CHAPTER FIVE: EFFECTS OF SANDY BEACH CUSPS ON WRACK ACCUMULATION, SEDIMENT CHARACTERISTICS AND MACROFAUNAL COMMUNITIES

Abstract

Wrack deposition on sandy beaches varies spatially and is affected by morphological features on the beach-face such as cusps. This study tested a series of hypotheses regarding the differences in wrack deposits, sediments and macrofaunal communities between cusp bays and horns. Bays had greater cover and larger pieces of wrack than horns. Sediment organic-matter content was greater on horns than in bays but mean particle size did not differ consistently between bays and horns. Macrofaunal diversity was higher in bays and this pattern was probably driven by differences in the cover of wrack between bays and horns. Cusp morphology thus influences the distribution of wrack on the beach-face, which in turn influences the distribution of macrofauna. Studies of sandy beaches with cusps should therefore be explicitly designed to sample cusp features and associated wrack deposits.

Introduction

The volume and deposition patterns of wrack accumulation are highly variable and can be influenced by a number of biotic and abiotic processes (Griffiths & Stenton-Dozey 1981; Colombini & Chelazzi 2003), including beach morphological features such as substrate type (Orr *et al.* 2005), rocky structures (Ochieng & Erftemeijer 1999) and cusps (McLachlan & Hesp 1984). Cusps are longshore undulations that appear like scallops in the beach face (Masselink & Hughes 2003); they break the beach face into an undulating series of bays and horns (Figure 5.1a). Cusp morphology is typically described as wide, gently-sloping and seaward-facing bays alternating with narrower, steeply-sloping and seaward-pointing horns. A single cusp includes an adjacent bay and horn. Cusp wavelength or cusp spacing (defined as the distance between the vertical peak of adjacent horns, Nolan *et al.* 1999) may be up to 50m on exposed ocean beaches

(Masselink & Hughes 2003). Cusps are typical of reflective beach types (Short 2006b) (i.e. with low wave energies and waves breaking or surging directly onto the beach, McLachlan & Brown 2006), but can also occur on intermediate beach types.

Studies of the swash circulation patterns within cusps have shown distinct differences between bays and horns (McLachlan & Hesp 1984; Masselink *et al.* 1997). Horns are characterised by high-velocity swash run-up and high infiltration rates, whereas bays have high-velocity backwash along the mid-line of the bay (McLachlan & Hesp 1984; Masselink & Hughes 2003). Sediment particle size can also differ between bays and horns but results have differed among studies (see Russel & McIntire 1965 for review). Several authors have reported no difference in mean grain size between bays and horns (see references in Russel & McIntire 1965) whilst others (e.g. McLachlan & Hesp 1984) have reported that horn sediments are coarser than bay sediments. Conversely, Masselink *et al.* (1997) reported that in the mid-shore, sediments in cusp bays were coarser than sediments on horns, whereas horn sediments were coarser than bay sediments on the lower beach face. A possible explanation invoking grain size for the divergent results previously reported is provided by Nolan *et al.* (1999). In a study encompassing beaches composed of a range of coarse sediments, Nolan *et al.* (1999) reported that horn sediments were coarser than bay sediments on gravel and mixed sand-gravel beaches but on sand beaches there was little difference in mean particle size between bays and horns. Barros *et al.* (2004) investigated the sediment characteristics of subtidal ripple marks (crests and troughs spaced less than 1m apart and with amplitudes of less than 15cm). The authors found that sediment particle sizes differed between crests (= horns) and troughs (= bays), and that these differences may be influenced by the size of the ripples (Barros *et al.* 2004).

Several studies have investigated the effects of cusp sediment characteristics and swash circulation patterns on the distribution of beach macrofauna within cusps (McLachlan & Hesp 1984; James 1999; Gimenez & Yannicelli 2000) but results have differed among studies. McLachlan and Hesp (1984) found that, on a reflective beach, species such as bivalves (*Donacilla angusta* and *Donax faba*) were concentrated in bays. Conversely, James (1999), employing a comprehensive sampling regime, recorded no significant differences in the abundance of bivalves (*Donax deltoides*) on an intermediate beach in New South Wales. James (1999) hypothesised that his results could be attributed to the weaker cusping on the intermediate beach he sampled compared to the better-developed cusps occurring on reflective beaches would result in weaker passive redistribution of sedentary fauna due to weaker swash movement. Studies on more mobile species (e.g. crabs) have indicated that their distribution may vary depending on their mobility and niche requirements, and the swash characteristics. Mobile macrofauna may occur throughout both bays and horns *(Hippa australis*, McLachlan & Hesp 1984) or concentrate in bays (*Emerita analoga*, Cubit 1969; *Emerita brasiliensis* and *Excirolana armata*, Gimenez & Yannicelli 2000) *(Emerita analoga, Cubit 1969; Emerita brasiliensis* and *Excirolana armata*, Gimenez & Yannicelli 2000) or on horns (*Excirolana brasiliensis*, Gimenez & Yannicelli 2000).

Deposition of wrack from the surf zone onto the beach and then redistribution of stranded wrack could also be affected by cusps. In a similar manner to the less mobile macrofauna, wrack may be passively accumulated in bays due to swash circulation. Alternatively, it may accumulate on cusp horns if it is sufficiently heavy, similar to the coarser sediment particles that accumulate on horns on some beaches. To date, only one study has attempted to quantify the patterns of wrack distribution between cusp bays and horns. In their study of one Western Australian beach, McLachlan and Hesp (1984) recorded significantly greater masses of wrack accumulated at the driftline of bays than horns. They, however, sampled only two cusps on one beach and thus their results cannot be considered generally applicable without further verification.

The aim of this study was to determine whether wrack accumulations, sediment characteristics and macrofaunal communities differ between horns and bays. I proposed a series of hypotheses concerning whether the deposition of wrack on beach cusps was influenced by cusp morphology. I hypothesised that: 1) a greater cover of wrack occurs in bays than on horns; 2) the size of individual wrack pieces will be larger in bays than on horns; and 3) the difference in wrack volume between bays and horns will be proportional to cusp size (i.e. the larger the cusp, the stronger the processes that cause the differences between bays and horns). Previous investigations (McLachlan & Hesp 1984; Masselink *et al.* 1997) have also indicated that the differences between bays and horns do not occur uniformly at all beach levels, and thus I proposed that wrack cover, sediment organic matter content and particle sizes would differ between bays and horns and with the distance from the upshore dune. Based on previous accounts of the transient nature of both cusps and wrack, I also tested the hypothesis that both cusp size and their associated wrack accumulations would differ temporally and spatially. Given the many studies that have previously reported greater abundances and diversities of beach macrofauna around wrack deposits (McLachlan 1985; Jedrzejczak 2002a; Dugan *et al.* 2003), I also proposed that macrofaunal communities in bays and on horns would differ, and that these differences may be attributed to the amount of wrack present.

Methods

Site selection

Sampling was conducted between February and July 2007 on four beaches in the Adelaide metropolitan area and Fleurieu Peninsula, South Australia (Table 5.1, Figure 5.2). Beaches were selected based on the criteria that they had distinct cusps (obvious bay and horn features) and at least some wrack along a well-defined driftline (DL, defined as the line parallel to the waterline with the greatest cover of wrack). Cusp "pairs" were defined as an adjacent bay (a low point relative to sea level) and horn (a high point relative to sea level) (Figure 5.1b). The beaches sampled were Port Willunga, Normanville, Hindmarsh River and Port Elliot (Figure 5.2). Port Willunga is located on the metropolitan coast and all other beaches are located on the Fleurieu Peninsula. Port Elliot is classified as Reflective (*sensu* Short 2006a) whereas the other 3 beaches are Intermediate (Low Tide Terrace) type (*sensu* Short 2006a).

Due to the transient nature of wrack and cusps (pers. obs.), the sampling design was ultimately unbalanced. Three sampling occasions were carried out between February 2006 and June 2007. On two of the three sampling occasions, there were either no distinct cusps or insufficient wrack accumulations at Port Willunga and Normanville, and hence these beaches were sampled only once each. On each sampling date, cusps and sufficient wrack were present at Port Elliot and Hindmarsh River, and thus these beaches were sampled on three occasions (Table 5.1). Further sampling was also carried out on 4 cusps at each of these two beaches on the 28 June 2007, and thus these beaches were sampled a total of 4 times. The number of cusps sampled on each beach on each occasion varied due to the number of suitable cusps and time limitations (Table 5.1). A total of 50 cusp systems (i.e. a paired bay and horn) were sampled over the entire study.

