CHAPTER SIX: ASSESSING THE INCORPORATION OF WRACK INTO BEACH AND NEARSHORE ECOSYSTEMS

Abstract

Wrack inputs can supply the bulk or sole source of primary production on some beaches and can provide an important potential food source and site for nutrient regeneration. In this chapter, the incorporation of wrack into beach and nearshore ecosystems was assessed via two pathways; decomposition and incorporation into trophic webs.

Wrack decomposition was assessed using litterbags containing wrack, which were deployed onto a beach and left *in situ* for up to 85 days. Decomposition was measured as mass loss and two experiments were conducted. In the first experiment, two mesh sizes were used for the litterbags (coarse mesh with holes 1.5 x 1.5 cm *vs.* fine mesh with holes 0.5 x 0.25mm, the latter to exclude macrofauna) and one algal (*Ecklonia radiata)* and one seagrass (*Posidonia sinuosa*) species were used. There was no difference in mass loss between the coarse and fine mesh litterbags but algal wrack appeared to lose a greater mass than seagrass wrack. Thus, in a second experiment, coarse mesh litterbags were used and two algal (*E. radiata* and *Sargassum* spp.) and two seagrass (*P. sinuosa* and *Posidonia coriacea*) species were used. In addition a subset of samples also analysed for elemental content (%C and %N) and stable isotope signatures ($\delta^{13}C$ and $\delta^{15}N$). In both studies, there was a rapid initial loss of mass followed by very slow or no further decomposition. The exception to this was the seagrass *P. coriacea*, which showed a slow but relatively steady loss of mass. The carbon content (%C) of the wrack did not differ over time, suggesting that most of the non-structural C had already been lost from the wrack prior to the start of the experiment. For %N the results were more variable among the species and over time, suggesting that the processes affecting %N differ among species and during decomposition (e.g. as microbial communities colonise and proliferate on the detritus). $\delta^{13}C$ did not change over time but $\delta^{15}N$ increased slightly suggesting that consumers may have colonised the wrack. Thus, rates of

decomposition and changes in elemental composition and isotopic signature may be taxon- (algae vs. seagrass) and species-specific, and vary depending on the structure and chemical composition of the material.

I used stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) to assess whether beach macrofauna or nearshore macro-invertebrates and fish might rely on wrack as a source of nutrition. I sampled a total of 15 beaches across 3 bio-geographical regions of South Australia (Metropolitan Adelaide, Fleurieu Peninsula and South East regions) in winter and summer of 2007. Wrack, beach macrofauna and nearshore invertebrates, fish and crabs were collected from each beach. Nearshore fish and macroinvertebrate communities differed between beaches, regions and visits, i.e. were variable in time and space. Seven species of fish were sampled using seine nets, which is similar to, or lower than, other studies. The amount of wrack on the beach and in the surf zone did not affect the abundance and species richness of fish and invertebrates. Stable isotopes indicated that seagrass wrack did not provide a food source for any of the consumers found in this study. Algae, particularly brown algae including kelps, appeared to be potential sources of nutrition for consumers such as amphipods and dipterans. Predation on these consumers by predators such as staphylinid beetles and nearshore fish and crabs may also facilitate the incorporation of organic matter into higher trophic levels. Wrack thus provides a pathway for the transfer of allochthonous organic matter and nutrients from offshore algal reefs into primary- and higher-level consumers in sandy beach and nearshore ecosystems.

Introduction

Wrack may provide the bulk or sole source of primary production inputs onto some sandy beaches (Alongi 1998) and each deposit is an important potential site for nutrient regeneration via its decomposition (Ochieng & Erftemeijer 1999). Decomposition is a combination of 3 major processes, fragmentation, leaching, and saprophytic decay (Robertson & Mann 1980; Harrison 1982; Boulton & Boon 1991). The rate at which these processes occur depends, among other factors, on the type of detritus (i.e. algal vs. seagrass material, and species identity) (Hansen 1984; Walker & McComb 1985; Mews *et al.* 2006), the initial condition of the detritus (Harrison & Mann 1975), meiofaunal activities (Rieper-Kirchner 1990), macrofaunal activities

(Robertson & Mann 1980; Jedrzejczak 2002b) and environmental conditions (Jedrzejczak 2002b). The processes, amount and rate of release of nutrients from decomposing wrack may be important to the associated bacterial, fungal and meiofaunal communities, as well as providing a source of nutrients to algae and seagrass growing offshore.

