CHAPTER SEVEN: EFFECTS OF WRACK REMOVAL ON MACROFAUNAL COMMUNITIES

Abstract

Wrack removal activities take place on sandy beaches around the world and there is concern that wrack removal activities may be detrimental to the beach and nearshore ecosystem. Previous studies have demonstrated that macrofaunal communities are less diverse and abundant, or have different species present, where wrack removal occurs. The aim of this chapter was thus to determine the effects of wrack removal on sandy beach macrofaunal communities in South Australia. I conducted two studies. First, I investigated the effects of large scale, commercial wrack harvest on the macrofaunal communities at Kingston SE. Second, I investigated the effects of experimental removal (to mimic cleaning) of wrack on macrofaunal communities at 4 sandy beaches near metropolitan Adelaide. Pit-fall trapping was used to sample macrofauna and the methods were similar to those used in Chapter 4.

I sampled the macrofaunal communities at Kingston Beach on two occasions. First, I conducted a pilot study to sample the macrofauna occurring in three positions within the drifline (DL); in bare sand, among wrack patches, and in deep piles of wrack. A total of 139 individuals from 14 species were captured in the 24 pit-fall traps deployed. Whilst the abundance and species richness of fauna did not differ significantly among the three positions, multivariate analyses indicated that the macrofaunal community differed among positions. On a second occasion, wrack was being harvested from the beach at Kingston at the time of my visit. I therefore sampled the macrofaunal communities occurring in 'Cleared' versus 'Natural' areas of the beach. The same three positions were sampled as in the pilot study. Here, a total of 3914 individuals, comprising 23 species were collected. Two species contributed 97% of the total abundance; the weevil, *Aphela phalenoides* (52%) and the talitrid amphipod *Talorchestia quadrimana* (46%). Both the abundance and species richness of macrofauna were significantly greater in the 'Natural' area than in the 'Cleared' area. Furthermore, the macrofaunal communities were significantly-different between 'Cleared' and 'Natural' areas. Sampling the macrofaunal

communities prior to the removal of wrack from the ‘Cleared’ area was not possible and it is thus difficult to conclude whether the macrofaunal communities differed due to the nature (type, age and volume) of wrack present, or due to the effects of wrack removal in the ‘Cleared’ area. It was clear however that the ‘Cleared’ and ‘Natural’ areas differed greatly in their macrofaunal communities.

The aim of the second study was to determine whether macrofaunal communities differed between areas of ‘natural’ and experimentally ‘cleaned’ beach and whether any effects differed temporally (i.e. seasonally) and/or spatially (i.e. between beaches). Sampling was conducted on 2 occasions (winter and summer of 2007) at four beaches (Robinson Point, Moana, Aldinga and Normanville, as in Chapter 4). Eight experimental plots were established in the driftline at each beach and were either ‘Cleaned’ ($n = 4$) by raking by hand or left undisturbed as ‘Natural’ plots ($n = 4$). Pit-fall traps were positioned in bare sand areas so that the effect of treatment was not confounded with the amount of wrack around the trap. Of the 254 pit-fall traps that were deployed and retrieved, only one trap was devoid of fauna and a total of 4765 individuals from 44 species were collected. Mean abundance was slightly higher for the ‘Cleaned’ plots than for the ‘Natural’ plots but species richness was higher in the ‘Natural’ plots than the ‘Cleaned’ plots. Neither of these effects were significant, nor was there a separation based on overall community structure.

In addition to pit-fall trapping, I also assessed the sand content of the material removed during the experimental clearing of wrack. A total of 928m^2 of beach was raked and 655 kgDW of material was removed over the experiment. Sand made up 81% of the DW and thus most of the material removed was sand rather than wrack. Estimates of the amount of sand that would be removed if any of the study beaches were raked were made using the mean amount of sand removed per m^2 from this study (0.57 kgDWm^{-2}). I estimate the mass of sand removed per linear km of beach (6.1m x 0.57 kgDWm^{-2} x 1000m) to be 3477kgDWkm^{-1}, indicating that losses of sand due to wrack removal may be substantial.

The experimental wrack removal method employed in the 2nd study here did not appear to have any measurable effects immediately on the macrofaunal communities. This is likely because the area of beach cleared was insufficient and that macrofauna moved from adjacent wrack-covered areas and from the dune into the cleared plots. I recommend that future studies use larger cleared areas of beach, attempt to use the same wrack removal methods and/or machinery used locally, and assess the macrofaunal communities repeatedly following wrack removal activities.

Introduction

Wrack removal activities take place on sandy beaches around the world, including in the USA (Engelhard & Withers 1998; Dugan *et al.* 2003; Williams *et al.* 2008), UK (Llewellyn & Shackley 1996), Europe (Malm *et al.* 2004; Fanini *et al.* 2005; Gheskiere *et al.* 2006; de Falco *et al.* 2008), Africa (Ochieng & Erftemeijer 1999) and Australia (Kendrick *et al.* 1995; Lavery *et al.* 1999; Fairweather & Henry 2003). Wrack removal activities occur for two main purposes; to increase public amenity or for the commercial harvest of wrack material. Removal of wrack, as a way of increasing the public amenity (safety and convenience) and scenic value of beaches has been termed beach ‘cleaning’, ‘raking’ or ‘grooming’. Beach ‘cleaning’ is usually carried out by local authorities (i.e. councils) and tends to occur in places and/or times of peak visitor usage, sporadically following large wrack deposition events (e.g. storms) or seasonally. These activities also often aim to remove anthropogenic debris (e.g. glass, syringes, and general refuse, Fairweather & Henry 2003) that may be deposited over the entire beach face as well as in the driftline. Removal of wrack for commercial purposes (i.e. wrack harvest) may be carried out in conjunction with beach ‘cleaning’. In Australia small operations harvest kelps and seagrasses to be processed into alginates, fertilizers and other agricultural products (Kendrick *et al.* 1995; Kirkman & Kendrick 1997). The frequency, timing, methods used, and the amount and type of material removed vary depending on the purpose, and the authority, council or commercial user removing the wrack.

Whilst there is concern that wrack removal activities may be detrimental to the beach and nearshore ecosystem, few studies have been conducted on the effects of wrack removal activities, particularly in Australia. Potential physical effects include a loss of sediments due to increased erosion (Ochieng & Erftemeijer 1999; Piriz *et al.* 2003) and prevention of the formation and seaward extension of dunes (Hemminga & Nieuwenhuize 1990; Nordstrom *et al.* 2000). Potential also exists for changes in sediment characteristics (e.g. grain size and distribution, organic matter content and depth of anoxic layer) (Engelhard & Withers 1998; Malm *et al.* 2004; Gheskiere *et al.* 2006) and beach elevation (i.e. beach slope) (Williams *et al.* 2008). The removal of wrack also constitutes a loss of potential habitat, food source and nutrients and the effects of wrack removal on faunal communities have also been demonstrated. Macrofaunal communities have been shown to be less diverse and abundant, or have different species present, where wrack removal occurs (Llewellyn & Shackley 1996; Engelhard & Withers 1998; Dugan *et al.* 2003). Birds that rely on wrack-associated macrofauna for food, or rely on the wrack for shelter and nesting sites may also be adversely affected by beach cleaning and wrack harvesting (McCulloch 1996; Dugan *et al.* 2003). 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; Lavery *et al.* 1999).

The physical processes of wrack clearing and harvest may also be detrimental to the beach ecosystem. The vehicles and machinery used may directly crush macrofauna (Llewellyn & Shackley 1996), disturb birds (McCulloch 1996; Dugan *et al.* 2003) and cause compaction of sediments (Llewellyn & Shackley 1996). The quantity of sand, which adheres to wrack and is thus removed as well, may also be considerable and have longer-term negative consequences for the beach. Estimates of the amount of sand removed during beach cleaning range from 50% (Piriz *et al*. 2003) to 84% of the total dry weight removed (Ochieng & Erftemeijer 1999). Where large scale or long-term removals of wrack occur, the amount of sand removed could be substantial and result in a significant loss of sand from the beach. The potential effects of wrack removal are thus varied and include effects on both the physical and biological components of the beach ecosystem.

The aim of this chapter was to determine the effects of wrack removal on sandy beach macrofaunal communities. There were two studies investigating: 1) the effects of large scale, commercial harvest of wrack on the macrofaunal communities at Kingston SE, and 2) the effects of experimental removal (to mimic cleaning) of wrack on macrofaunal communities at 4 sandy beaches near metropolitan Adelaide. I first sampled the macrofaunal communities at Kingston Beach occurring within the driftline in a pilot study to determine the appropriate number of replicates that should be used in a second (main) study at Kingston. Secondly, I sampled the macrofaunal communities occurring in cleared versus natural areas of Kingston Beach. The aim of the second study was to determine whether macrofaunal communities differed between areas of 'natural' and experimentally 'cleaned' beach and whether any effects differed temporally (i.e. seasonally) and/or spatially (i.e. between beaches). I also aimed to assess the sand content of the total material removed and investigate any relationships with the area of beach cleared or amount of material removed.

Methods

Kingston: Pilot study

A pilot study was carried out at Kingston Beach on the 12th – 13th of November, 2007. At that time, the beach was covered in a relatively uniform layer of wrack. Sampling was conducted in 3 Positions within the drifline (DL), based on the amount of wrack present in the surrounding $1m^2$. The Positions were DL B (traps placed in bare sand with less than 25% wrack in surrounding $1m^2$), DL W (traps placed among wrack patches), and DL P (traps placed in deep Piles of wrack). Thus, whilst the cover of wrack was similar between the DL W and DL P Positions, the volume of wrack was greater in the DL P Position. Four replicates (quadrats) were sampled for each Position. For each quadrat, two pit-fall traps were used as sub-samples, as recommended by the pilot study in Chapter 3. A total of 24 pit-fall traps were deployed and a total of 12 quadrats were sampled. The traps were deployed in the evening on the 12th of November and were collected the following day (approximately 15 hours later). The results of this pilot study were used to determine the appropriate number of replicates to sample in later studies at this beach.

Kingston: Cleared vs. natural areas

On one occasion (10th December 2007), wrack removal activities, being conducted by a council-appointed contractor, were in progress at the time of my visit to Kingston. An area at the northern end of the beach adjacent the jetty had previously been covered by deep (1-2 m) and extensive (covering the entire beach face) deposits of wrack. The contractor was tasked with removing the wrack to increase the public amenity of the beach (pers. comm.). A bulldozer was used to push wrack into large piles, several metres deep, and then a front-end loader was used to collect this wrack and load it into semi-trailers. A tractor towing a chain was then used to remove additional wrack piles and flatten the remaining wrack and sand surface. This section of beach, hereafter the ‘Cleared’ area, was approximately 65m wide by 400m alongshore. There was a large accumulation of wrack remaining on the beach, even following these wrack removal activities. The beach was covered with approximately 80% wrack, up to 60cm deep, which consisted of dark-coloured, fragmented seagrass (primarily *Posidonia sinuosa*). A more ‘Natural’ section of beach was located at the southern end of the Kingston town beach and stretched into the adjacent Wyomi Beach. The wrack deposits occurred as small clumps (up to $1m^2$ and a few centimetres deep) and formed a driftline approximately 20m across-shore. The beach width was similar to the Cleared area (60m) but the wrack cover was much lower (< 10 %). The wrack consisted of relatively-fresh seagrass material (*P. sinuosa*, *Posidonia coriacea* and *Amphibolis antarctica*) with small amounts of algal material. This area appeared to be relatively undisturbed by the wrack removal activities occurring at the other end of the beach.

I took this opportunity to carry out an investigation into whether the abundance and diversity of the macrofaunal community at Kingston differed between an area of ‘Natural’ beach and an area of ‘Cleared’ beach. Sampling was carried out at least 50m from the end of the Natural and Cleared areas of the beach and was carried out overnight from the 11^{th} to the 12^{th} of December 2007, 1 day after the wrack removal was completed.