Pilot study

A pilot study was conducted to establish a sampling protocol. Sampling was conducted in a bay at the midpoint between two adjacent horns, and at the vertical peak of the horn. Line intercept transects were laid parallel to the waterline at the DL and perpendicular to the waterline to assess the percent wrack coverage. The data indicated that shore-parallel transects were suitable for sampling the wrack accumulation at the DL. Due to the limited number of cusps present on the study beaches, I aimed to determine whether consecutive cusps could be sampled without bias from spatial autocorrelation. I therefore sampled a series of consecutive cusps and analysed data sets from all cusps (i.e. using consecutive cusps) and from a reduced data set consisting of cusps separated from each other by at least one bay or horn. Paired t-tests on % wrack yielded similar results for consecutive and non-consecutive cusps, and thus sampling consecutive cusps was deemed acceptable. Pairing any adjacent bay and horn was also deemed acceptable, i.e. that there is no fixed direction along the shore in which bays and horns are paired. Sampling of adjacent cusps has also been used in previous studies (e.g. Masselink *et al.* 1997).

Field methods

Sampling was conducted in bays at the midpoint between two adjacent horns, and at the vertical peak of the horn. Cusp spacing (C_S, m, Nolan *et al.* 1999) was determined with a tape measure as the distance between the vertical peaks of adjacent horns (Figure 5.1b).

As an estimate of the size of a cusp, cusp amplitude (C_A, m, sensu Nolan *et al.* 1999), defined as the maximum height difference (relief) of the cusp horn and the cusp bay, was measured (Figure 5.1b). A dumpy level (Horizon 2024 Auto Level, deviation = 2mm at 1km double run) was used to measure cusp amplitude to the nearest centimetre. For each bay or horn, a single 5m-long line-intercept transect, oriented parallel to the waterline, was used to determine the wrack percent cover at the DL.

On one occasion (June 28 2007), additional sampling was conducted at Pt Elliot and Hindmarsh River. On each beach, 4 cusps were sampled. Cusp spacing, amplitude and the percent cover of wrack were determined as above. To investigate whether wrack cover is determined solely by position within the cusp (bay vs. horn) or if wrack cover varies with distance from the dune (Hypothesis 3), the wrack percent cover was determined for each bay and horn at 2 distances from the dune: 1) at the bay DL and on the adjacent horn; and 2) at the horn DL and in the adjacent bay (Figure 5.1c), giving 4 distinctly-located transects per cusp (n = 32 transects in total). A single sediment sample was also collected at the midpoint of each transect (n = 32 cores). A cylindrical corer (core diameter = 11cm) was used to collect sediment samples to a depth of 10cm. Each sediment sample was homogenised and a sub-sample (80-100 g) was taken for sediment particle-size analysis and organic-matter (OM) content determination. Wrack and macrofaunal samples were also collected from the DL of each bay and horn. Twenty pieces of wrack were haphazardly collected from each DL (total n = 320 wrack pieces).

Sampling for macrofauna was carried out in and around the DL wrack accumulation (Figure 5.1c). A box corer (25 x 25cm, depth = 10cm) was used to take sediment samples to a depth of 10cm. Three haphazardly-located cores were taken for each bay or horn. Samples were sieved in a 500µm-mesh sieve for Hindmarsh River and 1000µm-mesh sieve for Pt Elliot (due to a coarser mean grain size). Sediment and fauna retained on the sieve were placed in plastic zip-lock bags for processing in the laboratory.

Laboratory methods

Organic-matter content was determined by loss on ignition (LOI). A sub-sample of sediment (approximately 5g) was dried to constant weight (80°C for 24 hours) and the dry weight (DW) determined. Sub-samples were ashed at 600°C for 90 minutes, cooled and the ash-free DW (AFDW) recorded. The LOI is expressed as % LOI = (DW-AFDW)/DW * 100. Particle-size analysis was conducted using laser diffraction. A Malvern Mastersizer 2000 with HydroMU attachment was used. The maximum particle size that can be used in this equipment is 2000µm. 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). Mean particle size of each sample was obtained directly from the Malvern 2000 software v5.31. Individual wrack pieces collected from the driftlines were rinsed to remove sand, blotted dry and weighed individually to determine their wet weight (WW, g).

Macrofauna were counted and identified to the lowest possible taxonomic unit. For each DL, the data from the 3 replicate cores were used to calculate four measures of macrofaunal community structure: 1) mean number of individuals per core; 2) total number of species (all cores summed for each transect); 3) mean number of species per core; and 4) mean number of individuals excluding the most abundant taxon (n = 16). This last measure was used because the macrofauna were numerically dominated by one species of isopod (the beach pill-bug *Actaecia pallida*, Family Scyphacidae) and thus to distinguish any patterns in the abundance of the less-abundant macrofaunal species, this species was omitted.

Statistical analyses

Univariate analyses

Adjacent bays and horns were paired for analyses and thus paired-sample t-tests were used to compare bay and horn characteristics. To test the hypothesis that a greater cover of wrack occurs in bays than on horns, a paired-sample t-test was conducted for the percent wrack cover at the DL for all cusps sampled (n = 50). A 2-sample t-test was used to test the hypothesis that the mass of individual wrack pieces was greater in bays than on horns (n = 20 per bay or horn). For each comparison, the relative effect size (E) was calculated, where E = ($mean_{Bay}$ – $mean_{Horn}$) / $mean_{Horn}$ (Karban & Huntzinger 2006).

To determine whether % wrack cover on bays and horns differed between the 2 distances from the dune, ANOVA was used. A 3-way ANOVA was used with the factors Beach (random factor, PE vs. HR), Position (fixed factor, B vs. H) and Distance from the dune (fixed factor, distance 1 = Bay DL and adjacent the bay DL vs. 2 = Horn DL and adjacent the horn DL) with a total of n = 32 transects. The same analyses were conducted for organic matter content, expressed as % LOI, and mean particle size (µm). Since Beach was a random factor, post-hoc tests of significant effects for the main effect of Beach or interactions between Beach and Position and/or Distance are not appropriate (Underwood 1997).

The beach-face slope between the vertical peak of the horn and the adjacent position at the midline of the bay can be used as a measure of cusp size (Masselink *et al.* 1997). This slope (hereafter BHslope) integrates cusp spacing and cusp amplitude so that BHslope = C_A/C_S, and is a dimensionless ratio (m/m). BHslope was calculated for each cusp; a larger value indicates a steeper slope between the bay and horn. To determine whether the difference in wrack cover between bays and horns (denoted as ΔWrack, whereby ΔWrack = B_{Wrack} - H_{Wrack}) is proportional to cusp size, cusp spacing (C_S), cusp amplitude (C_A) and BHslope were used as size measures. A linear regression with cusp size as the predictor and ΔWrack as the dependent variable was conducted. To test the hypothesis that cusp size and wrack accumulations differ temporally and spatially, a 2-way analysis of variance (ANOVA) for effects of Beach and Visit was carried out for four dependent variables, C_S, C_A, BHslope, and ΔWrack, at HR and PE on the 4 visits to those beaches. Both factors of Beach and Visit were considered random factors with 2 and 4 levels, respectively.

Two-way ANOVA was used to determine whether univariate measures of faunal communities differed between PE and HR (factor Beach) and between bays and horns (factor Position). Beach was considered a random factor and Position was a fixed factor. The mean values from each DL were used and thus $n = 16$. The variables analysed were mean number of individuals per core, total number of species, mean number of species per core, and mean number of individuals excluding the most abundant taxon (*A. pallida*). To determine whether the percent wrack cover influences the associated macrofaunal community analysis of covariance (ANCOVA) was used. A 2-way ANCOVA with Beach and Position as the factors and percent wrack cover (log [x + 1]-transformed) as the covariate was used for the four dependent variables listed above.

Data are presented as mean ± se. Assumptions were checked by visual examination of residuals and the data were transformed to normalise distributions and homogenise variance where appropriate. Percent wrack cover was 4th root-transformed due to the large number of zeros and small number of large values. Univariate analyses were carried out using SYSTAT v11 software.