Decomposition is often described as occurring in three stages; 1) an initial, rapid stage of mass loss due to leaching of soluble compounds; 2) followed by a much slower stage of decomposition involving fragmentation and consumption by macrofauna (Robertson & Mann 1980; Griffiths & Stenton-Dozey 1981) and the degradation of lignin (Berg & Laskowski 2006); and 3) in the third stage, when detritus is nearly humus, the decomposition rate is nearly nil (Berg & Laskowski 2006). The first 2 stages of decomposition are important in the regeneration of nutrients, and are thus of interest in assessing the contribution of wrack into the beach ecosystem. During these stages, the amount (as %DW) of carbon can be expected to decrease until only structural C remains and the decomposition rate slows. The final amount and rate of loss of C varies among species and under different environmental conditions (Berg & Laskowski 2006). During decomposition, %N may show an initial, rapid decrease, corresponding to leaching of labile compounds (Hansen 1984; Berg & Laskowski 2006). In later stages of decay %N may increase due to the growth of microbes on the detritus (Harrison & Mann 1975; Thayer *et al.* 1977; Berg & Laskowski 2006). C:N may vary over time depending on the relative rates of loss for these elements. Results have differed among studies (Harrison & Mann 1975; Thayer *et al.* 1977; Machas *et al.* 2006), with either no change in C:N (Walker & McComb 1985; Machas *et al.* 2006) or decreases in C:N due decay of the detritus (i.e. loss of C) whilst at the same time microbes proliferate (i.e. an increase in N) (Harrison & Mann 1975; Thayer *et al.* 1977). Shifts in stable isotope ratios have been reported by some authors (Currin *et al.* 1995) but other studies have reported no change during decomposition (Machas *et al.* 2006). $\delta^{15}N$ is suggested to change, if it does, due to the uptake of environmental N by microbial communities (Currin *et al.* 1995). Conversely, $\delta^{13}C$ should remain similar even in the presence of microbes, although there may be a slight increase (+1‰) due to trophic fractionation.

Decomposition acts on the structure and chemical composition of detritus. Since algae and seagrasses are divergent in these respects, their decomposition rates and processes can also be expected to differ. Previous studies have shown that, in general, seagrasses take longer to decompose than algae. For example, Hansen (1984) found that leaves of the seagrass *Posidonia sinuosa* took 327 days to decompose compared to 101 days for the red alga *Pterocladia lucida* and 21 days for the kelp *Ecklonia radiata* under the same conditions. Differences between different algal and/or seagrass species have also been found i.e. within each type. For example, Ochieng and Erftemeijer (1999) found that 50% of the AFDW was lost after 42 days for the seagrass *Thalassodendron ciliatum*, compared to a loss of 50% DW after only 10 days for *Zostera marina* found by Jedrzejczak (2002a). Furthermore, McKechnie and Fairweather (2003) found that after 32 days (the duration of their study) only 4% of the initial DW had been lost from *Posidonia sinuosa* wrack (i.e. 96% remained), representing a very slow rate of decomposition. This comparison is provided as a guide only because comparisons across studies using different methods and under different environmental conditions are difficult and should be made cautiously. Rates of decomposition appear to be species-specific and also vary among locations and times.