Sampling was conducted in the same three Positions as in the pilot study, i.e. DL W, DL B and DL P. In each area (i.e. Natural and Cleared), six replicates (quadrats) were sampled for each Position and two pit-fall traps (sub-samples) were used per quadrat. Thus, a total of 72 pit-fall traps were deployed and a total of 36 quadrats were sampled. Quadrats were positioned haphazardly within the driftline and were at least 3m apart.

Main study: Experimental removal of wrack- 4 beaches sampled in 2 seasons

The aim of this study was to determine whether ‘cleaned’ areas of beach, which have been experimentally cleared of wrack, had different macrofaunal communities from 'natural' areas of beach. The sampling regime was also designed to investigate seasonal differences in the faunal communities associated with wrack and any differences between beaches with varying wrack cover and composition. Sampling was conducted on 2 occasions; once in winter (9th – 11th July 2007) and once in summer (17th - 20th December 2007). Sampling was timed so that the driftline (and hence the pit-fall traps) would not be inundated overnight and thus in general sampling was carried out when high tides occurred in the late afternoon or evening. Four beaches along the southern metropolitan and upper Fleurieu Peninisula coastlines were sampled; Robinson Point, Moana, Aldinga and Normanville (Figure 4.1). The beaches were chosen so that they were in reasonable proximity to one another so that differences due to geographical location could be minimised, and were also sampled in Chapter 4.

On each beach, the overall percent wrack cover was estimated using the photopoint method (see Chapter 2). Eight experimental plots were established in the driftline (the line parallel with the water with the greatest amount of wrack) at each beach. Plots were 5m long and as wide as the driftline at any given point (see Results). Plots were separated by at least 10m. Percent wrack cover was estimated by eye for each plot. Plots were randomly allocated as either a Natural (control) or Cleaned plot to give 4 replicate plots per Treatment. Cleaned plots were then raked by hand using a metal garden rake to remove surface wrack and any wrack buried up to 5cm below the sand surface. Wrack was placed on a plastic tarp, 3 replicate sub-samples of known fraction were taken and the remaining wrack was removed from the experimental area. Natural plots were left undisturbed. Percent wrack cover for each plot was estimated by eye for Natural plots, and both before and after raking for Cleaned plots.

Within each plot, 2 quadrats (1m^2) were laid at least 2m apart. Percent wrack cover within each quadrat was estimated by eye. Two pit-fall traps (sub-samples) were used per quadrat. Traps were positioned in bare sand areas so that the effect of treatment was not confounded with the amount of wrack around the trap (see Chapter 4). Eight plots were used per beach on each visit (2 treatments x 4 plots), giving a total of 64 plots over the entire experiment (2 visits x 4 beaches x 8 plots) and a total of 256 pit-fall traps.

Field methods

The field methods for the pit-fall trapping were based on those used in Chapter 3 and 2 pit-fall traps were used in each quadrat. Pit-fall traps were set out in the evening and were retrieved the following morning, as close as possible to dusk and dawn, respectively. Due to logistical reasons, 2 beaches (randomly selected) were sampled on each evening. Sampling of all 4 beaches was carried out within a maximum of 3 nights to minimise bias between beaches due to temporal variation such as changes in tide times and/or range.

Laboratory methods

The contents of each pit-fall trap were rinsed over a 500um mesh sieve. The fauna retained on the sieve were then identified to the lowest possible taxonomic unit and counted. Since not all taxa could be identified to species, the level of taxonomic classification varied. Larvae were particularly difficult to assign to species and thus where larvae and adults that could potentially be the same species occurred, these were counted separately for the purposes of species richness counts. Note that the species list includes many taxa that were encountered in Chapter 4 (Appendix C), and thus for ease of interpretation the same species numbers have been assigned here (i.e. sp. 1, sp. 2). Thus for some Families there may be some species not listed here. For the Kingston studies, sub-samples (2 pit-fall traps/quadrat) were pooled to calculate the total number of individuals (abundance) and number of species (species richness) per quadrat. For the experimental wrack-removal study, the 2 quadrats were also pooled for each plot.

Sub-samples of the material removed from Cleared plots were returned to the laboratory and were processed to determine their wrack and sand contents. Sub-samples were weighed and then washed to separate wrack from sand. Wrack pieces larger than 500µm were blotted dry and weighed (WW, g). The slurry of sand and water obtained from rinsing the wrack was passed through a 63µm mesh sieve and the sand retained was weighed (WW, g). Both wrack and sand samples were then dried at 80ºC for 48 hours to obtain dry weights (DW, g). For each beach, 4 replicate samples of wrack were also sorted for species composition by mass (WW only).

Statistical data analysis

Univariate analyses

SYSTAT v.11 was used to carry out univariate analyses. Assumptions were checked by inspection of histograms and scatter plots of the residuals. Data were transformed (either √, log [x +1] or 4^{th} root) as appropriate.

Multivariate analyses

Multivariate analyses were run using PRIMER v.5 software. Data were standardised because the actual area/volume of beach sand sampled by a pit-fall trap may not be constant either between traps or between macrofaunal species. In addition, the trapping time was not identical between beaches and/or seasons (see above). Analyses were performed on standardised data without transformation and standardised data with log(x + 1) and 4^{th} root transformations. For Kingston, in the Pilot study, data were log (x+1)-transformed but in the second study the untransformed data showed the clearest patterns. For the main study, data were log (x+1)-transformed. Two-dimensional MDS plots were produced using Bray-Curtis similarities. Analysis of similarity (ANOSIM), with 999 permutations, was performed to assess any differences in taxonomic composition and relative abundances among the groups (i.e. for the factors of Treatment, Visit or Beach). Similarity percentages (SIMPER) analyses were run to determine within-group similarities and between-groups dissimilarities. A high value of percentage similarity within groups indicates group cohesion, and a high dissimilarity between groups indicates distinct communities. Indicator taxa were also identified using SIMPER analyses. A taxon may be considered a consistent indicator if their ratio of dissimilarity to standard deviation is equal to or greater than 1 (Clarke & Warwick 1994). The MVDISP routine was used to examine multivariate dispersion patterns in the data.

Kinsgton: Pilot study

A one-way Analysis of Variance (ANOVA) was used to determine whether the abundance and species richness of macrofauna differed between Positions. Position was a fixed factor with 3 levels; DL B, DL W and DL P. Analyses were conducted on either abundance or species richness with the two sub-samples (pit-fall traps) pooled for each quadrat. Power analyses were run to determine the appropriate number of quadrats per Position in a later study comparing natural and cleared beach areas (Treatment). Power analyses were run for a hypothetical 2-way ANOVA model with Position (3 levels) and Treatment (2 levels) and power was estimated for the effect of Position. Abundance and species richness data were analysed. The power analysis indicated that 6 quadrats per Position were required to detect differences in abundance and species richness between Positions.

A two-dimensional MDS plot was constructed based on Bray-Curtis similarities. One-way ANOSIM was performed to assess any differences in taxonomic composition and relative abundances among the Positions.

Kingston: Cleared vs. natural areas

Two-way ANOVAs were used to determine whether there were significant differences in the abundance or species richness of macrofauna between Areas and/or among Positions. Both factors were considered fixed: Area had 2 levels; Position had 3 levels. ANCOVA was used to determine whether the covariate of (√-transformed) % wrack cover in each quadrat could explain any additional variance in the abundance or species richness.

A two-dimensional MDS plot was constructed based on Bray-Curtis similarities. A two-way crossed ANOSIM test was performed to identify differences in taxonomic composition and relative abundances among Positions and Areas. SIMPER analyses were run to determine within-group similarities, between-groups dissimilarities and to determine which taxa were most influential.

Main study: Experimental removal of wrack- 4 beaches sampled in 2 seasons

Two traps from one quadrat were disturbed (removed and left lying on the sand surface) by people walking on the beach at Normanville (July sampling, Natural plot). Thus, this plot was removed from the analysis resulting in only $n = 3$ for this combination of Visit, Beach and Treatment. The design is thus unbalanced and Type III Sums of Squares were used for the ANOVA.

The material removed was assessed for concurrence between WW and DW values. The % DW of sand was regressed against the amount of material removed (kgDW), % cover of wrack prior to raking, and the area of beach raked (m^2) to assess whether the proportion of sand differed with these variables. Linear regressions were used to assess any relationships between the % cover of wrack prior to raking or the area of beach raked (independent variables) and the amount of material, sand and wrack removed per m^2 (dependent variables). Two-way ANOVAs were used to assess differences between Visits and among Beaches. Both Factors were considered random with 2 and 4 levels, respectively. The variables analysed were % DW sand and the amount (kgDW) of material, sand and wrack removed per m^2. The % wrack cover in the plot prior to raking was used as a covariate in ANCOVA for the 2-way model. Because material was removed only from the raked plots, these analyses include Cleared plots only (and hence there is no factor Treatment) and n = 32 plots.

A 3-way ANOVA was used to determine whether there were significant differences in the abundance and species richness of macrofauna. The three Factors were Visit (2 levels), Beach (4 levels) and Treatment (2 levels). Visit and Beach were considered random Factors and Treatment was classified as a fixed factor. ANCOVA was used to determine whether the covariate of (log [x +1]-transformed) % wrack cover in each quadrat could explain any additional variance in the abundance or species richness.

Bray-Curtis similarities were used to construct a two-dimensional MDS plot. A set of three, two-way crossed ANOSIM tests were performed to identify differences in taxonomic composition and relative abundances among Treatments, Visits and Beaches. The tests were: Visit x Treatment; Beach x Treatment; and Visit x Beach. SIMPER analyses were run to determine within-group similarities and between-groups dissimilarities for each factor. Data were also analysed using the AGGREGATE function in PRIMER to aggregate species data to Order level. A 2-D MDS was constructed and the same analyses were performed on this data set.

A composite 'factor', including information on all combinations of Visit, Beach and Treatment was constructed to allow some estimate of the combined effects of all three factors simultaneously. This yielded 32 combinations of Visit, Beach and

Treatment. A one-way ANOSIM and SIMPER were then used to determine whether the faunal communities differed among the 32 groups of the composite factor.

The BIO-ENV procedure in PRIMER was used to match environmental data to the macrofaunal communities. Because the environmental data were collected at the scale of a visit to a beach (i.e. $n = 8$), the macrofaunal data were pooled to the same scale. Environmental data included: % wrack cover on the whole beach; % wrack cover in the driftline; distance from base of the first dune to the DL; the width of DL; the total beach width; and the number of plant species in wrack deposits. For the cleared plots, the PRIMER routine BIOENV was used to match wrack composition data (% composition by species) to data on the harvested material composition (i.e. % sand, amounts of material, sand and wrack removed per m^2). Environmental data were also matched to wrack composition data using the PRIMER routine BIOENV. Environmental data included: the % DW sand; the amounts of material, sand and wrack removed per m^2; the area raked; % wrack cover prior to raking; the number of species in wrack deposits; and the % of the study site raked. The procedure RELATE was also used to assess concurrence between the similarity matrices for macrofauna and wrack composition. Macrofaunal, harvest material and wrack composition data similarity matrices were produced using Bray-Curtis similarities on raw data that were log (x + 1)-transformed.

Results

Kingston Pilot study

Descriptive findings

A total of 139 individuals, comprising 14 species, were captured in the 24 pit-fall traps (Table 7.1). This was, on average, 6 (± 2) individuals and 2.0 (± 0.3) species per trap. Individual traps had between 0 and 30 individuals and between 0 and 6 species. Of the 14 species captured, 3 occurred only once (singletons) and 2 occurred only twice (doubletons). The weevil *Aphela phalenoides* was the most abundant species, contributing 40% of the total abundance (55 individuals). A terrestrial isopod, Porcellionidae sp. 1, and a Staphylinid rove beetle, *Cafius* sp. 1, contributed 24% and 13% of the total abundance, respectively (Table 7.1).