Multivariate analyses

Macrofaunal data (per core) were analysed using multivariate techniques. Two-dimensional MDS plots were produced using Bray-Curtis similarities. Two-way crossed analyses of similarity (ANOSIM), with 999 permutations, were performed to assess any differences in taxonomic composition and relative abundances between the two Beaches and two Positions. Similarity percentages (SIMPER) analyses were run to determine within-group similarities and between-groups dissimilarities for Beaches and Positions. A high value of percentage similarity within groups indicates group cohesion and a high dissimilarity between groups indicates distinct communities. 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), as determined by SIMPER analysis. Analyses were performed on raw data and on 4th root-transformed data, which lessens the influence of the most abundant species (i.e. *A. pallida*). Multivariate analyses were run using PRIMER v.6 software and graphical representations were plotted using SYSTAT v11 software.

Results

Wrack deposits

Wrack cover ranged between 0 and 67% (mean: 9 ± 1%) overall and was between 0 and 21% on horns and 1 and 67% in bays (Figure 5.3). Mean wrack cover was 3 ± 0.7% and 16 ± 2% on horns and in bays, respectively, and thus on average, bays had 13 ± 2% more wrack than horns. The direction of the difference varied with more wrack on bays than horns in most cusps but more wrack on horns than bays in a few cases (Figure 5.3). The paired-samples t-test (on log [x +1]-transformed data) revealed that this was a significantly greater average percent wrack cover in bays than on horns ($p < 0.001$). There was on average E = 167% more wrack in bays than on horns. For cusps at HR and PE this pattern was also seen with significantly greater wrack cover on bays than horns ($p < 0.001$ for both Beaches, separately). At HR there was E = 147% more wrack on bays than horns and for PE the effect size was 158%.

Wrack pieces collected included small fragments of seagrass and algal material up to large portions of kelp plants. The WW of individual wrack pieces ranged between 0.001g and 339g and was on average 11 ± 2g. The mass of individual wrack pieces was significantly greater in bays (15 ± 3g) than on horns (8 ± 3g) for HR and PE combined ($p < 0.001$) and for each beach separately (HR: $p < 0.001$, PE: $p = 0.003$) (Figure 5.4). Thus, the mass of individual wrack pieces was 73% greater in bays than on horns for both beaches combined, and 175% and 26% for HR and PE, respectively.

Cusp morphology

Cusp spacing varied between 16.1 and 44.0m (mean 29.6 ± 1.1m) (Figure 5.5a). Within a cusp system, cusps bays were always lower than horns and cusp amplitude was on average 0.37 (± 0.02) m, with a range of 0.05 to 0.86m (Figure 5.5d). BHslope ranged between 0.002 and 0.031 with a mean of 0.013 (± 0.001) (Figure 5.5g). There was a significant positive correlation between cusp amplitude (√-transformed) and cusp spacing (Pearson $r = 0.612$, $p = 0.008$). Cusp spacing, cusp amplitude (√-transformed) and BHslope (√-transformed) did not differ significantly between beaches or between visits (Table 5.2); however, the interaction of Beach and Visit was significant for all three variables tested (C_S: p = 0.027, C_A: p = 0.003 and BHslope: p = 0.034). There were no significant differences in the variation in wrack cover between bays and horns between HR and PE, between Visits or for the interaction between Beach and Visits (p = 0.116) (Table 5.2).

Effects of cusp morphology on wrack deposits

The three measures of cusp morphology (C_A, C_S and BHslope) were positively and significantly correlated with Δwrack for HR (C_S: Pearson r = 0.423, P = 0.028, Figure 5.5b; C_A: Pearson r = 0.556, P = 0.003, Figure 5.5e; BHslope: Pearson r = 0.413, P = 0.032, Figure 5.5h; n = 27 for each). There were no significant correlations over all cusps sampled (Figure 5.5a, d and g; in all cases Pearson r < 0.253, P > 0.077, n = 49) or for PE (Figure 5.5c, f and i: Pearson r < 0.479, P > 0.060, n = 16).

There was a large difference in mean % wrack cover between bays and horns (17.3 ± 5.1% vs. 2.9 ± 1.0%) and between the two Distances from the dune (1: 17.0 ± 5.2% vs. 2: 3.2 ± 0.9) (Figure 5.6a). Despite this the 3-way ANOVA for Beach, Position and Distance from the dune on % wrack cover (4^{th} root-transformed) yielded no significant results (Table 5.3, Figure 5.6a).

Sediment OM content and particle sizes

The sediment OM content was low in all samples and ranged between 0.9 and 2.3% (overall mean 1.4 ± 0.05%) (Figure 5.6b). The 3-way ANOVA for Beach, Position and Distance from the dune indicated that horn sediments had significantly higher organic matter content (1.39 ± 0.06%) than bay sediments (1.34 ± 0.9%) (Figure 5.6b). There was also a significant effect of Beach but since Beach is a random factor this does not require further interpretation. There was a significant, positive correlation between the % cover of wrack (4^{th} root-transformed) and the OM content of underlying sediments (Pearson r = 0.373, p = 0.035, n = 32).

Mean particle size ranged between 275 and 309µm (overall mean 326 ± 5µm) (Figure 5.6c). The interaction between Beach, Position and Distance (3-way ANOVA) was not significant, nor were the interactions of Beach and Position, or Beach and Distance (Table 5.3). Mean particle size differed significantly between Beaches (Figure 5.6c, Table 5.3). There was no correlation between the % cover of wrack (4^{th} root-transformed) and the mean particle size of underlying sediments (Pearson $r = 0.049$, $p = 0.789$, $n = 32$).

Macrofauna

Of the 48 cores taken, 38 contained at least one individual animal, yielding a total of 607 individuals (Table 5.4). The number of individuals per core ranged between 0 and 193. A total of 10 species were caught (Table 5.4), including both marine and terrestrial forms, with between 0 and 5 species per core. The beach pill-bug, *A. pallida*, accounted for 78% of the total number of individuals (475 individuals) and was present in 22 cores. The amphipod sand hopper (*Talorchestia quadrimana*; Family Talitridae) and a swimming isopod (*Cirolana corpulenta*; Family Eurydicidae) accounted for 12% (74 individuals in 19 cores) and 6% (35 individuals in 22 cores), respectively, of the total number of individuals. Samples from Bays at PE had the highest total abundance of fauna (Table 5.4).

The mean number of individuals ranged between 0 and 65 individuals per core (mean 12.6 ± 5.1) (Figure 5.7a) and did not differ significantly between Beaches ($p = 0.237$), Positions ($p = 0.099$) or for the Beach and Position interaction ($p = 0.511$) (Table 5.5a). The total number of species per transect (all cores summed) was between 0 and 6 species, with the highest number of species per transect recorded for HR bays. On average, this was significantly greater on Bays (4.2 ± 0.6) than on Horns (2.5 ± 0.6) ($p = 0.038$) (Figure 5.7b) and differed significantly between the two beaches sampled ($p = 0.038$) (Table 5.5a). The interaction of Beach and Position was not significant ($p = 0.132$). The mean number of species per core was highest in HR bay samples and lowest in PE horn samples with a grand mean of 1.7 (± 0.3) species per core (Figure 5.7c). The effect of Position was significant with a higher number of species per core on Bays (2.3 ± 0.4) than on Horns (1.2 ± 0.3) (p = 0.011) and again there was a significant difference between Beaches (p = 0.011), but not for the interaction of Beach and Position (p = 0.134) (Table 5.5a). When *A. pallida* (i.e. the most abundant species) was excluded from the analysis, the mean number of individuals per core was reduced to 2.8 (± 0.6) (Figure 5.7d). Square-root-transformed data for this variable followed the same patterns as the mean number of species per transect: Bays (4.4 ± 0.8) had a greater number of individuals than horns (1.1 ± 0.4) (p = 0.004) but there was no effect of Beach (p = 0.702) nor the Beach x Position interaction (p = 0.694) (Table 5.5a).

The inclusion of the covariate wrack cover in the model Beach x Position (2-way ANCOVA) did not yield any statistically-significant results for the mean number of individuals, number of species per transect, mean number of species or mean number of individuals excluding *A. pallida*. Thus, the previously found difference between bays and horns in the total number of species per transect, mean number of species per transect and mean number of individuals excluding *A. pallida* may be explained by the difference in the cover of wrack between the two Positions.

The 2-dimensional MDS plot showed that samples from Bays were more closely grouped towards the centre of the plot whilst samples from Horns were plotted around the edges (Figure 5.8). Similarly, samples from HR were plotted in the centre of the plot whilst PE samples were distributed around the edges of the plot (Figure 5.8). Samples from each combination of Beach and Position tended to group together but there was some overlap between the groups of samples. The stress was low (0.13) indicating that the plot was a good 2-dimensional representation of the relationships among the samples (Clarke & Warwick 1994). These results were supported by SIMPER analyses. Within-groups similarity was 30.67% and 24.17% for HR and PE samples, respectively, and 27.97% and 22.83% for Bay and Horn samples, respectively. For 4th root-transformed data, SIMPER within-groups similarity was 47.48% and 35.13% for HR and PE samples, respectively, and 44.48% and 33.53% for Bay and Horn samples, respectively.