Results of previous studies investigating the role of macrofauna in the decomposition of wrack have yielded conflicting results. Such studies are usually carried out using litterbags made from varying mesh sizes to allow or prevent access by macrofauna to different degrees. For example, Jedrzejczak (2002a) found that exclusion of macrofauna from litterbags containing seagrass wrack, *Zostera marina*, had no effect on the rate of mass loss. In contrast, Robertson and Mann (1980) suggested that activities of herbivorous macrofauna can assist in the initial fragmentation of seagrass wrack, leading to increased leaching and colonisation by meiofauna. In addition, Griffiths and Stenton-Dozey (1981) found that consumption of algal wrack, particularly kelp, by macrofauna constitutes a significant loss of mass and further evidence of this is provided by the large number of herbivorous macrofauna utilising wrack deposits (see Chapter 3 and references therein), including the wrack deposits on South Australian beaches.

The diversity and abundance of marine and terrestrial macrofauna, birds and fish that are associated with wrack deposits has been well documented (Griffiths & Stenton-Dozey 1981; Koop & Griffiths 1982; Lavoie 1985; Ochieng & Erftemeijer 1999; Dugan *et al.* 2003; Chapter 3 of this study). Wrack deposits provide food and shelter both on the beach and in the surf zone but, at present, the extent to which macrofaunal consumers and fish rely on wrack as a source of nutrition is largely unknown. Herbivorous or detritivorous macrofauna such as amphipods have the potential to consume large quantities of macrophyte detritus (Griffiths & Stenton-Dozey 1981). Higher-order consumers are often present in beach-cast wrack deposits, and may rely on the herbivorous fauna as a source of prey (Griffiths & Stenton-Dozey 1981; Jedrzejczak 2002c; Olabarria *et al.* 2007). Detached macrophytes in nearshore waters are known to play an important role as habitat for pelagic macroinvertebrates (e.g. the amphipod *Allorchestes compressa*, Lenanton *et al.* 1982) and fish (Kingsford & Choat 1985; Lenanton & Caputi 1989). They provide shelter from predators (predatory fish and birds) and food resources in the form of wrack (i.e. consumed directly). Surf-zone wrack deposits also provide food resources indirectly through the provision of prey (e.g. amphipods), which can make up a considerable portion of the diet of juvenile fish (Lenanton *et al.* 1982). The importance of beach-wrack-associated fauna to fish is, as yet, unclear. In their study on New England (USA) beaches, Behbehani and Croker (1982) did not find the dominant, beach-inhabiting amphipod *Orchestia platensis* in the gut contents of any of the fish found in that study. Observations of wrack deposits on the incoming tide suggest that at least some fauna are washed off the beach and may become prey for fish in the nearshore zone (Griffiths & Stenton-Dozey 1981, pers. obs.). Wrack may thus provide the basis of a complex trophic system, with potential pathways for the transfer of nutrients and energy into primary and secondary consumers, and further up the food chain.

Isotopes are different forms of a chemical element that vary in their mass. Stable isotope ratios are the ratio of the rare, heavy stable isotopes of carbon and nitrogen to their lighter, more common forms. Isotopic signatures often persist, with varying levels of enrichment, across different trophic levels and may be used to match organisms with their source of organic material and determine their trophic level (Peterson & Fry 1987). $\delta^{13}C$ is expected to be enriched by 0-1‰ per trophic step

(Davenport & Bax 2002) and hence the $\delta^{13}C$ of consumers reflects those of their diet (e.g. algae, seagrass, other sources). The $\delta^{15}N$ of consumers is enriched by 1-5‰ per trophic step (Davenport & Bax 2002) and is indicative of trophic level (e.g. primary consumer of wrack, predator). A mean value of 3.4 ‰ $\delta^{15}N$ per trophic step can be applied to aquatic food webs (Post 2002). Thus, by determining the stable isotope ratios of wrack components and the potential consumers (macrofauna and fish), it may be possible to identify any trophic pathways between wrack and invertebrates associated with beach-cast and surf-zone wrack accumulations.

