CHAPTER THREE: BEACH MORPHOLOGY AND THE EFFECTS OF WRACK DEPOSITS ON SEDIMENT CHARACTERISTICS

Abstract

The amount of wrack deposited and retained on a beach may be affected by the beach's morphology. Conversely, wrack deposits have the potential to modify sediment dynamics on the beach face through accumulation and erosion of sediments around wrack deposits, and the incorporation of organic matter into beach sands. The aims of this chapter were thus to determine whether beach morphology differed temporally and spatially and whether the cover of wrack differs between beaches of different morphologies. I also assessed the effects of wrack deposits on sediment characteristics (organic matter content, sand particle size and sand compaction). Seventeen beaches in three regions of South Australia were sampled on 2 occasions; April ('summer profile') and August ('winter profile') of 2006. Beach profiles were plotted and four measures of beach morphology were calculated (beach width, beach fall, beach-face slope and Beach Index, BI, which can be used to classify beaches into their morphological types). Sediment samples were taken above, below the driftline and within the driftline (DL), including in both wrack patches and bare sediments in the driftline.

Beach profiles varied spatially and temporally but there was no systematic trend for wider, taller or steeper beaches, or towards beaches of a Reflective or Dissipative type, to occur on either visit or among the three study regions. There were no relationships between wrack cover and either beach width, beach fall or beach-face but as BI increased (i.e. on more Dissipative beaches) the cover of wrack also increased. At the scale of the whole beach, there was no relationship between wrack cover organic matter content but bulk density was negatively correlated with wrack cover, i.e. beaches with more wrack had less compacted sediments. Sediments from the South East region were consistently higher in organic matter content than those from the Fleurieu or Metro regions. This may be driven by both the higher cover and higher proportion of algal and kelp wrack in the South East region compared to the

other two regions. There were no differences in sediment characteristics (mean particle size, organic matter content and sand compaction) between wrack-covered and bare sand areas within the driftline. This result was somewhat surprising given the large wrack accumulations and visible differences in sediments (e.g. sand colour and the presence of wrack fragments) within the driftline. A possible explanation is the transience and variability in the size (cover and depth) of wrack deposits. Alternatively, the effects of wrack deposits may only occur in the surface sediments, and the depth of the sediment cores (15cm) taken in this study may have been too deep.

Beach morphology may thus affect the amount of wrack present on sandy beaches. In addition, wrack deposits have a limited but potentially important capacity to modify beach sediments through the input of organic matter and the reduction of sand compaction.

Introduction

The amount of wrack deposited and retained on a beach may be affected by the beach’s morphology (e.g. sediment particle size, beach slope and beach type) but, to date, few studies have investigated this link. Only one study (Orr *et al.* 2005) has investigated whether particle size influences wrack deposition. Orr *et al.* (2005) found that cobble beaches had a greater standing load and daily input of wrack than gravel or sand beaches, and proposed that this was due to wrack being trapped in the spaces between the cobbles. A possible confounding effect, which the authors did not appear to consider, was that cobble beaches have greater inputs and retention rates due to their close proximity to sources of macrophytes. The authors acknowledge that there were differences in the species composition of wrack deposits between the substrate types, and that there is favourable habitat for some types of algae (*Fucus* spp.) living in the low shore of the (cobble) beaches.

Wrack deposits can modify sediment dynamics on the beach face through accumulation and erosion of sediments around wrack deposits (Hemminga & Nieuwenhuize 1990; Nordstrom *et al.* 2000; 2006). Wrack deposits trap sediments on the beach by catching wind-blown sand of terrestrial (Hemminga & Nieuwenhuize

1990) and marine (Nordstrom *et al.* 2000) origin. Wrack deposits can also trap sand moved onto the beach by waves (Short & Hesp 1982) and may attenuate wave energy and reduce loss of sand due to water movements at high tide (McLachlan 1985). Previous studies have shown that wrack plays an important role in the development of coastal sand dunes (Hemminga & Nieuwenhuize 1990; Nordstrom *et al.* 2000). Wrack traps sediments as well as the seeds of pioneer dune vegetation (Nordstrom *et al.* 2000), which facilitates the stabilisation of the newly-forming dune. Gradual accretion of sand and wrack at the back of the beach, usually around the highest wrack line (i.e. the Spring tide high water), may result in the formation of a new frontal dune (Nordstrom *et al.* 2000). Dune formation rarely occurs on beaches that are mechanically cleaned because beach cleaning removes wrack and pioneer seeds (Nordstrom *et al.* 2000). Lower on the shore, trapping of wind-blown sand moving in an offshore direction can also prevent the loss of sand to the low shore and offshore (Nordstrom *et al.* 2000). As well as trapping sediments around them, wrack deposits can compact surface sediments and protect underlying sediments from erosion by wind and water (Nordstrom *et al.* 2006). Nordstrom *et al.* (2006) also found that downwind of wrack deposits, which protect existing sands and trap mobile sediments, there was a lack of sand to replace that being removed, and thus there was an area of greater loss. Overall, wrack deposits add to the complexity of beach face, creating rises and dips in the beach-face and beach profiles (width, fall and slope) may be modified depending on the cover and volume of wrack on the beach.

The accumulation and erosion of sediments around wrack deposits may result in a shift in the particle size distribution of sediments around and under wrack deposits but, to date, there has been little research conducted. Ince *et al.* (2007) found that there was an interactive effect of wrack cover (high versus low) and the position on the shore (upper and lower zones) on mean particle size. On beaches with high wrack cover, mean particle size was greater in the upper zone but on beaches with little or no wrack cover, mean grain size was greater in the lower zone (Ince *et al.* 2007). Their study, however, made comparisons at the scale of whole beaches but the effects of wrack accumulations of sediment-size distribution may occur at smaller spatial scales, i.e. immediately adjacent to wrack deposits. Wrack deposits can attenuate wave energy and increase filtration (McLachlan 1985; Ochieng &

Erftemeijer 1999), which may lead to greater accumulation of fine particles around wrack accumulations than occurs elsewhere on the beach.

Wrack deposits can provide large, and often the sole, inputs of organic matter (OM) to sandy beaches. Through decomposition, the consumption by detritivores, and re-working by wind and water, OM may be incorporated into beach sands. This has been shown for wrack deposits incorporated into sand dunes over long durations, with layers of sediment containing decomposing wrack being enriched in OM (mean 0.29%DW) compared to the overlying sediments (mean 0.13%DW) (Hemminga & Nieuwenhuize 1990). Evidence also exists that wrack can increase OM loads in sediments at shorter time scales. Rossi and Underwood (2002) found that by adding buried wrack to muddy and sandy sediments, total organic carbon increased, although this was a sporadic and variable result. Gheskiere *et al.* (2006) and Malm *et al.* (2004) found that by removing wrack through mechanical beach raking, total OM of beach (Gheskiere *et al.* 2006) and offshore sediments (Malm *et al.* 2004) decreased significantly. Conversely, some studies have reported that wrack has little effect on the OM content of sediments. Ince *et al.* (2007) found no difference in OM content between wrack-covered beaches and those with little wrack. Chapman and Roberts (2004) also reported that addition of wrack to saltmarsh habitats did not result in increased sediment organic matter content, although salt marshes are already relatively rich in OM compared to beaches. Lavery *et al.* (1999) found no effect of either long-term or short-term wrack removal on the OM content of estuarine sediments. Thus, whether mobile, surface deposits of wrack can increase the OM content of sands is debatable and requires further investigation.

South Australian sandy beaches span a range of morphological types (Short 2006b) but whether different types of beaches receive different amounts of wrack is, as yet, unknown. The potential for wrack deposits to affect the underlying sediments is also great but has also been largely ignored. The aims of this chapter were thus two-fold. Firstly, I aimed to determine whether beach morphology (beach width, beach fall, beach-face slope and beach index BI) differed temporally and spatially and whether the size (cover) of wrack deposits differs between beaches of different morphologies. Secondly, I aimed to assess the effects of wrack deposits on sediment characteristics such as sediment organic matter content, sand particle size, and sand compaction (bulk density and sediment penetration resistance). I tested the hypotheses that organic matter content and sand compaction would be positively correlated with % wrack cover, and mean particle size would be negatively correlated with % wrack cover. I also tested a series of hypotheses regarding whether sediment characteristics differed in sediments from various positions on the beach (i.e. at the driftline DL 'DL', above the DL 'ADL', and below the DL 'BDL'), and among sediments within the DL (i.e. in Bare sand 'DLB', under Wrack 'DLW', surface sediments 'DL0', and sediments at 10cm depth 'DL10'). I predicted that organic matter content (Malm *et al.* 2004; Gheskiere *et al.* 2006) and sand compaction (Nordstrom *et al.* 2006) will be greater at the DL (which has the highest wrack cover) than in the ADL or BDL, and that these variables will be greater for DLW sediments than for DLB sediments. For sand particle size, I predicted that fine sediments would accumulate around wrack deposits due to wave attenuation and trapping of wind-blown sand. I predicted that this would result in a smaller mean sediment particle size at the DL than the ADL or BDL and that mean particle size will be smaller under wrack deposits (DLW) compared to bare sand areas (DLB). I also tested whether organic matter content, mean particle size and sand compaction differed spatially and temporally.

Methodology

Site selection & sampling design

The sampling design for this chapter is similar to that used in Chapter 2; I sampled the same three Regions and 17 study beaches (Figures 2.1 and 2.2) but only 2 visits were made. Sampling was conducted in April and August of 2006. In April, beaches were considered to be in their 'summer profile', whilst in August beaches were in their 'winter profile'. Additional sampling for sediment compaction was also conducted in June of 2006 to enable a comparison of the two methods for assessing sediment compaction (i.e. bulk density and surface penetration resistance). Bucks Bay was sampled in June and August but not in April.

Field methods

On each beach a study site was selected haphazardly so that it was at least 100m from any rocky outcrops, groynes or structures on the beach or in the intertidal zone.

A study site consisted of a 100m alongshore section of beach and included the beach-face from the base of the first dune to the upper limit of the swash, including any tide pools or channels. The photopoint method (described in Chapter 2) was used to estimate % wrack cover for each beach.

Beach profiles

Beach profiles were created along transects oriented perpendicular to the dune. Transects sampled the entire beach face from the base of the first dune to the upper limit of the swash. A dumpy level (Horizon 2024 Auto Level, deviation = 2mm at 1km double run) and staff was used to measure the beach height at 1 or 2m intervals along the transect (Peterson *et al.* 2000) and, from this, beach profiles were plotted and three measures of beach morphology were calculated; i.e. beach width, beach fall and beach-face slope. Beach width (m) was measured as the distance from the base of the first dune to the upper limit of the swash (i.e. the length of the transect). Beach fall (m) was measured as the vertical height difference between the base of the first dune and the upper limit of the swash. Beach slope was calculated as Slope = Fall (m) / Width (m) and is a dimensionless measure. One transect was performed (n = 3) at each of 3 randomly selected locations within the 100m site. Beach profiles were created on two Visits; i.e. April and August.

Sediment core samples: Organic matter content and particle size

In both April and August, sediment samples were taken at the driftline (DL), which is defined as the line on the beach, parallel to the dune, with the greatest amount of freshly-deposited wrack. Samples were taken from Bare sand (DLB) or from under Wrack deposits (DLW). In August, sampling was also conducted at two additional beach levels: above the driftline, ADL; and below the driftline, BDL. On each beach, the ADL and BDL were positioned a random distance above and below the DL, respectively. Sediment cores were taken to a depth of 15cm using a cylindrical corer of 11cm diameter. Each sample was homogenised and a sub-sample was taken for use in OM content and particle-size analyses. Three, haphazardly-placed sediment cores were taken for each position or beach level.

Sand compaction: Bulk density and surface penetration resistance

Sand compaction was assessed using two methods, bulk density and surface penetration resistance. Sediments that are more compacted have a higher bulk density and a greater penetration resistance. Previous authors have used bulk density and penetration resistance as measures of the compaction of dune (Liddle & Greig-Smith 1974) and beach sands (Eleftheriou & McIntyre 2005) but bulk density and surface penetration resistance are not necessarily directly comparable. Each method was used on two Visits (April and June, and June and August, respectively) to enable comparisons between Visits for each method, and a direct comparison of the two methods could be made using the June data. Bulk density (April and June) was sampled within the DL at the sediment surface (0cm depth, DL0) and from 10cm depth (DL10). Penetration resistance was determined in June and August for six positions on the beach; within the DL at the sediment surface (DL0), at 10cm depth (DL10), in Bare sand (DLB) and under Wrack (DLW), and from the ADL and BDL (i.e. DLB, DLW, DL0, DL10, ADL and BDL). The methods comparison was carried out using the data from DL0 and DL10.