ANOSIM Global *R* values were 0.339 (p = 0.001) and 0.225 (p = 0.002) for Beach and Position, respectively, indicating significantly-different macrofaunal communities between Beaches and between Positions. Dissimilarity between samples from HR and PE (Beaches) was 83.83% and between samples from Bays and Horns (Positions) was 81.74%. Thus between Beaches and Positions there were very few species in common and/or quite different relative abundances. *A. pallida* was the only consistent indicator (Dissimilarity/SD > 1, Clarke & Warwick 1994) of Beach (HR > PE) and Position (B >H).

Results of the ANOSIM on 4th root-transformed data were similar to those for the raw data. Global *R* values were 0.323 (p = 0.003) and 0.276 (p = 0.001) for Beach and Position, respectively, indicating significantly different macrofaunal communities between Beaches and between Positions. SIMPER dissimilarity between samples from HR and PE (Beaches) was 72.20%. *A. pallida* and *T. quadrimana* were identified as indicators of beach; the former having a greater abundance at HR than at PE and the latter occurring in greater abundances at PE than HR. Dissimilarity between samples from Bays and Horns was 69.82%. *A. pallida*, *C. corpulenta* and *T. quadrimana* were identified as consistent indicators of Position with greater abundances in Bays than on Horns.

The multivariate analyses were also conducted on reduced data sets with species that occurred only once or twice removed. Removal of singletons and doubletons did not markedly change the results and so are not presented here.

Discussion

Cusp morphology (amplitude, spacing and BHslope) varied in space and time, demonstrating the dynamic nature of cusps and reflecting the range of processes affecting their formation, maintenance and modification (Russel & McIntire 1965; Masselink *et al.* 1997; Nolan *et al.* 1999). Cusps on any one beach or beach type (e.g. reflective or intermediate) cannot always be characterized as a given size, nor can cusps occurring at the same time at different beaches be characterised as the same size.

When comparing bays and horns or the 2 distances from the dune, there were no differences in the mean particle size of sediments. These results concur with previous accounts of sediment characteristics on cusps but also contrast with others, further contributing to the divergence of reports on the sediments of cusp bays and horns (see references in Russel & McIntire 1965). The results of this study concur with the results of Nolan *et al.* (1999) who found similar results for sandy beaches (i.e. no differentiation in particle size between bays and horns) but on mixed sand-gravel and gravel beaches horns had coarser sediments than bays. Differences in particle size between the two beaches sampled were not surprising given that PE is Reflective and HR is an Intermediate beach type (Table 5.1), and Reflective beaches typically have coarser sediments than Intermediate beaches (McLachlan & Brown 2006; Short 2006b).

Sediment organic matter content was higher on horns than in bays. This result may be explained by the fact that the bay receives the greatest backwash in the form of a mini-rip where the backwash from adjacent horns meets (Russel & McIntire 1965; Masselink *et al.* 1997). This mini-rip has been proposed to remove meiofauna from within the sediments (McLachlan & Hesp 1984) and could act in a similar manner to remove particulate organic matter. Futhermore, horns have higher water infiltration rates compared to bays , which may result in the accumulation of fine organic matter particles on horns, and thus a higher organic matter content (McLachlan and Hesp 1984).

Wrack accumulations differed between bays and horns with a greater cover and larger pieces of wrack in bays. Cusp bays tended to have a greater cover of wrack than adjacent cusp horns, a result in accordance with the previous study by McLachlan and Hesp (1984). Cusp bays also tended to accumulate larger pieces of wrack, which may contribute to the greater % cover of wrack in bays than on horns. I propose that this pattern of wrack distribution is due to the following processes: Cusp horns are steeply sloping at the seaward edge and wrack is transported by the movement of swash uprush and backwash. Thus I hypothesise that the swash on horns in insufficient to transport wrack pieces up the more-steeply sloping horn, whereas in the bay, the gentle slope requires less swash uprush to transport wrack up the beach face. This idea is supported by the finding that larger pieces of wrack were found in bays than on horns, since small pieces of wrack can be transported up the horn more easily than large ones. Alternatively, but less likely, is that the mechanism behind the accumulation of wrack in bays is similar to that proposed for the passive transport of fauna into the bays of cusps (McLachlan & Hesp 1984; James 1999), i.e. that a net movement of swash in this direction results in the transport of wrack into bays. Wrack is washed off horns into bays due to the high velocity of backwash moving down the steeper side of horns, where it then settles out at the midline of the bay where the backwash from 2 adjacent horns meets. I hypothesise that this is less likely since there would thus be no wrack at all on horns as all of it should be washed into the bays.

In my comparison of wrack cover on two beaches, cusp bays and horns, and at two distances from the dune, no significant results were achieved, despite large differences in the mean values (Table 5.3, Figure 5.6a). This is likely due to the low degrees of freedom (1,1) for the main effects of Position and Distance from the dune, and for the interaction of Position and Distance; low degrees of freedom require very large F-ratios to obtain a significant result (F_{crit} for 1,1df at $\alpha = 0.05 = 161.0$). The F-ratios for Position, Distance and Position x Distance were all much greater than 1 (Table 5.3), suggesting that with greater degrees of freedom and/or more replication, significant results may be obtained. This may be achieved by sampling additional positions (e.g. at points between the midline of cusp bay and the peak of the horn) and/or additional distances between the driftlines in the bay and on the horn.

Characteristics such as the mass, size and buoyancy of wrack (Orr *et al.* 2005) can also influence wrack performance in the swash and hence its distribution at low tide. Whilst the absolute amount of wrack on a given beach at a given time may vary considerably (Chapter 2), the pattern of greater wrack cover on bays than horns occurred consistently in space and time and regardless of differences in cusp morphology or size. Thus bays provide a greater quantity (cover) and different type (larger pieces and potentially different taxonomy, pers. obs.) of wrack than horns and within a beach. Wrack varies at spatial scales in the order of 10s and 100s of metres, resulting in heterogenous beach resources and available niches for macrofauna.

Macrofaunal communities differed between bays and horns with a higher diversity of macrofauna and higher abundance of less-common species in bays than on horns. The difference in wrack coverage between bays and horns drove the significance of the effect of Position in the ANOVA of the number of species per transect, mean number of species and number of individuals excluding *A. pallida*. The pattern of wrack deposition, with greater cover of wrack in bays than on horns could thus explain the variation in faunal communities between bays and horns. Whilst this study did not investigate the across-shore distribution of macrofauna, my results suggest that wrack, a potential shelter and food source for macrofauna, has a greater across-shore extent in bays, although this was not a significant effect. McLachlan and Hesp (1984) also found that fauna occupied a wider zone (across-shore) in the bay than on the horn (10 vs. 7m), a result that may be driven by the pattern of wrack deposition. Macrofaunal distribution is thus influenced by the pattern of wrack deposition, which aggregates resources into the bay.

Conclusion

Whilst cusp morphology is variable in space and time, its effects on wrack deposition within cusps occur more consistently. Steep horns and flat bays result in the differential deposition of wrack into bays, and thus these resources and their macrofaunal consumers aggregate in cusp bays. Cusp morphology thus influences the distribution of wrack on the beach face, which in turn influences the distribution of macrofauna. The presence of cusps should not be overlooked in ecological studies of beaches but instead should be explicitly incorporated into sampling efforts.

List of Figures

level, the line is shown and the p-value is indicated in bold.

Figure 5.6. a. Mean (± se) wrack % cover, b. mean (± se) % LOI and c. mean (± se) mean particle size (PS) from Bays (B) and Horns (H) at 2 distances from the dune (n = 32 in total). ■ = DL, □ = not the DL.

Figure 5.7. a) Mean (± se) mean number of individuals per core, b) mean (± se) total number of species, c) mean (± se) mean number of species per core and d) mean (± se) mean number of individuals excluding most abundant taxon (*A. pallida*) per core for samples from Bays and Horns at HR (■) and PE (□). n = 4. Note that for a), c) and d) this is the mean of the 3 sub-samples from each DL and for b) this is the total number of species for the 3 sub-samples from each DL.