The overall aim of this chapter was to seek indications of whether wrack is incorporated into beach and nearshore ecosystems through the constrasting pathways of decomposition versus incorporation into trophic webs. There were four components of the study; #1 and 2 relate to the decomposition of wrack and #3 and 4 relate to the incorporation into trophic webs via macrofaunal consumption of wrack: 1) determine the rate of decomposition (mass loss) of two algal species (*Ecklonia radiata* and *Sargassum* spp.) and two seagrass species (*Posidonia sinuosa* and *Posidonia coriacea*); 2) Determine if any changes in C and N contents or stable isotope signatures ($\delta^{13}C$ and $\delta^{15}N$) occur over time; 3) determine whether the abundance of invertebrates and fish in the nearshore zone differed between Regions, Beaches and/or Visits and if it was related to the amount of wrack in the surfzone; and 4) assess whether wrack is incorporated into beach and nearshore ecosystems via food webs using stable isotope signatures.

Litterbags were used to assess the rate of decomposition and changes in nutrient content and SI signature. Two studies were conducted. First, a study using litterbags constructed with fine versus coarse mesh, to prevent and allow macrofaunal access, respectively, was conducted using one algal (*E. radiata*) and one seagrass species (*P. sinuosa*). This study was conducted over a relatively short time period (43 days). I hypothesised that the rate of decomposition of wrack (as measured by mass loss) would be significantly different for algal *vs.* seagrass wrack and where macrofauna have access to wrack compared to where they are excluded. The second litterbag study used 2 algal (*E. radiata* and *Sargassum* spp.) and 2 seagrass (*P. sinuosa* and *P. coriacea*) species. Only coarse-mesh litterbags were used and it was carried out over 85 days. I predicted that: 1) total mass loss (i.e. cumulative mass loss) would increase

over time; 2) the rate of mass loss would decrease over time; and 3) the rate of mass loss would differ between algal and seagrass wrack. Given the conflicting reports, likely variation among species of seagrass and algae, the varying condition of the material used (i.e. wrack) and hence the processes it would undergo, I did not formulate specific hypotheses for elemental composition and stable isotopes. Instead, I tested the simple null hypotheses that %C, %N, C:N, $\delta^{13}C$ and $\delta^{15}N$ would remain the same over time.

The incorporation of wrack into beach and nearshore trophic webs was assessed using C and N stable isotopes. This section involves several components which are outlined in Figure 6.1. I attempted to identify links between beach wrack, macroinvertebrates associated with wrack on the beach, and fish and macroinvertebrates in the near-shore zone of sandy beaches along the metropolitan Adelaide coast, Fleurieu Peninsula and South East region of SA (Figure 6.2). I expected that fauna that rely directly or indirectly on wrack would have stable isotope signatures that reflected their trophic position and level of dependence on wrack. I expected that $\delta^{13}C$ would be enriched by 0-1‰ per trophic step and $\delta^{15}N$ would be enriched by 1-5‰ (Davenport and Bax 2002) or an average of 3.4‰ (Post 2002) per trophic step.

Methods

Litterbags

Study 1 Design

The main criteria for site selection were that the beach to be used would be reasonably isolated and have few or only a moderate number of visitors, have at least some wrack present at some time of the year (S. Duong, pers. obs.) and be located within reasonable proximity to Adelaide to access within one day. The site selected for the pilot study was Normanville on the Fleurieu Peninsula (Figure 6.2). Normanville is located approximately 75 km from the Adelaide central business district, and 30 km from the southern end of metropolitan Adelaide. The beach is 7.3 km long and is an intermediate beach type (Short 2006). The majority of visitors occur around the carpark, jetty and boat launching areas. A site was chosen

approximately 400m from these areas in a location that is generally frequented by walkers who remain in the low shore area (S. Duong, pers. obs.).

The study was carried out in November and December of 2006 at Normanville. The primary aim was to determine whether access by macrofauna affected the rate of decomposition and whether there were differences between algal and seagrass wrack. I also aimed to determine the appropriate time steps for retrieval of litterbags in a later study. The litterbags were deployed on the 28th of November and were retrieved 2, 4, 9, 20 and 43 days later. Two mesh sizes were used (coarse or fine) to allow or prevent macrofauna from entering the litterbags and one algal (*Ecklonia radiata*) and one seagrass (*Posidonia sinuosa*) species were used. Thus there were 4 treatments. Five litterbags per treatment were retrieved on each occasion except for on Day 9 when only 4 replicates of the fine-mesh seagrass litterbags were retrieved.