Bulk density samples were taken using an ice-cream scoop of fixed volume (17mL) to remove a standard sized sample from the top layer of sediment. Three replicate samples were taken at each depth or position. Penetration resistance ($kgcm^{-2}$) was determined using a pocket penetrometer (Geotester). The penetrometer head (either 6mm or 25mm diameter) was inserted into the sediment at an angle perpendicular to the sediment surface. Five replicate samples or measurements were taken for each depth, position or beach level. Samples from 10cm depth were taken by using a cylindrical corer of 11cm diameter to remove the sediment to a depth of 10cm. Disturbance and compression of the underlying sediments was minimised whilst removing the overlying sediment.

Laboratory methods

Organic matter content

Organic matter content was determined by loss on ignition (%). A sub-sample of sediment (approximately 5g) from each sediment core was dried to constant weight (80°C for 24 hours) and the dry weight (DW) determined. Sub-samples were ashed at

600°C for 60 minutes, cooled and the ash-free DW (AFDW) recorded. The loss on ignition is expressed as loss on ignition (%) = [(DW-AFDW)/DW]* 100.

Particle size

Particle-size analysis was conducted by two methods; dry sieving and laser diffraction. Sediment samples from April were dry sieved whilst samples from April were analysed using laser diffraction. For both methods, a sub-sample of each sediment core (approximately 100g) was dried to constant weight (80°C for 24 hours). Standard dry sieving methods were used. Sub-samples of sediment were weighed and shaken through a series of sieves (2000µm, 1000µm, 500µm, 250µm, 125µm, 63µm mesh) using a Rotap shaker for 15 minutes. The sediment remaining in each sieve and the collecting pan was then weighed for % size fraction. For the laser diffraction method, a Malvern Mastersizer 2000 with HydroMU attachment was used. The maximum particle size that can be used in this equipment is 2000µm. The sub-sample of dried sediment was therefore pre-sieved to remove particles >1000µm (2^{nd} largest dimension) (as per the recommendations of Malvern consultant, P. Barrett, personal communication, 2006), which were weighed dry to determine the % contribution to the whole sample. Approximately 4g of sediment per sample was used for each analysis. The pump speed was 3500 rpm, target obscuration was 7-10% and 5 consecutive measurements of 10 seconds were made. Sediment samples from Rapid Bay were not analysed using this method because the sediment grains were too coarse for analysis with the Mastersizer; samples were instead sieved as for the April samples.

Particles > 1000µm were removed from the sample prior to analysis by laser diffraction. This particle size distribution did not include these larger particles and thus they were mathematically re-incorporated into the particle size distribution by after analysis. For each sample, the sieve fractions (%, at quarter phi intervals) were exported from the Malvern software v5.31 and the data were corrected to include the >1000 µm fraction. For both sieving and laser diffraction, the software package Gradistat (Blott & Pye 2001) was used to calculate the mean sediment particle size for each sample using the Geometric Method of Moments (µm) and the Folk and Ward method (phi units). Mean particle size in phi units was used only for calculation of Beach Index (BI); mean particle size in µm was used in all other analyses.

Bulk density

Bulk density samples were dried to constant weight (80°C for 24 hours) and weighed (DW). The bulk density (BD) is calculated as: BD (gDW/mL) = gDW / volume (Eleftheriou & McIntyre 2005). The volume of each sample was 17mL and thus BD = gDW / 17mL.

Beach Index (BI)

Beach Index was calculated for each beach in April and August separately. Beach index was calculated such that BI = log10 (sand x tide / slope), where sand is the mean particle size in phi units + 1, tide is the maximum spring tide range in metres, and slope is the beach face slope (McLachlan & Dorvlo 2005). BI was calculated using the mean value of the three replicate transects from each beach. The maximum spring tide range was calculated separately for April and August using data obtained from the Australian Bureau of Meteorology (Paul Davill, National Tidal Centre, Bureau of Meteorology, pers. comm.). BI values can be used to classify beaches into their morphological types with BI values of < 1.5 considered as Reflective, 1.5 - 3.0 Intermediate and > 3.0 Dissipative (McLachlan & Dorvlo 2005).

Statistical analyses

For all analyses, assumptions were checked by visual examination of histograms and plots of the residuals, and transformations were performed where appropriate. Analyses were conducted using SYSTAT v.11.

Visit was considered a random factor (2 levels, April and August) in all analyses because, although sampling was conducted in ‘summer’ and ‘winter’ profiles (April and August, respectively), these months were chosen from a larger selection of possible months. Region was considered a fixed factor with 3 levels (SE, Fleurieu and Metro) in all analyses. Beach was a random factor nested within Region and had 5 levels.

At some beaches there was no BDL because the DL was at the upper limit of the swash (and in some cases formed a barrier to the swash, pers. obs.). Thus the sampling design was unbalanced with some samples missing from the BDL (3 beaches x 3 replicates = 9 samples missing). Analyses involving beach Levels and Beaches nested within Regions are thus overly complicated, requiring that several beaches be omitted from the analysis, and so were not attempted. Inspection of the data and graphs suggest that there are considerable differences between Beaches within each Region. At 3 beaches, sediments at 10cm depth were very wet and formed a slurry of sand and water. Samples could not be taken from these sediments and thus these 9 samples are missing from the bulk density data set and further contribute to the unbalanced sampling design.

For analyses involving the factors Visits and Beaches nested within Regions, a balanced sampling design with 5 Beaches per Region was used. Thus, Bucks Bay (not sampled in April) and Largs Bay (selected at random from the Metro beaches) were omitted (as for Chapter 2). The sampling design (for ANOVA) was thus 3 Regions, 5 Beaches per region (nested within Regions), sampled on 2 Visits.

Beach width, beach fall, beach-face slope and Beach Index (BI)

A 3-way ANOVA for Visits, Regions and Beaches nested within Regions was performed for beach width, beach fall and beach-face slope, with total n = 90 for each analysis. Beach width, beach fall, beach-face slope and BI were each regressed against % wrack cover from photopoints (i.e. at the whole beach scale, n = 32). For BI, a 2-way ANOVA for Visits and Regions was also performed with beaches as replicates. Due to outliers and beaches that could not be sampled (e.g. at Kingston sediment samples could not be obtained due to the extremely deep wrack deposits), there were 4 replicate beaches in the SE and Fleurieu regions and 6 replicate beaches in the Metro region. Analyses were also performed on a balanced data set with only 4 Beaches in each Regions. This did not change the results and thus these results are not presented.

Loss on ignition and particle size

A 3-way ANOVA for Visits, Region and Position (Bare vs. Wrack) was carried out on loss on ignition (%) and mean particle size (µm). Addition of the factor Beach (nested within Region) made this model overly complicated and the fixed factor main effects of Region and Position, and the interaction of Region and Position, could not be calculated as valid *F*-ratios. Thus, Beach (a random factor) was omitted from the analysis and data were instead presented graphically. For the August sampling, a separate 2-way ANOVA for Regions and Position (i.e. DLB, DLW, ADL and BDL) was conducted on loss on ignition and mean particle size. Note that in April Kingston was sampled but in August, the DL and BDL could not be sampled due to the large piles of wrack. In August, Bucks Bay was sampled instead, so on each occasion 5 beaches were sampled in each region.

Sand compaction: Bulk density and surface penetration resistance

To determine whether bulk density and surface penetration resistance yielded similar results, a linear regression between the results obtained by these two methods was performed for the June sampling. The mean value obtained from each method was calculated from five replicate samples for each position (DL0 and DL10) on each beach (17 beaches). One sample was accidentally dropped during processing and was therefore omitted. Thus, the total n = 34.

Bulk density was analysed by a 3-way ANOVA for Visits (April vs. June), Region and Depth (DL0 vs. DL10). In April, three replicate samples were taken but in June five replicate samples were taken. Thus, 2 replicate samples from June were randomly selected to be omitted from the analyses to obtain a balanced design. Surface penetration resistance was analysed using a 3-way ANOVA for Visits (June vs. August), Region and Position (DLB, DLW, DL0, DL10, ADL and BDL).

Relationship between % wrack cover and composition and sediment characteristics

Linear regressions were performed to assess relationships between percent wrack cover at each beach (obtained from photopoints, predictor variable) and the mean of each of the following variables (dependent variables); loss on ignition, mean particle size, bulk density (April only) and surface penetration resistance (August only). For loss on ignition and mean particle size n = 32 each. For bulk density (April only) and surface penetration resistance (August only) n = 16 each. An additional analysis was performed to assess whether there was any relationship between the proportion of algal or kelp wrack in deposits and loss on ignition. Percent mass of algae (%WW algae) and % mass of kelp (%WW kelp) in wrack samples was obtained from data gathered in Chapter 2. Linear regressions with mean %WW of algae or kelp as the predictors and mean loss on ignition as the dependent were performed. Each visit to a beach was considered as a replicate and thus n = 32.

Results

Beach profiles: Width, fall and beach-face slope

Beach profiles

On the beach face, beach height tended to decrease from the dune towards the swash (Figure 3.1). The height of the beach did occasionally increase or plateau, reflecting high shore berms and tide pools in the lower shore. On a few occasions the beach face height increased to be slightly higher than the base of the dune (maximum of 0.08m); this occurred in the high shore zone. Beach profiles along individual transects were, in some cases, quite uneven. Beach height tended to increase gradually from the base of the dune to the swash but dropped more sharply at times. This occurred, for example, at the break of the high shore berm (e.g. Aldinga, April, at 18-20m from the dune, Figure 3.1) and on the horn of beach cusps (e.g. Waitpinga, April, 24-28m, Figure 3.1), where present. Undulations also occurred due to tyre tracks, wrack piles and pits dug by human visitors. At some beaches, the three beach profiles taken on one visit clearly showed deep and wide wrack driftlines. This occurred in April at Brown Bay (45m to the end of the profile at the swash) and Normanville (25-35m), and at Kingston (20-35m) in August (Figure 3.1).

Beach profiles were very similar between April and August at 6 of the 16 beaches that were sampled twice; The Granites, Middleton, Victor Harbor, Maslins, Largs Bay and North Haven (Figure 3.1). At five beaches; Beachport, Waitpinga, Rapid Bay, Normanville and Aldinga, the profiles showed some changes between the two visits, mostly relating to small changes in the shape of the beach, with sand moving from the high shore to the low shore (and offshore), and vice versa (Figure 3.1). At both Brown Bay and Stinky Bay there was a dramatic decrease in beach width from April to August, but the shape of the beach changed in a different way at these two beaches. Beach profiles at Seacliff and Glenelg varied both within visits (i.e. along the beach between replicate transects) and between visits, with a decrease in beach width from April to August (Figure 3.1). Changes in beach profile between April and August at Kingston appeared to be due to an increase in the volume of wrack on this beach.

Beach width

Over the 99 transects (at 17 beaches over 2 visits, except Bucks Bay which was sampled in August only), beach width ranged between 12 and 116m (mean = 43.44 ± 2.48m) (Figure 3.2a). On average, Victor Harbor was the narrowest beach (15.83 ± 1.17m) and Largs Bay was the widest (108.00 ± 4.00m) (Figure 3.2a). The beaches were, on average, narrower in August (38.94 ± 3.66m) than in April (48.23 ± 3.25m). This trend was seen at 9 of the 16 beaches that were sampled twice, and on the remaining beaches beach width was either similar between visits or was only slightly greater in April than in August. On average, the Metro beaches (62.28 ± 4.75m) were wider than the SE (35.58 ± 2.47m) and Fleurieu (29.5 ± 2.47m) beaches.

Beach fall

The maximum beach fall was 3.19m and the minimum was 0.20m. On average the swash was 2.00m (± 0.06) lower than the base of the dune. The mean beach fall was greatest at Maslins (2.78 ± 0.10m) and least at Kingston (1.38 ± 0.02m) (Figure 3.2b). Beach fall was slightly greater in April (2.19 ± 0.07m) than in August (1.83 ± 0.08m). On average, beach fall was greater in the Metro region (2.24 ± 0.10m) compared with the beaches in the Fleurieu (2.02 ± 0.08m) and SE (1.75 ± 0.09m) regions.

Beach-face slope

Beach-face slope was on average 0.058 (± 0.003) (a dimensionless measure), with the steepest transect having a slope of 0.128 and the shallowest transect having a slope of 0.013. On average, Victor Harbor was the steepest beach (0.115 ± 0.004) and Largs Bay was the flattest (0.018 ± 0.001) (Figure 3.2c). Beaches tended to be slightly steeper in August than in April, with mean beach-face slopes of 0.059 (± 0.004) and 0.056 (± 0.004), respectively. Beaches in the Fleurieu region (0.079 ± 0.005) were, on average, steeper than beaches in the SE (0.056 ± 0.004) and Metro (0.042 ± 0.003) regions.

