CHAPTER TWO: PATTERNS OF WRACK ON SOUTH AUSTRALIAN SANDY BEACHES

Abstract

The volume and composition of wrack deposits is known to influence the rate and processes that wrack undergoes whilst on the beach. Previous research has shown that the size of wrack deposits varies considerably in time and among locations, with deposits ranging from individual plants to accumulations that cover the entire beach. The composition of wrack deposits also varies greatly, containing varying proportions of macroalgae, seagrass and other material such as epiphytes, sponges, carrion, terrestrial and dune vegetation and anthropogenic debris. There is currently little information on the size and type of wrack on South Australian (SA) sandy beaches and, to date, only one study investigating wrack deposits has been carried out. This research thus aimed to quantitatively assess the cover and composition of wrack deposits on sandy beaches within three bio-geographical regions of SA; the Metropolitan coast within Gulf St Vincent, the Fleurieu Peninsula, and the South East. A total of 17 beaches were sampled at bimonthly intervals between June 2005 and August 2006. A 'photopoint' technique was developed to allow rapid estimation of percent wrack cover, and was tested against conventional transect sampling. Wrack composition was quantified by collecting wrack from the driftline of each beach, which was then sorted, identified and weighed to obtain the biomass and species richness of algae, seagrass and other material.

Photopoints provide an accurate method, yielding similar results to transects, but are much faster, taking less than 5 minutes per beach for sampling and data entry, compared to approximately 2 hours for transect sampling. Wrack cover ranged between 1 and 95% of the beach face and was highly variable both in time (among visits) and space (among beaches and regions). The wrack deposits sampled in this study contained a total of 242 species (and 'other' material), reflecting the high diversity of seagrass and algal species in SA and exceeding values previously reported in the literature. The species composition and relative masses of those species varied both spatially and temporally. Beaches with high wrack cover also

tended to have wrack deposits with more variable composition. The Metro and Fleurieu regions were characterised by seagrass-dominated wrack deposits, whilst the South East samples were dominated by algae. South East wrack deposits were also more diverse, with higher total numbers of species and higher algal diversity, driven by the great diversity of kelps, green algae and red algae in that region. Beaches in the South East region could be further separated into 2 groups; those south of Cape Jaffa, which were dominated by algae (including higher number of kelps, red and green algae), and those to the north of Cape Jaffa, which had a higher proportion of seagrass wrack. SA wrack deposits thus contribute a complex, diverse and spatially and temporally variable resource to the beach and nearshore ecosystem.

Introduction

Wrack deposits can potentially play an important role in coastal and nearshore ecosystems. The rate and processes that wrack undergoes whilst on the beach depends, at least in part, on the rate and volume of the inputs and the type of detritus.

Wrack deposits may range in size from a few fragments of individual plants to accumulations that cover the whole beach and reach depths of up to several metres (Kendrick *et al.* 1995; Kirkman & Kendrick 1997). Many beaches receive no macrophyte inputs, in stark contrast to beaches that may be covered from the base of the dune down to the swash in deep piles of wrack. Particularly large wrack deposits have been reported from Kingston in the South East of South Australia (McKechnie & Fairweather 2003), Marmion, Western Australia (Hansen 1984b) and South Africa (Griffiths *et al.* 1983; McGwynne *et al.* 1988). Wrack is composed primarily of macroalgal and seagrass material but can include small proportions of epiphytic plants and animals, sponges, dead marine animals and birds (Colombini & Chelazzi 2003), terrestrial and dune vegetation and anthropogenic debris (Van der Merwe & McLachlan 1987; Maccarone *et al.* 1993). Wrack deposits may be dominated by one or more algal or seagrass species, or contain a mix of algae and/or seagrass in varying proportions.

The amount and composition of wrack deposited onto beaches is ultimately determined by environmental conditions at the source(s) of the macrophytes

(Ochieng & Erftemeijer 1999) and at the beach (McLachlan 1985; Ochieng & Erftemeijer 1999; Orr *et al.* 2005). Storms can detach large quantities of macrophytes in sporadic bursts (Hobday 2000) but natural senescence of algae and/or seagrass may result in seasonality in the supply of detritus (ZoBell 1971). The wave exposure and tidal regime at the source and receiving beach may also affect the amount (Orr *et al.* 2005) and distribution (McLachlan 1985; Ochieng & Erftemeijer 1999) of wrack on the beach. The combination of these factors can result in great spatial and temporal variability in the cover, volume and composition of wrack on beaches.

Quantification of the biomass and composition of wrack present on a beach can be difficult due to the dynamic nature of wrack deposits, but is a crucial step in further understanding its ecological importance. Currently, researchers use transects (Dugan *et al.* 2003), quadrats (Ochieng & Erftemeijer 1999), measurements of the dimensions of large accumulations (Malm *et al.* 2004) or collections and weighing of wrack (Yatsuya *et al.* 2007) to quantify the size of wrack deposits. These methods can be both complicated & time consuming, thus limiting their potential application. Thus, McKechnie & Fairweather (2003) recognised the need for a faster, yet still accurate, method and developed a photopoint technique to estimate wrack percent coverage. Although promising, their testing was limited and the authors recommended further testing and modification of the method.

Throughout the world, research has shown that wrack deposits vary considerably among locations (ZoBell 1971; Hansen 1984a; Ochieng & Erftemeijer 1999; Colombini & Chelazzi 2003; McKechnie & Fairweather 2003; Orr *et al.* 2005; Yatsuya *et al.* 2007). The South Australian (SA) coast stretches for 3273 km (Short 2006a), of which 62% is sandy beaches (Short 2006a). The SA coast has also been reported to have a large diversity of seagrass and algal species (Womersley 1984; 1987; 1994a; b; c). There is currently little information on the amount and type of wrack on SA sandy beaches and, to date, only one study investigating wrack deposits (McKechnie & Fairweather 2003) has been carried out. This study found that wrack deposits in this state occur in a variety of forms (i.e. cover, volume and composition), vary noticeably over time, and form a prominent feature of some beaches. McKechnie and Fairweather (2003) provides an excellent foundation and useful methods for a longer-term study of local wrack deposits. This research is critical as a basis for furthering our understanding of wrack's role in the local nearshore ecosystem.

The aims of this study consisted of 2 main parts: further methods development; and a survey of wrack deposits on South Australian sandy beaches. First, I aimed to test the accuracy of, and modify if necessary, a rapid method for determining the cover of wrack on sandy beaches. I based my methods on the photopoint method of McKechnie and Fairweather (2003), made modifications and tested the new method for use in the latter parts of this chapter and thereafter in the remainder of this thesis (except where indicated otherwise). This included testing the method on beaches with a wide range of wrack covers, determining the optimal orientation for photopoints and whether the method could be used on beaches that had not been previously sampled by conventional transects, and developing an improved system for scoring the photos. The second aim was to characterise the wrack deposits on South Australian sandy beaches in terms of the amount (cover and volume) of wrack and the species composition of wrack deposits. I aimed to investigate temporal variations and spatial variation between and within three bio-geographical regions of SA.

Methods

Sampling design

Spatial variation: Regions and beaches

Sampling was conducted in three of SA's biogeographical regions; the Metropolitan coast within Gulf St Vincent (Metro), the Fleurieu Peninsula (Fleurieu), and the South East (SE) (Figure 2.1). A total of 17 beaches were repeatedly sampled across the three study regions (Figure 2.1, Table 2.1). In each of the SE and Metro regions, 6 beaches were sampled. In each of these regions, 2 of the beaches experience wrack removal or modification due to sand replenishment activities (Figure 2.2). In the Fleurieu region 5 beaches were sampled but none of these have any wrack removal activities. Beaches were chosen to give a reasonable geographical spread throughout each region, to represent a variety of beach morphologies and a range of wrack percent covers. On each beach, one haphazardly located site was sampled at each visit.

Temporal variation

To investigate the temporal variation in wrack deposits, sampling (wrack cover and composition) was carried out at bimonthly intervals between June 2005 and August 2006. All beaches in the Metro region were visited 7 times (Table 2.1). In the SE region, Bucks Bay was sampled only on visits 6 and 7 but all other beaches were sampled on 7 visits. In the Fleurieu region, all beaches were sampled on 6 visits, corresponding to visits 2 to 7 that were sampled for the other regions (Table 2.1).

Since it was not possible to sample all beaches on a single day, the term 'Visit' was chosen as a neutral name for the time factor. A single 'Visit' thus represents a sampling event which occurred over a period of one to two months (Table 2.1) when environmental conditions (e.g. weather, currents and biological conditions) should be similar across all regions and beaches. 'Visit' is considered a random factor in all statistical analyses.

Field methods

On each visit to a 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 foredune to the upper limit of the swash, including any tide pools or channels.

Wrack cover and depth: Transect sampling

The amount of wrack was measured using two metrics, cover (2-dimensional measure of abundance) and volume (3-dimensional measure of abundance). The cover and depth of wrack was quantified using a series of line intercept transects oriented in 2 directions relative to the beach face: 1. perpendicular to the dune and 2. parallel to the dune (Figure 2.3). Perpendicular transects sampled the entire beach face from the base of the first dune to the upper limit of the swash. One transect oriented perpendicular to the dune was performed (n = 3) at each of 3 randomly selected locations within the 100m site (Figure 2.3). Transects oriented parallel to the dune were used to assess wrack deposits at 3 levels on the beach (i.e. tidal heights): 1. the driftline, DL, which is defined as the level on the beach, parallel to the dune, with the greatest amount of freshly deposited wrack; 2. above the driftline, ADL; and 3. below the driftline, BDL (Figure 2.3). The DL was located by visual inspection of the beach. On each beach the ADL and BDL levels were positioned a random distance above and below the DL, respectively. At each level, three randomly-spaced, 5-metre-long transects were carried out parallel to the dune. Thus a total of 9 transects were performed (3 levels x 3 replicates) on each sampling occasion.

For all transects, a line-intercept transect method was used and the substrate type (sand, gravel, wrack etc.) was recorded with its distance along the line. Only patches of substrate with a linear extent of at least 2cm were recorded. Percent wrack cover was calculated for each transect by summation and divisions and wrack included marine algae and seagrass, plants of terrestrial origin, and other material commonly classed as wrack including wood, bark, animal carcasses and anthropogenic litter.

Wrack volume was determined by measuring the wrack depth every 0.5m along each transect. This yielded 11 depth measurements for each 5m-long parallel transect and (2 * W + 1) depth measurements for perpendicular transects, where W = beach width to the nearest metre. For each transect the mean wrack depth was then determined.

Rapid visual assessment of wrack cover: Photopoint method

The photopoint technique of McKechnie and Fairweather (2003) was used as the basis for the photopoint method used in this study. As per their recommendations, additional testing of the method was carried out to determine whether the method can be used on beaches with a wide range of wrack percent covers and to determine the optimal orientation for photopoints. Beaches with a wide range of wrack percent covers were thus chosen and sampling was carried out at all beaches between June 2005 and April 2006. Photos were taken in 3 orientations relative to the beach-face: 1. parallel to the dune at the DL (as per McKechnie & Fairweather 2003); 2. parallel to the dune at the midpoint between the toe of the dune and the swash line; and 3. perpendicular to the dune (beach normal) from the toe of the dune towards the swash (Figure 2.3). The camera was set at a constant focal range and photos were taken in landscape orientation. Unlike McKechnie and Fairweather (2003) the height of the photographer varied (by up to 30cm) because different photographers were used throughout the study. This is a more realistic situation since many people may contribute to a data set and thus this study provides a better test of the photopoint method as it would be applied in broader situations.

In the first year of the study, the photopoint method was used in conjunction with the transect sampling for a range of wrack states (cover, volume) to verify the appropriateness (precision, accuracy) of the technique and to determine in which direction photos should be taken for the remainder of the study. Results indicated that the photopoint method was accurate and gave similar percent cover values to those obtained in the transect sampling (see Results). Transect sampling was therefore discontinued in April of 2006 and photopoints were used as the sole estimate of % wrack cover. These data were used in subsequent analyses.

Wrack composition

Wrack composition was studied by sampling wrack deposits at the DL. Sampling was conducted at bimonthly intervals in accordance with the main sampling regime (see Chapter 1). On each occasion, three replicate samples were haphazardly collected from the DL by hand gathering wrack, including macrofauna and any sand adhering to the wrack, and placing it into A4 plastic zip-lock bags (approximately $0.006m^3$). Samples were approximately 0.2-0.5kgWW, depending on wrack type and condition.

Laboratory methods

Photopoint method

Unlike McKechnie and Fairweather (2003), beaches were not sampled at the same exact location on each visit. This was because I aimed to determine whether the method could be used on beaches that had not been previously sampled (i.e. that had not had reference photos taken and transect sampling conducted). Thus rather than score photos using reference photos of previously sampled beaches, I used percent cover charts that are used to estimate canopy cover in terrestrial vegetation surveys (McDonald *et al.* 1990). Photos were assessed for % cover of wrack on a scale (0-100%) and were classed from 0 to 11 (Table 2.2a). Each photo was given two replicate, non-consecutive percentage cover scorings (Sousa 1979; McKechnie & Fairweather 2003) to minimise error and bias.

Visual examination of the photopoint data indicated that at low % wrack cover (i.e. class 1, 1-10% wrack), there was poor correlation between the % wrack values obtained from transects and those obtained from the photopoint method (see Results). This was likely due to the method used for assigning % cover, i.e. photos with between 1 and 10% wrack cover were scored as class 1 and were assigned the value of 5% wrack cover (i.e. midpoint) and the discrepancy from 5% could be relatively great. On the other hand, transects can give wrack cover values anywhere in the range of 1-10% for this class. I therefore wanted to determine if photos from class 1 could be more accurately scored to give a better correlation with transect data. Photos that were scored as class 1 were re-scored and assigned an integer % wrack cover (i.e. range 1-10%) (Table 2.2b). Photos were again given 2 non-consecutive scores to minimise bias and error, and the mean wrack cover determined from the 2 scores. Photos that were originally scored in classes 2 to11 were re-assigned to classes 11 to 20, respectively (Table 2.2b).

Wrack composition

Algal and seagrass material was sorted to the finest possible taxonomic level and weighed to determine wrack composition (identity and percent wet weight of each species/genus). In most cases, algae and seagrass were identified to genus or species. Where identification to species level was not possible but morphospecies of the same genus occurred, algae and seagrass were identified as Genus sp. 1, sp. 2 etc.. The brown algae *Sargassum* spp. and *Cystophora* spp. were identified only to genus and so % mass was determined for each genus as a whole. These genera thus contribute a large proportion of the total % mass. Seagrass of the genus *Amphibolis* was identified as *A. antarctica*, *A. griffithii* or *Amphibolis* stems and roots (i.e. species undetermined since no leaves were attached [which are a key indication of species]). *Amphibolis* stems and roots were included in the species count only when neither *A. antarctica* nor *A. griffithii* were found in the sample. This is therefore a conservative measure of the diversity of *Amphibolis*.