Study 2 Design

In February of 2007 another litterbag experiment was commenced in which 228 litterbags were deployed at Normanville. Unfortunately, vandals completely destroyed the experiment after the first retrieval (3 days after commencement) and the experiment was abandoned. Following the vandalism of that litterbag deployment at Normanville, a new study site was chosen in an attempt to minimise the likelihood of vandalism. This site was Beach 210, located approximately 7 km north of Normanville (Figure 6.2). This site differed in that it was a small beach, approximately 180 m long, and it is backed by steep cliffs and rocks. Access is difficult, along a narrow path on the cliff-side and over rocks at the base of the cliff. Access is possible only around quite low tides. These characteristics make the beach ideal as a secluded location but limited retrieval dates to those with suitable low tides and calm weather. Thus, the intended retrieval dates, which were intended to follow a logarithmic time scale, were changed sometimes to allow safe access to the beach.

Analysis of the data from the first litterbag study indicated that access by macrofauna had no significant effect on the rate of mass loss (see Results). Thus only one mesh size (coarse mesh with holes approximately 1.5 cm x 1.5 cm) was used in this second study and coarse mesh was chosen to simulate the most natural conditions possible,

i.e. to allow access by macrofauna and the most natural drying/wetting regime possible. There were differences between the algal and seagrass wrack but only one species of each was used in Study 1. Thus, to further investigate the differences between algal and seagrass wrack, I used 2 algal (*Sargassum* spp. and *Ecklonia radiata*) and 2 seagrass species (*Posidonia sinuosa* and *Posidonia coriacea*), all of which occur along the Adelaide metropolitan and Fleurieu Peninsula coasts. The algae and seagrass species chosen differ from each other in terms of morphology and structure. *Sargassum* and *E. radiata* differ in morphology because *E. radiata* is more leathery and has a lower surface area to volume ratio than *Sargassum*. *P. sinuosa* is thin and easily fragmented whereas *P. coriacea* is robust and wiry, and is often covered by epiphytic bryozoans (pers. obs.).

Litterbags were deployed on the 8th of March 2007 and were retrieved after 17, 27, 46 and 85 days. On each occasion 7 litterbags of each species were collected. This experiment was terminated prematurely and unexpectedly. In July of 2007 a severe storm occurred and caused massive erosion of beaches along all of the Adelaide metropolitan and Fleurieu Peninsula coasts. Following this storm, I returned to Beach 210 but the entire experiment had been washed away. Thus, the 2 additional collections which I had intended to make after approximately 130 and 200 days were not possible.

Litterbag preparation

Wrack was chosen as the material to be placed in litterbags. Previous studies have demonstrated that freshly abscised material from live plants decomposes and/or is consumed by macrofauna at a different rate than older material and/or wrack (Boulton & Boon 1991). All of the wrack used in each litterbag study was collected on the same day and all of the wrack for each species was collected at the same beach and from the same driftline. Thus, the age and condition of each species was more consistent for each study. Algal and seagrass wrack were collected from local (Adelaide metropolitan and Fleurieu Peninsula) beaches. Wrack was collected a maximum of 48 hours prior to deployment of litterbags. Wrack was collected by hand, transported to the laboratory and refrigerated, before being sorted to obtain monospecific wrack samples that were free from any anthropogenic debris, sand and

macrofauna. Coarse mesh litterbags of approximately 15 x 20 cm had holes large enough (approximately 1.5 cm x 1.5 cm) to allow access by most beach macrofauna. The fine mesh litterbags used in study 1 were designed to exclude beach macrofauna and were made from mesh with holes 0.5 x 0.25mm, and were approximately 15 x 30 cm. Litterbags were prepared by placing 20 ± 0.5g (Wet Weight) of a single species of algae or seagrass wrack into labelled litterbags. In the second study, an extra 32 litterbags were prepared and deployed, to allow for any loss of litterbags due to vandalism, erosion of the beach resulting in loss of equipment or failure to re-locate litterbags.