ANOVAs: Width, fall and beach-face slope

Results of the 3-way ANOVA for Visits, Regions and Beaches nested within Regions were similar for beach width, beach fall and beach-face slope (Table 3.1). All three measures of beach morphology varied with both time and space; the interaction of Visit and Beach nested within Region was significant in each case ($p < 0.001$, $n = 90$ for each analysis, Table 3.1). Beach width and slope varied between Beaches nested within Regions ($p < 0.05$ and $p < 0.01$, respectively) and beaches were significantly wider in April than in August ($p < 0.05$) (Table 3.1).

Beach index (BI)

BI ranged between 0.9 (Reflective beach type) and 2.74 (Intermediate beach type) and had a mean of 2.07 (± 0.06) (Table 3.2). The SE region had the highest mean BI (2.21 ± 0.10) (i.e. beaches that were Intermediate in type but tended toward being dissipative rather than reflective), whilst beaches in the Fleurieu region were, on average, more Reflective (2.04 ± 0.10). The Metro region beaches were intermediate with a mean BI of 2.09 (± 0.07). Mean BI was lower in August than in April (1.99 ± 0.07 vs. 2.22 ± 0.07) but the 2-way ANOVA for Visits and Regions indicated that this was not a significant result (Table 3.3); although the F-ratio was large (11.806), there was a low df (1, 2) and hence a high critical F (18.5) and thus a non-significant result was achieved. There was also no significant effect of Region and the interaction of Visit and Region was not significant (Table 3.3).

Relationship between width, fall, slope or BI and % wrack cover

Mean wrack cover (at the whole beach scale) was 22.6% (± 4.7) and had a wide range of between 1 and 95% cover. In August, Rapid Bay had the lowest BI recorded for any beach (0.93) which was due to the very large mean particle size (-0.425 phi units). This case was subsequently identified as an outlier in the regression analysis, and was thus omitted from the subsequent analyses. The minimum BI for the remaining cases was thus 1.49.

Scatterplots of beach width (4^{th} root transformed), beach fall (√-transformed) and beach slope (√-transformed) vs. % wrack cover (4^{th} root transformed) suggested that there were no relationships between these variables and the cover of wrack (Figure 3.3a-c); non-significant linear regressions supported this. The scatterplot of BI vs. % wrack cover (4^{th} root transformed) (Figure 3.3d), suggested that as BI increased (i.e. more Dissipative beaches) the cover of wrack also increased. Linear regression supported this; there was a positive and significant relationship between these variables (Pearson $r = 0.501$, $p = 0.004$, $n = 31$) (Figure 3.3d).

Organic matter content

Organic matter content, expressed as loss on ignition (%), ranged between 0.24% and 7.62% for sediments in the DL (Figure 3.4a), except for one outlier from Kingston in August (Visit 2), for which loss on ignition was 25.4%. This sample was composed mostly of wrack and thus was removed from the data set. Within the DL, loss on ignition was, on average, 1.90% (±0.11).

Bare sand vs. under wrack

Mean loss on ignition was slightly higher in April than in August (1.99 ± 0.16% vs. 1.81 ± 0.14%, respectively). The SE region had the highest mean loss on ignition (3.50 ± 1.3), the Fleurieu region sediments contained, on average, 1.37 (± 0.10%) organic matter, whilst the Metro region sediments had the lowest organic matter content (0.99 ± 0.12%) (Figure 3.4a). Averaged over both Visits and all Regions, loss on ignition within the DL was slightly higher under Wrack patches than from Bare sand areas (1.91 ± 0.15% vs. 1.88 ± 0.14%, respectively). The 3-way ANOVA for Visits, Region and Position (Bare vs. Wrack) yielded only one significant result;

loss on ignition (√-transformed) was significantly different between the each of the three Regions ($p < 0.05$, SE > Fleurieu > Metro) (Table 3.4).

Comparison of beach levels and positions within the DL

In August, sampling was conducted at the DL in Bare sand patches (DLB) and under Wrack (DLW), and in the ADL and BDL. The SE region had the highest mean loss on ignition (3.12 ± 1.4%). The Fleurieu region sediments contained, on average, 1.34 (± 0.10%) organic matter and the Metro region sediments had the lowest organic matter content (0.80 ± 0.06%) (Figure 3.5a). Mean loss on ignition (%) was greatest in the DL; in the under Wrack sediments (DLW, 1.81 ± 0.20%) and the Bare sand sediments (DLB 1.80 ± 0.19%) (Figure 3.5a). The BDL had a lower mean loss on ignition (1.72 ± 0.21%) and the ADL samples (1.45 ± 0.15%) had the lowest mean loss on ignition (%) of all the positions sampled. Loss on ignition (√-transformed) was significantly different among each of the three Regions ($p < 0.001$, SE > Fleurieu > Metro) and among the four Positions ($p = 0.040$, ADL < BDL = DLW = DLB) (Table 3.5, Figure 3.5a).

Mean particle size

Within the DL, mean particle size was, on average, 299µm (± 13) (fine sand on the Udden-Wentworth scale, Wentworth 1922) but there was a large range of sizes encountered, with the smallest mean particle size (in a single sample) of 82µm (silt by the Udden-Wentworth scale, Wentworth 1922) and the largest of 1881µm (very coarse sand, Udden-Wentworth scale, Wentworth 1922) (Figure 3.4b). Samples from Rapid Bay had mean particle sizes that were between 415 and 1881µm (mean 933 ± 107). These samples caused a large skew in the data and two of these samples were identified as outliers. Rapid Bay was therefore omitted from the analyses but the data are included in the descriptive statistics and are shown in Figure 3.4b.

Bare sand vs. under wrack

Mean particle size was higher in August than in April (351 ± 30µm vs. 210 ± 11µm, respectively). The Fleurieu region had the coarsest sediments. The mean particle size was, on average, 388µm (± 46). This was largely driven by the very coarse sands found at Rapid Bay, which contributed to the maximum mean particle size of 1881µm. In the Metro region, mean particle size was lower (242 ± 10µm) and the sediments in the SE region were the finest (221 ± 15µm). Within the DL, sediments from under Wrack were finer than those from Bare sand areas (277 ± 20µm vs. 284 ± 26µm, respectively). The 3-way ANOVA for Visits, Region and Position (Bare vs. Wrack) yielded two significant results; mean particle size (4^{th} root-transformed) differed between visits ($p < 0.001$, August > April) and with the interaction of Visit and Region ($p < 0.001$) (Table 3.4).

Comparison of beach levels and positions within the DL

In August, mean particle size was determined for four positions on the beach (DLB, DLW, ADL and BDL). Sediments in the DL were coarser than those in the ADL and BDL and the sediments from Bare sand patches (DLB, 355 ± 48µm) were coarser than those from under Wrack (DLW, 348 ± 34µm) (Figure 3.5b). BDL sediments were, on average, 331µm (± 42) and were finer than ADL sands (342 ± 19µm). The Fleurieu region had the coarsest sediments with a mean particle size of, on average, 492µm (± 50); again this result was driven mainly by the very coarse sands at Rapid Bay. Sediments in the Metro region were the finest (255 ± 9µm) whilst the SE region had an intermediate mean particle size (300 ± 15µm). Mean particle size was significantly different among the three Regions ($p < 0.001$, Fleurieu > SE = Metro) and among the four Positions ($p = 0.011$, Figure 3.5b), but the interaction of these factors was not significant (Table 3.5).

Sand compaction

Method comparison: Bulk density vs. penetration resistance

Inspection of the scatterplot of mean bulk density vs. mean penetration resistance (√-transformed) (June samples, depths 0 and 10cm, Figure 3.6) suggested that there was no relationship between the two measures of sand compaction for all data together or for either sampling depth. Linear regression indicated that there was a weak, positive correlation between bulk density and penetration resistance (Pearson $r = 0.197$, $p < 0.307$, $n = 29$). Since the regression was not significant and there no relationship between penetration resistance and bulk density, the data from these two methods were analysed separately.

Bulk density

Mean bulk density was 1.466gDW/mL (± 0.017) and ranged between 0.660 and 2.038gDW/mL (Figure 3.4c). Sand compaction was lowest in the SE region (1.280 ± 0.033gDW/mL), compared with the Metro (1.543 ± 0.024gDW/mL) and Fleurieu (1.560 ± 0.021gDW/mL) regions. Sediments were more compacted in April than in June (1.521 ± 0.027gDW/mL vs. 1.429 ± 0.022gDW/mL, respectively) and those at 10cm depth were slightly more compacted than the surface sediments (1.494 ± 0.024gDW/mL vs. 1.438 ± 0.025gDW/mL, respectively). The 3-way ANOVA for Visits (April vs. June), Region and Depth (0 vs. 10cm) yielded only one significant result; bulk density was significantly greater in April than in June (Table 3.6).

Penetration resistance

Penetration resistance was, on average, 4.163kgcm^{-2} (± 0.081) and ranged between 0.300 and 10.860kgcm^{-2} (Figure 3.4d). Sand compaction was higher in the SE region (4.712 ± 0.142kgcm^{-2}), than in the Fleurieu (4.417 ± 0.163 kgcm^{-2}) and Metro (3.479 ± 0.110 kgcm^{-2}) regions. Sediments were more compacted in June than in August (4.883 ± 0.108kgcm^{-2} vs. 3.459 ± 0.110kgcm^{-2}, respectively). Sediments from 10cm depth were the more compacted than the surface sediments (4.756 ± 0.233kgcm^{-2} vs. 4.136 ± 0.174kgcm^{-2}, respectively), and sediments from under Wrack deposits were more compacted than those from Bare sand patches within the DL (4.053 ± 0.181 kgcm^{-2} vs. 3.940 ± 0.180kgcm^{-2}, respectively) (Table 3.7). Sediments from the BDL were more compacted (4.256 ± 0.236kgcm^{-2}) than those from the DL (4.136 ± 0.174kgcm^{-2}; DL0 samples, equivalent to samples taken from the ADL and BDL) and the ADL (3.950 ± 0.186kgcm^{-2}). The 3-way ANOVA for Visits (June vs. August), Region and Position (DLB, DLW, DL0, DL10, ADL and BDL) indicated that penetration resistance varies with the interaction of Visits, Regions and Position (Table 3.1). Penetration resistance was also significantly greater in June than in August (Table 3.7).

Relationship between % wrack cover and sediment characteristics

The scatterplot of % wrack cover and mean loss on ignition (√-transformed) showed a slight trend for an increase in loss on ignition with increasing wrack cover (Figure 3.9a) but the linear regression between these two variables was not significant (Pearson $r = 0.274$, $p = 0.129$, $n = 32$, Figure 3.9a). There was a significant, negative correlation between % wrack cover and mean particle size (√-transformed) (Pearson $r = 0.512$, $p = 0.003$, $n = 31$, Figure 3.9b); i.e. beaches with higher wrack cover had finer sediments. Results for sand compaction differed for bulk density and penetration resistance, which were used in April and August, respectively. Bulk density (April data) was negatively correlated with % wrack (Pearson $r = 0.622$, $p < 0.01$, $n = 16$, Figure 3.9c) indicating that beaches with higher wrack cover had less compacted sediments. There was no relationship between % wrack cover and penetration resistance (August data) (Pearson $r = 0.236$, $p = 0.379$, $n = 16$, Figure 3.9d). For all analyses, % wrack cover was 4^{th}-root-transformed.

There were significant positive relationships between both the % WW of algae and loss on ignition (√-transformed) at each beach (Pearson $r = 0.378$, $p = 0.033$, $n = 32$), and the % WW of kelp wrack (log [x +1]-transformed) and loss on ignition (√-transformed) at each beach (Pearson $r = 0.477$, $p = 0.006$, $n = 32$), although in both regressions there was a large proportion of unexplained variance (Figure 3.10).

Discussion

Beach profiles (width, fall and slope) and beach type (BI) were within the range reported for sandy beaches globally and within SA (McLachlan & Dorvlo 2005; Short 2006b). Only one beach was classified as Reflective (Rapid Bay BI = 1.40 and 0.93 for April and August, respectively) and the remaining beaches were classified as Intermediate on both visits (Table 3.2). Brown Bay in April (BI = 2.74) had the highest recorded BI. Despite being classified by Short (2006a) as a Dissipative beach, Middleton was identified as an Intermediate-type beach (BI = 2.47 and 2.37 for April and August, respectively) (Table 3.2). In general, the BI values obtained in this study tended to be narrower in range than their classification by Short (2006b) warranted. This may be due to the timing of sampling, since there was no sampling at the height of summer, when beaches should be widest and flattest. Beach profiles varied spatially and temporally, as can be expected in such dynamic environments as sandy beaches. There was no systematic trend for wider, taller or steeper beaches, or towards beaches of a Reflective or Dissipative type, to occur on either visit or among the three study regions. Thus, beaches with a range of morphologies were sampled within and across these three regions.