Carrion, sponges, feathers, terrestrial plant material, anthropogenic debris and other miscellaneous items were also identified and weighed. This material was grouped as ‘other’ and each type of material was a counted as a ‘species’ for the purpose of species richness assessment. Seagrass fibre balls were included as “other” material because these are composed of a mix of seagrass, algal and other material and thus cannot be considered solely of seagrass origin. The mass of fragments was also determined for each sample. Fragments included any material which was less than 3cm size in its maximum dimension. Samples were checked with particular care to see if any of the invasive green alga *Caulerpa taxifolia* was present. Any material that resembled *C. taxifolia* was checked carefully to ensure accurate identification. No *C. taxifolia* was found in any samples, nor was it seen on the beach at any stage. All attempts were made to accurately identify material but identification of algae (particularly red algae) was difficult or impossible in some cases due to fragmentation, desiccation, decomposition and the lack of reproductive material. The data may therefore reflect the species richness of algal and seagrass species, if not the actual identity of species.

The biomass (percent wet weight) and species richness of algae, seagrass and other material were used in univariate and multivariate analyses. To simplify the analyses, biomass data from individual species were pooled into several categories: brown algae excluding kelps (hereafter brown algae); kelps; green algae; red algae; algae (including all of those previously mentioned); seagrass; other material; and fragments. Diversity data consisted of the number of constituent species or other material types in each category. Fragments were considered as one species and thus there is no diversity data for the fragments category. The total number of species (including other material and fragments counted as one each) was also calculated.

Statistical analyses

To achieve a balanced sampling design for the purposes of ANOVA, Bucks Bay (sampled only twice) and Largs Bay (chosen at random from the Metro beaches) were omitted (Figure 2.2). Visit 1 was also excluded from the data set to give a balanced sampling regime for just 6 visits (Table 2.1). Thus, for the following ANOVAs, the sampling design was 3 regions, 5 beaches per region, sampled on 6 visits.

Photopoint data

Concurrence of results from transect sampling and the photopoint method was checked by visual inspection of scatterplots and linear regression. Percent cover from transects was used as the predictor (x) and % cover from photopoints as the dependent variable (y). If photopoints give similar results to transects, plots of % cover of wrack determined by transect versus photopoint methods should reveal a tight scatter of points around the 1:1 line and so there should be a strong, positive linear relationship.

The results obtained from sampling using the three photo orientations were checked for concurrence of mean cover with the results of the transect sampling. Data from transects performed parallel to the beach were analysed either for the DL only or from all three beach levels (DL, ADL and BDL) combined to represent different sampling regimes, the latter being more thorough since it samples more of the beach face. The specific comparisons made were:

1. Transects at the DL vs. Photopoint at the DL;
2. Transects parallel to the beach at the 3 levels (DL, ADL and BDL) combined vs. Photopoint at the DL;
3. Transects parallel to the beach at the 3 levels (DL, ADL and BDL) combined vs. Photopoint at the midpoint of the beach;
4. Transects perpendicular to the beach vs. Photopoint perpendicular to the beach;
5. Transects perpendicular to the beach vs. Photopoint at the DL;
6. The grand mean of all Transects vs. Photopoint at the DL; and
7. The grand mean of all Transects vs. Photopoint at the midpoint of the beach (Table 2.3).

The number of samples (where both transects and the photopoint method were used to estimate % wrack cover) varied for the three different photo orientations and the combinations of transect orientations and is indicated with the results of each analysis (see Table 2.3).

The optimal photo orientation for the photopoint method was determined as being that with the strongest positive and significant correlation with the results of the transect sampling. This photo orientation was then used for all subsequent photopoint sampling and was used as an estimate of % wrack cover for the remaining parts of this chapter and throughout the remainder of this thesis.

The accuracy of the photopoint method on beaches of different widths was also assessed for photos taken at the DL since this orientation best matched the results obtained by transect sampling (see Results). The difference between the % cover estimates obtained by transects and by photopoints was used as a measure of accuracy, such that:

Difference = % cover by transects - % cover by photopoint

To investigate whether the photopoint method is more or less accurate on beaches with high or low wrack cover, the difference relative to the cover determined by transects was determined such that:

Relative difference = (% cover by transects - % cover by photopoint) / % cover by transects

The relative distance thus is a dimensionless measure with no units. Negative values for the difference and relative difference indicate that the photopoint method overestimated wrack cover, whilst a positive value indicates that the photopoint method underestimated wrack cover. Since wider beach width is often associated with flatter beach-face slopes (Short & Hesp 1982; McLachlan & Brown 2006), this analysis can also be used to infer the accuracy of the photopoint method on beaches with different slopes, as recommended by McKechnie and Fairweather (2003), who suggested that parallax due to beach slope may affect the technique's accuracy. Beach width was obtained from the 3 transects taken perpendicular to the shore for each beach. Beach width was used as the predictor variable (x) and the difference and relative difference were used as the response variables (y) in linear regressions.

Wrack % cover

Photopoints at the DL were used to estimate % wrack cover on each of the 17 main study beaches (Figure 2.1) at approximately bi-monthly intervals between September 2005 and August 2006 (Table 2.1). The field of view was over 500m alongshore, and thus photos would need to be taken at least that far apart to maintain independence between replicates. Since this could not be guaranteed, especially on short beaches, only one photo per beach per visit was used.

A 2-way factorial ANOVA was used to determine whether differences in wrack cover occurred between the three study Regions and/or between Visits (6 visits).

Since one photo per beach was taken, beaches are considered replicates (5 beaches per region) and thus the total *n* = 90. Region was considered a fixed factor and Visit a random factor.

To assess seasonal differences in wrack cover, data from the 4 visits conducted during summer (2 visits) and winter (2 visits) (Table 2.1) were used in a 3-way factorial ANOVA for Season, Visit (nested within Season) and Region. Season was fixed with 2 levels and Region was also fixed factor (with 3 levels). Visit was a random factor, nested within Seasons. Beaches were again considered replicates (5 beaches per region) and thus the total *n* = 60.

The relationship between wrack % cover and wrack depth was examined from the transect sampling. The mean wrack cover was plotted against mean wrack depth for the 12 transects performed on each visit to a beach (*n* = 68). Examination of the scatterplot showed that the relationship was non-linear. Due to the higher variance in wrack depth at high wrack cover, non-linear modelling was not carried out.

Examination of mean % wrack cover data suggested that beaches with low wrack cover had less variable wrack % cover than beaches with high wrack cover. Mean % wrack cover was plotted against the variance (as se) in wrack cover for that beach and linear regression was performed.

Wrack composition

Measures of wrack composition (species count by groups and % mass by groups) were analysed by univariate statistics. The sampling design was 3 Regions, 5 Beaches per region and 6 sampling Visits. Three-way, nested ANOVAs were carried out for each variable with the factors Region (fixed factor), Beach nested within Region (random factor), and Visit (random factor). The replicates were the three wrack samples taken from each beach on each visit. Due to the complex, nested design, the main effect of Region could not be determined. Full 3-way ANOVA tables for composition are presented in Appendix A.

Composition data were also analysed using multivariate techniques. The three replicate samples from each beach on each sampling occasion were used to obtain the mean % mass of each species, category and/or group. Data were collected over 7 visits from 17 beaches in the three study regions; however, Fleurieu beaches were not sampled on Visit 1 and Bucks Bay was sampled only on Visits 6 and 7 (Table 2.1, Figure 2.2). These samples were included in these multivariate analyses (but not in the previously described univariate analyses) since the multivariate statistics performed by PRIMER via permutations can cope with an unbalanced design (Clarke & Warwick 1994). Analyses were performed on raw biomass data by species (including other material). Analyses were also run on data aggregated by groups using the same categories as for the univariate analyses (i.e. brown algae excluding kelps, kelps, green algae, red algae, seagrass, other material and fragments).

Two-dimensional MDS plots were produced based on Bray-Curtis similarities among samples. Two-way crossed analyses of similarity (ANOSIM), with 999 permutations, were performed to assess any differences in taxonomic composition and relative mass of wrack components among the three Regions and seven Visits. Similarity percentages (SIMPER) analyses were run to determine within-group similarities and between-groups dissimilarities for Regions. Within-group similarities for Beaches was also assessed by SIMPER. A high percentage similarity within groups indicates group cohesion and a high dissimilarity between groups indicates distinct communities. Indicator taxa of between-groups dissimilarity were identified from SIMPER analyses. A taxon may be considered a consistent indicator if their ratio of dissimilarity to standard deviation is equal to or greater than 1 (Clarke & Warwick 1994).

Examination of SIMPER-derived values of within-groups similarity for beaches and mean % wrack cover data suggested that beaches with low wrack cover had more similar composition of the wrack deposits than beaches with high wrack cover. Mean % wrack cover per beach and the variance (as se) in wrack cover for that beach were plotted against SIMPER within-groups similarity (%) and linear regressions were performed.

Assumptions were checked by visual examination of histograms, probability plots and scatter plots of the residuals, and transformations were performed where appropriate. Univariate analyses were conducted using SYSTAT v.11. Multivariate analyses were run using PRIMER v.5 or v.6 software and graphical representations were plotted using SYSTAT v.11 software.

Results

Rapid visual assessment of wrack cover: Photopoint method

Percent wrack cover values for sampling conducted to test and develop the photopoint method were, on average, 19.4% (± 2.7 se), 10.9% (± 1.7) and 10.9% (± 1.6) for photopoints at the DL, midpoint of the beach and perpendicular to the dune, respectively. The mean % wrack cover for photopoints was thus nearly twice the mean for photopoints at the midpoint of the beach and perpendicular to the dune. The grand mean for all photopoints was 13.2 (± 1.0). Mean % wrack cover from the transect method was 29.0% (± 3.3) for the DL, 17.8% (± 2.7) for transects parallel to the dune, 11.6% (± 1.7) for transects perpendicular to the dune. The grand mean for all transects was 16.8% (± 2.2). Mean % cover and the range of % cover values were similar for the two methods.

In all comparisons there was a significant positive relationship between the % cover of wrack determined by transects and photopoints (Table 2.3, Figure 2.4). There was a strong positive skew in all data sets due to more beaches with low wrack cover being sampled. For each regression, the distributions of % cover for the predictor and response variables were similar and residuals plots were checked and deemed acceptable.

The grand means of % cover from transect sampling & photopoints oriented beach parallel at the DL had the strongest linear correlation (Figure 2.4a). There was a close match between the regression & 1:1 lines (Figure 2.4a) & the regression was highly significant, with 79% of the variance accounted for. There was also a strong correlation between the % cover of wrack determined by transects oriented beach-parallel (at the 3 levels; DL, ADL & BDL) and the photopoint taken at the DL (Figure 2.4b, Table 2.3).

McKechnie and Fairweather (2003) used the mean values obtained from multiple visits to each beach (i.e. there was one mean per beach). The data from each site were thus pooled for a similar analysis with each data point representing a single beach. The % cover of wrack determined by all transects (grand mean) and photopoint at the DL showed a strong, highly-significant correlation, positive (Pearson $r = 0.888$, $p < 0.001$, $n = 24$), & there was a close match between the regression & 1:1 lines. Likewise there was a similar correlation between the % cover from transects oriented beach parallel at the 3 levels (DL, ADL & BDL) and from the photopoint at the DL (Pearson $r = 0.865$, $p < 0.001$, $n = 19$).

The % cover values obtained from photopoints taken at the DL and at the midpoint of the beach were also compared. There was a strong and highly significant relationship (Pearson $r = 0.831$, $p < 0.001$, $n = 61$). The scatterplot (Figure 2.5) showed that values from the DL were higher than those from the midpoint of the beach, a result that can be reasonably expected since these photos will capture more of the DL in view than those taken at the midpoint. The slope of the regression line supports this observation, with a slope of only 0.462 (intercept = 2.058), which is less than that of the 1:1 line.

Photopoint data based on 20 cover classes (Table 2.2) were also analysed for the photopoint taken at the DL tested against values obtained from transects for which there was a strong and significant correlation. These were 1) the grand mean of all transects and 2) transects taken parallel with the beach (Table 2.3). By scoring photos with low wrack cover (1-10%) at 1% intervals, the accuracy of the photopoint method increased. The strength of the correlation between the grand mean of all transects and photopoints at the DL increased from Pearson $r = 0.888$ to Pearson $r = 0.946$ ($p < 0.001$ and $n = 65$ in both cases) (Figure 2.4c). The strength of the correlation with transects taken parallel with the beach also increased from Pearson $r = 0.872$ to Pearson $r = 0.937$ ($p < 0.001$ and $n = 68$ in both cases) (Figure 2.4d). Thus, an additional 10.5% and 11.7% of the variance was explained, respectively.

To determine whether there was any relationship between beach width and the accuracy of the photopoint method, for each visit to a beach ($n = 64$), beach width and the difference or relative difference between % cover from transects and photopoints were regressed. Beach width ranged between 10.3 and 188.5m with a mean of 49m (± 3.6) and was square-root transformed for analysis. The photopoint method both over- and underestimated wrack cover; overestimating cover by up to 35.1% and underestimating cover by up to 13.1% (Figure 2.6a). On average photopoint overestimated wrack cover by 2.0% (± 1.3). Based on the relative difference between transects and the photopoint method, photopoints on average overestimated wrack cover. One large outlier was removed from the data set; this outlier occurred because the wrack cover for that beach, as determined by transects, was virtually 0%, and thus there was a large relative difference (overestimated by 19.8 times) between transect and photopoint estimates of % cover (0.07 vs. 1.5%). The photopoint method, on average, overestimated wrack cover by 0.4 (± 0.1) (no units); overestimating by up 3.3 and underestimating by up to 0.8 (Figure 2.6b). There was no relationship between beach width and accuracy (Pearson $r = 0.160$, $p = 0.206$) or beach width and relative accuracy (Pearson $r = 0.172$, $p = 0.177$).

Transect sampling: Percent wrack cover and wrack depth

Percent cover and wrack depth were obtained from transect sampling. Mean cover was 16.2% (± 0.9) and ranged between 0 and 100% for each transect. Mean wrack depth was 1.2cm (± 0.2), with a range of 0 to 74.5cm. To determine whether there was any relationship between wrack cover and depth, for each visit to a beach ($n = 68$), the mean wrack cover and mean depth were regressed with % cover as the independent variable and depth as the dependent variable. Data were 4^{th} root transformed due to the large number of zeros in the data set. There was a positive relationship between % cover and wrack depth but the relationship was not linear (Figure 2.7).