The two sub-samples (pit-fall traps) were pooled for each quadrat yielding abundances of between 0 and 45 individuals per quadrat and species richnesses of between 0 and 7 species per quadrat. This was, on average, 12 (± 4) individuals and 3.3 (± 0.6) species per quadrat. Of the three Positions, Bare sand (B) had the highest mean abundance (24 ± 8 individuals) compared to wrack Piles (6 ± 4 individuals) and among Wrack (5 ± 1 individuals) (Figure 7.1a). Species richness was also highest in Bare sand (4.8 ± 1.1 species), followed by among Wrack (3.0 ± 0.4 individuals) and wrack Piles (2.0 ± 0.9 species) (Figure 7.1b). Despite the apparent differences, the one-way ANOVA for Position indicated that the abundance (p = 0.082) and species richness (p = 0.153) of fauna did not differ significantly among Positions (Table 7.2, Figure 7.1a and b), especially due to the variability seen for B and P samples.

The power analyses to determine the appropriate number of quadrats per Position indicated that, using 5 replicate quadrats per Position, a power of 83% was achieved for abundance and using 6 replicates a power of 85% was achieved for species richness. Thus, for the second study at Kingston, 6 replicate quadrats per Position were used.

The 2-dimensional MDS plot showed a clear separation of samples based on Position, with each Position distinct from the other two (Figure 7.2). This was supported by the one-way ANOSIM which indicated that Positions had dissimilar species and/or abundances of those species (Global R = 0.843, p = 0.002). Furthermore, each pairwise comparison was also significant (p = 0.029 in each case) with Bare sand and wrack Piles most dissimilar (R = 1.000), followed by wrack Piles and among Wrack (R = 0.981), and Bare sand and among Wrack (R = 0.635). 2-D stress was low (0.01) indicating that the plot was an excellent 2-D representation of the relationships among the samples (Clarke & Warwick 1994).

Kingston: Cleared vs. natural areas

Descriptive findings

A total of 3914 individuals, comprising 23 species were collected (Table 7.3). Of the 72 pit-fall traps that were deployed, 4 traps were devoid of fauna. There were, on average, 54 (± 8) individuals and 2.5 (± 0.2) species per trap. The two sub-samples per quadrat were pooled, resulting in every quadrat having at least one individual present. There were, on average, 109 (± 22) individuals and 3.7 (± 0.3) species per quadrat (n = 36 quadrats). Abundance ranged between 1 and 407 individuals per quadrat and species richness ranged between 1 and 8 species per quadrat. Twelve of the 23 species were considered 'rare'; 8 species occurred only once (singletons) and a further 4 occurred only twice (doubletons). Thus, of the 23 species, 11 species were considered 'common'. One species of weevil, *Aphela phalenoides*, accounted for over 52% of the total individuals, and another species, the talitrid amphipod *Talorchestia quadrimana*, accounted for 46% of the abundance (Table 7.3). Thus, these two species contributed 97% of the total abundance.

The mean abundance was much greater in the Natural area than in the Cleared area (214 ± 25 vs. 3 ± 0.3 individuals, respectively, Figure 7.3a, Table 7.3). Species richness was also higher for the Natural area than for the Cleared area (4.8 ± 0.3 vs. 2.6 ± 0.3 species, Figure 7.3b, Table 7.3). Quadrats in Bare sand had, on average, the highest number of individuals (123 ± 39) and species (3.9 ± 0.4) whilst quadrats in wrack Piles had the lowest mean abundance (90 ± 31 individuals) and species richness (3.6 ± 0.4 species) (Figure 7.3). Quadrats among Wrack had mean abundance of 113 (± 44) individuals (Figure 7.3a) and species richness of 3.7 (± 0.6) species (Figure 7.3b).

Wrack cover (in each quadrat) ranged between 0 and 100% and was, on average, 58% (± 6). Wrack cover was higher in the 'Cleared' area than in the 'Natural' area (78 ± 7% vs. 39 ± 9%, respectively). The Bare sand Position had the lowest wrack cover (22 ± 7%), compared to wrack Piles (60 ± 10%) and among Wrack (94 ± 2%) quadrats.

Univariate analyses

Two-way ANOVAs indicated that the 'Natural' area had higher abundance and species richness than the 'Cleared' area ($p < 0.001$ for both analyses, Table 7.4). There were no other significant main effects or interactions (Table 7.4). Percent wrack cover (per quadrat, √- transformed) was used as a covariate in a 2-way ANCOVA. The covariate was not significant (p = 0.362 and 0.058 for abundance and species richness, respectively) and the main effect of ‘Area’ remained significant ($p < 0.001$ for both analyses, Table 7.4).

Macrofauna: Multivariate analyses

The 2-dimensional MDS plot showed that the samples from the ‘Cleared’ area were more spread out that those from the ‘Natural’ area (Figure 7.4). This was supported by the multivariate dispersion index (MVDISP routine in PRIMER), which was higher for the ‘Cleared’ samples (1.438) than for the ‘Natural’ samples (0.562). The ‘Natural’ samples plotted in a tightly clustered group that overlapped some of the ‘Cleared’ samples (Figure 7.4). There did not appear to be any grouping based on Position (Figure 7.4). The 2-D stress was low (0.02) indicating that the plot was a good 2-dimensional representation of the relationships among the samples (Clarke & Warwick 1994).

The interpretation of the MDS was supported by ANOSIM. The ANOSIM Global R value for ‘Area’ was 0.232 ($p = 0.001$), indicating significantly-different macrofaunal communities between ‘Cleared’ and ‘Natural’ areas. The ANOSIM indicated, however, that macrofaunal communities were similar among Positions (Global R = 0.005, $p = 0.410$). The SIMPER analysis identified two species as consistent indicators of ‘Area’ (i.e. had Dissimilarity/SD > 1, Clarke & Warwick 1994). These were the weevil *A. phalenoides* and the beach-hopper *T. quadrimana,* which both had greater abundances in the ‘Natural’ area than in the ‘Cleared’ area.

Main study: Experimental removal of wrack- 4 beaches sampled in 2 seasons

Removal of wrack and composition of removed material

Over the 4 beaches and 2 visits, a total of 928m^2 of beach was raked. The area raked for each plot was between 10 and 45m^2 and was, on average, 29m^2 (± 1.4) (n = 32). This equated to an average of 0.52% (± 0.05) of the study site area but only 0.02% (± 0.003) of the total beach area per plot. On a single visit to a beach, between 0.19 and 1.07 % of the study area was raked. Raking was carried out in the driftline, which (by definition) has the highest wrack cover of any area of the beach. Prior to raking, plots had between 5 and 75% wrack cover, with mean wrack cover of 26% (± 3). Following raking, mean wrack cover in the raked plots was reduced to 2.2% (± 0.2). After raking, wrack cover in the Cleaned plots ranged between 1 and 5%. Thus, although only a small percentage of the beach was raked, 19% of the DL area was raked and a large proportion of the wrack present was removed.

A total of 1571kgWW or 655 kgDW of material was removed. The material removed contained a mixture of sand and wrack. Sand comprised 62% (± 2) of the WW and 81% (± 1) of the DW. Thus, most of the material removed was sand rather than wrack. There was a strong, positive relationship between the WW and DW of material (sand and wrack), sand and wrack removed (Figure 7.5). Thus, for the remaining analyses kgDW was used as the units to enable comparison between this study and others.

The % DW of sand was not related to the amount of material removed, % wrack cover prior to raking or the area of beach raked (Figure 7.6). The % DW of sand did, however, differ significantly with the interaction of Visits and Beaches (Table 7.5).

The area raked per plot (10 - 45 m^2) varied considerably (due to differences in the width of the driftline) and there was no relationship between the area of beach raked (m^2) and the amount of material, sand or wrack removed (Figure 7.7). Thus the amount of material, sand and wrack removed (kgDW) was standardized to per unit area ($kgDWm^{-2}$) to enable comparisons between plots, visits and beaches. The mean amount of material removed was 0.71 $kgDWm^{-2}$ (± 0.12) and there was a large range with between 0.06 and 2.62 $kgDWm^{-2}$ removed. The amount of sand and wrack removed ranged between 0.05 and 2.13 $kgDWm^{-2}$ of sand (mean 0.57 ± 0.09 $kgDWm^{-2}$) and 0.01 and 0.61 $kgDWm^{-2}$ of wrack (mean 0.14 ± 0.03 $kgDWm^{-2}$). There were significant, positive relationships between the % cover of wrack prior to raking and the amount of material, sand and wrack removed per m^2 (Figure 7.8).

The amount of material and wrack removed per m^2, differed significantly with the interaction of Beach and Visit ($p = 0.039$ and $p < 0.001$, respectively, Table 7.5). The amount of sand removed per m^2, differed significantly between Visits ($p < 0.05$) (Table 7.5). For the amount of material removed per m^2, the inclusion of the covariate (% wrack cover prior to raking) did not change the significance of the other effects and the covariate itself was not significant. The covariate (% wrack cover prior to raking) was significant in the ANCOVA for the amount of sand removed per m^2 but its inclusion did not change the significance of the main effects or the interaction. For the amount of wrack removed per m^2 the covariate was significant (p = 0.002) and the interaction of Visit and Beach remained significant. The main effect of Visit was also significant but this main effect was subsumed by the significant interaction.

Macrofauna: Descriptive findings

Of the 254 pit-fall traps that were deployed and retrieved over the sampling effort, only one trap was devoid of fauna. A total of 4765 individuals, comprising 44 species were collected. The taxa found were very similar to those found in Chapter 3, which are listed in Appendix C. An additional 8 taxa were found in this study (Appendix C) including 4 beetle species. There were, on average, 19 (± 1) individuals and 3.7 (± 0.1) species per trap. There were up to 159 individuals and 8 species per trap. The two sub-samples (quadrats) were pooled for each plot yielding, on average, 75 (± 7) individuals and 6.6 (± 0.3) species per plot (n = 63 plots). Species richness ranged between 2 and 13 species per plot, and the number of individuals was between 9 and 221 individuals. Of the 44 species recorded, 18 species were considered ‘rare’; 12 species occurred only once (singletons) and a further 6 occurred only twice (doubletons). Thus, of the 44 species, 26 species were considered ‘common’, and these accounted for over 99% of the individuals. Five species each accounted for over 5% of the total individuals; the talitrid amphipod *Talorchestia quadrimana* (39%), the beach pill-bug *Actaecia pallida* (15%), the weevil *Aphela phalenoides* (15%), a mite Parasitidae sp. 1 (13%) and a spider Lycosidae sp. 2 (5%).

The 44 ‘species’ represented 17 orders. Eleven of the 17 orders were monospecific. The Order Amphipoda contributed only 1 species, *T. quadrimana,* but that species alone accounted for 55% of the abundance. The Coleoptera (beetles) had the highest species richness (17 species) and collectively contributed 15% of the abundance. Diptera contributed 5 species but less than 1% of the total abundance. Isopoda, Hymenoptera and Araneae each contributed 3 species, and the Parasitidae contributed 2 species. Both the Isopoda and Parasitidae were reasonably abundant, collectively contributing 10 and 9% of the abundance, respectively, and both orders were dominated by one species, *A. pallida* and Mite sp.1, respectively.

Mean abundance was slightly higher for the Cleaned plots than for the Natural plots (81 ± 10 individuals vs. 68 ± 10 individuals) but species richness was higher in the Natural plots than the Cleaned plots (7.0 ± 0.4 vs. 6.2 ± 0.4 species) (Figure 7.9). Both abundance and species richness were highest at Normanville (123 ± 18 individuals and 8.0 ± 0.4 species) (Figure 7.9). Moana had the lowest abundance (50 ± 8 individuals) but despite this, the species richness was relatively high at this beach (7.9 ± 0.6 species) (Figure 7.9a). Aldinga had the lowest species richness (5.2 ± 0.5 species) (Figure 7.9b). Aldinga and Robinson Point had similar abundances and species richnesses. Mean abundance was higher in July than in December (95 ± 11 vs. 55 ± 7 individuals, Figure 7.9a) but species richness was higher in December than in July (6.7 ± 0.5 vs. 6.5 ± 0.3 species, Figure 7.9b).