The four measures of beach morphology that were used in this study (beach width, beach fall, beach-face slope and BI) yielded differing results when used to predict the amount of wrack cover on these beaches. None of the measures of the shape of the beach (beach width, beach fall, beach-face slope) were related to the cover of wrack on the beach. BI, which also includes mean particle size and maximum spring tide range in its calculation, was positively correlated with % wrack cover, i.e. flatter and more dissipative-type beaches (characterized by flat slopes and fine sediments) had greater wrack cover than steep, Reflective beaches (steeply sloping beaches with coarse sediments). Thus, measures of beach morphology that include more information may be better at explaining the variation in wrack cover. The finding that BI was positively correlated with % wrack is novel. Whilst studies have shown that the abundance and diversity of beach macrofauna is positively correlated with BI (McLachlan & Dorvlo 2005; 2007), there have previously been none, to my knowledge, investigating whether beach type influences the deposition of wrack. Wrack is known to provide a source of food and habitat for beach macrofauna (Bustamante & Branch 1996; Colombini *et al.* 2000; Dugan *et al.* 2003; Ince *et al.* 2007; Lastra *et al.* 2008), with many studies showing positive relationships between wrack biomass and faunal diversity and abundance. I suggest that the trend for higher wrack cover to occur on more Dissipative beaches may contribute to the greater abundances and diversity of fauna found on these beaches. This could be the subject of further research on sandy beaches.

The organic matter (OM) content of these sediments had a large range and varied between 0.2% - 7.6%. This is higher than that reported by Ince *et al.* (2007), who recorded loss on ignition values of between 0.04 and 1.4% in their comparison of beaches with high and low wrack cover, and Gheskiere *et al.* (2006), who recorded loss on ignition of 1.00 to 1.25% for unraked beaches. Possible reasons for the relatively high OM content of some sediments sampled here may include: the high wrack cover on some of the beaches sampled in this study (see Chapter 2); the relatively finer sediments, and hence slower flushing of interstitial pore spaces (Alongi 1998), that occur on the beaches studies here; or the age, type and state of decomposition of the wrack present. The OM content was noticeably higher (25%) in one sample taken at Kingston. This sample was composed primarily of decomposing wrack, was dark in colour, and was obtained from Kingston, where deposits of wrack can be several metres deep, cover the entire beach face and remain on the beach for many months. This sample was similar to those described by Hemminga and Nieuwenhuize (1990), who reported that samples containing decomposed wrack were higher in OM content than those from the overlying sediments.

At the scale of the whole beach, there no relationship between OM and wrack cover. This result is similar to Ince *et al.* (2007), who reported no difference in the OM content of sediments between high and low wrack cover beaches. Futhermore, there was no difference in the OM content between the bare sand and under wrack sediments within the driftline. Sediments from above the driftline had lower OM content than any other area on the beach but those from below the driftline were similar in OM content to those from the driftline. Possible explanations for this may be that there were larger amounts of wrack in the below driftline area, or that the particulate OM that is released from wrack in the driftline leaches into the below driftline area.

Sediments from the SE region were consistently higher (over twice the amount, Figure 3.4a) in OM content than those from the Fleurieu region, which were also more enriched than those from the Metro region. Wrack cover was higher in the SE region than in either the Fleurieu or Metro regions (Chapter 2). Thus, there may be a link between high wrack cover and high organic matter content of sediments. Although Fleurieu sediments were more enriched than those from the Metro region, there was no difference in wrack cover between these regions (Chapter 2), and hence there must be other reasons for this difference. Since there was no bias in beach morphology between regions, and hence filtration rates, beach morphology is an unlikely explanation.

There were positive relationships between the proportion of algae and the proportion of kelp in the wrack deposits and the loss on ignition from the beach sediments. This suggests that algal and/or kelp wrack may contribute a greater amount of OM to beach sediments than seagrass wrack. The rate and processes associated with wrack decomposition will be investigated in Chapter 6. Differences in the composition of wrack deposits between regions may also contribute to the difference in organic matter content between the SE, Fleurieu and Metro regions. The SE region has the highest proportion of algal and kelp wrack of these three regions, and had significantly higher loss on ignition. Thus, both the higher cover and higher proportion of algal and kelp wrack in the SE may contribute to the higher OM content of beach sands in that region.

Mean particle size spanned a wide range from silt to very coarse sand and differed as an interaction between regions and visits. Sediments graded from coarse to fine from the above the driftline, to the driftline and into below the driftline, but the only significant result was that above the driftline had the coarsest sediments. This may be a function of the higher proportion of shell grit found in the high shore region (pers. obs.) and is a result similar to that found by Langley (2006). Within the driftline, there was no difference in mean particle size between bare and wrack-covered areas. Mean particle size and wrack cover were negatively correlated, i.e. beaches with finer sands had higher wrack cover. This is the opposite result to that found by Ince *et al.* (2007), who found that there was no difference between beaches with high and low cover. Thus, although previous studies have demonstrated that wrack acts as sediment trap (Nordstrom *et al.* 2000; 2006), the sediments trapped by wrack accumulations do not differ from the existing sediments in terms of their particle size. The negative correlation between particle size and wrack cover is likely due to differences in beach morphology (finer sands occur on more Dissipative-type beaches, McLachlan & Brown 2006) resulting in different amounts of wrack being deposited on the beach rather than wrack deposits resulting in the accumulation of finer sediments. This is the opposite result to Orr *et al.* (2005), who found that cobble beaches accumulate more wrack than sand and gravel beaches but the coarsest sediments in this study spanned only the range of sand and some gravel. Thus, the trend for wrack cover to decrease with increasing particle size may not hold for coarser sediment types (gravel and sand).

Sand compaction, measured by penetration resistance, was variable in both time and space, varying with the interaction of Visits, Regions and Position on the beach. There was no consistent difference among the beach levels or among positions within the DL (wrack covered or bare sands, and surface sands vs. those from 10cm depth). Bulk density was negatively correlated with wrack cover, i.e. beaches with more wrack had less compacted sediments. A possible mechanism for this is that freshly-trapped sands are less compacted than the existing sediments. There was no relationship found in August using penetration resistance as the measure of compaction. Whether this was due to the method used or a lack of a relationship is uncertain but should be investigated further by conducting additional sampling using both methods. Sand compaction (measured by both bulk density and penetration resistance over three visits) increased as beaches moved from summer to winter profiles, although this was not formally tested because only one visit was made in each season. This may be due to increased movement of sediments by water and wind during rougher winter periods. Wrack deposits thus appear to affect sand compaction at a whole beach scale, but appear to have no measurable effect on sand compaction within small spatial scales (e.g. within the driftline).

The lack of differences in sediment characteristics (mean particle size, OM content and sand compaction) between wrack-covered and bare sand areas within the driftline was somewhat surprising. Wrack patches within the driftline were large and thick in some cases and visible differences (e.g. sand colour and the presence of wrack fragments within the sediments) were notable under these wrack deposits. The transience and variability in the size (cover and depth) of wrack deposits within the driftline may explain the lack of consistent differences between wrack and sand areas. In some cases the wrack areas had very low wrack cover, and the effects of such sparse wrack patches may be minimal. Future studies would benefit from taking measurements of the wrack deposit at the same scale as the measurements of sediment characteristics are made (e.g. within a quadrat around the sediment core). Sediment cores were taken to a depth of 15cm in this study. Sampling of the surface layer only (e.g. the top 2-5cm) may also detect differences between wrack and bare sands. Surface sediments are more likely to be affected by wrack deposits through enrichment by organic matter due to their close proximity, and accumulated sediments are likely to be only a few centimetres deep around the wrack accumulations sampled in this study (pers. obs.).

The wrack deposits sampled here were from the freshest driftline on the beach but did differ in composition, age, stage of decomposition and the tidal height at which they occurred. The wrack also tended to occur on the surface, with buried wrack usually only occurring in high cover and deep deposits. The effects of wrack deposits of differing ages, compositions, and position (i.e. buried versus surface wrack) on sediment characteristics were not assessed here but may also influence the rate and processes occurring. For example, wrack deposits that remain on the beach for longer periods of time, usually occurring in the high shore, have a greater duration over which they affect sediments, and may tend to accumulate wind-blown sediments more than deposits occurring in the damp low shore. Conversely, wrack deposits in the low shore may be washed away on the following high tide but, whilst there, may affect wave attenuation and particle filtration. Further investigations should include sampling of wrack deposits from a range of tidal heights, fresh versus aged wrack deposits, and buried versus surface deposits.

Conclusion

Beaches that were more dissipative in nature, and had finer sands, had greater cover of wrack than beaches of the reflective type with coarse sands. High wrack cover appeared to result in increased organic matter content within the sediments and less compact sands, although the latter was not a consistent finding. The effects of wrack deposits occur throughout the driftline and are not confined to the sediments directly under wrack patches, as demonstrated by the lack of differences between bare sands and wrack patches within the driftline. Thus, it appears that beach morphology affects the amount of wrack present on sandy beaches, and that wrack deposits have a limited but potentially important capacity to modify beach sediments through the input of organic matter and the reduction of sand compaction.

List of Figures

= white and Metro = grey. Letters are used to indicate post-hoc differences between positions; positions with the same letters do not differ significantly from one another.

Figure 3.6. Scatterplot of mean bulk density (grams dry weight per ml, gDW/mL) vs. mean penetration resistance (kgcm^{-2}, √-transformed) for samples taken in June, n = 29. The line shows the significant linear regression. Pearson $r = 0.197$, $p < 0.307$, n = 29.

Figure 3.7. Mean (± se) bulk density (grams dry weight per ml, gDW/mL) of sediments within the DL from the surface (S) and 10cm deep (D) in April and June. n = 186. The three study regions are shown in different colours; SE = black, Fleurieu = white and Metro = grey.

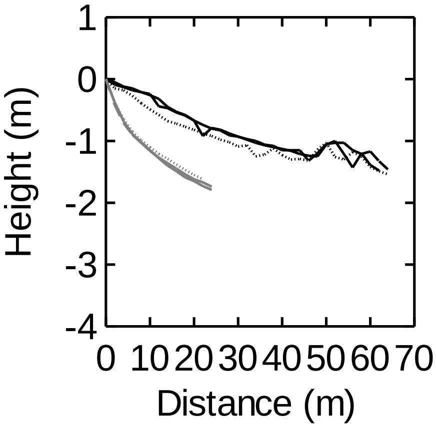
Figure 3.8. Mean (± se) surface penetration resistance (kgcm^{-2}) for the six positions sampled (Above DL = ADL, Below DL = BDL, Bare sand in the DL = DLB, under Wrack in the DL = DLW, surface sediments in the DL = DL 0cm, and sediments from 10cm depth in the DL = DL 10cm) in the 3 regions for June and August. n = 920. The three study regions are shown in different colours; SE = black, Fleurieu = white and Metro = grey.

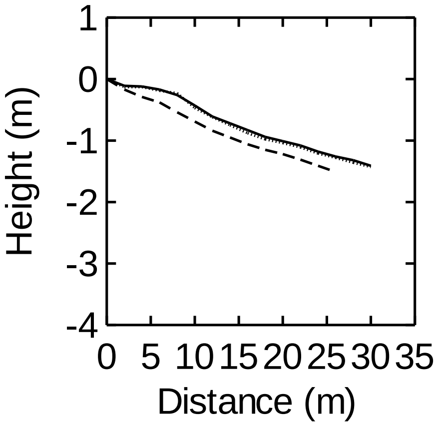
Figure 3.9. Scatterplots of % wrack cover (4th root-transformed) vs. a) loss on ignition (%, √-transformed), b) mean particle size (µm), c) bulk density (grams dry weight per ml, gDW/mL) and d) surface penetration resistance (kgcm^{-2}) for the main study beaches on two visits (April and August). Linear regressions are plotted where significant results were obtained. Loss on ignition: Pearson $r = 0.274$, $p = 0.129$, n = 32. Mean particle size: Pearson $r = 0.512$, $p = 0.003$, $n = 31$. Bulk density: Pearson r = 0.622, $p < 0.01$, $n = 16$. Surface penetration resistance: Pearson $r = 0.236$, p = 0.379, $n = 16$.