Percent wrack cover

Wrack cover ranged between 1 and 95% for individual visits to beaches and was on average 20.4% (± 1.9). At the level of replicates (i.e. Beaches), mean wrack cover (over all visits) ranged between 1.8% (± 0.3) and 66.2% (± 10.5) (Figure 2.8). The Fleurieu region had the lowest mean wrack cover per beach (13.2 ± 2.3%) and the smallest range of cover values (1-60%) (Figure 2.9), followed by the Metro region with, on average, 16.3% (± 2.5). Metro beaches had between 1 and 95% wrack cover. The SE had the greatest mean wrack cover per beach (28.3 ± 3.7%) with a range of 1.5 to 95% cover. There were no clear trends in % wrack cover over time for beaches within regions or among regions (Figure 2.9), or for all beaches together, i.e. there were no peaks or troughs for any given visit.

For each of the main study beaches, % wrack cover was calculated for all visits to each beach (Figures 2.8 and 2.9), including the main study visits and any additional visits carried out opportunistically. Maslins and Waitpinga had consistently low % wrack cover, with less than 10% cover on all visits (Figure 2.8). Wrack cover at Rapid Bay, The Granites and Glenelg was also consistently low, remaining less than 20% on each sampling occasion (Figure 2.8). Aldinga, Seacliff and Victor Harbor typically had a low to moderate cover of wrack, and wrack cover did not vary substantially between consecutive visits. Wrack cover at Beachport, Largs Bay, Middleton and Normanville also tended to be low to moderate but cover varied more between visits, i.e. tended to peak and dip. Brown Bay, Stinky Bay and North Haven had higher wrack covers than the aforementioned beaches and cover at these beaches also varied considerably between consecutive visits. Kingston had a large range of % wrack covers (Figure 2.8); on several occasions cover was estimated at 95% and on others cover was 20% or less. Some of the variation in wrack % cover was driven by the cleaning activities at this beach. On 2 visits, mechanical cleaning of the beach had recently taken place (S. Duong, pers. obs.). Cleaning activities appeared to affect almost the entire beach face, with total or partial removal of the wrack layer.

Beaches with high mean wrack cover also tended to have greater variation in wrack cover, i.e. wrack cover varied between low and high among visits. The linear regression of mean % wrack cover for each beach and the variance (standard error, se) in wrack cover for each beach were positively and strongly correlated (Pearson $r = 0.951$, $p < 0.001$, $n = 17$) (Figure 2.11).

Two-way ANOVA on % wrack cover (√-transformed) for Region and Visit indicated that there was a significant difference in mean wrack cover between the 3 study regions (Table 2.4). There were no differences between Visits or for the interaction of Region and Visit. Tukey's HSD post-hoc test identified that the SE region had significantly greater wrack cover than the Metro and Fleurieu regions but there was no difference between the latter two regions (Figure 2.9).

The 3-way ANOVA on % wrack cover (log [x + 1]-transformed) for Season, Visit (nested within Season) and Region indicated that there was a significant difference in mean wrack cover between the 3 study regions (Figure 2.10, Table 2.5). There were no differences between Seasons, Visits or for any of the interactions (Table 2.5).

Wrack composition

General description

A total of 242 species and 'other' groups were found in the wrack samples (Appendix A). The red algae were the most diverse group and comprised 124 species (Appendix A). There were 55 species of brown algae, including 3 species of kelps, 24 species of green algae, 20 'other' categories, 18 seagrass categories plus fragments. The mean number of species per sample was 14.4 (± 0.3), of which algae contributed more species (6.5 ± 0.3) than seagrass (3.5 ± 0.1) or other material (4.4 ± 0.1). Brown algae excluding kelps comprised the greatest mean number of algal species per sample (3.9 ± 0.1), followed by red algae (2.0 ± 0.2), green algae (0.6 ± 0.1) and kelps (0.02 ± 0.01).

Algal, seagrass and other materials were present at all beaches sampled on at least one visit (Table 2.6). All wrack samples had a minimum of 2 species (including other and fragments) per sample. Wrack deposits at Stinky Bay were the most diverse in terms of the mean and maximum total number of species and number of algal species per sample (Table 2.6). Beaches from the Metro and Fleurieu regions tended to have a higher diversity of seagrass and higher % mass of seagrass than the beaches from the SE region, except Kingston and the Granites, which were similar to the beaches in the other regions. The % mass of algae tended to be greater in the SE samples. Thus, wrack deposits on beaches in the SE, except Kingston and the Granites were algal-dominated whereas wrack on Metro beaches was seagrass-dominated. The % mass of other materials in each sample was, on average, less than 10% at all beaches except for North Haven (43.7%) and Middleton (21.7%) (Table 2.6), which had larger proportions of seagrass fibre balls than the other beaches.

Twenty-five species (including other materials and fragments) comprised at least 5% by mass of the wrack found at any beach (samples pooled over all visits) and so were classed as dominant species (Table 2.7). This included 13 species of brown algae (including 3 kelps), 2 species each of green and red algae, seagrass fibre balls and fragments (Table 2.7). The brown alga *Sargassum* spp. and fragments were found at every beach (i.e. 17 beaches) and an additional four species were found at all beaches except one (Table 2.7). None of the dominant species were found at only one beach; the minimum number of beaches at which dominant species were present was 3. Three species occurred in only one region; these species were the bull kelp *Durvillaea potatorum*, the brown alga *Perithalia caudata* and the green alga *Codium fragile*, all of which only occurred in the SE region. An additional 2 species (the green alga *Caulerpa flexilis* and the red alga *Phacelocarpus perperocarpus*) occurred only in the SE and Fleurieu regions. Only one dominant species was not found in the SE; the brown alga *Caulocystis uvifera*. Whilst all 6 species of seagrass were found in all three regions, including the SE, the four beaches east of Kingston had wrack deposits composed of 1% or less of each of these seagrasses (Table 2.7).

The mean total number of species per sample was greatest in the SE region (20.0 ± 1.4) but similar to the Fleurieu region (19.0 ± 0.9) and only slightly less (15.2 ± 0.6) in the Metro (Figure 2.12a). The diversity of algae was highest in the SE and contributing to this trend, the diversity of kelps, green algae and red algae were also highest in this region. The Fleurieu region had the greatest mean number of brown alga species, and the greatest mean number of 'others' per sample. Mean seagrass diversity was highest in the Metro region. In all regions, algae contributed more species than seagrass to each sample. The magnitude of this difference was greatest in the SE region; algae contributed, on average, 8.4 (± 0.7) algal species compared to 2.4 (± 0.2) species of seagrass. In the Fleurieu region, algae contributed nearly twice as many species as seagrass (6.7 ± 0.4 vs. 3.8 ± 0.2) but in the Metro region algae and seagrass contributed nearly the same number of species (4.6 ± 0.3 vs. 4.2 ± 0.1) (Figure 2.12). In the Fleurieu and Metro regions, brown algae contributed the greatest number of algal species but in the SE the number of red algal species was slightly greater than the number of brown algal species (3.4 ± 0.5 vs. 3.0 ± 0.2) (Figure 2.12). The number of species (total and by groups) varied slightly over time but there were no distinctive trends (Figure 2.12).

Samples contained, on average, a greater mass of algal material than seagrass, making up 58.1% (± 2.0) and 20.9% (± 1.4) of the sample mass, respectively (Figure 2.13). Biomass was dominated by the brown algae, with samples containing on average 38.9% (± 1.8) by mass. Kelps comprised an average of 12.9% (± 1.4) of the sample, with red and green algae making up small proportions of the biomass (4.3 ± 0.6% and 2.3 ± 0.5%). 'Other' material made up 7.1% (± 1.0) of the biomass and fragmented material comprised 13.9% (± 1.0) of the samples (Figure 2.13).

Biomass data, separated by region, followed similar patterns to the trends seen for diversity (Figure 2.13). Samples from all three regions were dominated by algal material rather than seagrass, 'other' or fragments, and in all three regions brown algae contributed the greatest % mass (Figure 2.13). In the SE region, kelps also contributed a large proportion of the algal biomass (29.9 ± 3.1%), greater than in either the Fleurieu (7.5 ± 1.7%) or the Metro regions (1.3 ± 0.5%). The SE samples also had a greater mean % mass of red and green algae than the other two regions. The mean % mass of brown algae was highest in the Fleurieu samples, intermediate in the Metro and lowest in the SE. The Metro region had the greatest proportion of seagrass, 'other' and fragmented material (Figure 2.13).

The composition of wrack deposits varied between visits when data were separated by region (Figure 2.13). In the SE region, kelps and brown and algae combined consistently contributed between 55 and 75% of the sample mass. There was a slight increase in the % mass of seagrass on Visit 4, which also occurred in the Fleurieu and Metro regions. The composition of wrack samples in the Fleurieu region was also reasonably consistent between visits with the exception of the absence of kelps on one visit only (Visit 3). In the Metro region, kelps and red algae were absent on some visits, and there was a considerable increase in the % mass of seagrass on Visits 4 and 6. The contribution of each group of wrack components was consistent over time for all samples together. There was a slight increase in the % mass of seagrass on Visit 4, with a concurrent decrease in the % mass of brown algae. All groups were represented on each visit.

Univariate analyses

The 3-way ANOVA on the number of species per group resulted in a significant interaction of Beach (Region) x Visit for all groups (i.e. brown algae, kelps, green algae, red algae, algae, seagrass and 'other' material) ($p < 0.001$ in all cases) (Table 2.8a). There were no significant interactions between Region and Visits for any of the variables tested. The main effect of Beach (Region) was significant for all groups ($p < 0.001$ in all cases, except 'other' for which $p < 0.01$). The main effect of Visit was also significant for the number of species in the kelp, seagrass and 'other' groups ($p < 0.01$ in all cases). The significant interaction of Beach (Region) x Visit subsumes the significant results for the main effects of Beach (Region) and Visit where they occurred, and since the interaction involves random factors, no further interpretation is appropriate (Underwood 1997).

Similar results were obtained for the analysis of composition data based on % mass by groups. There was a significant interaction of Beach (Region) x Visit for all groups (i.e. brown algae, kelps, green algae, red algae, algae, seagrass, other material and fragments) ($p < 0.001$ in all cases) (Table 2.8b). The interaction of Region and Visits was not significant for any of the variables tested. The main effect of Beach (Region) was significant for all groups ($p < 0.001$ in all cases except for green algae and 'other' material, for which $p < 0.01$). The main effect of Visit was also significant for the % mass of 'other' groups and fragments ($p < 0.05$ in both cases). The significant interaction of Beach (Region) x Visit subsumes all other significant results but does not warrant further interpretation.

Multivariate analyses

The 2-dimensional MDS plot (Figure 2.14a) shows three groupings of samples corresponding to the three Regions. In general, the plot represented the geographical separation between Regions and Beaches well, i.e. SE samples were plotted adjacent the Fleurieu samples which were in turn plotted next to the Metro samples. The exception to this was the SE, with samples plotting in 2 groups. One group was plotted with the Metro samples and another group was clearly distinct from the other two regions. The SE samples that were plotted with the Metro samples were from Kingston, a beach with predominantly seagrass wrack. The overlap between samples from the SE and Fleurieu Regions was minimal and occurred between samples that were geographically closest to each other i.e. between The Granites and Middleton which occur at the ‘end’ of SE and Fleurieu regions, respectively. Samples from the Fleurieu and Metro Regions were also plotted in 2 clusters but with a greater overlap between the Regions. The same MDS plot was produced with symbols plotted by Visits (Figure 2.14b). There was no clear separation of samples based on Visits, nor was there a separation of samples due to season (i.e. summer vs. winter).

Multivariate statistics supported this interpretation of the MDS plot. The 2-way crossed ANOSIM (Regions x Visits) on the data by species indicated that there were significant differences in the composition of wrack deposits between Regions (Global $R = 0.204$, $p = 0.001$). Pairwise comparisons indicated that wrack samples from the SE region were composed of different species and/or relative masses of those species to those from the Metro and Fleurieu regions (SE and Metro: $R = 0.355$, $p = 0.001$; SE and Fleurieu: $R = 0.143$, $p = 0.016$). There was no significant difference in the composition of samples from the Metro and Fleurieu regions ($R = 0.044$, $p = 0.210$). The Global R for the factor Visits was small (-0.01) and was non-significant ($p = 0.593$), indicating that the visits could not be distinguished from each other. SIMPER within-group similarity based on Regions was low (< 33%) in all 3 regions. The SE had the lowest percentage similarity (17.8%), indicating that these samples were not very similar to each other. Within groups similarity was also low for the Metro region (30.8%), and was greatest, but still low, in the Fleurieu region (32.89%) indicating that wrack composition was slightly more consistent between samples (beaches and visits) in this region. The brown alga *Sargassum* spp. contributed the greatest % to between groups (Regions) dissimilarity. The % mass of *Sargassum* spp. was consistently greater in the Fleurieu region samples than in either the Metro or SE samples. The mass of fragments was also a consistent indicator of Region (i.e. Metro > Fleurieu > SE). The brown alga *Cystophora* spp. contributed to the dissimilarity between Regions and was greater in the SE region than in the Fleurieu and greater in the Fleurieu than in the Metro region. Despite the difference in the average mass of *Cystophora* spp. between samples from the SE and Metro regions (SE > Metro), it was not identified as an indicative of the difference between these regions (Diss/SD = 0.88). SIMPER within-group similarity was highest (i.e. samples were similar between visits) at Waitpinga (59.8%), Rapid Bay (59.3%) and

Maslins (57.7%). Stinky Bay had the lowest within-group similarity (22.8%) indicating that samples from this beach were substantially different between visits.

The MDS created for Beaches with data pooled over all visits, clearly indicated that the composition of wrack at beaches within regions was similar (Figure 2.14c). Beaches from the SE plotted separately from the Fleurieu and Metro samples, except for Kingston, which was plotted with the Metro samples, and The Granites, which plotted closer to the Fleurieu and Metro samples. A one-way ANOSIM with the factor Beach supported this; the Global R was 0.568 (p = 0.001). Pairwise differences are not discussed here because the beaches sampled were a random selection.