Mean wrack cover per plot, following the experimental clearing, was 2% (± 0.2) in Cleaned plots and was much higher (24 ± 3%) in Natural plots, with a larger range and variability in Natural plots (1-5% in Cleaned plots vs. 5-60% in Natural plots). After clearing, mean wrack cover was slightly higher at Robinson Point (21 ± 5%) compared with the other three Beaches (9-12%) due to the higher wrack cover in the Natural plots. Mean wrack cover did not differ greatly between Visits (15 ± 3% vs. 11 ± 2% for July and December, respectively).

Macrofauna: Univariate analyses

There was a significant, 2-way interaction between Visit and Beach for abundance ($p < 0.001$) and species richness ($p = 0.006$) (Table 7.6). None of the other interactions or main effects were significant (Table 7.6). For the main, fixed effect of Treatment, the F-ratio could not be constructed. The mean abundance and species richness for Cleared and Natural plots were not substantially different (Figure 7.9), however and none of the interactions involving Treatment were significant. The significant interaction involves the random Factors Visit and Beach and thus no further interpretation is required.

Percent wrack cover (per plot, after wrack removal, log (x +1)-transformed) was used as a covariate in the 3-way ANCOVA. The covariate was not significant for abundance and the 2-way interaction (Visit x Beach) remained significant for both abundance and species richness. The significance of the other interactions and main effects did not change.

Macrofauna: Multivariate analyses

The 2-dimensional MDS plot showed no separation of samples based on Treatment (Figure 7.10a). The MDS with symbols plotted by Beach and Visit showed clear separation of samples based on Beach and Visit (Figure 7.10b). The July samples were plotted separately from the December samples and in a tighter group (Figure 7.10b). Multivariate dispersion supported this observation; dispersion was higher for December than for July (1.354 vs. 0.623, IMD = 0.732). The separation of samples based on Beach (Figure 7.10b) was less obvious, with some overlap between the Beaches on each Visit, particularly in July. The stress was low (0.16) and thus the MDS was deemed an adequate representation of the relationships among the samples.

A set of three, two-way crossed ANOSIM tests were performed to identify differences in macrofauanl communities between Treatments, Visits and Beaches (Table 7.7). The tests were Visit x Treatment, Beach x Treatment and Visit x Beach. The Factors Beach and Visit were significant in both ANOSIM tests (Table 7.7) but Treatment was not significant in either the Visit x Treatment or Beach x Treatment test. Thus, macrofaunal communities differed among Visits and Beaches only. Examination of the pair-wise differences for Beaches when crossed with Visits indicated significant differences between each pair of Beaches (Table 7.8). When crossed with Treatment, there were pair-wise differences between each pair of beaches except Robinson Point and Aldinga (Table 7.8). The composite ‘factor’, including information on Visit, Beach and Treatment was used as the factor in a one-way ANOSIM. The Global R was large (0.806) and significant ($p = 0.001$) and of the 120 pair-wise comparisons, 107 were significant ($p < 0.05$).

Data were also analysed with the 44 species aggregated into their 17 Orders. The patterns seen were very similar (i.e. similar Global *R* and pair-wise *R* values) to those found for the data including all available taxonomic information (Table 7.7). The PRIMER routine RELATE was run to compare the similarity matrices produced from the 44 species and from the 17 Orders. The Rho value was high (0.882) and significant ($p = 0.001$) indicating that the data showed similar patterns, regardless of taxonomic level.

Four species were classified as indicator species (i.e. had Dissimilarity/SD > 1, Clarke & Warwick 1994 and contributed at least 10% to between-groups dissimilarity) of Visit (Table 7.9). These were Curculionidae sp. 1, Mite sp. 1, *A. pallida* and *T. quadrimana* (Table 7.9). Each of these species had greater abundances in July than in December. Five species were identified as consistent indicators of Beach in at least one pair-wise comparison; these were the four previously mentioned species plus the staphylinid beetle *Cafius* sp. 1 (Table 7.9).

BIOENV was used to match environmental data to the macrofaunal communities at the scale of a visit to a beach. The highest correlation ($\rho_w = 0.471$) included 3 variables: % wrack cover in the driftline; the width of DL; and the number of plant species in the wrack deposit. The best single variable predictor of macrofaunal communities was the % wrack cover in the driftline ($\rho_w = 0.335$).

BIOENV was used to match harvest material data (% sand content, amount of material, sand and wrack removed per m^2) to the wrack composition data to determine whether wrack composition affected the sand content or amount of the harvested material. The best predictor of the composition of the harvest material involved a combination of 5 plant species (*Acrocarpia paniculata, Ecklonia radiata, Hormosira banksii, Amphibolis grifithii* and *Zostera* sp.) but the correlation coefficient (ρ_w) was low at 0.295. The BIOENV procedure was also used to correlate environmental variables and patterns in the macrofaunal communities (for the cleared plots only). The highest correlation ($\rho_w = 0.481$) included 4 variables: the area raked; % wrack cover prior to raking; the amount of sand removed per m^2; and the number of species in the wrack deposit. The best single variable predictor of macrofaunal communities was the amount of wrack removed per m^2 ($\rho_w = 0.403$).

RELATE was used to assess concurrence between the similarity matrices for macrofauna and wrack composition. The Rho value was reasonably low (0.324) but was significant (p = 0.001), indicating that the wrack composition patterns and macrofaunal communities showed broadly similar patterns.

Discussion

The macrofauna encountered in this study were diverse, and their abundance, species richness and overall community structure varied in time and space. The fauna encountered and the patterns in abundance and species richness were similar to those reported in Chapter 3.

The macrofaunal communities present in the 'Natural' and 'Cleared' areas of Kingston were very different in terms of the abundance, species richness and other aspects of community structure. The 'Natural' area had a far more diverse and abundant macrofauna than the 'Cleared' area. These results concur with previous studies by Llewellyn and Shackley (1996) and Engelhard and Withers (1998), and support my observations on the lack of fauna at cleaned beaches along the Adelaide metropolitan coast. On visits to Glenelg and Seacliff (which experience beach cleaning and sand replenishment, respectively), I noted very few fauna on the beach or in the wrack samples I sorted for composition (Chapter 2). Furthermore, when I attempted to obtain macrofauna for stable isotope analysis in Chapter 6, I was unable to obtain sufficient (or any) individuals from these beaches. The 'Cleared' area communities were more dissimilar (i.e. had higher multivariate dispersion) than the 'Natural' communities. Dispersion has previously been used as an indicator of disturbance; more dispersed communities are considered more disturbed (Clarke & Warwick 1994). The index of multivariate dispersion (IMD) was 0.879, which is close to the maximum of +1. This suggests that the macrofaunal community in the 'Cleared' area had been disturbed, a likely result given the wrack removal activities that had recently taken place.

It is difficult to conclude whether the macrofaunal communities differed between 'Cleared' and 'Natural' areas due to the nature (type, age and volume) of wrack present, or due to the effects of wrack removal in the 'Cleared' area. The opportunistic nature of this sampling event meant that sampling the macrofaunal communities prior to the removal of wrack from the 'Cleared' area was not possible. Abundance and species richness values in the 'Cleared' area were similar to, although slightly lower than, those recorded in the pilot study (3.0 ± 0.3 vs. 12 ± 4 individuals and 2.6 ± 0.3 vs. 3.3 ± 0.6 species, respectively). The wrack deposits present in the Pilot study were similar, although not as uniform in cover, to those that remained after the wrack removal activities had taken place in the 'Cleared' area. The Pilot study was conducted approximately one month before the second study at Kingston. Thus, it may be possible that the macrofaunal community in the 'Cleared' area was similar to that which was previously there. It is likely that a combination of factors (i.e. both wrack deposit type and clearing) is responsible for the stark difference in the macrofaunal communities. It is clear; however, that the 'Natural' area of beach had a far higher diversity and abundance of macrofauna than the 'Cleared' area.

The experimental wrack removal method employed in the 2^{nd} study here did not appear to have any measurable effects immediately on the macrofaunal communities. There were no differences in abundance, species richness or macrofaunal communities due to the clearing Treatment. Wrack was removed from four beaches using hand-held rakes, and small areas of the driftline were cleared. It is likely that that the area of beach cleared was insufficient. I propose that macrofauna moved from adjacent (and quite close) wrack-covered areas and from the dune into the cleared plots. This is possible given the small areas cleared for each plot (between 10 and 45 m^2) and the mobile nature of many of these macrofauna (Egglishaw 1965), which may be moving between habitats on the beach. The feasibility of clearing larger areas of beach may make expanding this experimental work difficult. Raking wrack by hand was strenuous and time consuming, and furthermore may not adequately simulate the effects of mechanical cleaning. The use of raking machinery such as that used by local councils may provide a better solution. With the cooperation of councils and/or contracted workers, sampling could be conducted around (i.e. before versus after) planned wrack removal activities. Although due to a fortuitous coincidence, the success of the sampling at Kingston further supports the benefits of sampling in conjunction with large-scale wrack removal, such as that carried out by the council-appointed contractor. The timing of sampling, relative to the removal of wrack may also explain the lack of treatment effect.

Sampling was conducted on the following night only, and thus long-term effects post-clearing were not assessed. Although one may expect any effects of wrack removal to be greatest immediately following wrack removal, this may not be the case. Raking and sampling activities may disturb macrofauna and make them more active immediately following removal activities, or fauna that are present in the raked area but are buried deeper than the rake reaches may still be present in the plot. Thus, sampling macrofauna after a period of days to weeks may also be informative. This should be carried out in plots that have not been previously sampled, since repeated sampling of the same plots may result in diminishing numbers of macrofauna due to their direct removal rather than through any effect of clearing. Thus, I recommend that future studies use larger cleared areas of beach, attempt to use the same wrack removal methods and/or machinery used locally, and assess the macrofaunal communities repeatedly following wrack removal activities. Before, after, control, impact (BACI) studies with multiple ‘after’ samplings may be useful tools.

Of the material removed, 62% of the WW and 81% of the DW was sand. These values are similar to those reported in the literature; Piriz *et al*. (2003, in Argentinia) estimated sand content at 50%DW and Ochieng and Erftemeijer (1999, in Kenya) estimated 85%DW sand. Thus, a large proportion of the material removed is sand rather than wrack *per se*. The % of sand differed significantly in space and time but was not related to the amount of material removed, wrack cover or area of beach raked. This suggests that the proportion of sand in the material removed is determined by other factors. These may include the wrack type, wrack age and moisture content, sand characteristics (e.g. grain size), whether wrack is present on the surface or is buried, and wetting of the wrack by tides and precipitation. Whilst collecting wrack, I noted that freshly-deposited wrack, wrack that had been dampened by rain, and buried wrack all tended to have large quantities of adhering sand.

Using the data obtained here, I have estimated the amount of sand that would be removed if any of these beaches were raked. If we assume that raking occurs along the driftline of a beach (this is a conservative underestimate since raking is usually conducted over most of the high and mid-shore, pers. obs.), then we can use the average driftline width (6.1m) recorded for these beaches. Using the mean amount of sand removed per m^2 from this study (0.57 $kgDWm^{-2}$) as a multiplier, we can then estimate the mass of sand removed per linear km of beach (6.1m x 0.57 $kgDWm^{-2}$ x 1000m), giving 3477$kgDWkm^{-1}$. Beach length can also be included and thus we can estimate the mass of sand removed if any of these beaches were raked.

Applying the same calculations, I estimated the quantity of sand removed from beaches along the Adelaide metropolitan coast that are known to be raked. Glenelg, with a beach length of 2km (Short 2006a) would thus lose 6954$kgDWkm^{-1}$ of sand per raking event (Table 7.10). These calculations are approximate only. I have used the % DW of sand from hand raking, which may be different to that achieved using mechanical rakes, some of which have sieving devices to retain wrack and coarse material but return sand to the beach. Using the width of the driftline as the width of beach raked, I have conservatively estimated the width of beach that is raked; it may be much higher and would vary depending on the cover and distribution of the wrack deposit. I thus calculated the amount of sand that would be removed under various beach cleaning strategies, varying the length and width of beach that was raked (Table 7.10). Some of these estimates are extreme; the maximum mass calculated was 77.5 tonnesDW of sand (Table 7.10). Such extremes are unlikely to occur but these calculations provide an indication that the quantities of sand removed from beaches during beach cleaning activities may be quite substantial. Mechanical rakes that return sand to the beach may minimise the removal of the sand but I suggest that these sediments are physically disturbed, and may be more prone to erosion by wind and waves.