Figure 3.10. Scatterplots of a) mean % wet weight (%WW) of algae and b) mean %WW of kelp (log [x +1]-transformed) vs. mean loss on ignition (%, √-transformed) for the main study beaches on two visits (April and August). Linear regressions are plotted where significant results were obtained. Mean %WW algae: Pearson $r = 0.378$, $p = 0.033$, $n = 32$. Mean %WW kelp: Pearson $r = 0.477$, $p = 0.006$, $n = 32$.

Brown Bay

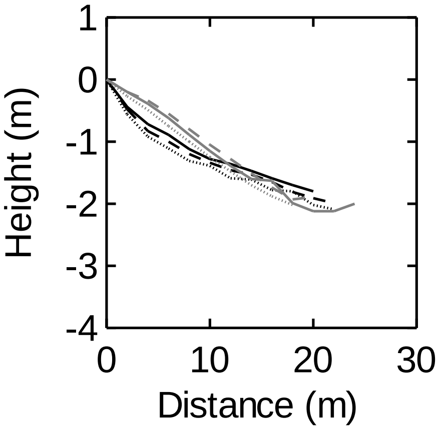
Bucks Bay

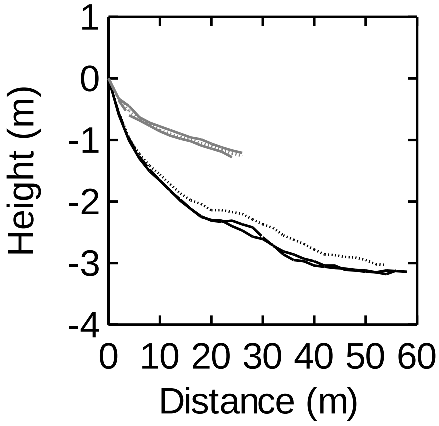




Beachport

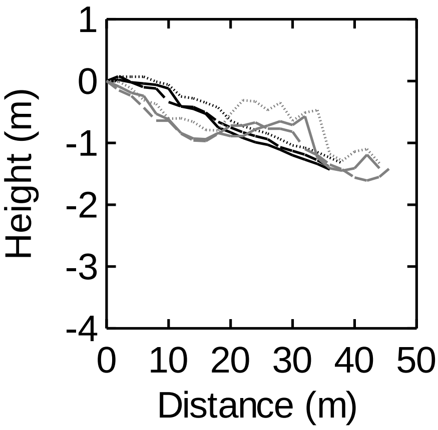
Stinky Bay

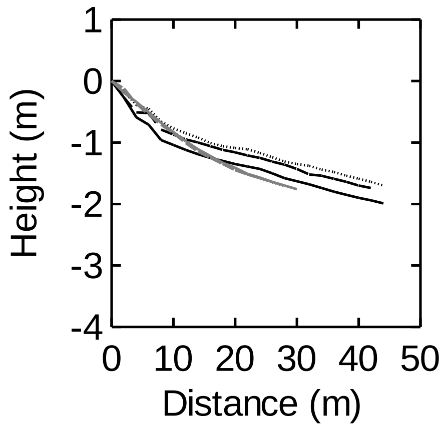




Kingston

Granites

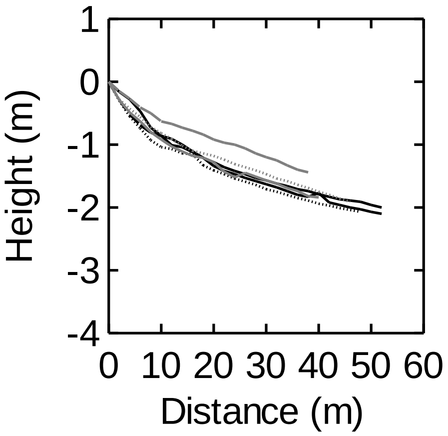




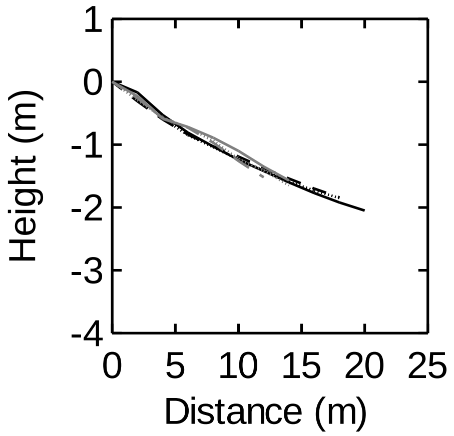
Middleton

Victor Harbor

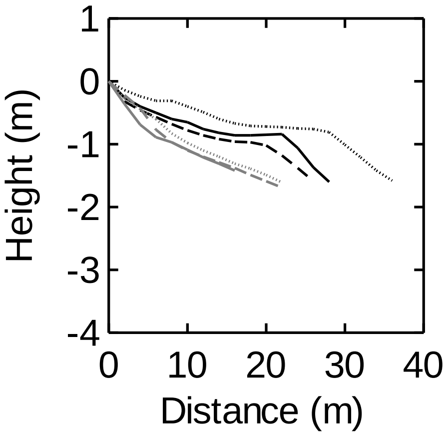
Figure 3.1 Part 1: SE



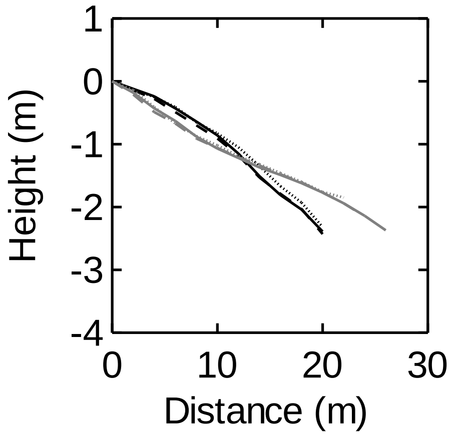