Multivariate analyses were also run on data aggregated by groups (i.e. using the same taxonomic groups used for univariate analyses). The patterns in the data were similar. In the 2-D MDS, samples from the three regions plotted separately but there was a greater degree of overlap between the regions. The same samples from Kingston (SE) plotted with the Metro samples and there was more overlap between Visits. 2-D stress was 0.15, indicating that the plot was a good 2-D representation of the relationships among the samples. The 2-way crossed ANOSIM (Regions x Visits) yielded a Global R for the factor Visits of -0.041 that was non-significant (p = 0.907), indicating that the visits could not be distinguished from each other. The negative R value, although not significant, was likely due to the outlying samples from North Haven (Figure 2.14a and b). These samples had the highest proportion of 'other' material, in this case seagrass fibre balls, of any samples. For the factor Region, the Global R was 0.103 and was significant (p = 0.01). Pairwise comparisons indicated that there were significant differences in the composition of samples between the Metro and SE regions but there were no significant differences between samples from the other combinations of regions. SIMPER within-group similarity was 39.7%, 47.3% and 55.7% for the SE, Metro and Fleurieu regions, respectively. Thus samples from the Fleurieu region were the most similar to one another. Brown algae contributed the greatest biomass, the greatest % to within-group similarity and the greatest % to between-groups dissimilarity in all regions. The brown algae were identified as a consistent indicator of region (Fleurieu > Metro > SE). The biomass of kelp was consistently greater in the SE region than either the Fleurieu or Metro. Seagrass biomass and the mass of fragments were also consistent indicators of

Region (Metro > Fleurieu >SE for both variables). SIMPER within-group similarity was again highest in samples from Waitpinga (80.7%), Maslins (77.9%) and Rapid Bay (74.9%). Samples from North Haven had the lowest within-group similarity 40.1% with the 'other' category (predominantly seagrass fibre balls) contributing the greatest biomass.

Relationship between % wrack cover and composition

SIMPER within-group similarity was negatively correlated with both mean % wrack cover and the variance in wrack cover (Pearson r = -0.565, p = 0.018, n = 17 and Pearson r = 0.636, p = 0.006, n = 17) (Figure 2.15a and b). Therefore, at beaches with low wrack cover, within-group similarity was higher and wrack composition was thus more similar among visits and samples.

Discussion

Photopoint method

The photopoints gave similar results for % wrack cover as the transect method. Photopoints were equally good at estimating the cover of wrack for individual visits to a beach and for estimating the mean cover across visits. Photos taken parallel to the dune at the driftline yielded results that were the closest to those given by the transect sampling. McKechnie and Fairweather (2003) scored photos into 12 cover classes but a considerable improvement in the accuracy of the photopoint method was achieved by classing photos into 20 classes, with a finer scale used for beaches with low wrack cover (0-10%). Potential sources of error (i.e. causing lack of concurrence with transect sampling) most likely arose from 2 sources. Firstly, the scoring of wrack percent cover was done visually and errors may have occurred due to human error (e.g. mis-identification of substrate type [wrack, sand, cobble], inability to assess % cover). This was minimised by standardising the person scoring the photos and careful examination of photos. Secondly, errors may be associated with the transect method since the transect sampling equally weights all transects (i.e. the grand mean of all transects or mean of all beach-parallel transects was used). The photopoint method tended to slightly overestimate % wrack cover but there does not appear to be a systematic bias to greatly over- or under-estimate wrack cover. Users should be aware, however, that on very wide beaches, wrack cover may be slightly overestimated compared to transescts. Overall, the photopoint method can thus be used to accurately but quickly estimate wrack cover on a range of sandy beaches.

The simplicity and rapid nature of the photopoint technique mean that it has a broad range of potential applications. The photopoint technique requires little training or expertise, and can be carried out effectively by most people capable of using a camera. Scoring of photos is also relatively simple and can be done accurately with the assistance of reference charts (e.g. McDonald *et al.* 1990). Photos also provide a permanent record of the beach (wrack cover as well as other characteristics) that can be used again. The photopoint method was much faster (< 5% of the time required) than the transect method. For each beach, the transect methods took approximately ¾ hour for transects oriented beach parallel and 1 hour for transects oriented beach perpendicular. The time taken varied greatly, however, and depended on the amount and distribution (i.e. continuous vs. patchy) of the wrack deposits. Approximately 15 minutes was also required for data entry and processing. Thus the transect method required approximately 2 hours per beach. In contrast, the photopoint method required less than 5 minutes per beach for both fieldwork and data entry. The rapidity of the photopoint method allows a greater number of sites, beaches or visits to be sampled with little time and expense to the researcher, and thus can provide information that was previously difficult or unfeasible to obtain. Photopoints could be used to inform managers of wrack cleaning and harvest activities, as well as assessing wrack stocks around the state and possibly to identify unknown or unused resources. Primary Industries and Resources South Australia (PIRSA), in their capacity as managers of the wrack harvest, require that licence holders provide data on wrack volume/cover before and after harvest (PIRSA 2003). Prior to now, there was no feasible way to do so; however, photopoints provide a rapid tool to monitor the activities and check the compliance of licensed harvestors. Expressions of interest in a rapid tool for assessing wrack cover have also come from community members and non-government organisations, particularly those involved in the conservation of birds on sandy beaches (McCulloch 2000). Photopoints may provide a useful community monitoring tool, as an aid to research and for the general public's interest. The photopoint method thus provides a useful tool for scientists, natural resource managers and community groups.

Wrack cover and composition

Wrack cover on a given visit to a beach spanned a wide range; from 1 to 95% of the beach face was covered by wrack. Some beaches had consistently low wrack cover but others varied greatly between visits, with the cover on individual beaches varying by over 80% between visits over a one year period. Beaches with high mean wrack cover also tended to have greater variation in wrack cover, i.e. wrack cover varied between low and high between visits. For all beaches together, and for each region, there were no clear trends for higher or lower wrack cover over any of the visits I made. Beaches from the SE region did tend to have a greater cover of wrack than beaches from either the Metro or Fleurieu regions. Thus, wrack cover varies between bio-geographical regions, likely due to the supply of macrophytes to these beaches, and temporally, with variation at individual beaches occurring at temporal scales of months (or less).

There was no trend for higher wrack cover to occur in any season. This result contrasts with those of McKechnie and Fairweather (2003), who studied the same 3 regions of South Australia. McKechnie and Fairweather (2003) found that in one year, the cover of wrack was higher in winter than in summer. Other studies have also shown that wrack cover varies seasonally, e.g. with higher cover in winter (Robertson & Hansen 1982; Yatsuya *et al.* 2007), in spring and summer (Piriz *et al.* 2003) or in autumn (de Falco *et al.* 2008). Thus, seasonal trends in wrack cover appear to differ between locations, possibly due to the wide range of factors affecting wrack cover (e.g. weather, tidal and current regimes and the type of macrophyte(s)). There may in fact be a trend for seasonality in wrack cover on some South Australian beaches but only one visit was made to each beach every 2 months, and given that wrack deposits are highly influenced by tides, currents and winds, such patterns may have been missed. Additional sampling of beaches at finer temporal scales (e.g. daily or weekly) may assist in clarifying this.

The wrack deposits sampled in this study contained a total of 242 species, reflecting the high diversity of seagrass and algal species in South Australia. The species composition and relative masses of those species (and groups of species) varied both spatially and temporally. The diversity of the algae and seagrasses in this study exceeded any reported in the literature but this study also exceeded others in terms of the number of beaches, the geographical range of the beaches and the number of visits made to the beaches. For example, Ochieng and Efftemeijer (1999) reported only 4 species of seagrass and 2 species of algae but they sampled only 3 sites along one stretch of coast in Kenya. On the 10 beaches sampled by Orr *et al*. (2005) in Canada, 19 species of algae, including red, green and brown, and 2 seagrasses were found. The largest number of species reported in any previous study was 44 (including 19 red algae, 13 brown algae and 8 green algae) (Piriz *et al.* 2003). Thus, whilst the number of species reported by Piriz *et al*. (2003) was lower, approximately one fifth of the number found in this study., the relative proportions of red, brown and green algae were similar (Appendix B). Whilst the number of species (total and for each taxonomic group) varied between regions and visits, the relative masses of those species varied between beaches (i.e. at a finer spatial scale). Beaches with high wrack cover also tended to have wrack deposits with more variable composition. These wrack deposits are thus diverse, spatially variable and dynamic.

Twenty-five species were identified as dominant at, at least, one beach. Ten brown algae were identified as dominant, reflecting their tendency to dominate wrack samples, in terms of the number of species and % mass, from all beaches. All three kelp species were also classed as dominant, reflecting their tendency to make up large proportions of the wrack deposits when they were present, probably due to their large size. Six of these dominant species were also ubiquitous, in that they occurred at all 17 beaches sampled.

The Metro and Fleurieu regions were characterised by seagrass-dominated wrack deposits, whilst the SE samples were dominated by algae. SE samples were also more diverse, with higher total numbers of species and higher algal diversity, driven by the great diversity of kelps, green algae and red algae in that region. This result was not surprising given the particularly high diversity of algae which occurs in the SE region (Womersley 1984; 1987; 1994a; b; c). The exception to this was 2 beaches in the SE, Kingston and The Granites. Kingston is dominated by seagrass wrack (*Posidonia sinuosa*) and fragments; a composition more typically found in the Metro region. The composition of wrack from The Granites was more similar to the Fleurieu and Metro regions in general. Cape Jaffa, in the SE Region, is proposed as the north-western boundary of the distribution of the large kelps *Durvillaea* *potatorum* and *Macrocystis angustifolia* (Womersley 1987). The beaches located to the north-west of Cape Jaffa (i.e. Kingston and The Granites) did have different species and, in particular, higher proportions of seagrass rather than algal wrack compared to those south east of Cape Jaffa. To the north west of Cape Jaffa, small amounts of *M. angustifolia* (usually old, dry floats with small parts of blades attached) were found in the wrack deposits (i.e. at Kingston and The Granites, and in the Fleurieu and Metro regions). Previous studies have also documented the movement of kelps (i.e. *Macrocystis pyrifera*, which also possesses floats) over hundreds of kilometres (Edgar 1987; Harrold & Lisin 1989; Hobday 2000), and Womersley (Womersley 1987) has also previously noted that drift specimens of *M. angustofolia* have been found in the SA gulfs.

Sorting wrack into groups (i.e. brown algae, kelp, green algae, red algae, seagrass, other materials and fragments) was sufficient to separate samples from the three regions, and gave similar results to those achieved by sorting samples to a finer taxonomic level. Sorting of samples into species required between 15 minutes and 2 hours for the most diverse samples but, on average, took 30 minutes. Comparatively, sorting samples into the taxonomic groups used here required approximately 10 minutes per sample. Thus sorting times can be reduced by up to two thirds and the level of expertise required is much lower yet the information yielded is sufficient to distinguish between regions.

South Australian wrack deposits contribute a complex, diverse and spatially and temporally variable resource to the beach and nearshore ecosystem. Both the cover and composition of wrack deposits are known to influence the role of wrack in the processes of sediment accumulation and erosion (Nordstrom *et al.* 2000; 2007), wrack decomposition (Jedrzejczak 2002b), the incorporation of wrack into the trophic web (Adin & Riera 2003; Ince *et al.* 2007), and its role as a habitat for beach invertebrates (McLachlan 1985; Marsden 1991; Ince *et al.* 2007; Olabarria *et al.* 2007). Variability in cover and composition further contribute complexity to these dynamic processes, and must be borne in mind when characterising sandy beaches and the ecological processes occurring there. Investigating the role of wrack in the beach and nearshore ecosystem will be the focus of the following chapters of this thesis.

Conclusion

The photopoint method provides an accurate, simple and rapid method for estimating the cover of wrack on a range of sandy beaches. It has a range of potential applications and its use will assist researchers, managers and community groups in studying wrack deposits. South Australian wrack deposits vary greatly in their extent (cover) and composition and both varied at temporal scales of months or less. There were no seasonal trends in wrack cover. Wrack deposits contained a diverse mix of seagrass and algal components and the species list was more diverse than any previously reported. Beaches in the SE region had higher wrack cover and more diverse wrack deposits than the Fleurieu and Metro regions. Fleurieu and Metro wrack deposits were dominated by seagrass wrack. Beaches in the SE could be separated into 2 groups; those south of Cape Jaffa, which were dominated by algae (including higher number of kelps, red and green algae), and those to the north of Cape Jaffa, which had a higher proportion of seagrass wrack.

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the DL scored as 20 classes (slope = 0.998, intercept = 0.414, Pearson $r = 0.937$, $p < 0.001$). The linear regression and 95% confidence intervals are plotted where the regression was significant. $n = 65$ for all regressions.

Figure 2.5. Scatterplot of % wrack cover obtained from photopoints at the DL (x) vs. photopoints at the midpoint of the beach (y) (slope = 0.462, intercept = 2.058, Pearson $r = 0.831$, $p < 0.001$, $n = 61$). The linear regression and 95% confidence intervals are plotted.

Figure 2.6. Scatterplots of beach width (x) vs. accuracy of the photopoint method with accuracy expressed as a) the difference between % cover values obtained from transects and photopoint (Pearson $r = 0.160$, $p = 0.206$); and b) the relative difference between % cover values obtained from transects and photopoint (Pearson $r = 0.172$, $p = 0.177$). Negative y values indicate that the photopoint method overestimated wrack cover, whilst a positive value indicates that the photopoint method underestimated wrack cover. $n = 64$ for both regressions.

Figure 2.7. Scatterplot of % wrack cover vs. wrack depth (cm) from transects. Both % wrack cover and wrack depth were 4^{th}-root transformed. A LOWESS smoother is fitted through the data. $n = 68$.

Figure 2.8. Mean (± se), minimum and maximum % wrack cover for each beach. ● = mean, ❋ = maximum and ✚ = minimum.

Figure 2.9. Mean (± se) % wrack cover over time (Visits) for the three study regions. Line styles by Region: dashed black = SE, solid black = Fleurieu, solid grey = Metro.

Figure 2.10. Mean (± se) % wrack cover in summer (S1 and S2) and winter (W1 and W2) for the three study regions. Line styles by Region: dashed black = SE, solid black = Fleurieu, solid grey = Metro.

Figure 2.11. Scatterplot of mean % wrack cover (x) vs. the standard error (se) of the mean % wrack cover. Means were calculated from all visits made to each beach. The linear regression and 95% confidence intervals are plotted. $n = 17$ beaches.

Figure 2.12. Wrack composition as number of species by groups for samples separated by Visits for a) SE, b) Fleurieu and c) Metro.

Figure 2.13. Wrack composition as % mass by groups for samples separated by Visits for a) SE, b) Fleurieu and c) Metro.

Figure 2.14. 2-dimensional MDS plots of wrack composition for a) samples from all beaches and visits plotted by colour for regions (grey = SE, white = Fleurieu, black = Metro) and by symbol for beaches (*n* = 107), b) samples from all beaches and visits by visits (*n* = 107) (black = winter, grey = summer, white = autumn and spring, see legend for visits) and c) samples for beaches pooled over visits (*n* = 17) with symbols plotted by region (grey ○ = SE, white □ = Fleurieu, black △ = Metro). 2-D stress was for a) and b) was 0.20 and for c) was 0.09, indicating that the plots were adequate 2-D representations of the relationships among the samples.