Conclusion

The macrofaunal community present in the 'Natural' area of Kingston beach was far more diverse and abundant, and included different species, compared to the 'Cleared' area at Kingston. My experimental removals of wrack did not appear to have any measurable effects on the macrofaunal communities but this research provides valuable insights into the methods that could be employed in future studies. The majority (81%DW) of the material that was removed from the beach in the raking experiments was sand, and my estimates of the amount of sand that would be removed in beach cleaning operations at a local beach suggest that losses of sand may be substantial. I recommend that future studies into the effects of wrack removal use large cleared areas of beach, attempt to use the same wrack removal methods and/or machinery used locally, and assess the macrofaunal communities repeatedly and over longer times following wrack removal activities.

List of Figures

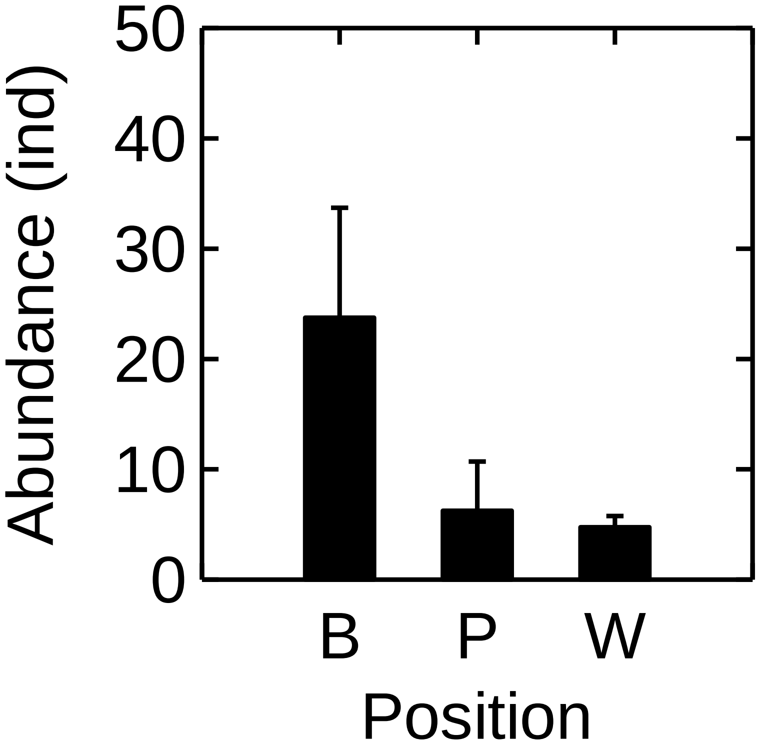
Figure 7.7. Scatterplots of a) the amount of material removed (kgDW, log-transformed, Pearson $r = 0.327$, $p = 0.067$), b) the amount of sand removed (kgDW, log-transformed, Pearson $r = 0.336$, $p = 0.060$) and c) the amount of wrack removed (kgDW, log-transformed, Pearson $r = 0.270$, $p = 0.135$) vs. the area of beach raked (m^2). $n = 32$ for each regression.

Figure 7.8. Scatterplots of a) the amount of material removed per m^2(√-transformed, Pearson $r = 0.586$, $p < 0.001$), b) the amount of sand removed per m^2 (√-transformed, Pearson $r = 0.584$, $p < 0.001$) and c) the amount of wrack removed per m^2 (√-transformed, Pearson $r = 0.536$, $p = 0.001$) vs. % wrack cover before raking (√-transformed). The lines plotted show the significant linear regressions. $n = 32$ for each regression.

Figure 7.9. Main study: Mean (± se) a) Abundance and b) species richness for each Beach, Visit and Treatment. Fills indicate Visit and Treatment: □ = December, Cleaned; ■ = December, Natural; ▨ = July, Cleaned; and ▒ = July, Natural.

Figure 7.10. Main study: MDS ordination plot of macrofaunal communities with a) symbols plotted by Treatment and b) symbols plotted by Beach and Visit. For a) Closed squares = Natural, open circles = Cleaned. For b) Circle = Aldinga, square = Moana, triangle = Normanville, diamond = Robinson Point. Open = July, Closed = December. 2-D Stress = 0.16.

a)


Abundance (ind)
50
40
30
20
10
0
B
P
W
Position

b)

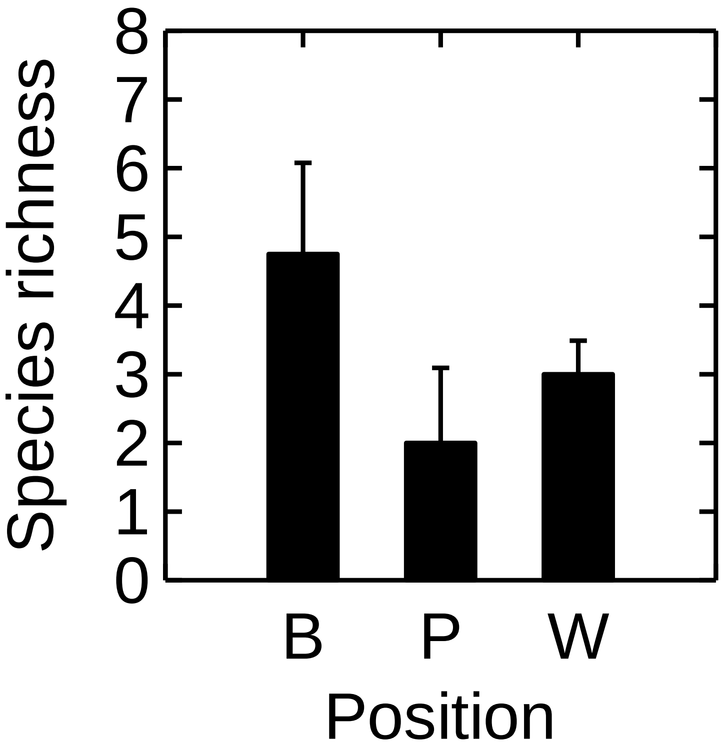

Species richness
8
7
6
5
4
3
2
1
0
B
P
W
Position

Figure 7.1

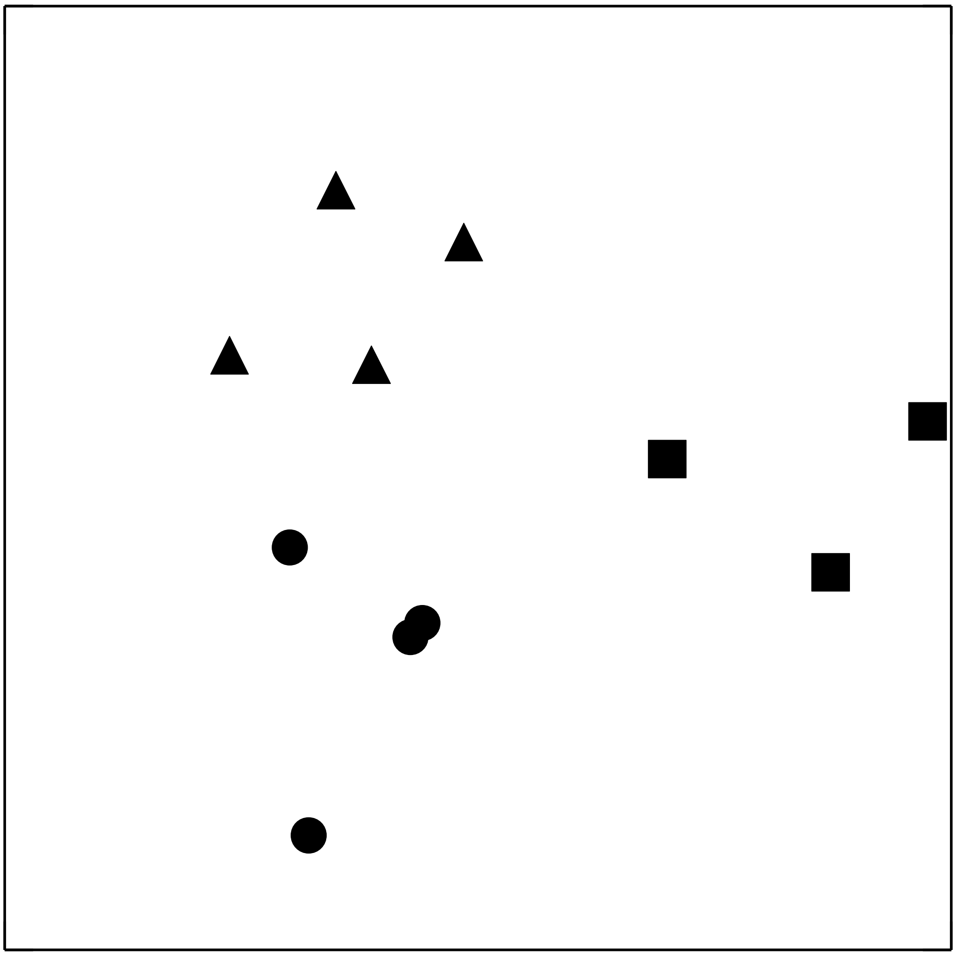
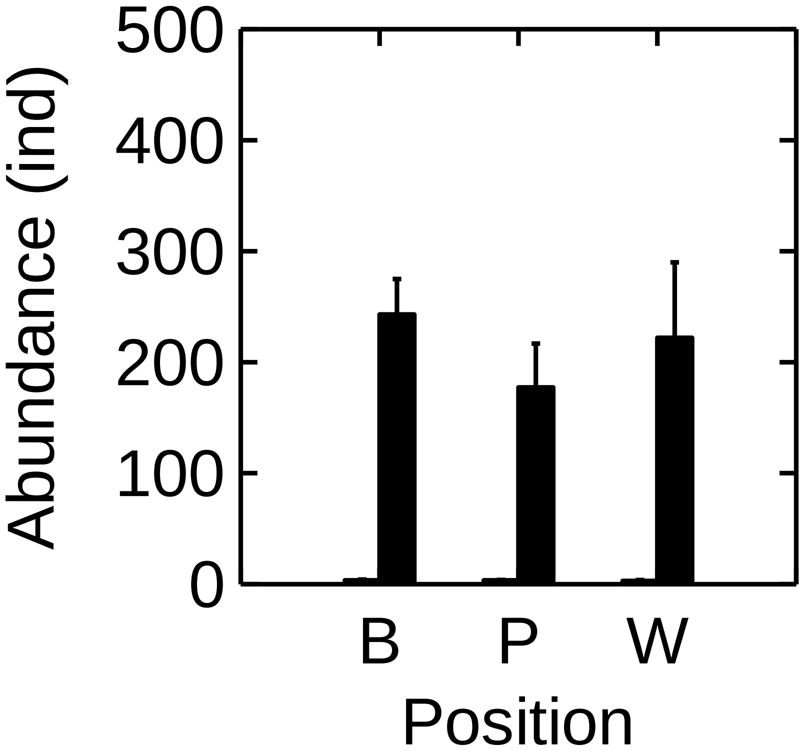
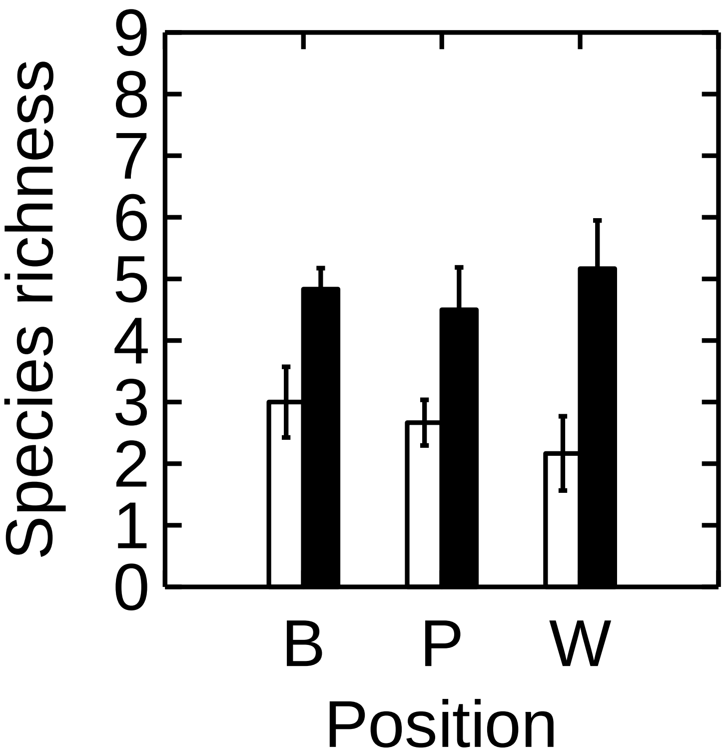