Waitpinga



Rapid Bay



Normanville



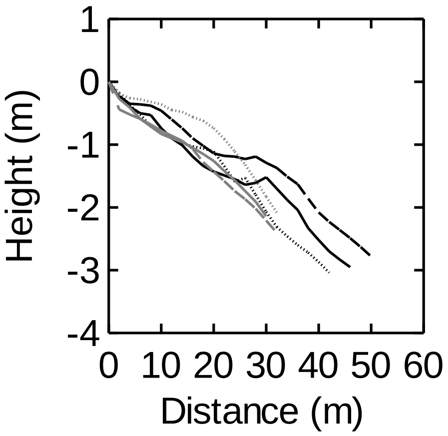


Figure 3.1 Part 2: Fleurieu

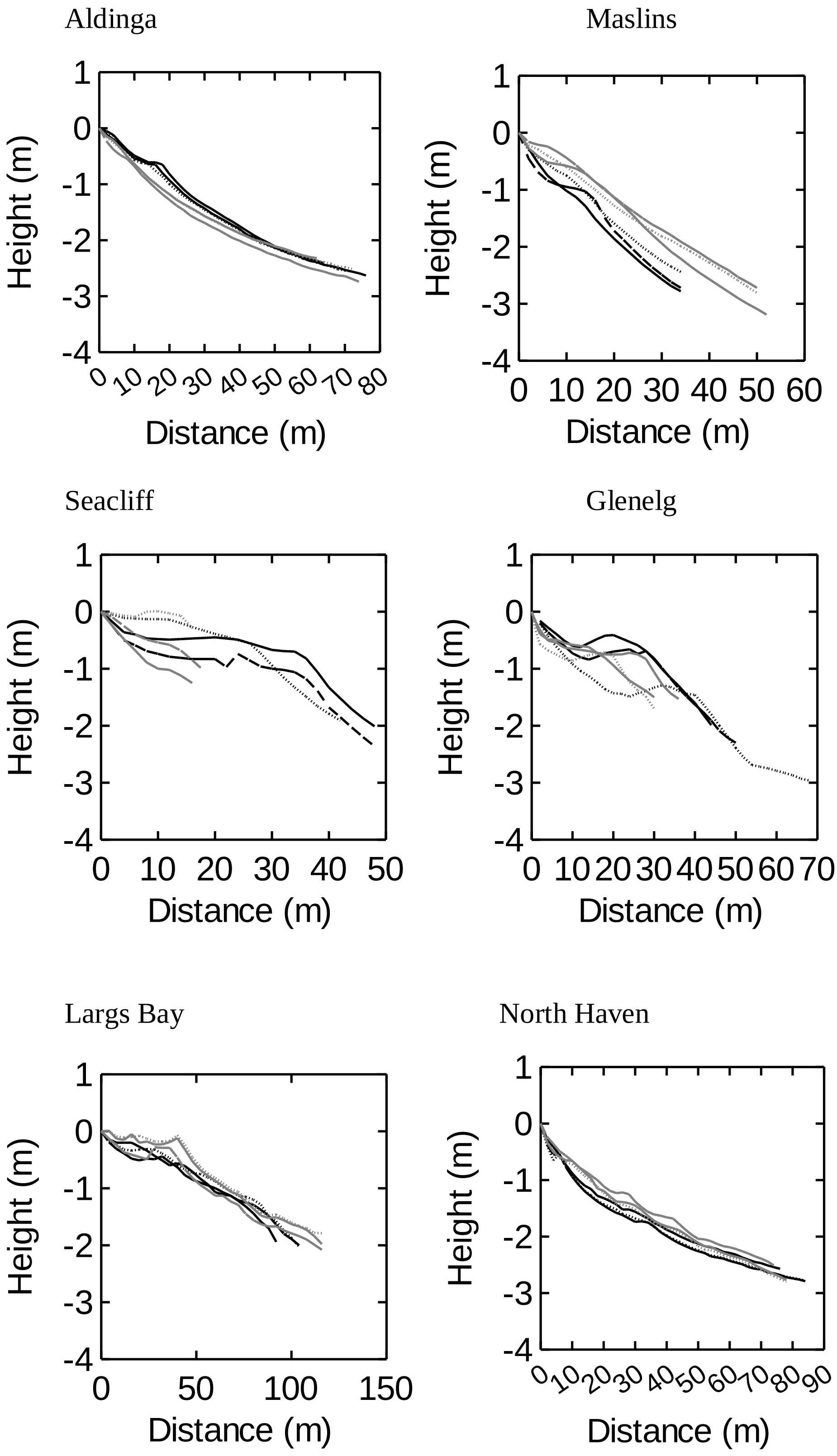


Figure 3.1 Part 3: Metro

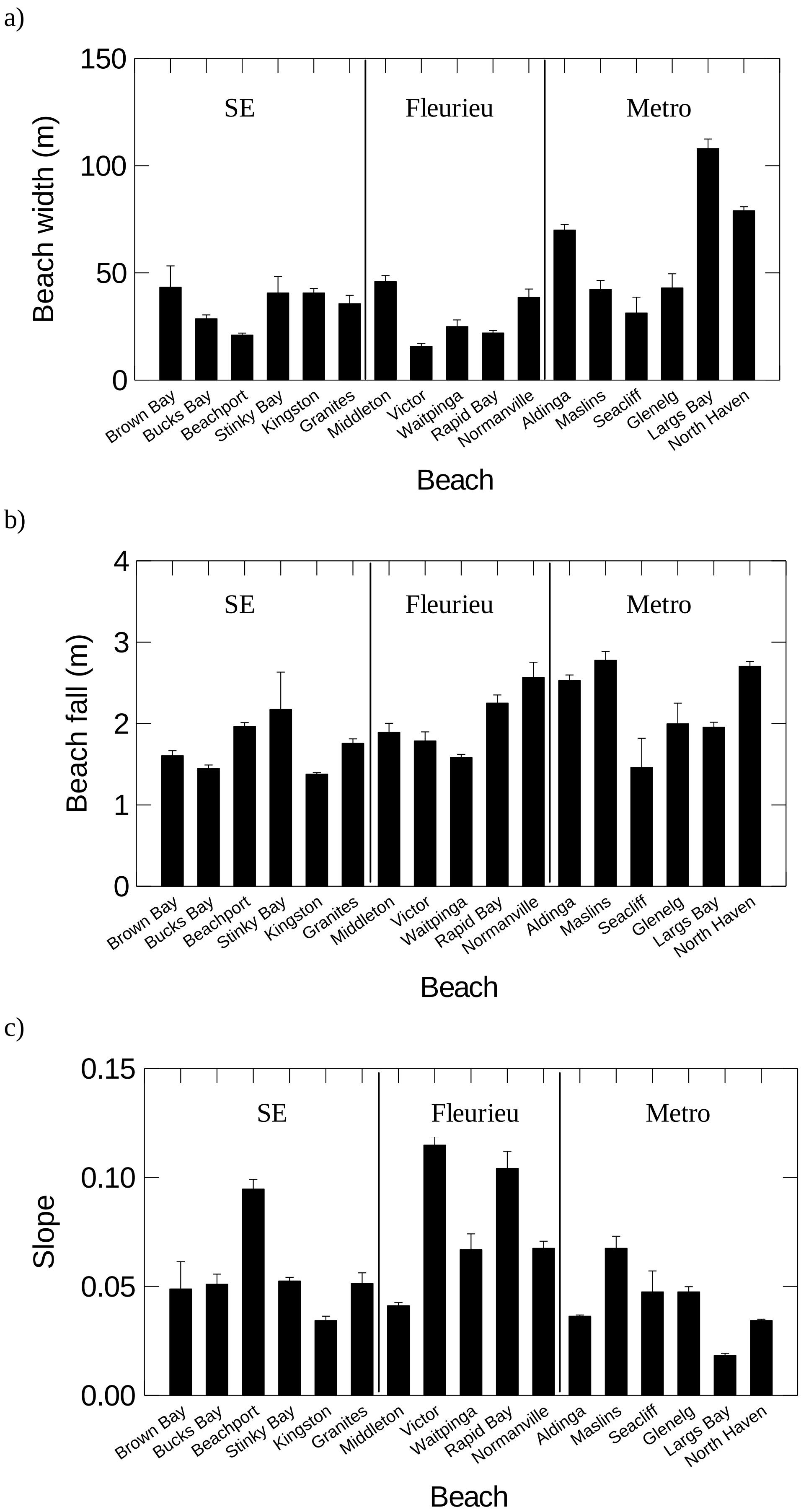

a)
150
100
50
0
Beach width (m)
SE
Fleurieu
Metro
Brown Bay
Bucks Bay
Beachport
Stinky Bay
Kingston
Granites
Middleton
Victor
Waitpinga
Rapid Bay
Normanville
Aldinga
Maslins
Seacliff
Glenelg
Largs Bay
North Haven
Beach
b)
4
3
2
1
0
Beach fall (m)
SE
Fleurieu
Metro
Beach
c)
0.15
0.10
0.05
0.00
Slope
SE
Fleurieu
Metro
Beach

Figure 3.2

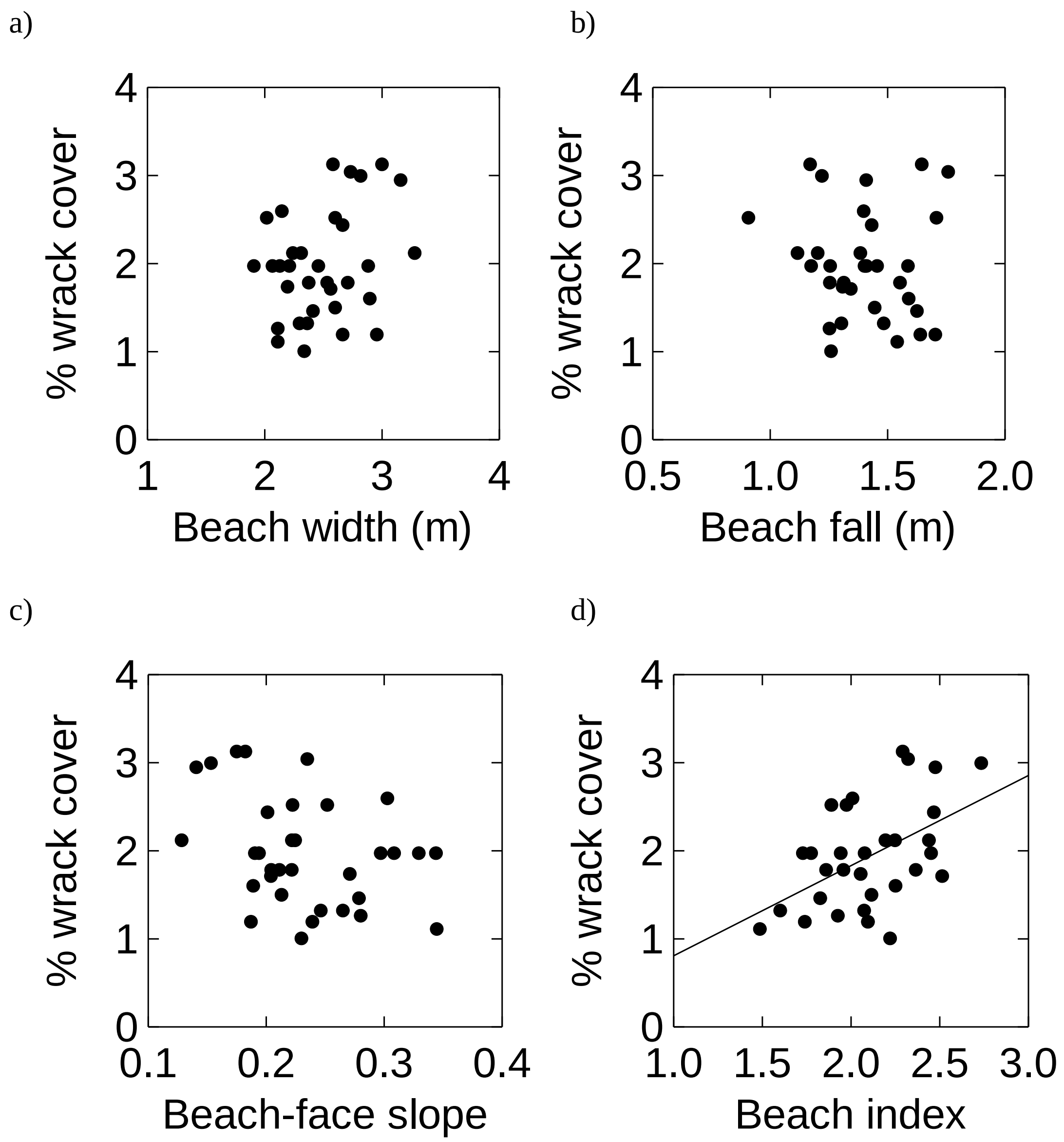
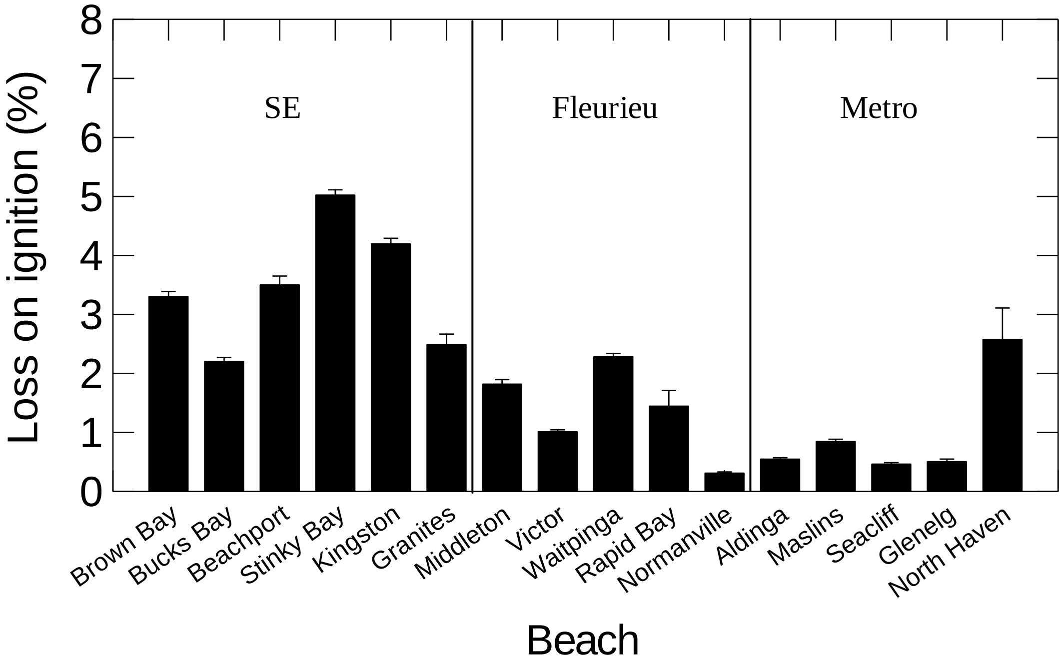

a)
b)
c)
d)
% wrack cover
Beach width (m)
Beach fall (m)
Beach-face slope
Beach index

Figure 3.3

a)



b)

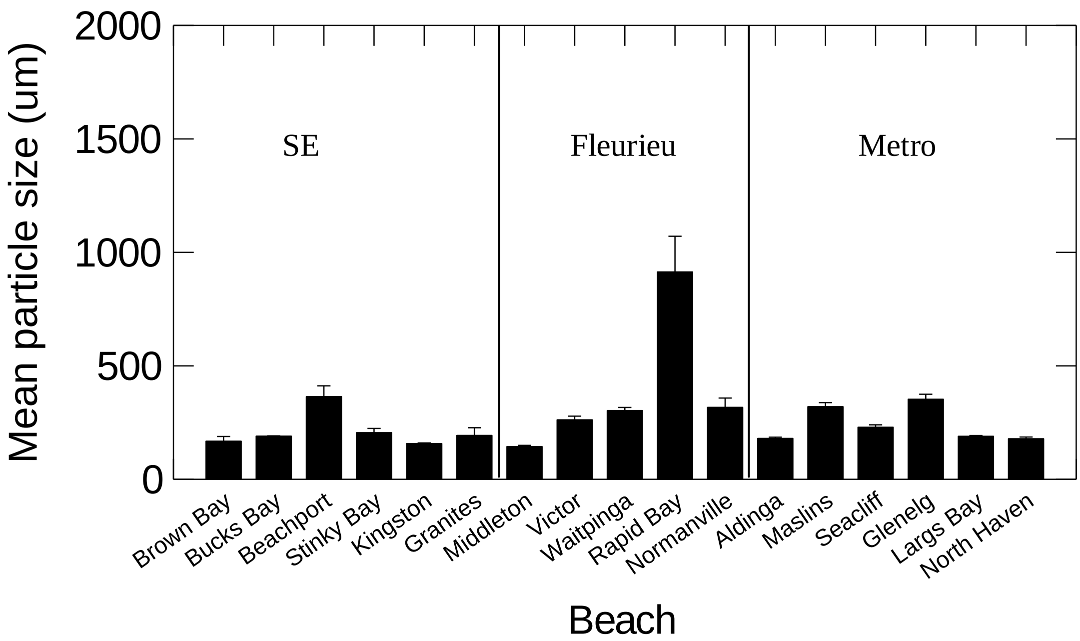
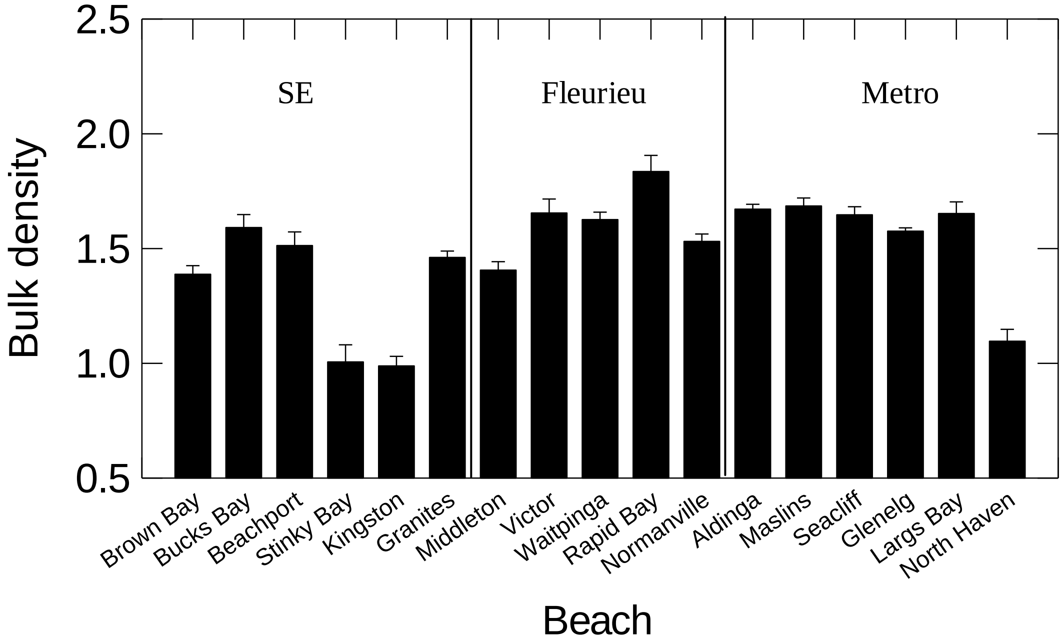


Figure 3.4a and b

c)



d)

