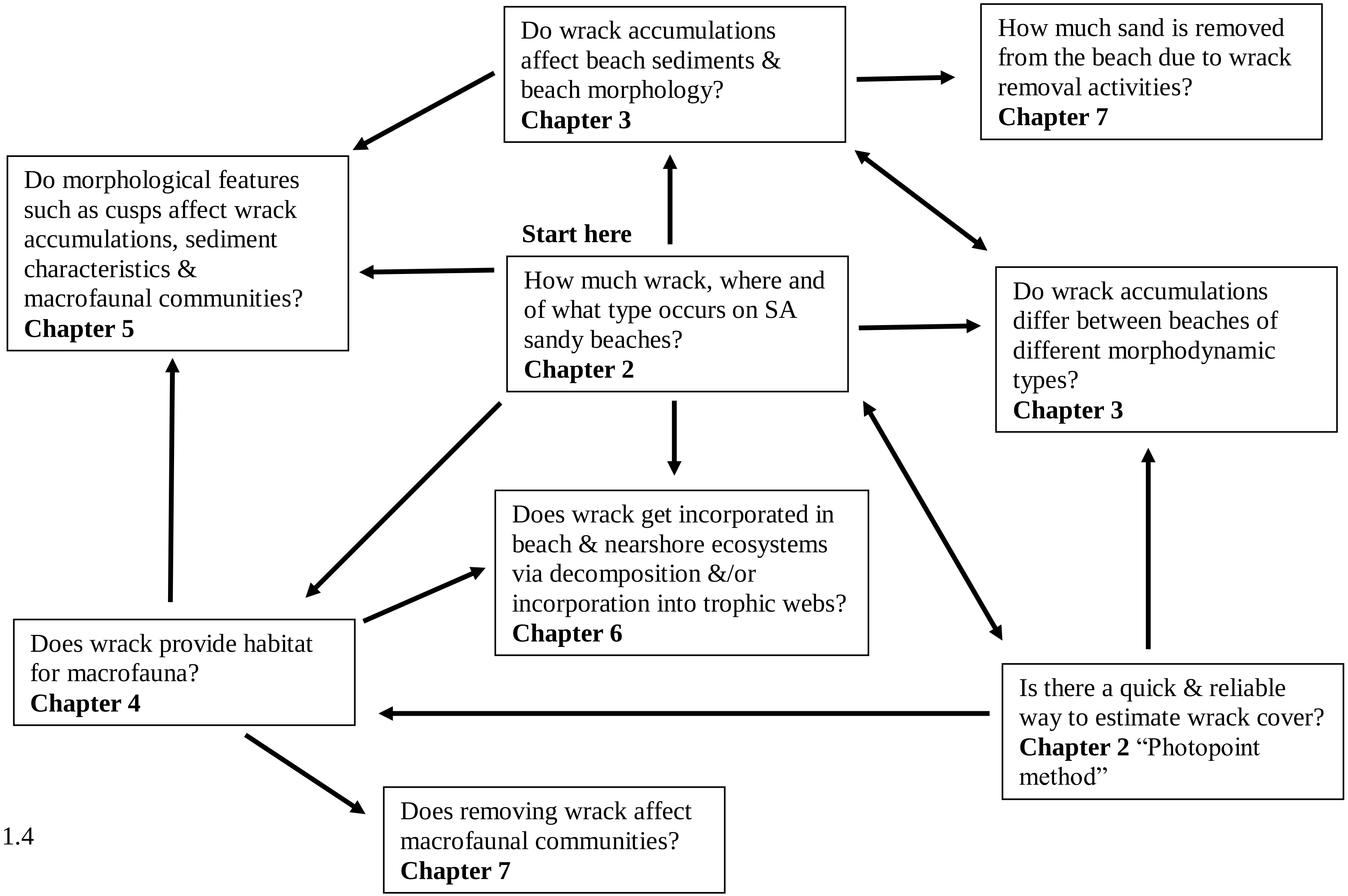
Figure 1.1

Figure 1.2

Figure 1.3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Does removing wrack affect macrofaunal communities? Chapter 7

Figure 1.4

Table 1. Summary of studies into the role of wrack deposits in beach and nearshore ecosystems. This is not a comprehensive list and contains only selected references. In particular, research that has focussed on a single (or few) species has been omitted.

Effect		**Studies**
Modify sediment characteristics & beach profiles		McLachlan 1985
		Hemminga & Nieuwenhuize 1990
		Ochieng & Erftemeijer 1999
		Nordstrom *et al.* 2000
Nutrient regeneration via its decomposition		Robertson & Mann 1980
		Harrison 1982
		Robertson & Hansen 1982
		Duggins & Eckman 1997
		Jedrzejczak 2002b
Habitat & food for:	meiofauna	Koop & Griffiths 1982
		McLachlan 1985
		McGwynne *et al.* 1988
		Gheskiere *et al*. 2006
		Urban-Malinga *et al*. 2008
	marine & terrestrial macrofauna	Egglishaw 1965
		Griffiths & Stenton-Dozey 1981
		Behbehani & Croker 1982
		Lavoie 1985
		McLachlan 1985
		Inglis 1989
		Bustamante & Branch 1996
		Llewellyn & Schackley 1996
		Ochieng & Erftemeijer 1999
		Colombini *et al.* 2000
		Jedrzejczak 2002c

Effect		**Studies**
Habitat & food for:	marine & terrestrial macrofauna	Dugan *et al*. 2003 Jaramillo *et al*. 2006 Ince *et al*. 2007 Olabarria *et al*. 2007 Lastra *et al*. 2008 Rodil *et al*. 2008
	birds	Bradley & Bradley 1993 Dugan *et al.* 2003 Hubbard & Dugan 2003
	fish	Lenanton *et al.* 1982 Kingsford & Choat 1985 Lasiak 1986 Lenanton & Caputi 1989 Jenkins & Wheatley 1998 Jackson *et al.* 2002 Crawley *et al*. 2006