Figure 7.2

a)


Abundance (ind)
500
400
300
200
100
0
B
P
W
Position

b)


Species richness
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8
7
6
5
4
3
2
1
0
B
P
W
Position

Figure 7.3

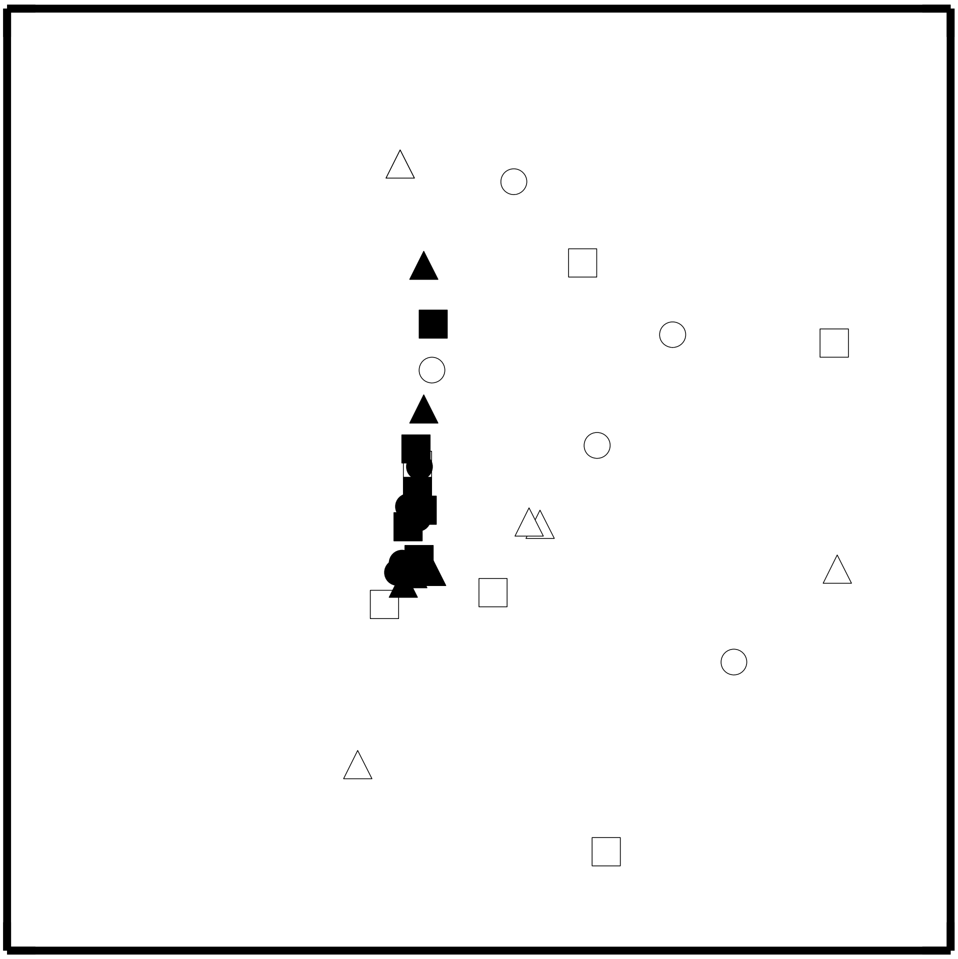


Figure 7.4

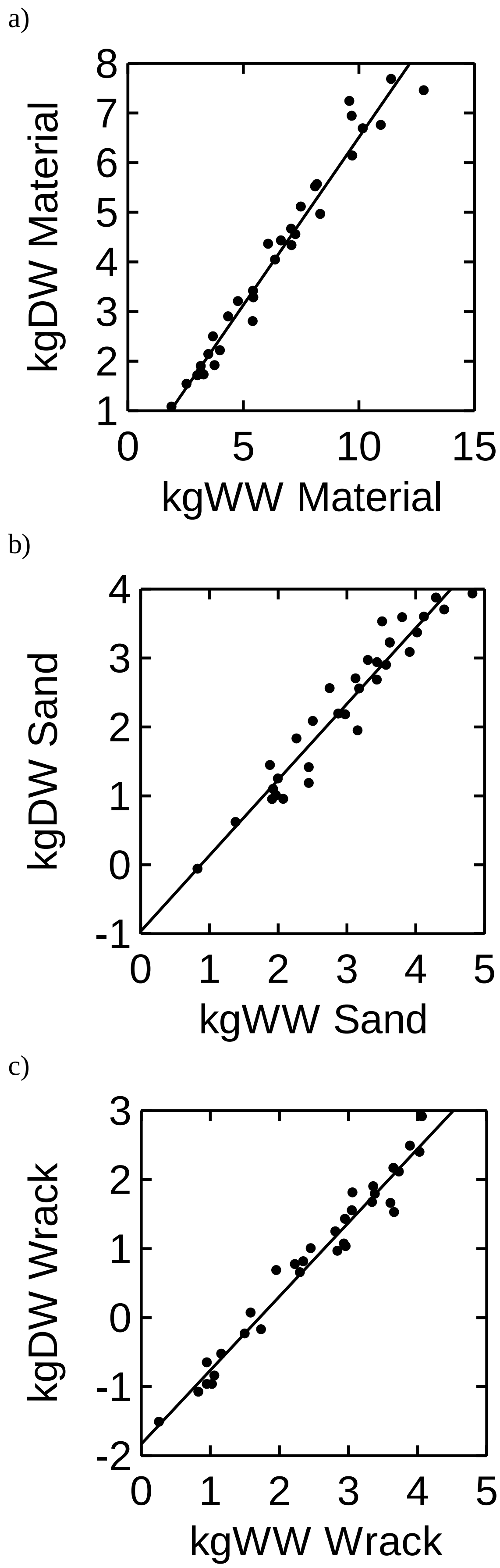

a)
kgDW Material
kgWW Material
8
7
6
5
4
3
2
1
0
5
10
15
b)
kgDW Sand
kgWW Sand
4
3
2
1
0
-1
0
1
2
3
4
5
c)
kgDW Wrack
kgWW Wrack
3
2
1
0
-1
-2
0
1
2
3
4
5

Figure 7.5

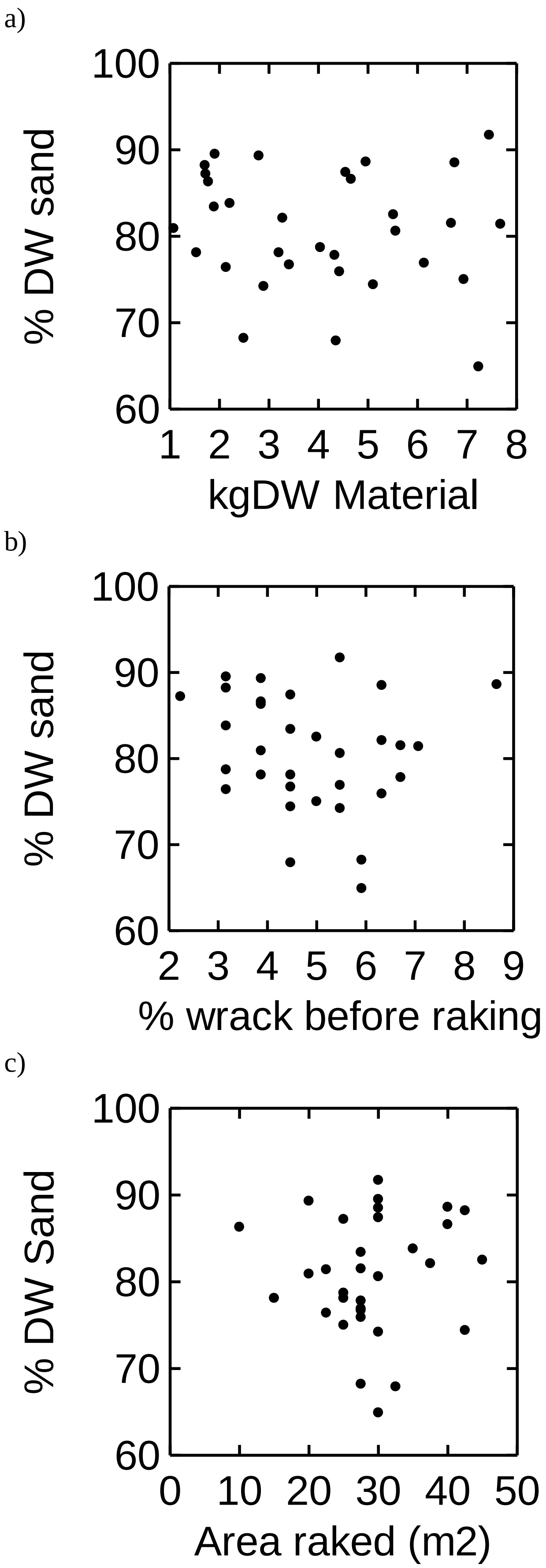
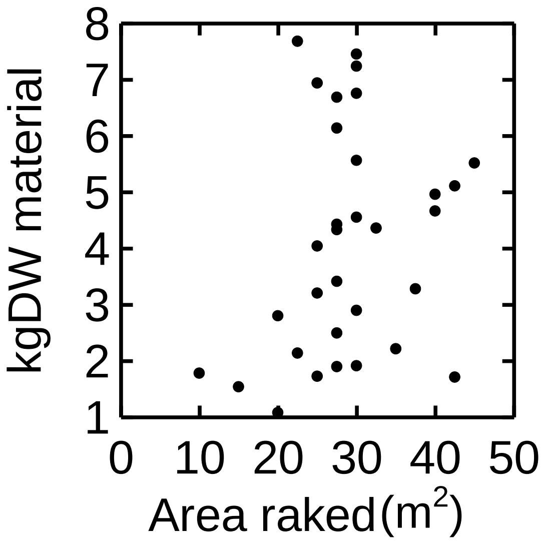

a)
100
90
80
70
60
% DW sand
1 2 3 4 5 6 7 8
kgDW Material
b)
100
90
80
70
60
% DW sand
2 3 4 5 6 7 8 9
% wrack before raking
c)
100
90
80
70
60
% DW Sand
0 10 20 30 40 50
Area raked (m2)

Figure 7.6

a)



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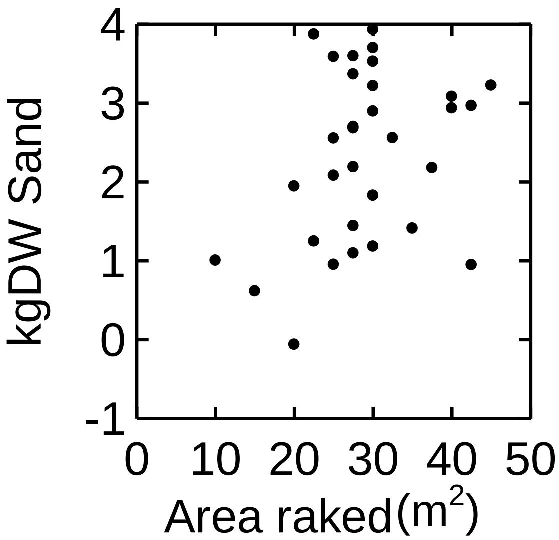


c)