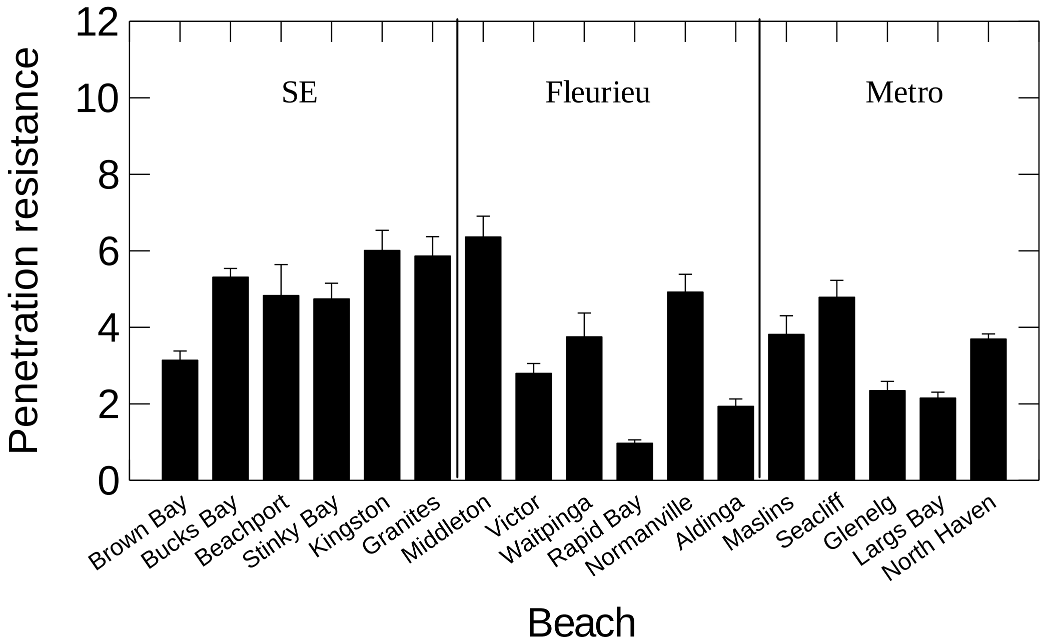
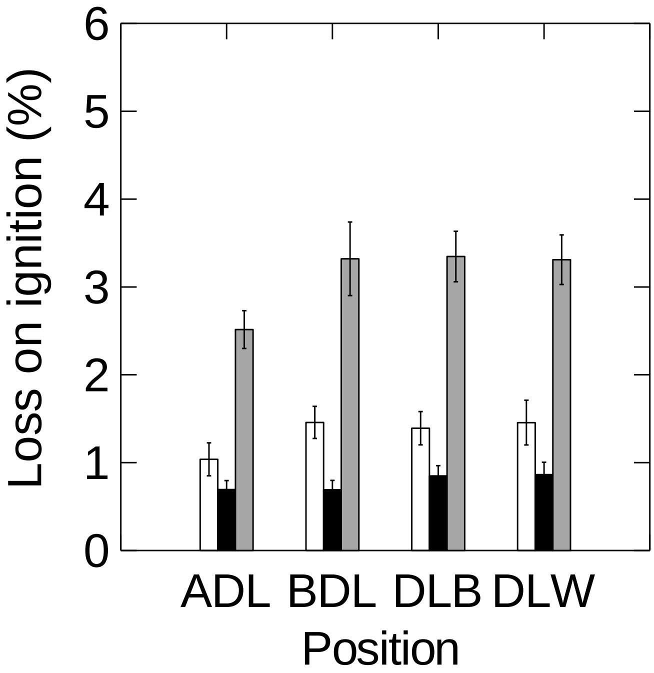


Figure 3.4c and d

a)


6
5
4
3
2
1
0
Loss on ignition (%)
ADL BDL DLB DLW
Position

b)

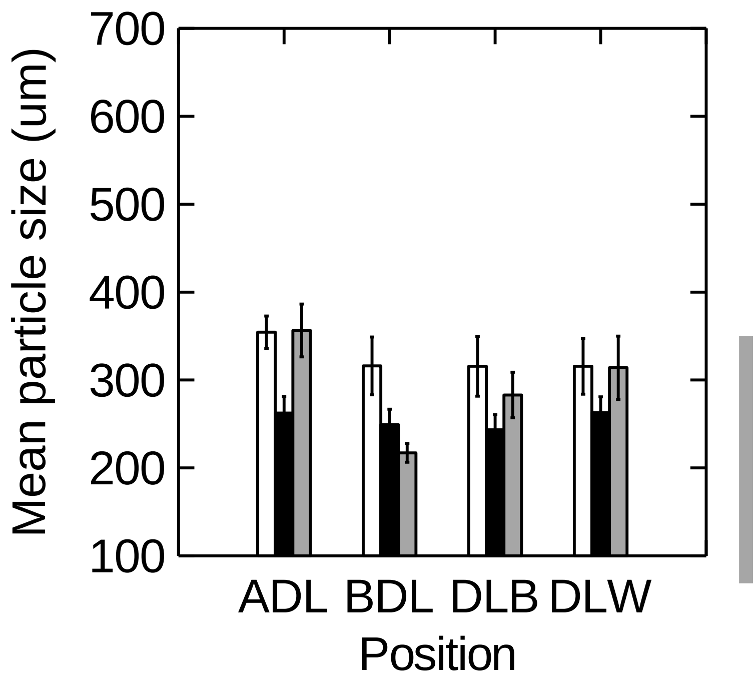

700
600
500
400
300
200
100
Mean particle size (um)
ADL BDL DLB DLW
Position

Figure 3.5

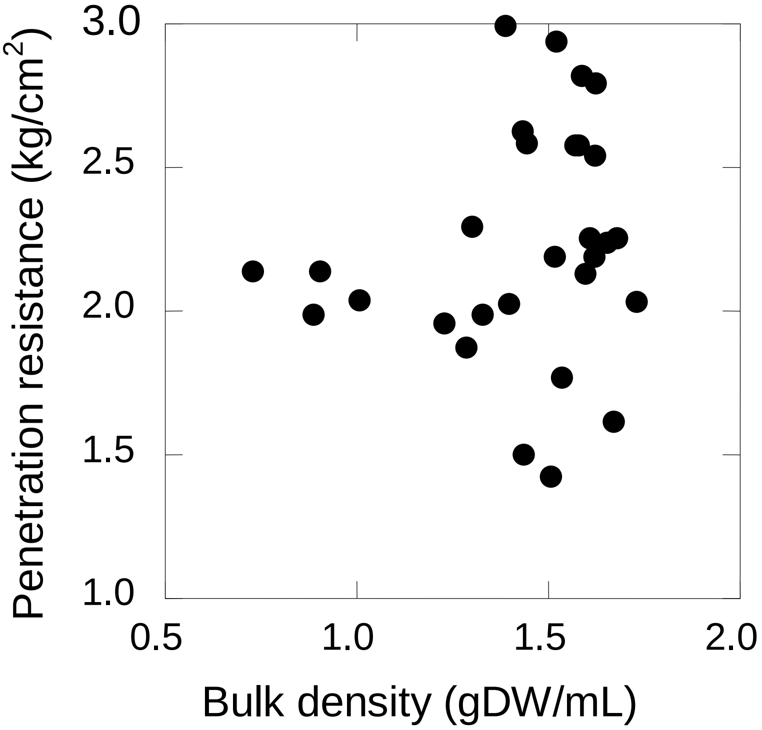

Penetration resistance (kg/cm^2)
3.0
2.5
2.0
1.5
1.0
0.5
1.0
1.5
2.0
Bulk density (gDW/mL)

Figure 3.6

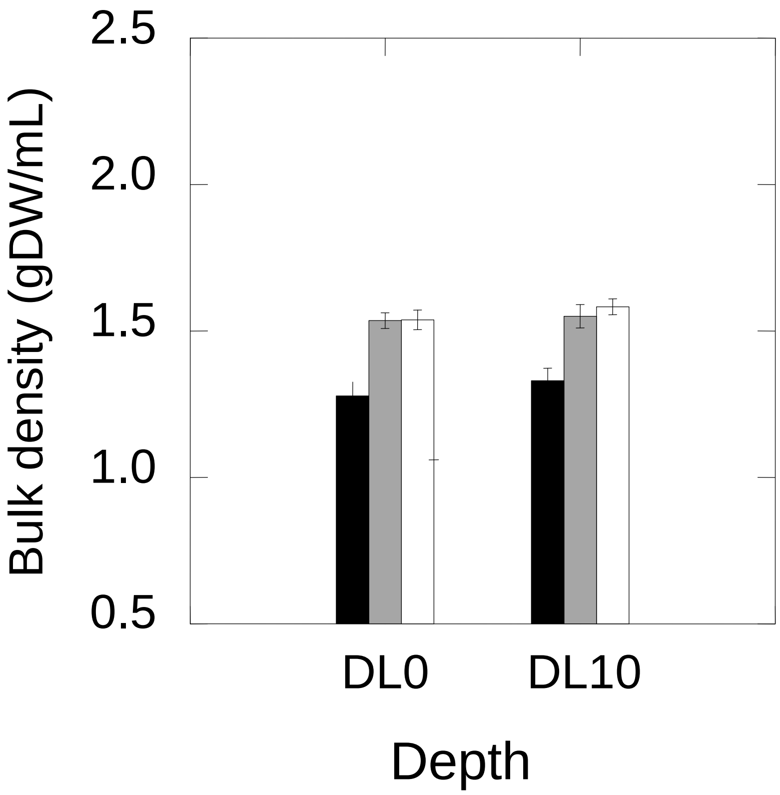


Figure 3.7

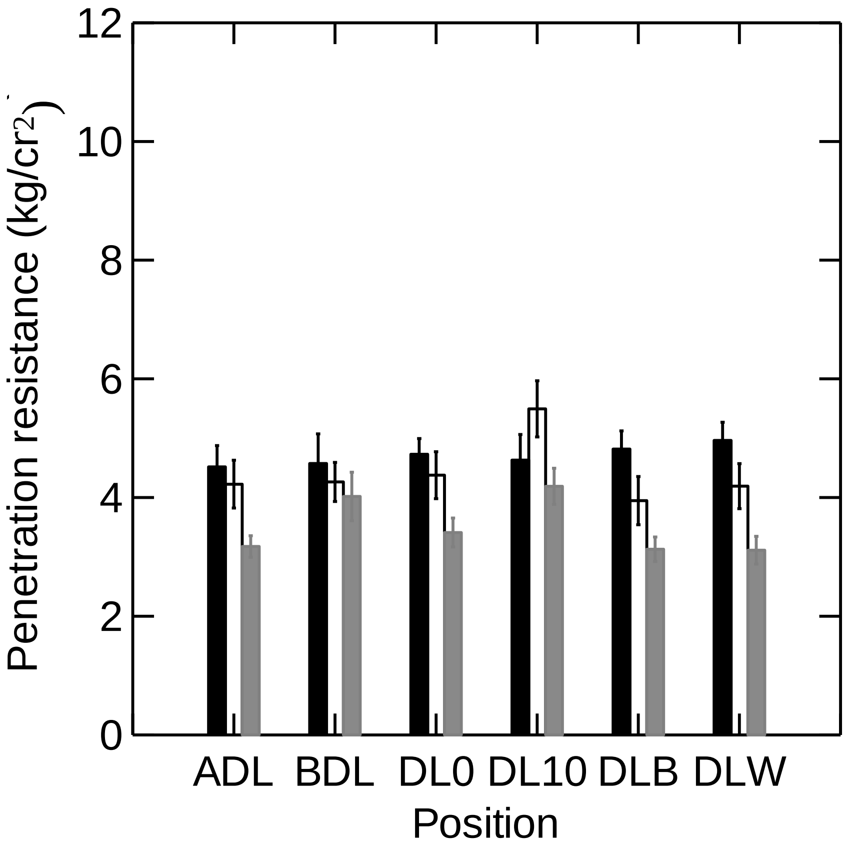

12
10
8
6
4
2
0
Penetration resistance (kg/cr2)
ADL BDL DL0 DL10 DLB DLW
Position