Figure 5.8. MDS plot of macrofaunal communities from Bays (● and ■) and Horns (○ and □) at PE (■ and □) and HR (● and ○) (n = 16, with the 3 samples from each DL averaged). 2-dimensional stress = 0.13.

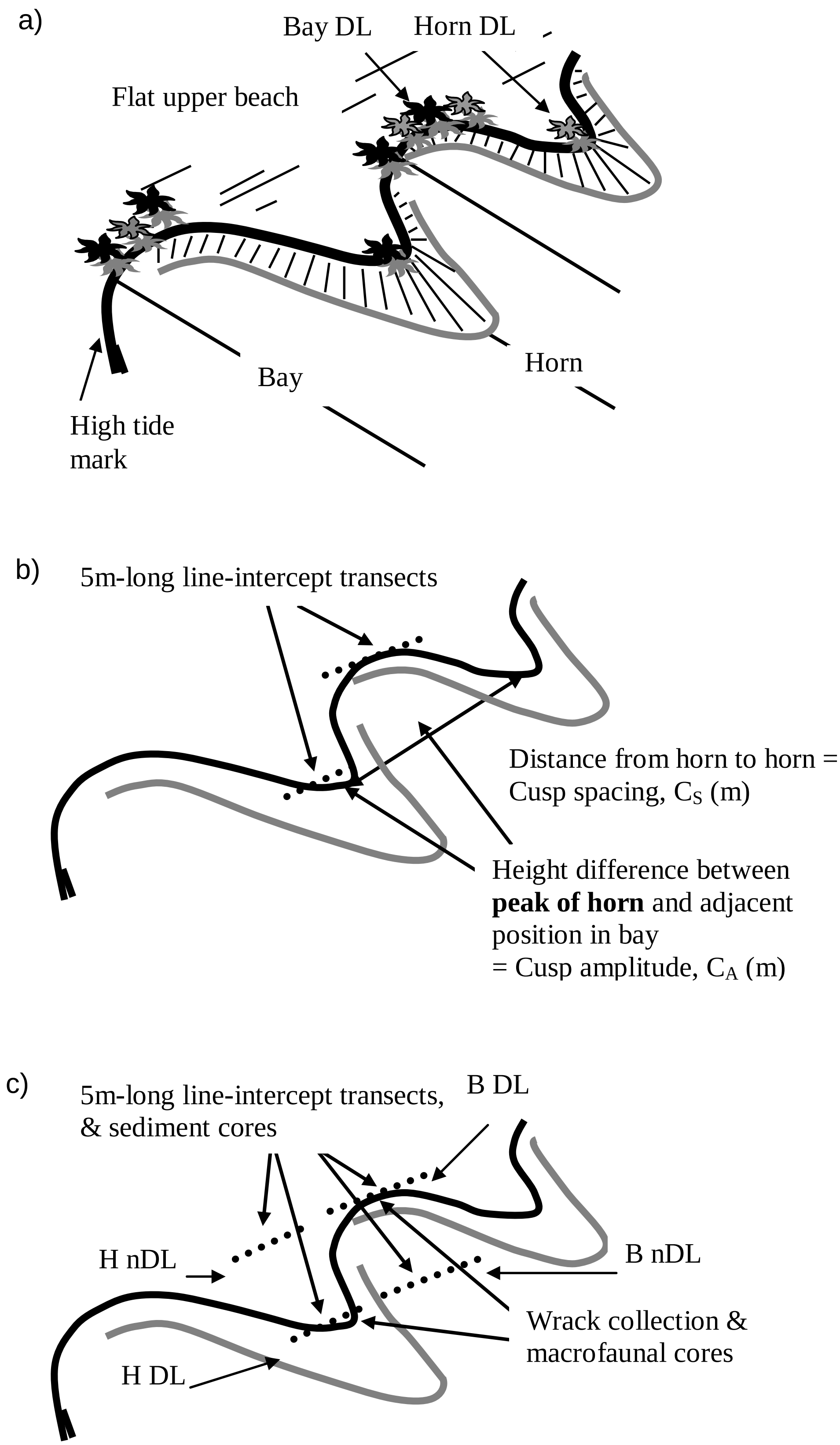
a)
Bay DL
Horn DL
Flat upper beach
Horn
Bay
High tide mark
b)
5m-long line-intercept transects
Distance from horn to horn = Cusp spacing, C_S (m)
Height difference between **peak of horn** and adjacent position in bay = Cusp amplitude, C_A (m)
c)
5m-long line-intercept transects, & sediment cores
B DL
H nDL
B nDL
Wrack collection & macrofaunal cores
H DL

Figure 5.1

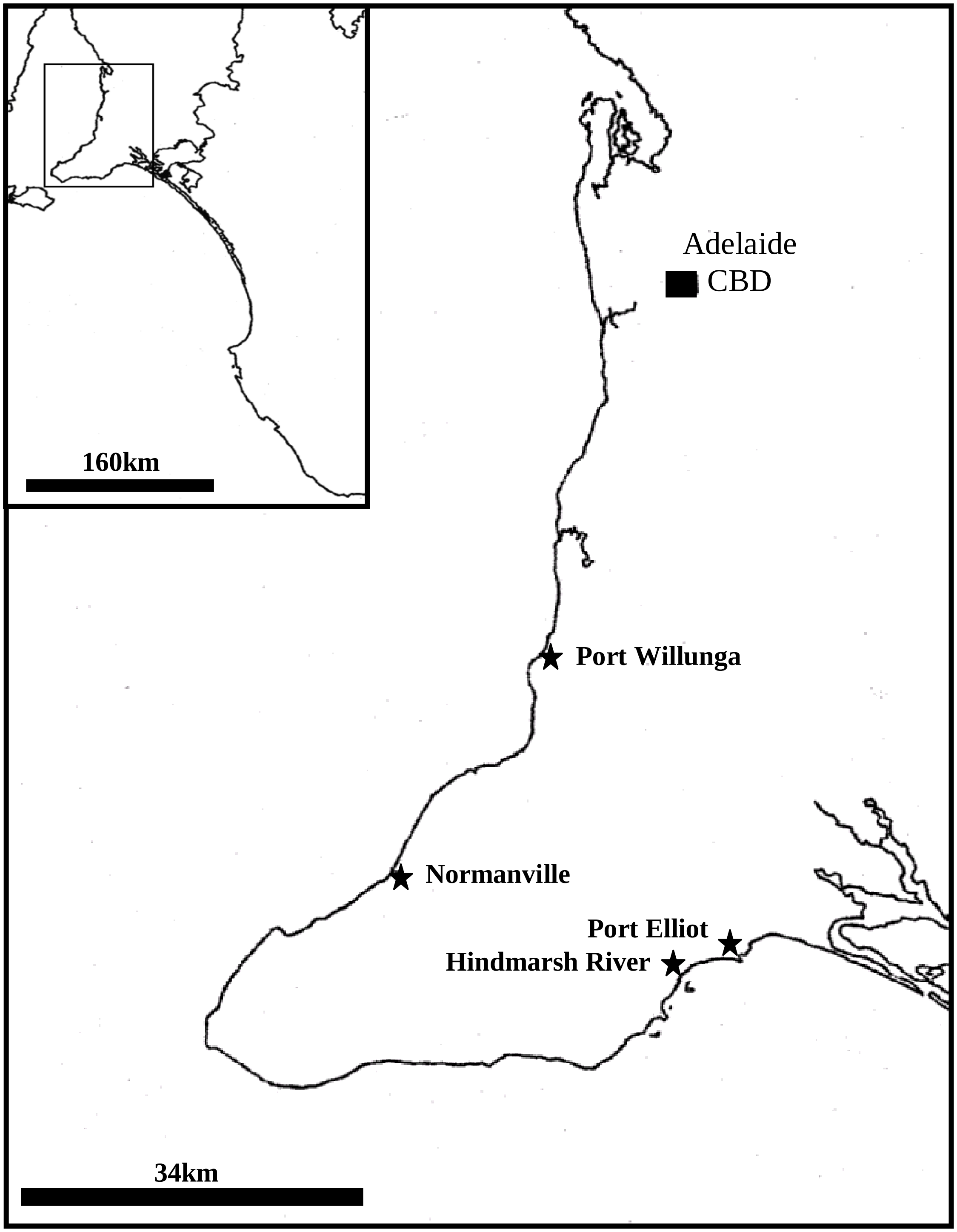
160km
Adelaide
CBD
Port Willunga
Normanville
Port Elliot
Hindmarsh River
34km