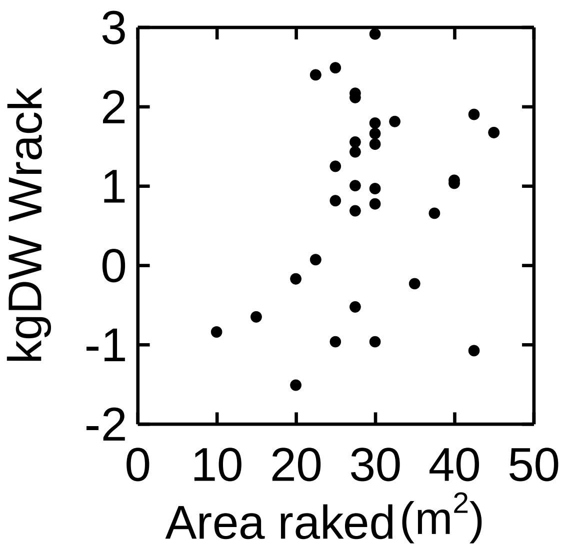
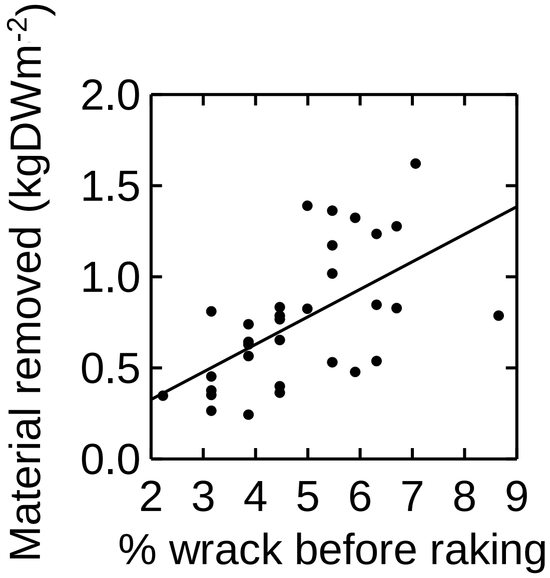


Figure 7.7

a)



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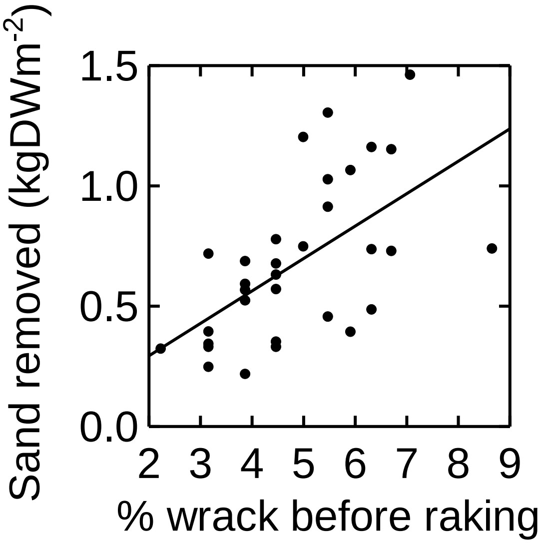


c)

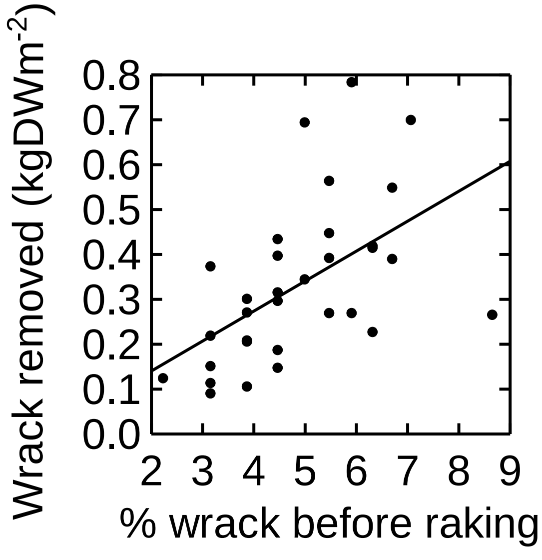
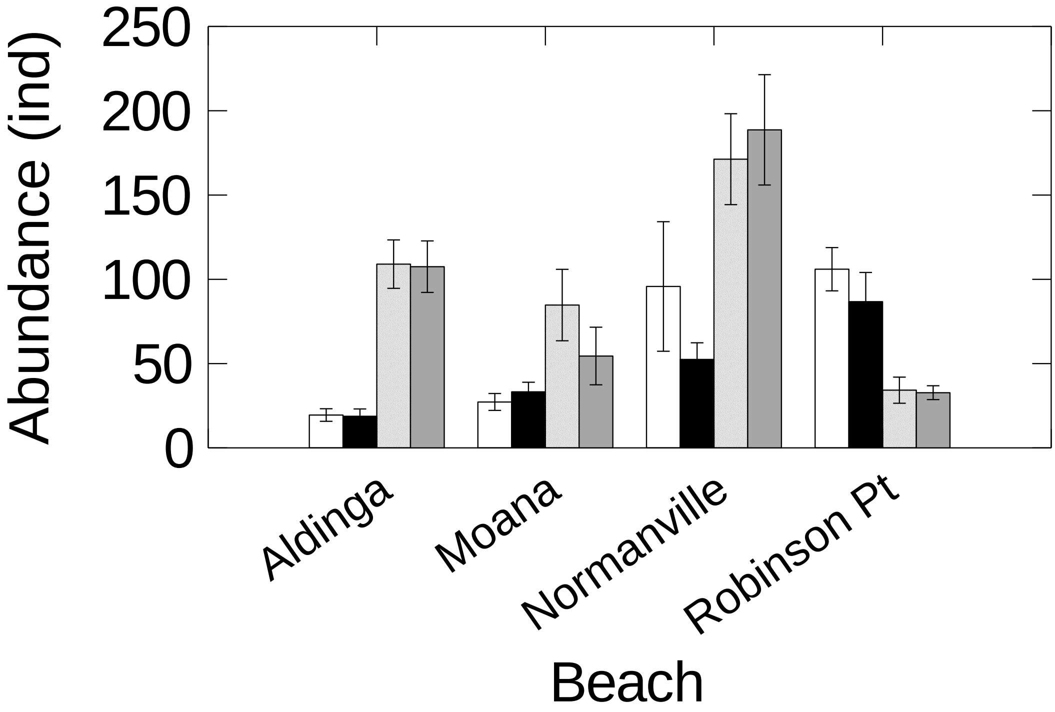


Figure 7.8

a)


Abundance (ind)
250
200
150
100
50
0
Aldinga
Moana
Normanville
Robinson Pt
Beach

b)

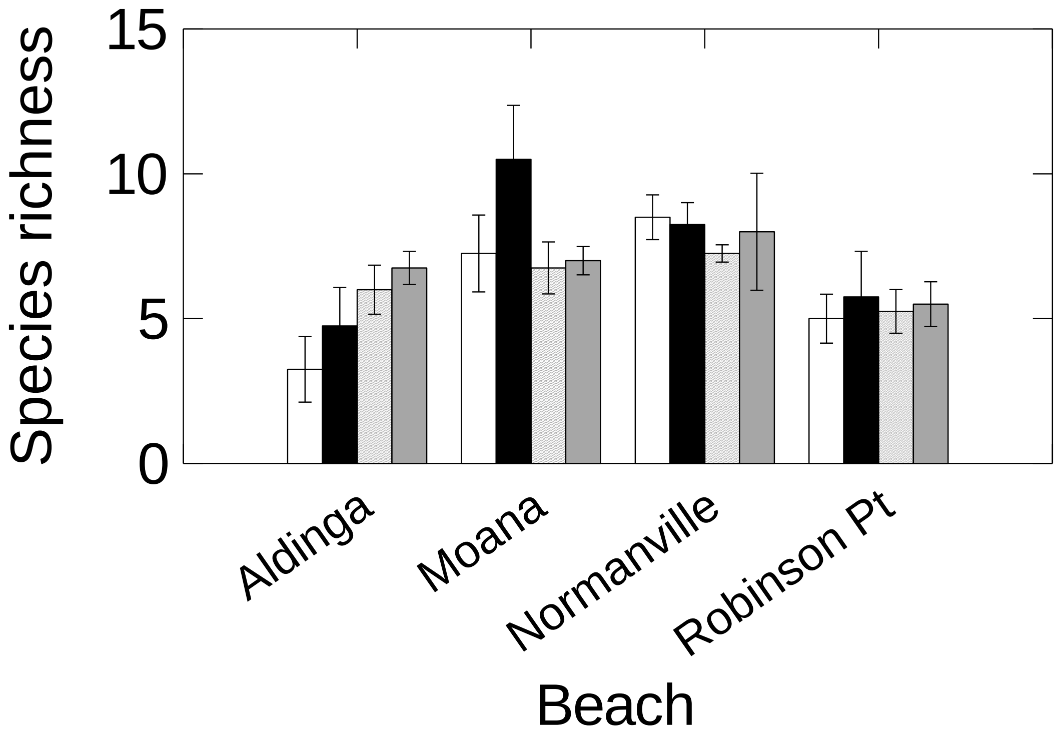
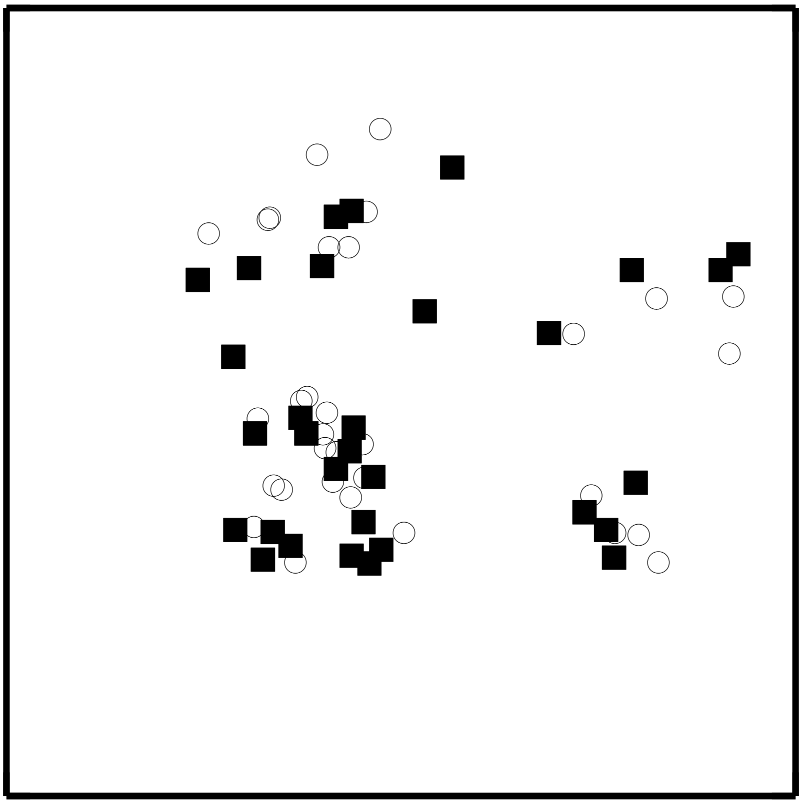

Species richness
15
10
5
0
Aldinga
Moana
Normanville
Robinson Pt
Beach

Figure 7.9

a)



b)