Figure 3.8

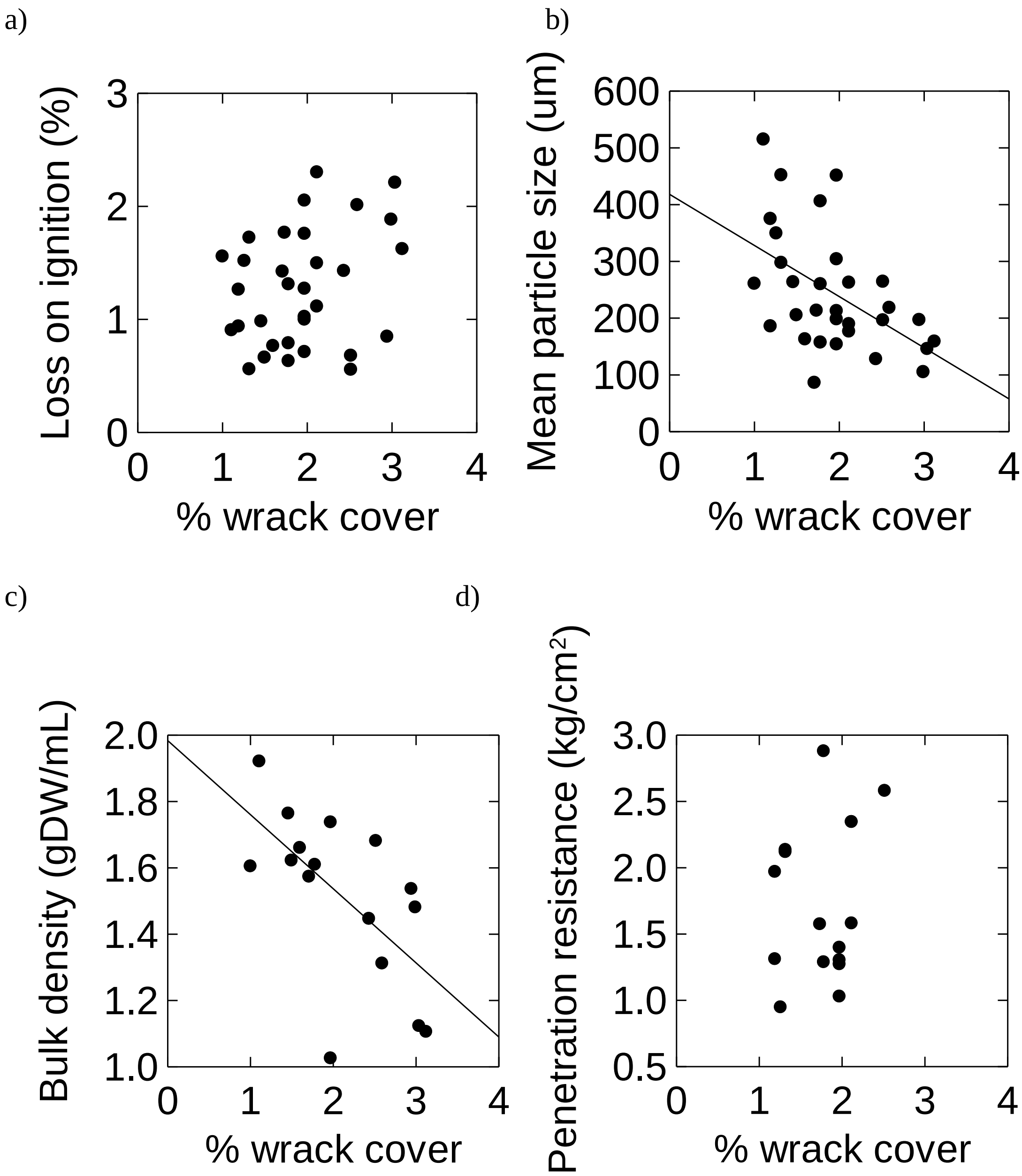
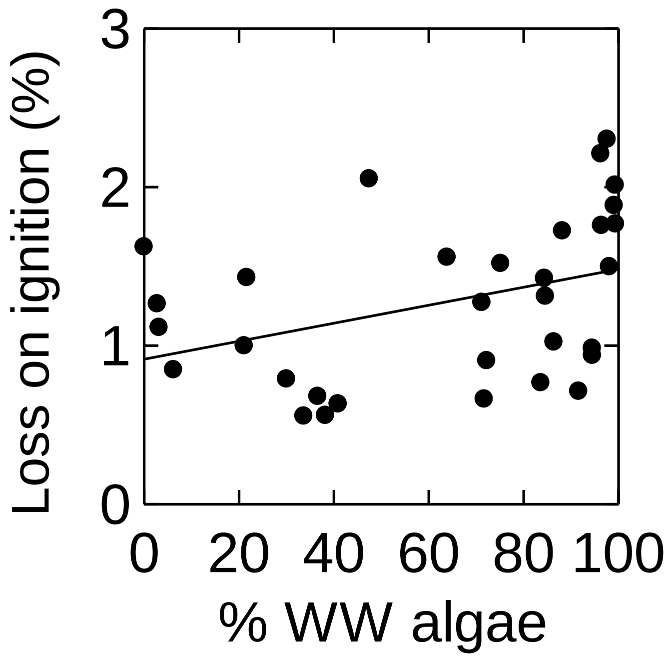

a)
b)
c)
d)
Loss on ignition (%)
3
2
1
0
0
1
2
3
4
% wrack cover
Mean particle size (um)
600
500
400
300
200
100
0
% wrack cover
Bulk density (gDW/mL)
2.0
1.8
1.6
1.4
1.2
1.0
% wrack cover
Penetration resistance (kg/cm2)
3.0
2.5
2.0
1.5
1.0
0.5
% wrack cover

Figure 3.9

a)



b)

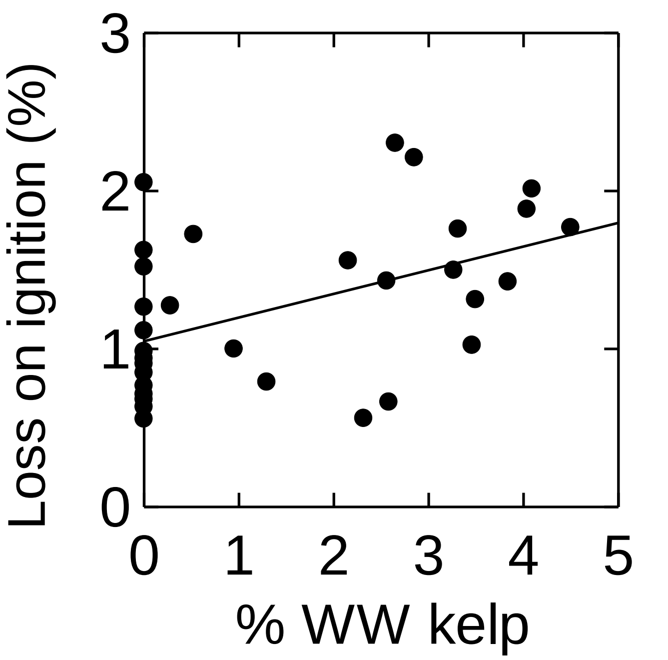


Figure 3.10

Table 3.1. Summary of the results of the three-way ANOVA for Visits, Regions and Beaches nested within Regions for beach width, beach fall and beach-face slope. NS = not statistically significant for α = 0.05. *p*-values in **bold** indicate significance at α = 0.05.

		Beach width (log-transformed)			Beach fall			Slope		
Source	df	MS	*F*-ratio	*p*	MS	*F*-ratio	*p*	MS	*F*-ratio	*p*
Visit	1	1.945	6.49351	< **0.05**	2.848	4.74114	NS	0.0004	0.75000	NS
Beach(Region)	12	0.888	2.96385	< **0.05**	1.117	1.85946	NS	0.003	5.69643	< **0.01**
Visit x Region	2	0.082	0.27271	NS	0.002	0.00358	NS	0.0004	0.73214	NS
Visit x Beach(Region)	12	0.300	38.9026	< **0.001**	0.601	16.20885	< **0.001**	0.001	9.27778	< **0.001**
Error	60	0.008			0.037			0.00006		

Table 3.2. Summary of beach type determined by Short (2006a) and beach index (BI) calculated for April and August for the main study beaches. Note that Bucks Bay was not sampled in April. Sediments could not be obtained from Kingston in August due to the deep wrack deposits covering most of the beach and the compost-like material that was present directly beneath the wrack. LTT = Low Tide Terrace, TBR = Transverse Bar and Rip, R = Reflective, D = Dissipative, RBB = Rhythmic Bar and Beach.

	Brown Bay	Bucks Bay	Beachport	Stinky Bay	Kingston	The Granites	Middleton	Victor Harbor	Waitpinga	Rapid Bay	Normanville	Aldinga	Maslins	Seacliff	Glenelg	Largs Bay	North Haven
Region			South East						Fleurieu						Metro		
Short (2006a) beach type	LTT/ TBR	LTT	TBR	LTT	R/ LTT	TBR	D	R	RBB	R/ Cobb -le	LTT	LTT	LTT/ TBR	LTT	LTT	LTT	LTT
BI April	2.74	-	2.01	2.32	2.45	2.52	2.47	1.94	2.22	1.49	1.98	2.25	1.83	2.12	1.96	2.48	2.29
BI August	2.06	2.25	1.73	2.20	-	2.08	2.37	1.78	1.93	0.93	1.60	2.08	1.74	1.89	1.86	2.44	2.10

Table 3.3. Summary of the results of the two-way ANOVA for Visits and Regions for Beach Index, n = 28. NS = not statistically significant for α = 0.05.

Source	df	MS	*F*-ratio	*p*
Visit	1	0.425	11.806	NS
Region	2	0.062	0.912	0.417
Visit x Region	2	0.036	0.535	0.593
Error	22	0.068		

Table 3.4. Summary of the results of the three-way ANOVA for Visits, Regions and Wrack cover (bare sand vs. under wrack) for loss on ignition (%, √-transformed, n = 180) and mean particle size (4th root-transformed, n = 174). NS = not statistically significant for $\alpha = 0.05$. p-values in **bold** indicate significance at $\alpha = 0.05$.

	Loss on ignition (√-transformed)				Mean particle size (4th root-transformed)			
Source	df	MS	F-ratio	p	df	MS	F-ratio	p
Visit	1	0.222	1.804	0.181	1	7.447	69.040	< **0.001**
Region	2	14.562	91.013	< **0.05**	2	0.558	0.459	NS
Wrack	1	0.001	0.333	NS	1	0.005	0.157	NS
Visit x Region	2	0.160	1.300	0.275	2	1.216	11.273	< **0.001**
Visit x Wrack	1	0.003	0.027	0.869	1	0.033	0.305	0.581
Region x Wrack	2	0.010	0.833	NS	2	0.020	10.000	NS
Visit x Region x Wrack	2	0.012	0.098	0.906	2	0.002	0.019	0.982
Error	168	0.123			162	0.108		

Table 3.5. Summary of the results of the two-way ANOVA for Regions and Position on the beach for loss on ignition (%, √-transformed) and mean particle size (4^{th} root-transformed), n = 177. p-values in **bold** indicate significance at $\alpha = 0.05$.

		Loss on ignition (√-transformed)			Mean particle size (4^{th} root-transformed)		
Source	df	MS	*F*-ratio	*p*	MS	*F*-ratio	*p*
Region	2	12.968	135.844	< **0.001**	57.670	8.333	< **0.001**
Position	3	0.271	2.838	0.040	26.327	3.804	0.011
Region x Position	6	0.037	0.387	0.887	9.670	1.397	0.219
Error	165	0.095			6.921		

Table 3.6. Summary of the results of the three-way ANOVA for Visits, Regions and Depth (surface vs. 10cm deep) for bulk density, n = 186. NS = not statistically significant for $\alpha = 0.05$. p-values in **bold** indicate significance at $\alpha = 0.05$.

Source	df	MS	*F*-ratio	*p*
Visit	1	0.281	4.997	**0.027**
Region	2	1.350	16.265	NS
Depth	1	0.069	2.760	NS
Visit x Region	2	0.083	1.480	0.231
Visit x Depth	1	0.025	0.450	0.503
Region x Depth	2	0.010	0.278	NS
Visit x Region x Depth	2	0.036	0.634	0.532
Error	174	0.056		

Table 3.7. Summary of the results of the three-way ANOVA for Visits, Regions and Position on the beach (Above DL = ADL, Below DL = BDL, Bare sand in the DL = DLB, under Wrack in the DL = DLW, surface sediments in the DL = DL 0cm, and sediments from 10cm depth in the DL = DL 10cm) for surface penetration resistance ($\surd$-transformed), n = 920. NS = not statistically significant for $\alpha = 0.05$. p-values in **bold** indicate significance at $\alpha = 0.05$.

Source	df	MS	*F*-ratio	*p*
Visit	1	33.948	111.318	< **0.001**
Region	2	7.069	10.519	NS
Position	5	0.672	3.411	NS
Visit x Region	2	0.672	2.204	0.111
Visit x Position	5	0.197	0.647	0.664
Region x Position	10	0.308	0.386	NS
Visit x Region x Position	10	0.797	2.612	**0.004**
Error	884	0.305		