Figure 2.15. Scatterplot of a) mean % wrack cover for each beach (x) vs. SIMPER within groups similarity for each beach and b) the standard error (se) of the mean % wrack vs. SIMPER within groups similarity for each beach. Mean % wrack cover was calculated from all visits made to each beach. The linear regression and 95% confidence intervals are plotted. *n* = 17 beaches for both regressions.

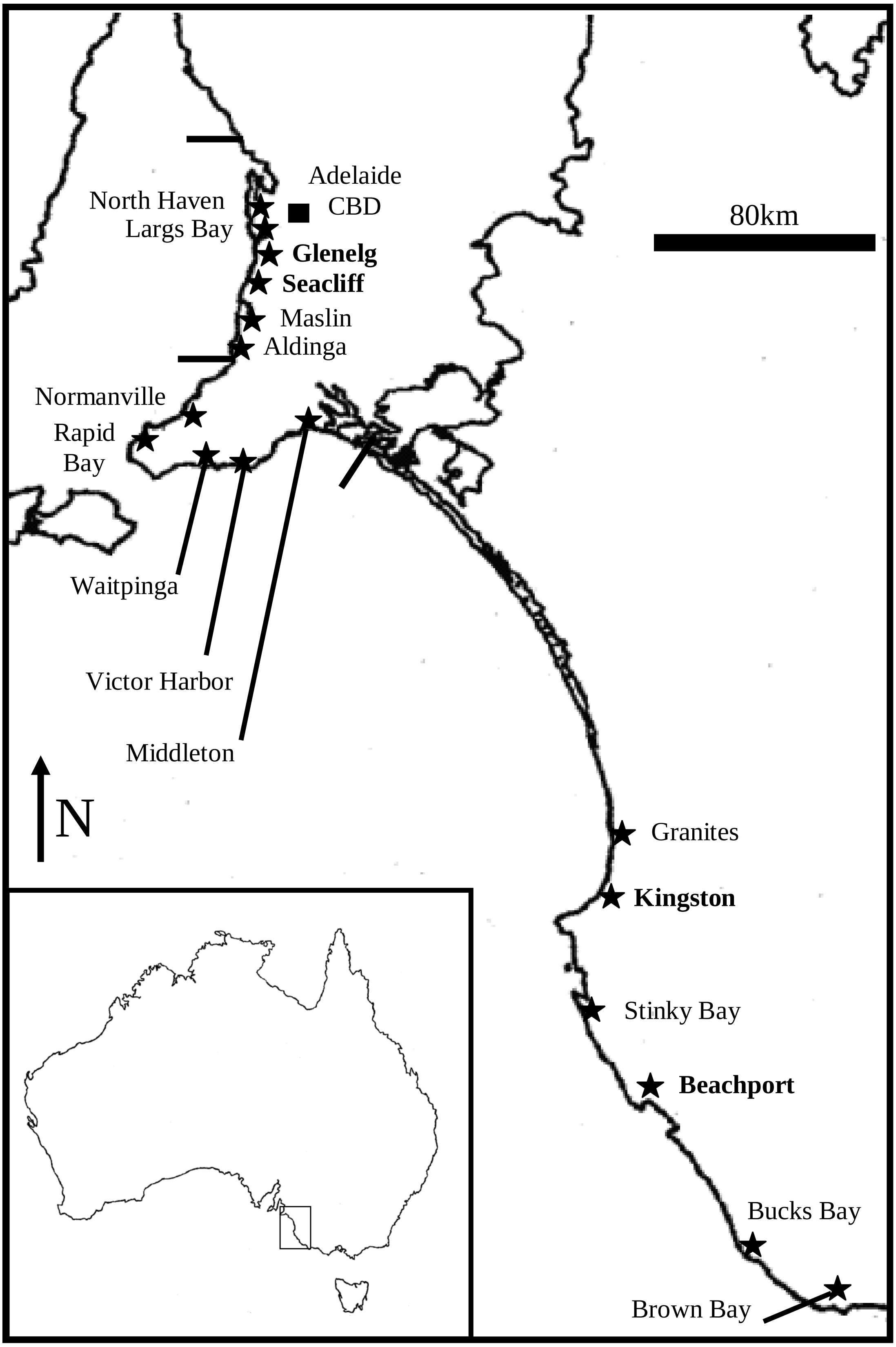

Adelaide
CBD
North Haven
Largs Bay
Glenelg
Seacliff
Maslin
Aldinga
Normanville
Rapid
Bay
Waitpinga
Victor Harbor
Middleton
80km
N
Granites
Kingston
Stinky Bay
Beachport
Bucks Bay
Brown Bay

Figure 2.1

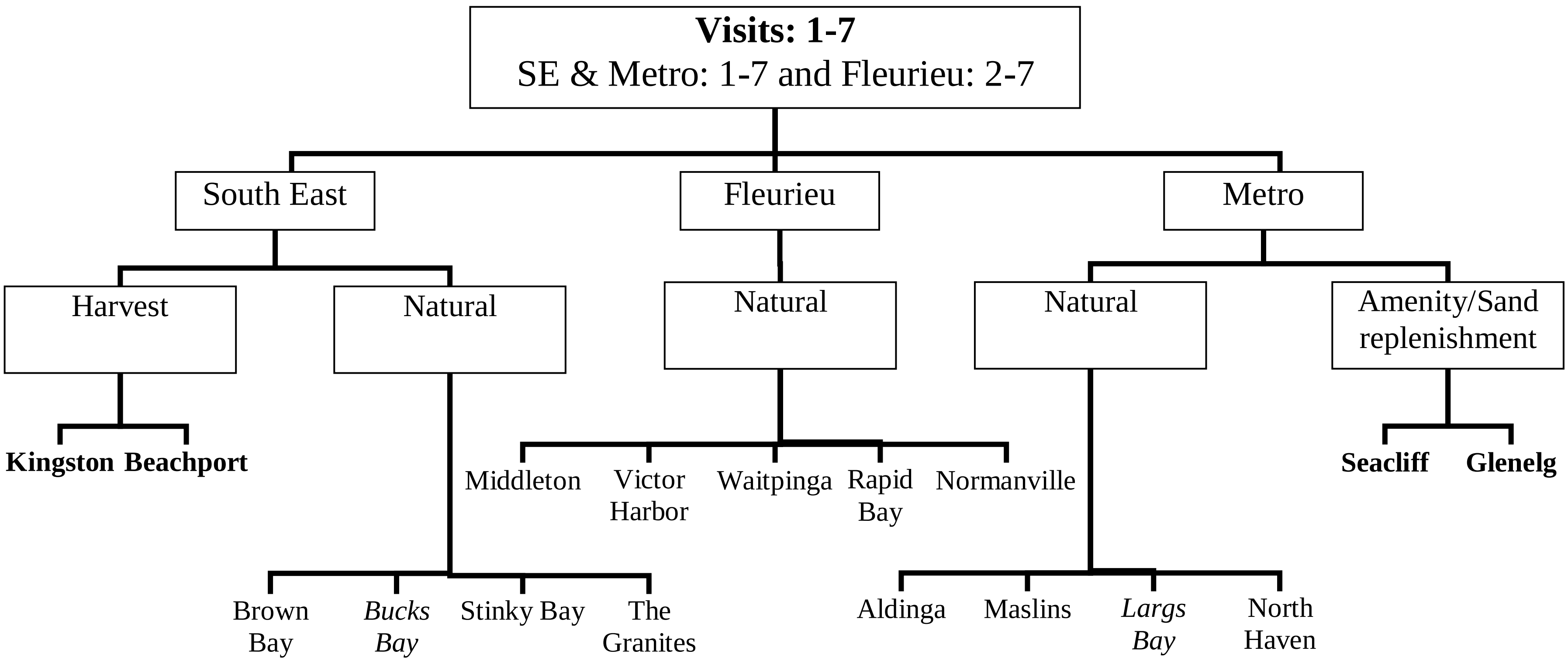

Visits: 1-7
SE & Metro: 1-7 and Fleurieu: 2-7
South East
Fleurieu
Metro
Harvest
Natural
Natural
Natural
Amenity/Sand replenishment
Kingston
Beachport
Middleton
Victor Harbor
Waitpinga
Rapid Bay
Normanville
Seacliff
Glenelg
Brown Bay
Bucks Bay
Stinky Bay
The Granites
Aldinga
Maslins
Largs Bay
North Haven

Figure 2.2

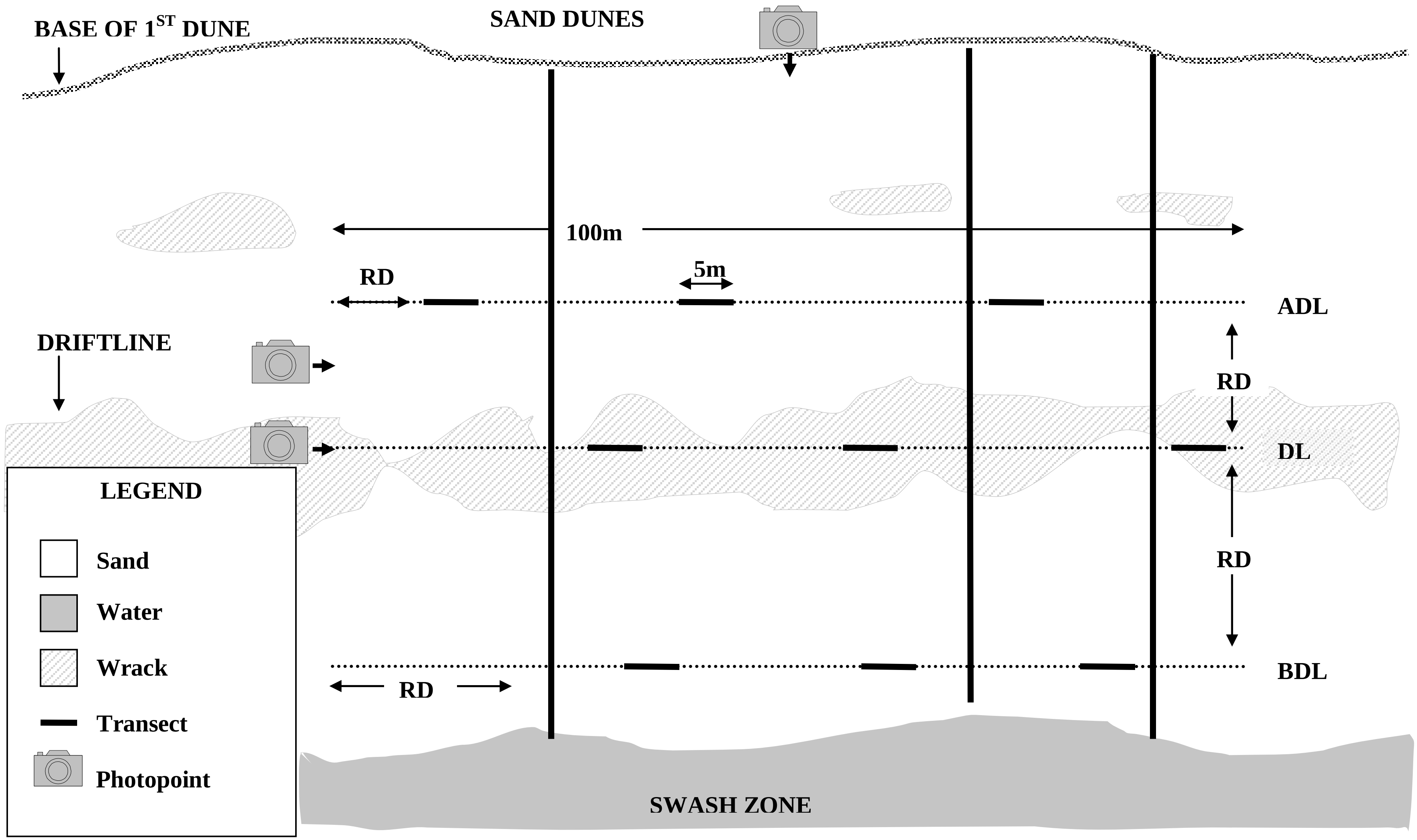

BASE OF 1ST DUNE
SAND DUNES
100m
RD
5m
ADL
DRIFTLINE
RD
DL
RD
BDL
RD
SWASH ZONE
LEGEND
Sand
Water
Wrack
Transect
Photopoint