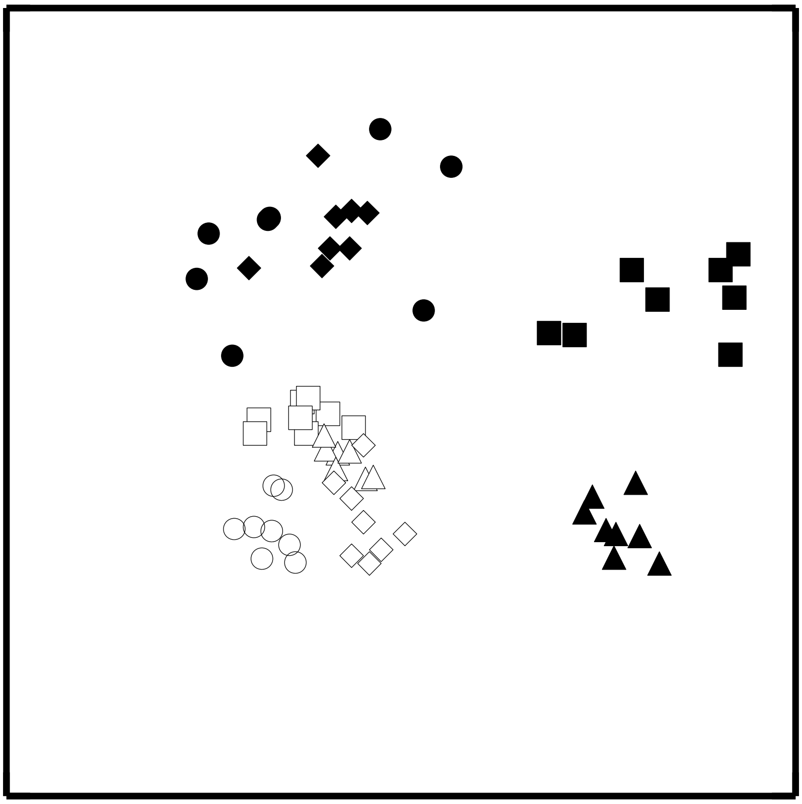


Figure 7.10

Table 7.1. Kingston Pilot Study: Numbers of individuals caught in pit-fall taps in Bare sand (B), wrack Piles (P) and among Wrack (W) at Kingston. *n* = 4 quadrats in each Position.

Position	**Bare sand**	**Wrack Pile**	**Among Wrack**	**Total**	**% of total**
Aphela phalenoides	46	1	8	55	40
Porcellionidae sp. 1	34	0	0	34	24
Cafius sp. 1	0	18	0	18	13
Grylloblattidae sp. 1	5	0	0	5	4
Belostromatidae	2	0	2	4	3
Coelopidae sp. 1	1	3	0	4	3
Lycosidae sp. 2	2	0	3	5	4
Araneae sp. 1	1	0	3	4	3
Coelopidae sp. 2	0	2	0	2	1
Scarabaeidae sp. 1	1	0	2	3	2
Formicidae sp. 2	1	0	1	2	1
Trachyscelis ciliaris	1	0	0	1	1
Tenebrionidae sp. 1	1	0	0	1	1
Talorchestia quadrimana	0	1	0	1	1
Total individuals	95	25	19	139	
Species richness	11	5	6	14	

Table 7.2. Kingston Pilot study: Summary of the one-way ANOVA for Position for abundance and species richness.

		Abundance (log (x+1)-transformed)			Species richness(√-transformed)		
Source	df	MS	*F*-ratio	*p*	MS	*F*-ratio	*p*
Position	2	2.510	3.337	0.082	0.897	2.326	0.153
Error	9	0.752			0.386		

Table 7.3. Kingston main study: Numbers of individuals caught in pit-fall taps in the 'Cleared' and 'Natural' areas at Kingston. *n* = 18 quadrats in each Area.

Order	**Species**	**Cleared**	**Natural**	**All**
Coleoptera	*Aphela phalenoides*	16	2004	2020
Crustacea	*Talorchestia quadrimana*	19	1775	1794
Coleoptera	*Cafius* sp. 2	2	21	23
Diptera	Coelopidae sp. 1	2	16	18
Arachnida	Thomisidae sp. 1	10	2	12
Arachnida	Lycosidae sp. 2	5	3	8
Coleoptera	Curculionidae larva sp. 1	0	8	8
Coleoptera	Curculionidae sp. 1	0	6	6
Coleoptera	Carabidae sp. 4	3	0	3
Coleoptera	Carabidae sp. 3	0	3	3
Mecoptera	Mecoptera larva sp. 1	0	3	3
Coleoptera	Curculionidae sp. 2	0	2	2
Coleoptera	Carabidae sp. 1	0	2	2
Coleoptera	Coleoptera, Unknown family	1	1	2
Coleoptera	Elateridae sp. 1	0	2	2
Coleoptera	Scarabaeidae sp. 2	0	1	1
Coleoptera	Carabidae sp. 2	0	1	1
Coleoptera	Tenebrionidae sp. 2	0	1	1
Grylloblattodea	Grylloblattidae sp. 2	1	0	1
Coleoptera	Tenebrionidae sp. 1	1	0	1
Diptera	Coelopidae sp. 2	0	1	1
Myriapoda	Julidae sp. 1	0	1	1
Trichoptera	Trichoptera larva sp. 1	0	1	1
	Abundance	60	3854	3914
	Species richness	10	20	23
	Mean % wrack	78	39	59

Table 7.4. Kingston: Summary of the two-way ANOVAs for Area (Cleared vs. Natural) and Position (Bare sand, wrack Piles or among Wrack) for abundance and species richness. Significant *p*-values are indicated in **bold**.

		Abundance (log (x+1)-transformed)			Species richness (√-transformed)		
Source	df	MS	*F*-ratio	*p*	MS	*F*-ratio	*p*
Area	1	131.467	617.297	< **0.001**	3.264	28.411	< **0.001**
Position	2	0.141	0.660	0.524	0.046	0.400	0.674
Area x Position	2	0.150	0.704	0.502	0.123	1.074	0.354
Error	30	0.213			0.115		

Table 7.5. Main study: Summary of the two-way ANOVAs for Visit and Beach % DW sand, the amount of material, sand and wrack removed per m^2 ($kgDWm^{-2}$). Significant *p*-values are indicated in **bold**.

		% DW sand			Material removed (√-transformed)		
Source	df	MS	*F*-ratio	*p*	MS	*F*-ratio	*p*
Visit	1	60.775	0.262	NS	1.786	9.302	NS
Beach	3	29.181	0.126	NS	0.148	0.771	NS
Visit x Beach	3	231.865	9.821	< **0.001**	0.192	3.265	**0.039**
Error	24	23.610			0.059		

Continued

		Sand removed (√-transformed)			Wrack removed (√-transformed)		
Source	df	MS	*F*-ratio	*p*	MS	*F*-ratio	*p*
Visit	1	1.384	11.533	< **0.05**	0.383	4.074	NS
Beach	3	0.134	1.117	NS	0.019	0.202	NS
Visit x Beach	3	0.120	2.342	0.098	0.094	8.582	< **0.001**
Error	24	0.051			0.011		

Table 7.6. Main study: Summary of the three-way ANOVA for Visit, Beach and Treatment for abundance and species richness. Significant *p*-values are indicated in **bold**.

		Abundance (log (x +1)-transformed)			Species richness (√- transformed)		
Source	df	MS	*F*-ratio	*p*	MS	*F*-ratio	*p*
Visit	1	5.703	1.044	NS	0.016	0.027	NS
Beach	3	2.658	0.486	NS	1.502	2.537	NS
Treatment	1	0.231		undefined	0.472		undefined
Visit x Beach	3	5.464	43.096	< **0.001**	0.592	4.693	**0.006**
Visit x Treatment	1	0.007	0.026	NS	0.101	1.464	NS
Beach x Treatment	3	0.014	0.051	NS	0.067	0.971	NS
Visit x Beach x Treatment	3	0.274	2.162	0.105	0.069	0.543	0.655
Error	47	0.127			0.126		

Table 7.7. Main study: Summary of the three, 2-way crossed ANOSIM tests for log (x+1)-transformed data using a) all 44 species individually and b) data aggregated to Order. *p* –values are in **bold** when significant at α = 0.05.

a) By species

Factor	Global *R* (*p*)		Factor	Global *R* (*p*)
Visit	0.473 (**0.001**)	x	Treatment	-0.030 (0.795)
Beach	0.270 (**0.001**)	x	Treatment	-0.058 (0.922)
Visit	0.965 (**0.001**)	x	Beach	0.878 (**0.001**)

b) By order

Factor	Global *R* (*p*)		Factor	Global *R* (*p*)
Visit	0.343 (**0.001**)	x	Treatment	-0.025 (0.751)
Beach	0.281 (**0.001**)	x	Treatment	-0.025 (0.641)
Visit	0.907 (**0.001**)	x	Beach	0.819 (**0.001**)

Table 7.8. Main study: ANOSIM Pairwise comparisons log (x+1)-transformed data for Beach in 2-way crossed ANOSIM for a) Beach x Visit and b) Beach x Treatment. For a) *p* = 0.001 for all pair-wise tests and thus are not shown in the table. For b) *p* is indicated in brackets and in **bold** when significant at α = 0.05.

a) Beach x Visit

	Robinson Pt	Moana	Aldinga	Normanville
Robinson Pt	-			
Moana	0.929	-		
Aldinga	0.645	0.946	-	
Normanville	0.834	0.864	0.996	-

b) Beach x Treatment

	Robinson Pt	Moana	Aldinga	Normanville
Robinson Pt	-			
Moana	0.282 (**0.001**)	-		
Aldinga	0.090 (0.112)	0.192 (**0.005**)	-	
Normanville	0.267 (**0.004**)	0.353 (**0.001**)	0.472 (**0.001**)	-

Table 7.9. Study 2: Indicator taxa as identified by SIMPER. Only consistent species contributing over 10% to the dissimilarity and that have Diss/SD > 1 are presented.

Species	**Comparison**			**Diss/SD**	**% Contribution**
		Visits			
	July		**December**		
Curculionidae sp. 1	21.5	>	1.5	1.8	12.3
Mite sp. 1	18.5	>	0.7	1.2	10.7
A. pallida	14.3	>	8.2	1.3	10.5
T. quadrimana	33.6	>	25.5	1.6	10.5
		Beaches			
	Robinson Pt		**Moana**		
Staphylinoidea sp. 1	0.6	<	7.0	2.0	12.1
A. pallida	9.4	>	2.6	1.5	10.1
	Robinson Pt		**Aldinga**		
A. pallida	9.4	>	0.9	1.5	16.8
Mite sp. 1	1.1	<	32.7	1.2	16.4
Curculionidae sp. 1	3.8	<	13.6	1.3	12.3
	Robinson Pt		**Normanville**		
T. quadrimana	45.4	>	38.7	1.4	14.4
A. pallida	9.4	<	33.1	1.2	10.4
	Moana		**Aldinga**		
Mite sp. 1	2.4	<	32.7	1.7	11.8
Staphylinoidea sp. 1	7.0	>	1.3	1.8	10.1
	Moana		**Normanville**		
Staphylinoidea sp. 1	7.0	>	0.2	3.8	12.6
A. pallida	2.6	<	33.1	1.9	11.2
	Aldinga		**Normanville**		
A. pallida	0.9	<	33.1	3.1	17.0
T. quadrimana	13.2	<	38.7	1.4	11.9
Mite sp. 1	32.7	>	1.1	1.2	11.9

Table 7.10. Projected quantities (tonnes DW) of sand that would be removed from Glenelg Beach under different raking strategies based on the length and width of the beach raked. Beach length was obtained from Short (2006a) and beach width (mean, minimum and maximum) was obtained from Chapter 3 of this thesis. Mean DL width is from this Chapter. Calculations are based on the mean amount of sand removed per area of beach raked in this study (i.e. 0.57kgDWm^{-2}).

				Proportion of Glenelg beach width		
Proportion of Glenelg beach length	**Length (km)**	**Mean DL width 6.1m**	**1/2 of Mean 21.5m**	**Minimum 30m**	**Mean 43m**	**Maximum 68m**
1/4	0.5	1.7	6.1	8.6	12.3	19.4
1/2	1.0	3.5	12.3	17.1	24.5	38.8
3/4	1.5	5.2	18.4	25.7	36.8	58.1
Entire beach	2.0	7.0	24.5	34.2	49.0	77.5