Figure 5.2

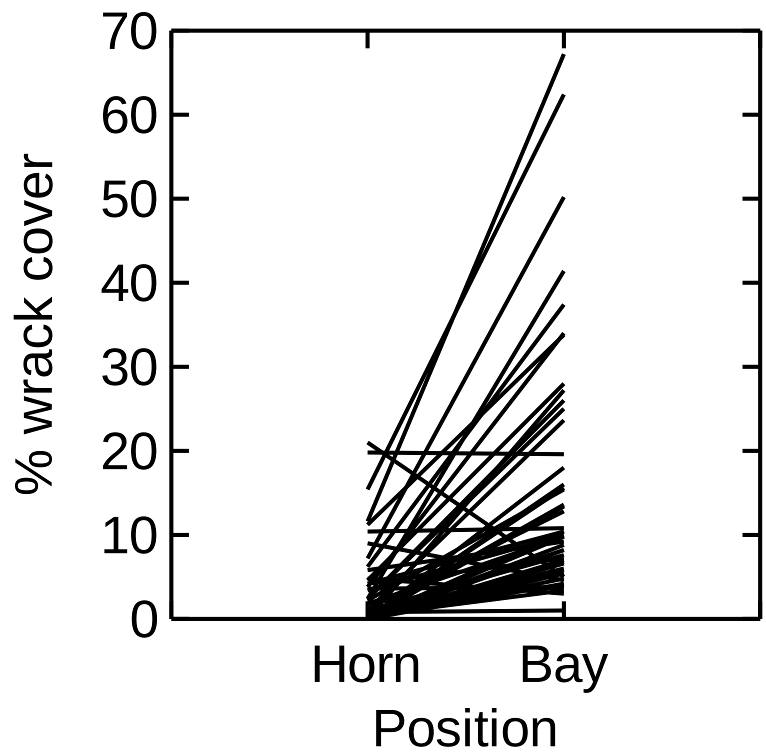

Figure 5.3

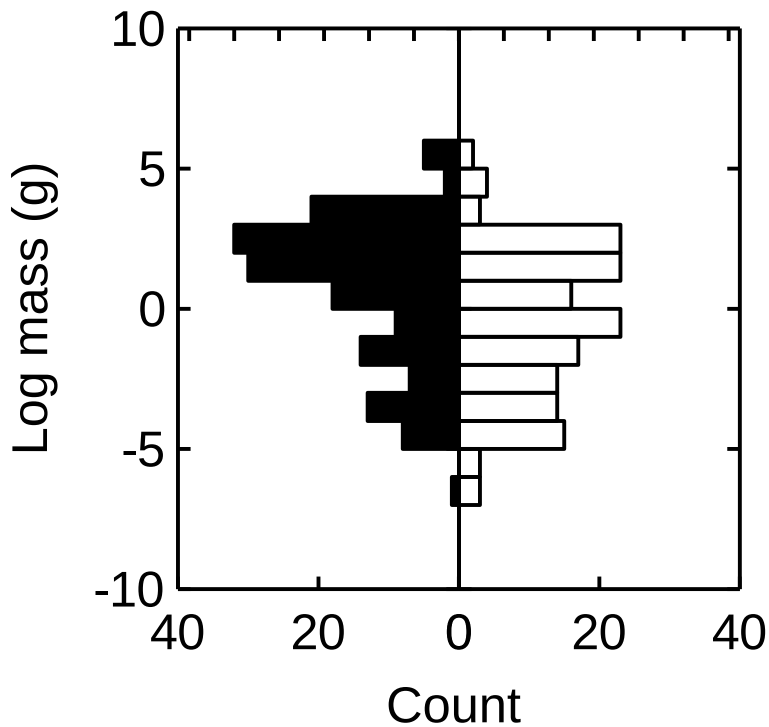

Figure 5.4

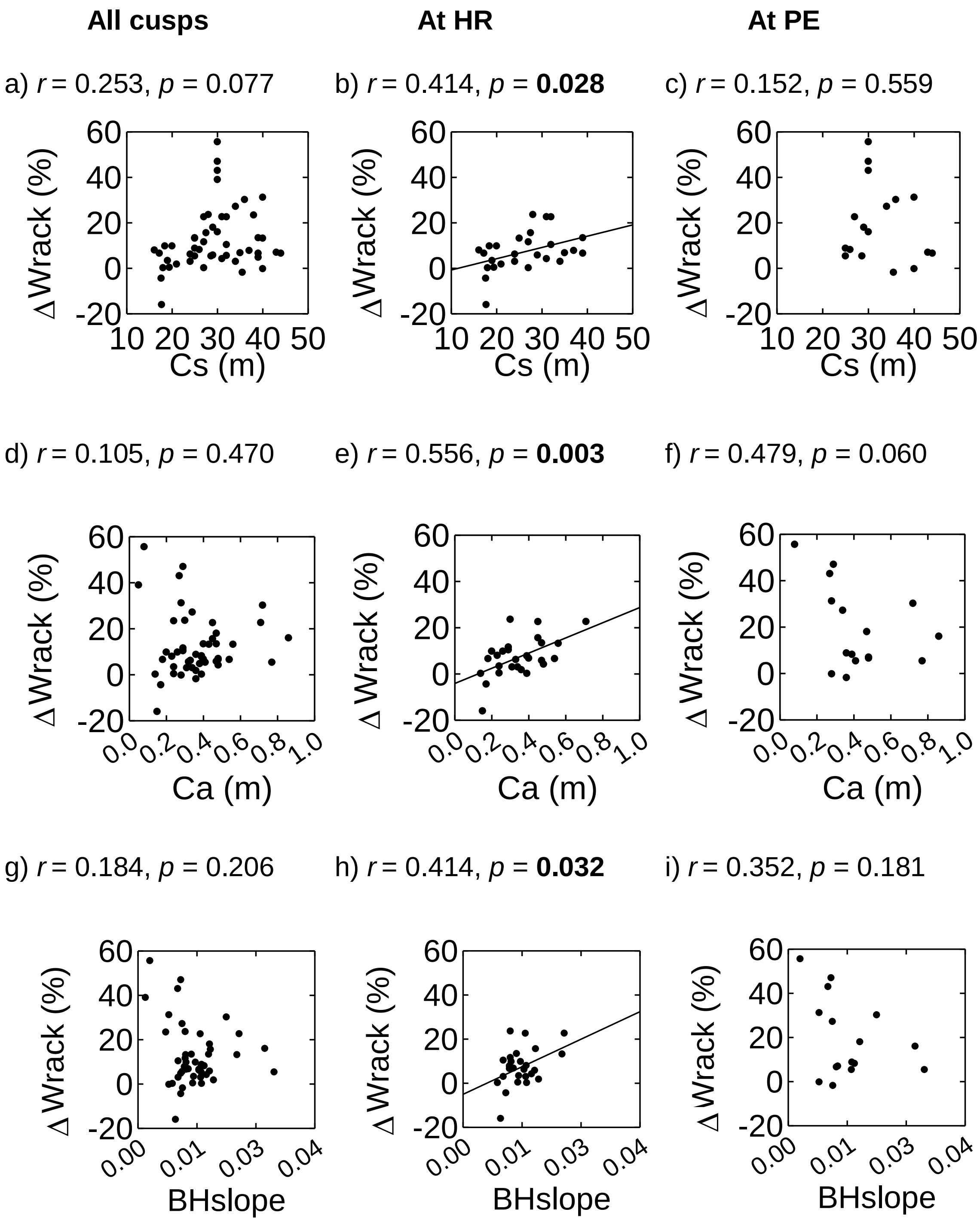
All cusps
At HR
At PE
a) r = 0.253, p = 0.077
b) r = 0.414, p = **0.028**
c) r = 0.152, p = 0.559
d) r = 0.105, p = 0.470
e) r = 0.556, p = **0.003**
f) r = 0.479, p = 0.060
g) r = 0.184, p = 0.206
h) r = 0.414, p = **0.032**
i) r = 0.352, p = 0.181
Δ Wrack (%)
Cs (m)
Ca (m)
BHslope
60
40
20
0
-20
10 20 30 40 50
0.0 0.2 0.4 0.6 0.8 1.0
0.00 0.01 0.03 0.04