Figure 2.3

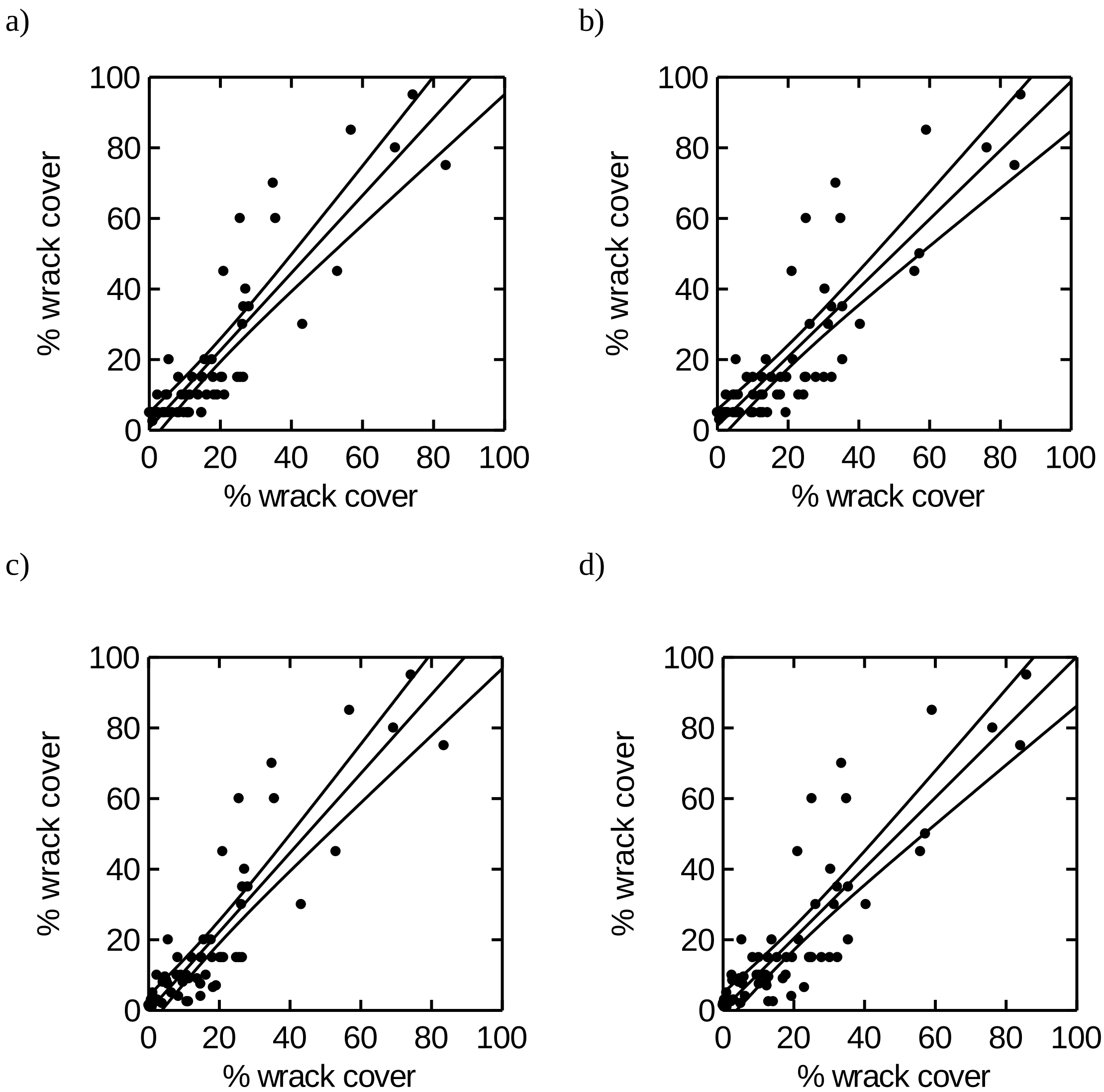


Figure 2.4

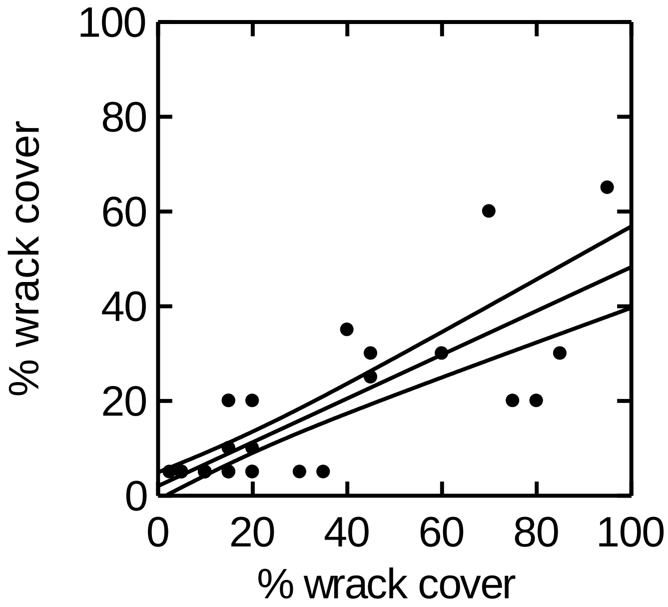
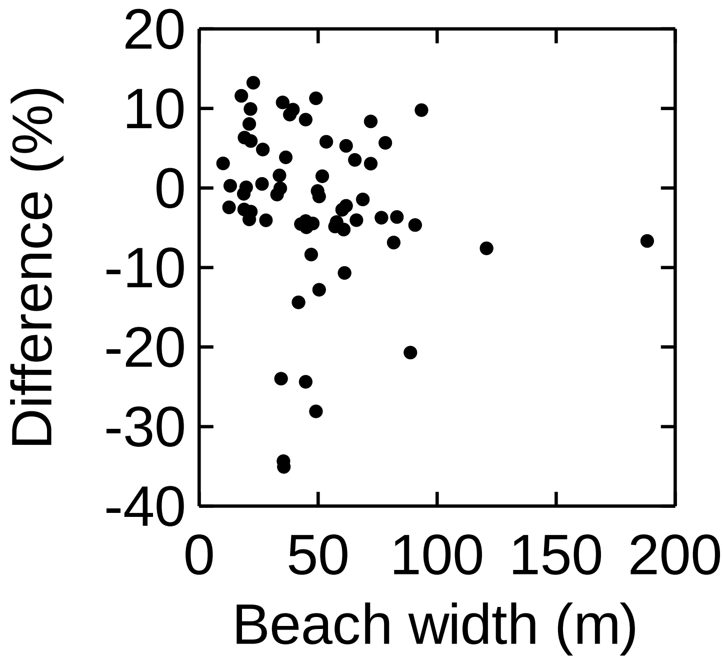


Figure 2.5

a)


20
10
0
-10
-20
-30
-40
Difference (%)
0
50
100
150
200
Beach width (m)

b)

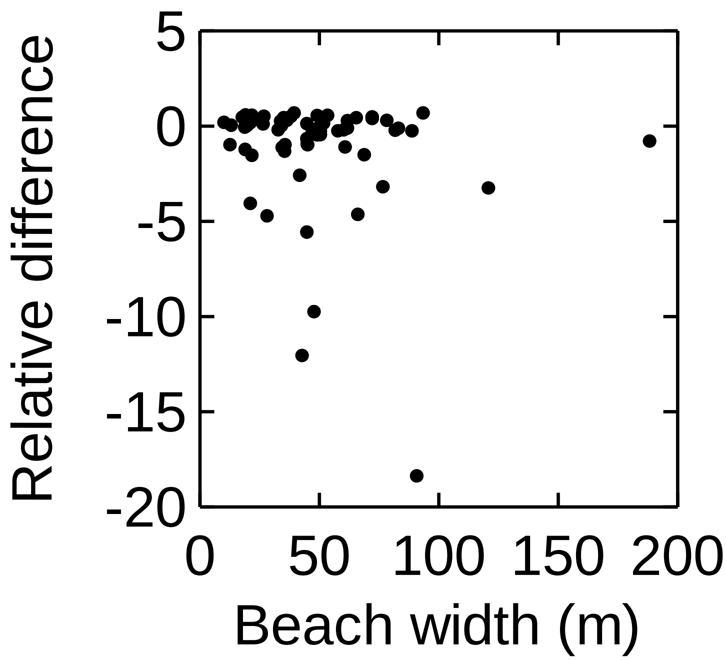

5
0
-5
-10
-15
-20
Relative difference
0
50
100
150
200
Beach width (m)

Figure 2.6

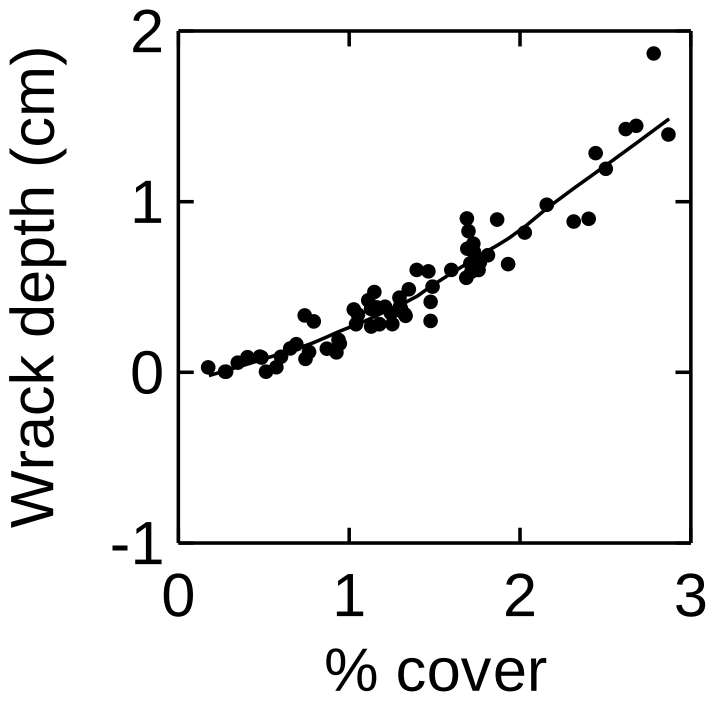
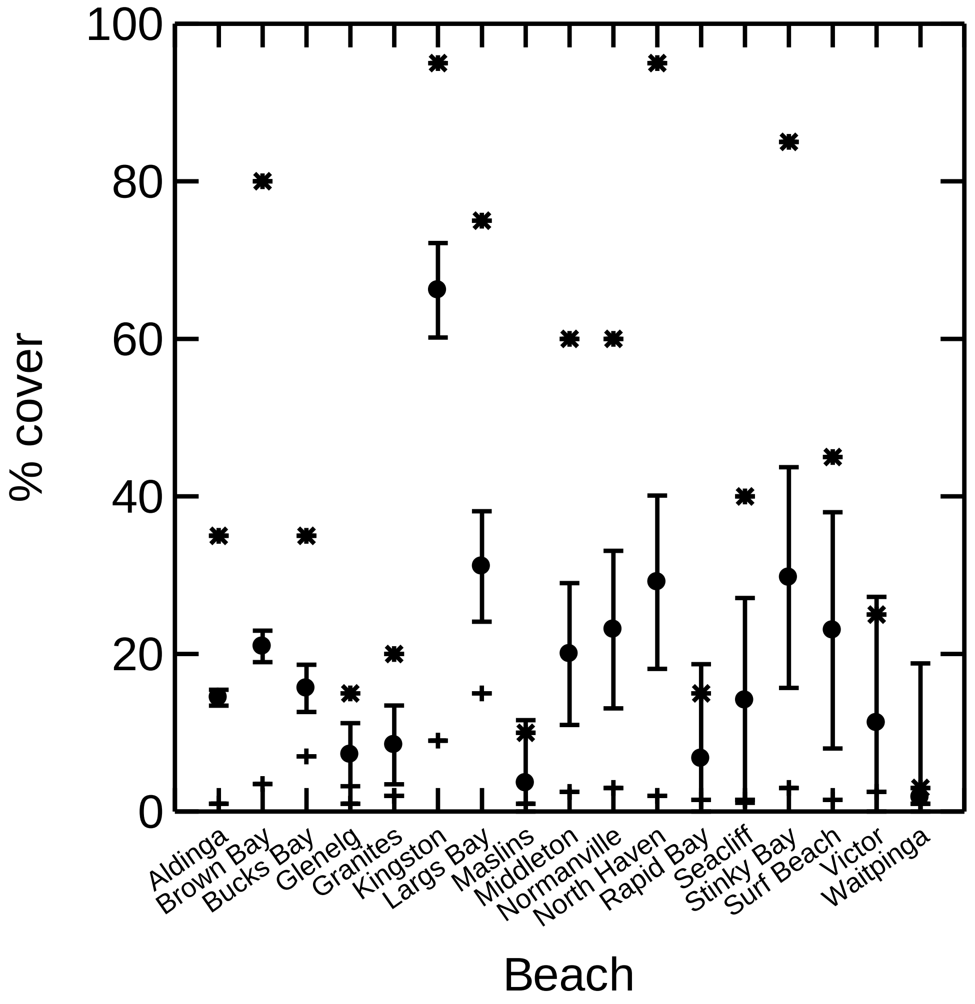


Figure 2.7



100
80
60
40
20
0
% cover
Aldinga
Brown Bay
Bucks Bay
Glenelg
Granites
Kingston
Largs Bay
Maslins
Middleton
Normanville
North Haven
Rapid Bay
Seacliff
Stinky Bay
Surf Beach
Victor
Waitpinga
Beach