Figure 5.5

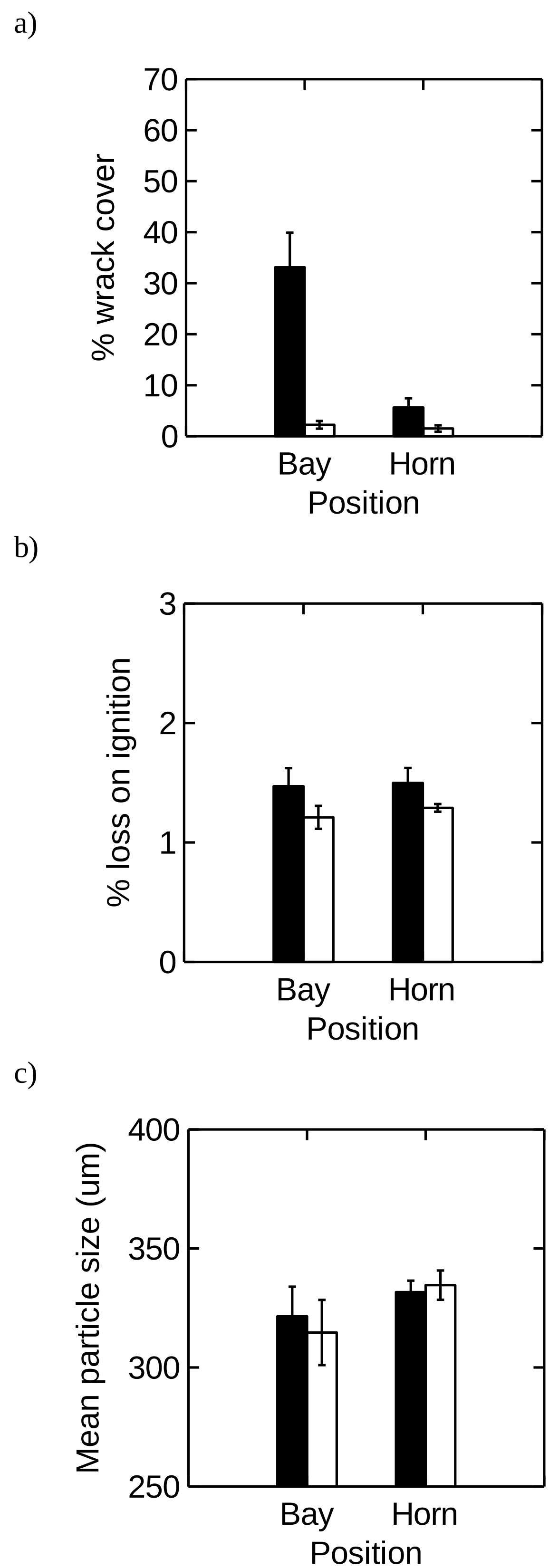
a)
70
60
50
40
30
20
10
0
% wrack cover
Bay
Horn
Position
b)
3
2
1
0
% loss on ignition
Bay
Horn
Position
c)
400
350
300
250
Mean particle size (um)
Bay
Horn
Position

Figure 5.6

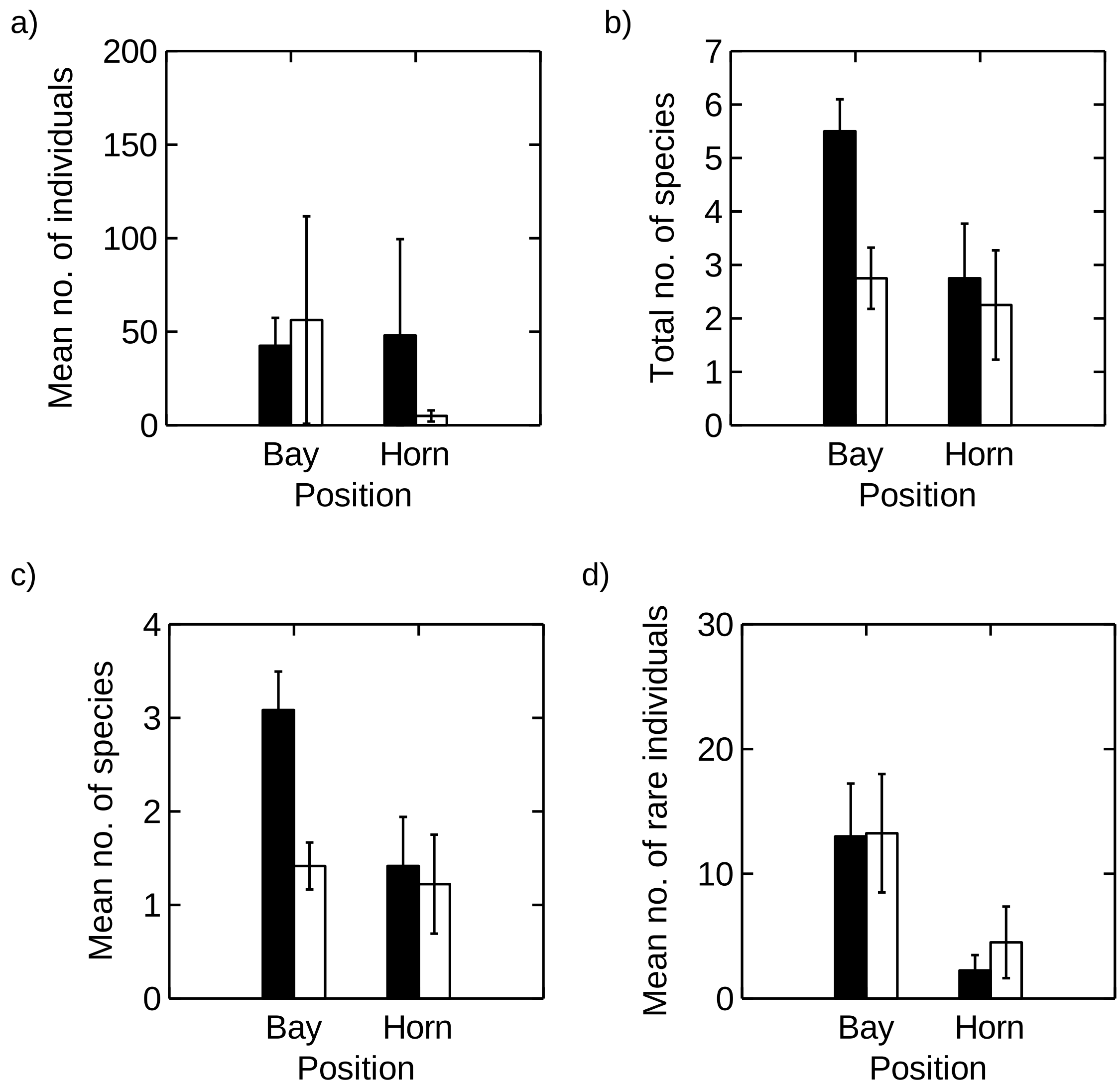
a)
Mean no. of individuals
200
150
100
50
0
Bay
Horn
Position
b)
Total no. of species
7
6
5
4
3
2
1
0
Bay
Horn
Position
c)
Mean no. of species
4
3
2
1
0
Bay
Horn
Position
d)
Mean no. of rare individuals
30
20
10
0
Bay
Horn
Position

Figure 5.7

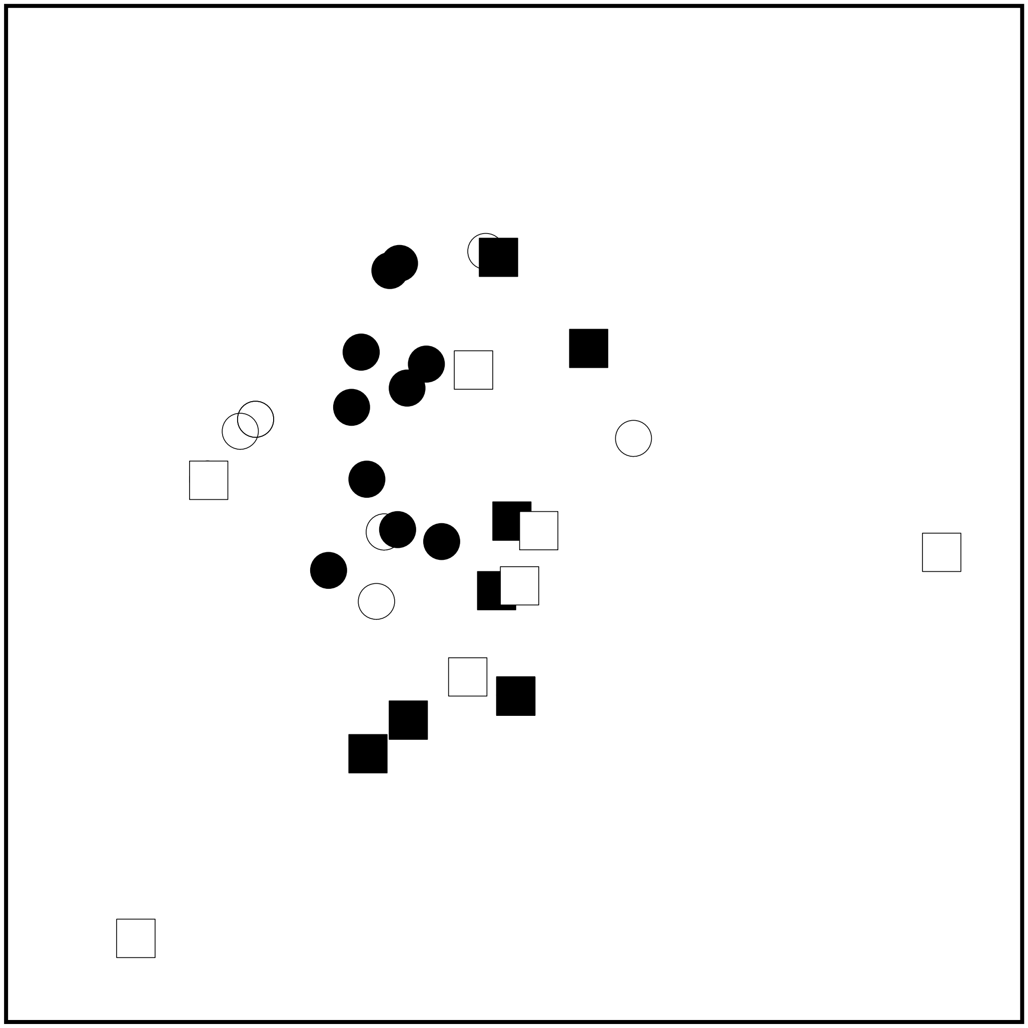

Figure 5.8

Table 5.1**.** Summary of site characteristics, sampling occasions and wrack cover on study beaches. † For beach type: R = Reflective beach, I = Intermediate beach (Short 2006a). Beach type and beach length were obtained from Short (2006a). Cusp spacing (C_S), cusp amplitude (C_A), BHslope, % wrack on Bay and % wrack on Horn are presented as mean (± se) and n = the sum of the number of cusps sampled on each occasion. ‡ For Port Elliot on visit 3, values for C_A and BHSlope n = 3 only due to errors in recording measurements.

	Port Elliot	Hindmarsh River	Normanville	Port Willunga
Region	Fleurieu	Fleurieu	Fleurieu	Metropolitan
Latitude	35º31'	35º32'	35º26'	35°16'
Longitude	138º40'	138 º 37'	138º19'	138° 26'
Beach type †	R	I	I	I
Beach length, km	0.7	0.9	7.3	1.5
Sampling dates & no. of cusps sampled	13/10/06: 3; 11/12/06: 6; 1/06/07: 4; 28/06/07: 4‡	13/10/06: 3; 11/12/06: 6; 1/06/07: 14; 28/06/07: 4	13/10/06: 3	13/10/06: 3
Cusp spacing, C_S, m	32.5 (± 1.5)	26.1 (± 1.4)	37.0 (± 2.5)	31.0 (± 3.8)
Cusp amplitude, C_A, m	0.43 (± 0.05)	0.35 (± 0.03)	0.38 (± 0.03)	0.23 (± 0.10)
BHslope	0.014 (± 0.002)	0.013 (± 0.001)	0.010 (± 0.000)	0.008 (± 0.004)
% wrack in Bay	24.2 (± 5.0)	10.1 (± 1.2)	8.1 (± 2.8)	27.6 (± 8.1)
% wrack on Horn	4.8 (± 1.5)	2.8 (± 0.9)	0.3 (± 0.1)	2.3 (± 1.3)

Table 5.2. Summary of 2-way ANOVA results for Beach and Visit for cusp spacing (C_S, m), cusp amplitude ($\sqrt{C_A}$, m), the slope between the bay and the horn ($\sqrt{BHSlope}$, m/m) and difference in % wrack cover between bay and horn (ΔW, %) (see Table 5.1 for *n*). NS = not statistically significant for $\alpha = 0.05$. *p*-values in **bold** indicate significance at $\alpha = 0.05$.

	C_S				$\sqrt{C_A}$				$\sqrt{\text{BHSlope}}$				ΔW			
Source	df	MS	*F*	*p*	df	MS	*F*	*p*	df	MS	*F*	*p*	df	MS	*F*	*p*
Beach	1	646.858	6.421	NS	1	0.054	0.915	NS	1	0.00001	0.007	NS	1	1351.558	6.319	NS
Visit	3	133.571	4.557	NS	3	0.056	0.949	NS	3	0.00054	1.227	NS	3	873.310	4.083	NS
Beach x Visit	3	100.742	3.437	**0.027**	3	0.059	5.487	**0.003**	3	0.00142	3.227	**0.034**	3	213.873	2.113	0.116
Residual	36	29.312			35	0.011			35	0.00044			36	101.226		

Table 5.3. Summary of 3-way ANOVA results for Beach, Position and Distance from the dune for a) %wrack (4th root transformed), b) %LOI and c) mean particle size. Total n = 32. NS = not statistically significant for α = 0.05. p-values in **bold** indicate significance at α = 0.05.

		% Wrack, 4th root transformed			% LOI			Mean particle size (µm)		
Source	df	MS	*F*	*p*	MS	*F*	*p*	MS	*F*	*p*
Beach	1	1.024	4.088	0.054	0.485	7.680	**0.011**	7402.646	16.838	< **0.001**
Position	1	2.578	5.416	NS	0.023	1131.500	< **0.025**	1803.752	1.435	NS
Distance	1	2.047	39.205	NS	0.005	0.020	NS	190.067	31.209	NS
Beach x Position	1	0.476	1.899	0.181	0.001	0.001	0.987	1257.336	2.860	0.104
Beach x Distance	1	0.052	0.208	0.652	0.266	4.220	0.051	6.090	0.014	0.907
Position x Distance	1	9.881	14.621	NS	0.442	5.578	NS	29.803	0.114	NS
Beach x Position x Distance	1	0.676	2.696	0.114	0.079	1.254	0.274	261.278	0.594	0.448
Residual	24	0.251			0.063			439.629		

Table 5.4. Total abundance of macrofaunal taxa collected from sediments at Hindmarsh River and Port Elliot from Bays and Horns (n = 12 cores for each combination of beach and position).

		Beach	Hindmarsh River		Port Elliot		
		Position	Bay	Horn	Bay	Horn	**Total**
Amphipoda	Talitridae	*Talorchestia quadrimana*	27	3	33	11	74
Isopoda	Scyphacidae	*Actaecia pallida*	118	183	172	2	475
	Eurydicidae	*Cirolana corpulenta*	12	4	15	4	35
Coleoptera	Staphylinidae	Staphylinid sp.	1	0	0	1	2
	Curculionidae	*Aphela phalenoides*	3	1	0	1	5
	Curculionidae	Larva sp.	4	0	2	0	6
	Lathridiidae	Lathridiidae sp.	1	0	0	0	1
Diptera		Fly sp. 1	1	0	3	1	6
		Fly sp. 2	3	0	0	0	3
Hymenoptera	Formicidae	Ant sp.	0	1	0	0	1
		Total abundance	170	192	225	20	607
		Cumulative number of species	9	4	5	6	10

Table 5.5. Summary of 2-way ANOVA for Beach and Position for mean number of individuals, number of species per transect, mean number of species and mean number of individuals excluding *A. pallida* (n = 16). p-values in **bold** indicate significance at $\alpha = 0.05$.

		Mean individuals, 4^{th} root			No. of spp/transect			Mean no. of spp.			Mean individuals excl. *A. pallida*, $\sqrt{}$		
Source	df	MS	F	p	MS	F	p	MS	F	p	MS	F	p
Beach	1	0.691	1.549	0.237	10.563	5.452	**0.038**	4.696	8.898	**0.011**	0.066	0.153	0.702
Position	1	1.421	3.188	0.099	10.563	5.452	**0.038**	4.694	8.894	**0.011**	5.523	12.802	**0.004**
Beach x Position	1	0.204	0.458	0.511	5.063	2.613	0.132	1.362	2.581	0.134	0.070	0.162	0.694
Residual	12	0.446			1.938			0.528			0.431		