Figure 2.8

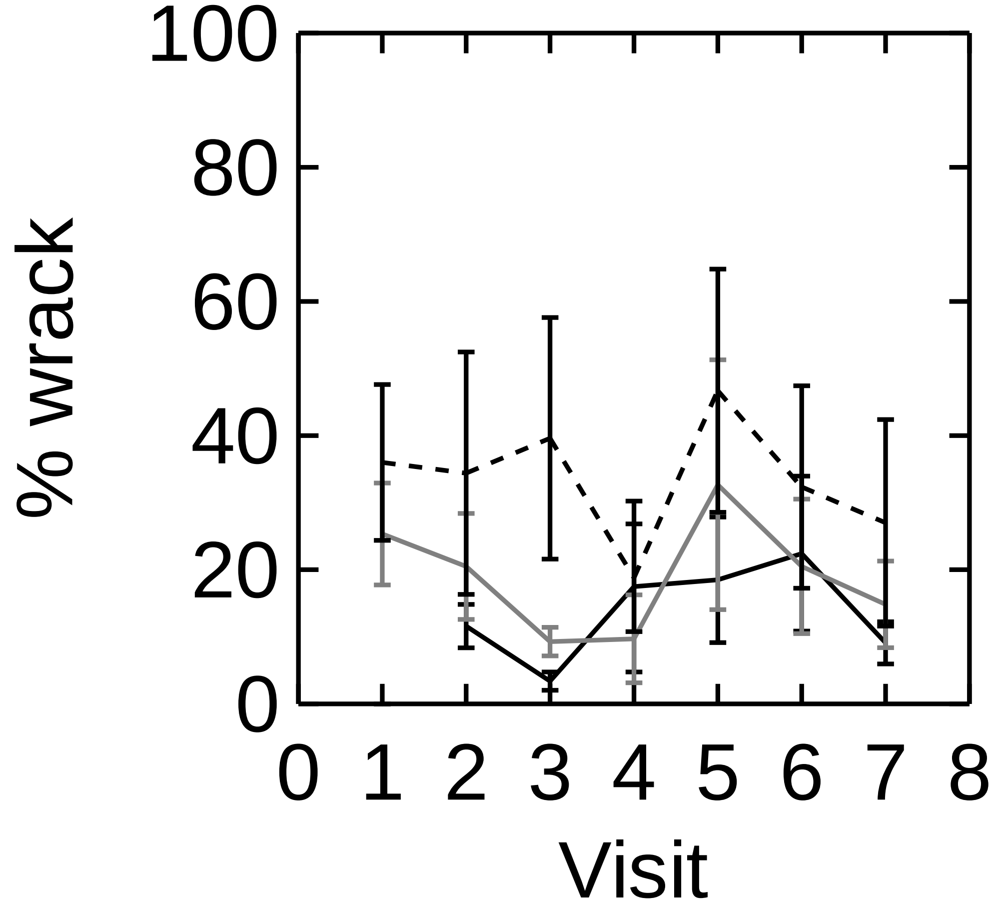


Figure 2.9

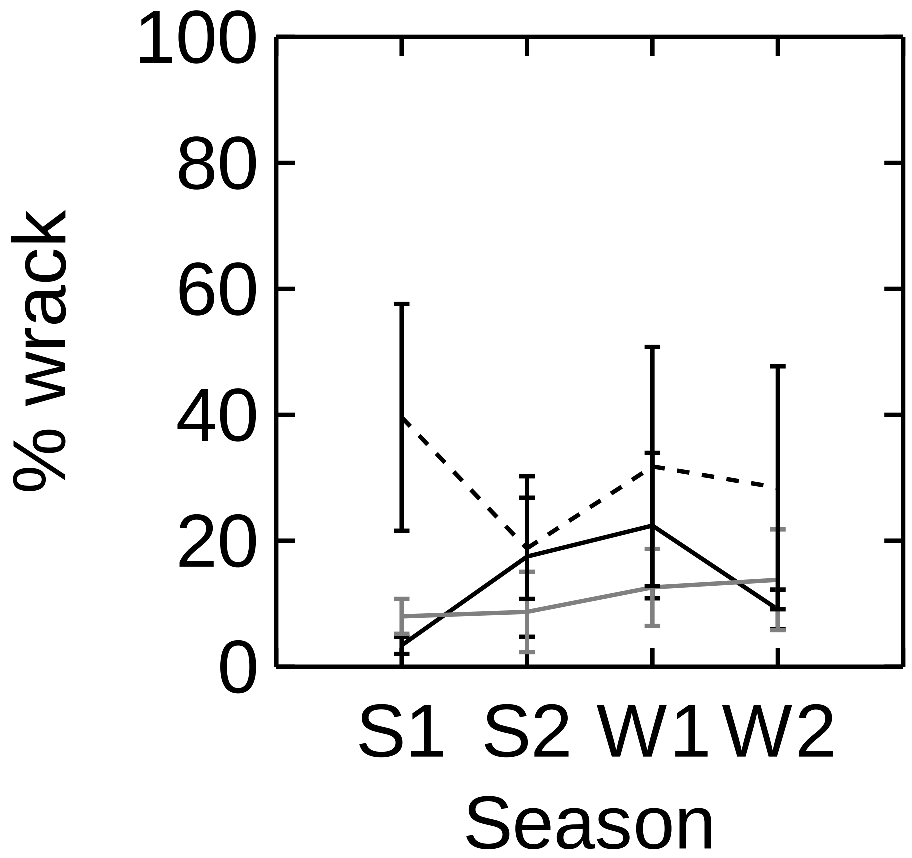


Figure 2.10

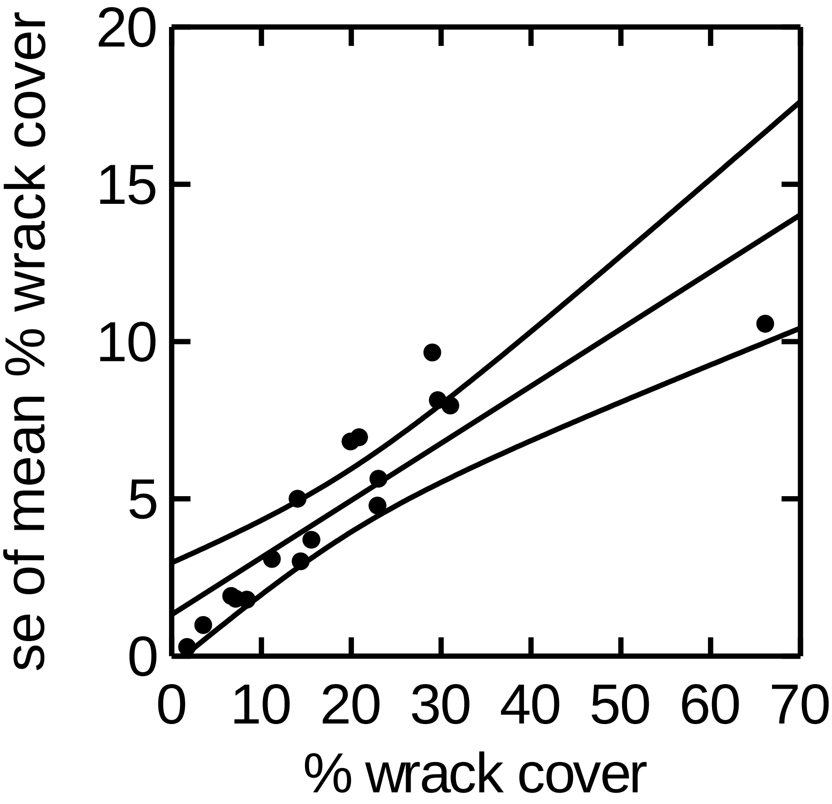

20
15
10
5
0
se of mean % wrack cover
0
10
20
30
40
50
60
70
% wrack cover

Figure 2.11

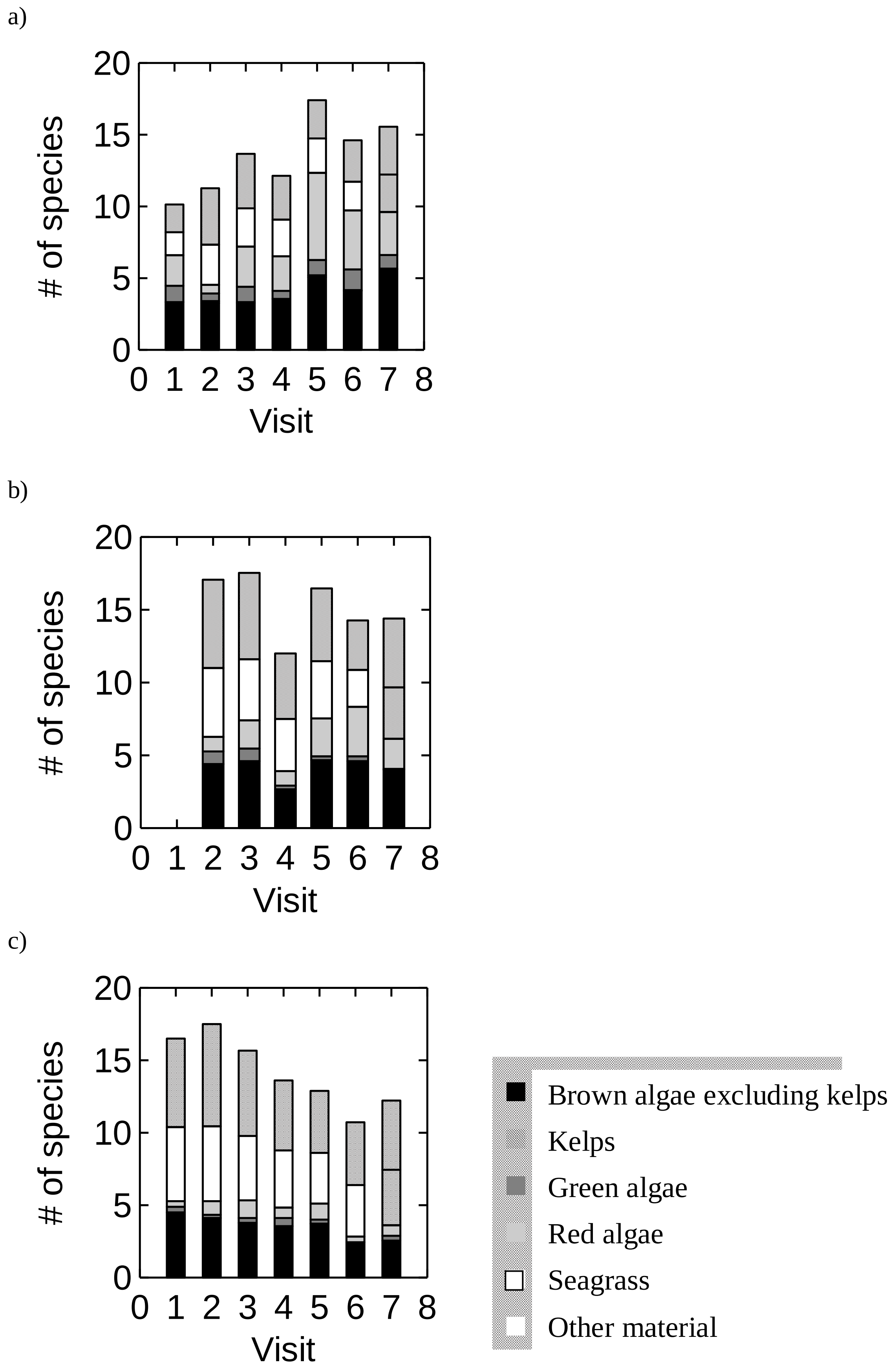
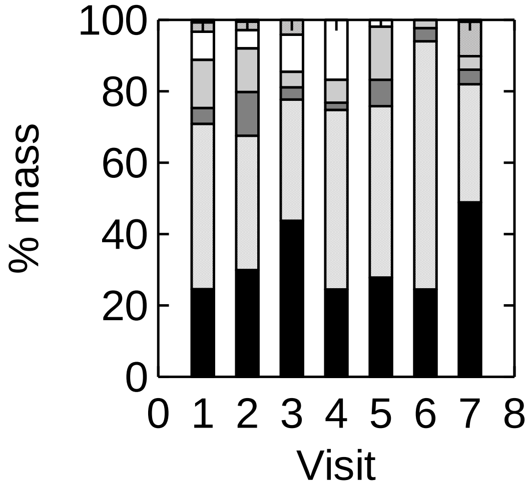
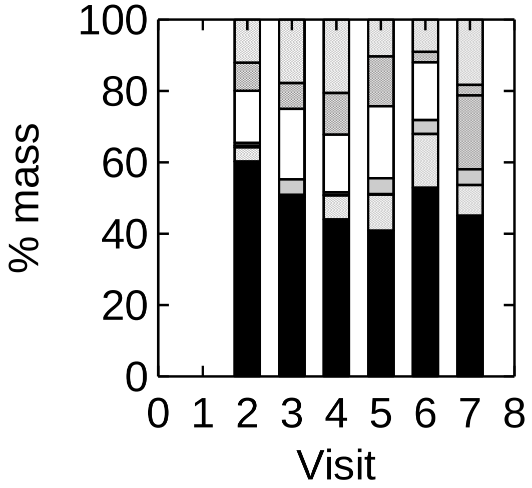

a)
20
15
10
5
0
# of species
0 1 2 3 4 5 6 7 8
Visit
b)
20
15
10
5
0
# of species
0 1 2 3 4 5 6 7 8
Visit
c)
20
15
10
5
0
# of species
0 1 2 3 4 5 6 7 8
Visit
Brown algae excluding kelps
Kelps
Green algae
Red algae
Seagrass
Other material

Figure 2.12

a)



b)



c)

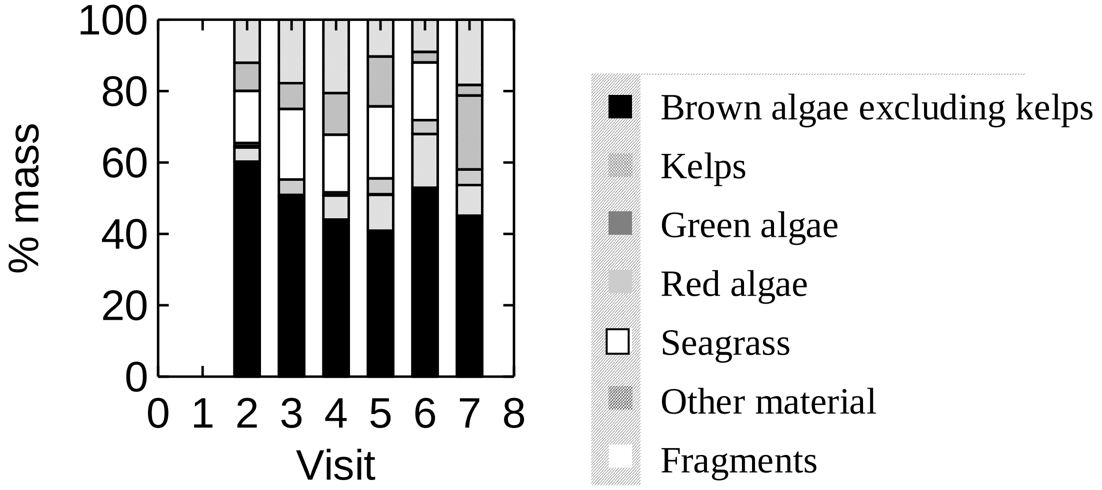


Figure 2.13

a)

b)

c)

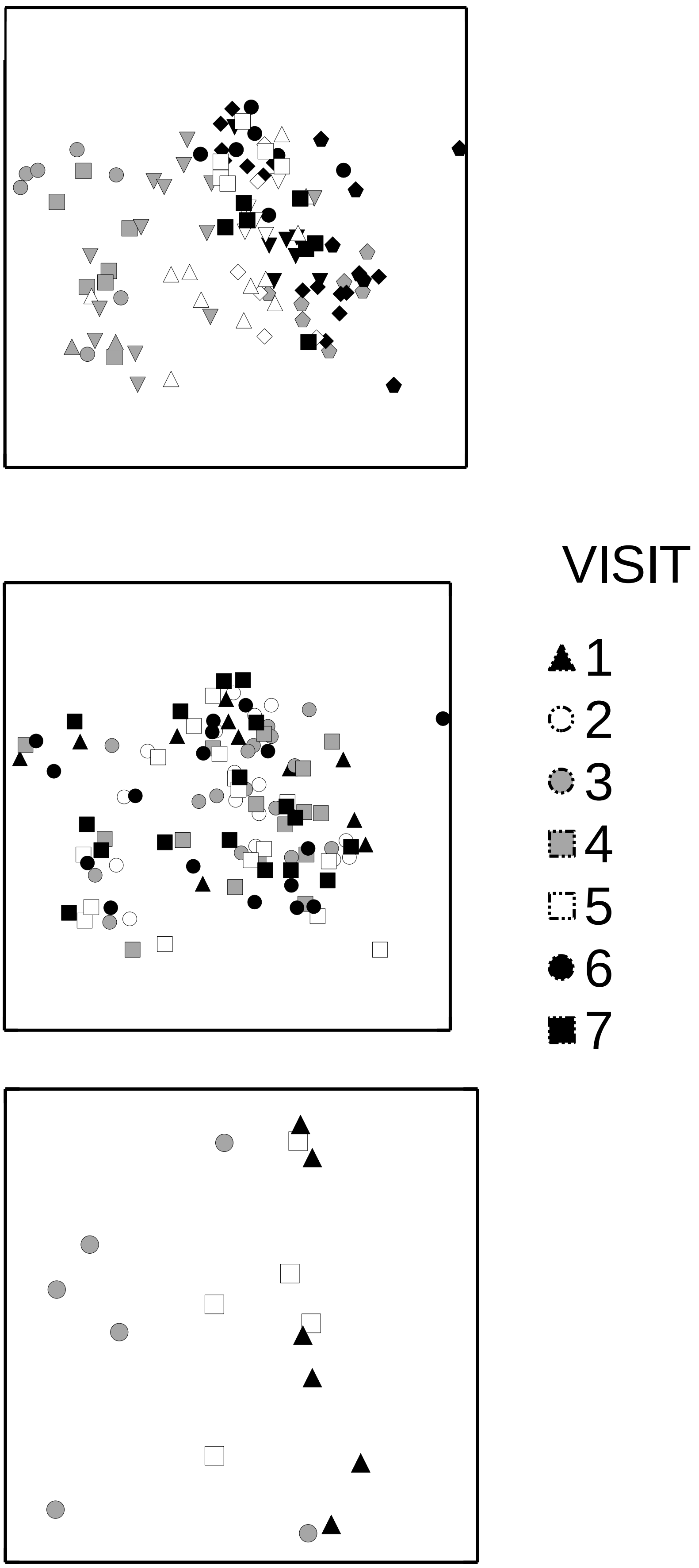
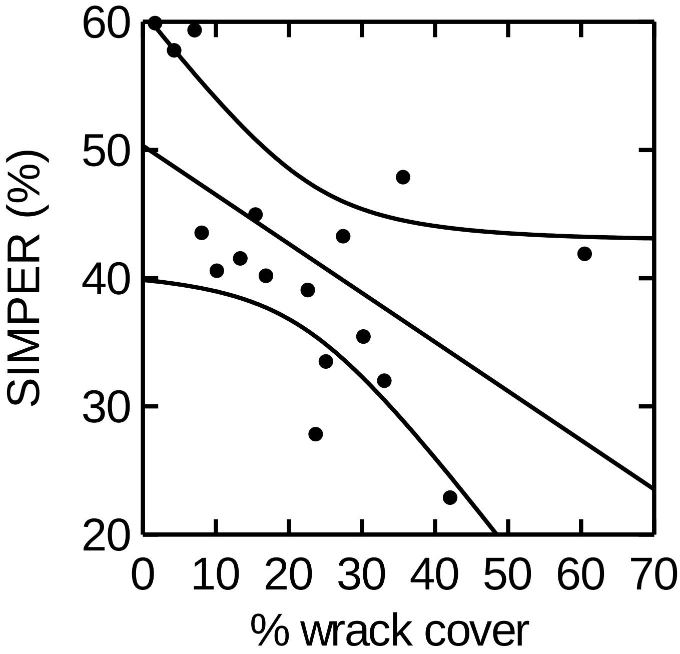


Figure 2.14

a)



b)

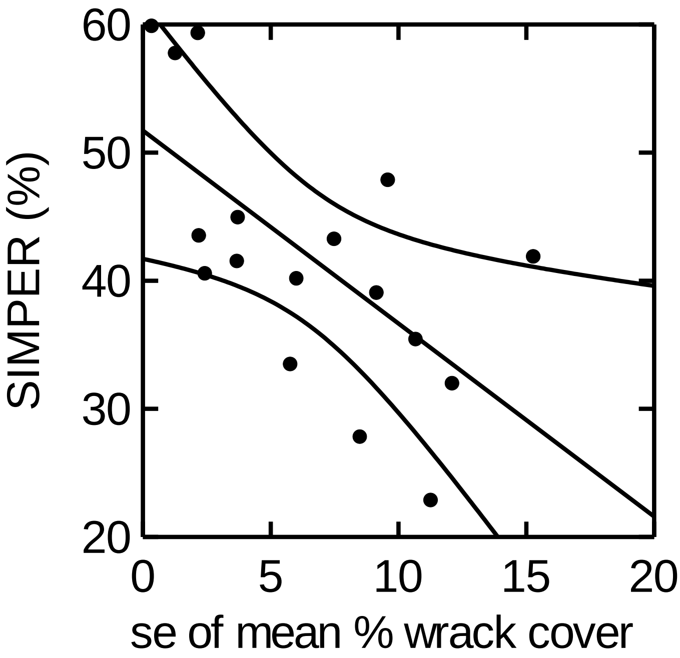


Figure 2.15

Table 2.1. List of main sampling visits (1-7) and corresponding months sampled for each region. ‘S’ indicates summer and ‘W’ indicates winter sampling used in analysis of seasonal trends in wrack cover.

	Month and year sampled		
Visit	**South East**	**Fleurieu**	**Metro**
1	June ‘05	Not sampled	July ‘05
2	Sept ‘05	Oct ‘05	Oct ‘05
3 (S)	Nov ‘05	Dec ‘05	Nov-Dec ‘05
4 (S)	Feb ‘06	Jan-Feb ‘06	Feb ‘06
5	Apr ‘06	Mar-Apr ‘06	Apr ‘06
6 (W)	June ‘06	June ‘06	June ‘06
7 (W)	Aug ‘06	Aug ‘06	Aug ‘06

Table 2.2. Table of wrack cover classes, range of percent wrack cover for each class and mid-point for calculations for photopoint method based on a) 11 cover classes (0 to 11) and b) 20 cover classes (0 to 20). Photos were classified into cover classes based on visual estimates of percent wrack cover.

a)

Class	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
% Cover	0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-99	100
Midpoint	0	5	15	25	35	45	55	65	75	85	95	100

b)

Class	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
% Cover	0	1	2	3	4	5	6	7	8	9	10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-99	100
Midpoint	0	1	2	3	4	5	6	7	8	9	10	15	25	35	45	55	65	75	85	95	100

Table 2.3. Summary of results of linear regressions for percent cover of wrack obtained from transects and photopoint methods.

Transects	vs	Photopoint	*n*	*p*	*Pearson r*	Slope	Intercept
DL		DL	68	< **0.001**	0.786	0.654	0.487
Parallel		DL	68	< **0.001**	0.872	0.975	1.290
Parallel		Midpoint	55	< **0.001**	0.817	0.425	3.345
Perpendicular		Perpendicular	65	< **0.001**	0.782	0.719	2.542
Perpendicular		DL	65	< **0.001**	0.770	1.160	4.578
Grand mean		DL	65	< **0.001**	0.888	1.097	0.669
Grand mean		Midpoint	55	< **0.001**	0.680	0.469	3.136

Table 2.4. Summary of ANOVA results for % wrack cover (√-transformed) for Regions and Visits (n = 90).

Source	df	MS	F	p
Region	2	37.053	14.565	**< 0.01**
Visit	5	4.854	0.931	0.466
Region x Visit	10	2.544	0.488	0.893
Residual	72	5.212		

Table 2.5. Summary of ANOVA results for % wrack cover (log [x + 1]-transformed) for Seasons, Visits (nested within Seasons) and Regions (n = 60).

Source	df	MS	*F*-ratio	*p*
Season	1	2.458	5.612	NS
Visit (Season)	2	0.438	0.323	NS
Region	2	7.706	7.424	**< 0.05**
Season x Region	2	1.310	1.262	NS
Visit (Season) x Region	4	1.038	0.766	NS
Error	48	1.355		

Table 2.6. Wrack composition (number of species and % mass by groups) at the main study beaches over all visits.

		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	SE						Fleurieu					Metro					
	n	21	6	21	21	21	21	18	18	18	18	18	21	21	21	21	21	21
# spp.	Mean	13.3	37.7	20.0	38.1	9.5	14.9	20.7	23.1	17.9	19.2	13.1	14.8	16.9	20.8	19.5	10.8	8.4
	Min.	3	24	4	10	2	9	12	9	7	5	5	6	10	8	7	3	2
	Max.	48	53	37	75	19	24	48	37	29	34	23	27	28	37	33	25	14
# algal spp.	Mean	6.0	17.8	8.3	18.4	2.8	4.6	7.3	8.6	5.8	6.9	4.5	4.7	5.6	6.9	6.3	2.8	1.4
	Min.	1	11	2	5	0	2	3	3	2	1	1	2	3	2	1	0	0
	Max.	23	25	15	35	8	9	24	15	10	13	9	9	10	14	13	9	4
# seagrass spp.	Mean	0.9	1.3	2.4	0.9	3.5	4.4	3.7	4.6	3.0	3.8	3.8	4.0	3.9	4.9	4.5	4.1	4.0
	Min.	0	1	0	0	2	3	0	3	0	2	2	2	1	3	2	1	2
	Max.	2	2	6	3	5	6	5	6	6	7	5	7	6	7	8	5	6
# other groups	Mean	0.5	0.7	1.0	0.5	0.4	1.2	2.4	1.3	3.4	1.7	0.3	1.3	1.8	2.2	2.3	1.1	1.6
	Min.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Max.	3	1	5	3	2	4	5	7	7	4	2	3	5	5	8	4	3
% mass algal spp.	Mean	96.5	98.3	96.8	92.5	21.7	72.4	57.2	48.5	79.6	61.2	44.8	64.4	78.9	50.0	37.6	6.2	9.7
	Min.	67.8	96.8	85.0	46.7	0	23.4	2.4	3.8	45.7	27.1	3.2	14.4	30.0	0.9	1.5	0	0
	Max.	100	99.7	99.9	99.9	68.8	98.3	100	93.7	98.1	91.7	92.3	96.5	99.0	89.0	78.2	29.1	63.7
% mass seagrass spp.	Mean	0.1	0.4	1.4	0.2	39.8	23.5	13.7	25.0	1.2	13.8	47.1	23.2	9.8	29.5	35.1	49.9	26.4
	Min.	0	0.2	0	0	12.8	0.6	0	5.2	0	1.9	0.6	0.9	0.5	3.0	2.1	16.2	0.1
	Max.	1.0	1.0	10.4	0.9	100	73.7	33.2	62.7	3.4	33.0	90.8	77.2	63.8	94.3	73.7	97.2	100
% mass other groups	Mean	2.2	1.1	0.4	0.1	0.6	2.4	21.7	3.8	9.0	2.3	0.1	4.2	3.2	3.4	9.8	8.3	43.7
	Min.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Max.	31.6	2.2	4.1	0.6	6.0	26.6	70.8	27.2	30.8	9.6	1.1	52.8	35.2	13.6	77.9	61.9	99.6

Table 2.7. List of dominant wrack components (i.e. species or other materials that comprised at least 5% by mass of the wrack found at any beach (samples pooled over all visits). Values in the table are % by mass. A blank indicates that the species was not found at that site. K = kelp. See Appendix A for taxonomic classifications.

	Brown Bay	Bucks Bay	Beachport	Stinky Bay	Kingston	Granites	Middleton	Victor Harbor	Waitpinga	Rapid Bay	Normanville	Aldinga	Maslins	Seacliff	Glenelg	Largs Bay	North Haven	# of beaches
	SE						Fleurieu					Metro						
Brown algae																		
Sargassum spp.	3	2	1	1	<1	13	14	2	51	29	20	39	52	17	13	1	4	17
Cystophora spp.	3	1	13	9	3	22	9	3	8	16	5	8	9	2	3	1		16
Scaberia agardhii	<1		1	<1	<1	18	3	2	9	6	6	5	10	14	7	1	3	16
Caulocystis cephalornithos	1	1	<1	<1			1	<1	<1	3	2	6	3	4	2	<1		14
Ecklonia radiata (K)	9	48	18	13	<1	1	11	14	<1	2	5	<1		6	2			14
Acrocarpia robusta	6	9	11	7		1	3	16			<1			<1				9
Caulocystis uvifera							<1		1	2	1	6	3	2	4		2	9
Macrocystis angustifolia (K)	52	1	30	7	1	9	1		2				<1					9
Acrocarpia paniculata	<1	3	5	4					<1									5
Scytothalia doryocarpa			3				<1	3	5	<1								5
Perithalia caudata	4	14	4	3														4
Carpoglossum confluens				1		6	5											3
Durvillaea potatorum (K)	1		6	2														3

	Brown Bay	Bucks Bay	Beachport	Stinky Bay	Kingston	Granites	Middleton	Victor Harbor	Waitpinga	Rapid Bay	Normanville	Aldinga	Maslins	Seacliff	Glenelg	Largs Bay	North Haven	# of beaches
	SE						Fleurieu					Metro						
Green algae																		
Caulerpa flexilis	<1	10	<1	1				<1	<1									6
Codium fragile	11		1	4	3	<1												5
Red algae																		
Phacelocarpus peperocarpus	1	1	<1	8			2	<1										6
Carpothamnion gunnianum					5									<1		<1		3
Seagrass																		
Amphibolis antarctica	<1		<1	<1	4	<1	1	2	<1	4	11	<1	<1	4	1	2	<1	16
Amphibolis stems and roots	<1	<1	<1		7	1	10	9	<1	3	1	<1	1	1	1	2	3	16
Posidonia coriacea			1	<1	1	10	2	<1	<1	<1	<1	20	9	2	<1	<1	<1	15
Posidonia sinuosa			<1	<1	22	5	1	5	<1	6	31	2	<1	19	25	39	19	15
Amphibolis griffithii			<1		2	1	<1	5	<1	<1	3	<1	<1	1	3	2	<1	14
Posidonia australis	<1		<1		3	5		<1	<1	<1		<1	<1	1	3	2	<1	13
Other																		
Fragments	1	<1	1	7	38	2	7	23	10	23	8	8	8	17	17	36	20	17
Seagrass fibreball			<1		<1	1	15	2		<1		4	<1	<1	7	7	40	12

Table 2.8. Summary of 3-way ANOVA for Regions, Beaches nested within Regions and Visits for a) number of species by groups and b) % mass by groups. *n* = 109 samples.

a) Number of species by groups

Source	df	Brown algae	Kelp	Green algae	Red algae (log x+1)	Algae (√)	Seagrass	Other
Region	2				undefined			
Beach (Region)	12	< **0.001**	< **0.001**	< **0.001**	< **0.001**	< **0.001**	< **0.001**	< **0.01**
Visit	5	NS	NS	NS	NS	NS	< **0.01**	< **0.01**
Region x Visit	10	NS	NS	NS	NS	NS	NS	NS
Beach (Region) x Visit	60	< **0.001**	< **0.001**	< **0.001**	< **0.001**	< **0.001**	< **0.001**	< **0.001**
Error	180							

b) % mass by groups

Source	df	Brown algae (Arcsine)	Kelp (Arcsine)	Green algae (4^{th} root)	Red algae (4^{th} root)	Algae (Arcsine)	Seagrass (4^{th} root)	Other	Fragments (4^{th} root)
Region	2					undefined			
Beach (Region)	12	< **0.001**	< **0.001**	< **0.01**	< **0.001**	< **0.001**	< **0.001**	< **0.01**	< **0.001**
Visit	5	NS	NS	NS	NS	NS	NS	< **0.05**	< **0.05**
Region x Visit	10	NS	NS	NS	NS	NS	NS	NS	NS
Beach (Region) x Visit	60	< **0.001**	< **0.001**	< **0.001**	< **0.001**	< **0.001**	< **0.001**	< **0.001**	< **0.001**
Error	180								