Deployment

Litterbags were positioned in a line parallel to the beach face, at a tidal height which would receive some tidal wetting but not be subjected to frequent harsh swash conditions. There was already a small amount of wrack present in the area where the litterbags were deployed. Anchors, consisting of a 30 x 30 cm ply-wood board were buried to a depth of at least 30 cm (McKechnie & Fairweather 2003). Each anchor had five ropes, approximately 80cm long attached, which were positioned so that they were exposed at the surface. Litterbags were haphazardly assigned to each anchor and rope position, and each litterbag was secured firmly to a single rope. The location of each litterbag was recorded to facilitate retrieval, and the litterbags were lightly covered with sand (to a depth of approximately 2 cm) to obscure them from the view of potential vandals. In the second study, any litterbags that were visible on the surface were similarly covered again on retrieval visits to prevent vandalism.

Retrieval

On each retrieval occasion, the litterbags to be collected were randomly selected from the pool of remaining litterbags. Litterbags were located (often involving digging up to 20cm deep to uncover them from the sand), placed into a plastic zip-lock bag and untied from the anchor. Any adhering sand and macrofauna were also collected and attempts were made to minimise loss of any wrack from the litterbag during collection. If any litterbag could not be located, a replacement litterbag containing the same species was haphazardly chosen and collected. Attempts were made to minimise disturbance to remaining litterbags. Because litterbags could not

be processed immediately, all litterbags (including on Day 0) were frozen on the day of collection so that decomposition was suspended at that time.

Processing

The contents of each litterbag was washed over a 500um sieve and the wrack (excluding any foreign wrack not of the original species) was blotted dry and weighed (WW). Any macrofauna were collected and identified to the lowest possible taxonomic unit. Wrack was dried to constant weight at 50ºC for approximately 48 hours and reweighed (DW). To estimate the initial (Day 0) DW of each litterbag, a WW to DW conversion factor was calculated for each species. Five replicate litterbags of each species were not deployed on day 0 (but were treated identically to all other litterbags). Litterbags were processed as above to determine both WW and DW. The conversion factor was then calculated such that = DW / WW and the initial DW was calculated such that Initial DW = Initial WW x conversion factor. The % WW lost and % DW lost were calculated for each litterbag such that % loss = [(Initial – Final) / Initial] * 100. Material was weighed on scales accurate to 3 decimal places.

For the second study, C and N content and stable isotope signatures were determined for each species on day 0 (i.e. initial) and for material retrieved on collections 2 (Day 27) and 4 (Day 85). For each species on each occasion, three replicates were chosen at random. Dried material was ground to a fine powder using a mortar and pestle.

C and N content (%) of samples was determined on a LECO Truspec C/N analyser with autosampler. For C analysis, EDTA was used as the calibration standard and Glycine was used as a quality control. For N analysis, Acetalinide was used as the calibration standard and EDTA was used as a quality control. Instrument error was 0-1% for C and 2-3% for N. %C, %N and C:N ratios were used for statistical analyses.

Stable isotope analysis was carried out in the Flinders Advanced Analytical Laboratory in Adelaide, South Australia using an Isoprime Isotope Ratio Mass Spectrometer (GV Instruments, Manchester, UK) and an elemental analyser (EuroVector, Milan, Italy). In-house standards, dummy samples, sample repeats and

blanks were implemented by laboratory staff during analysis to ensure quality control of the analysis. Stable isotope ratios of δ13C/δ12C and δ15N/δ14N are expressed as the relative per mil (‰) difference between the sample and conventional standards (PeeDee Belemnite carbonate and atmospheric nitrogen, respectively) given by the formula:

$$\delta X = (Rsample / Rstandard - 1) \times 1000 (‰)$$

where X = ^{13}C or ^{15}N and R = $\delta^{13}C / \delta^{12}C$ or $\delta^{15}N / \delta^{14}N$ (Peterson & Fry 1987). Instrumental precision was on average 0.03‰ for both $\delta^{13}C$ and $\delta^{15}N$.

In both studies I also collected the fauna from each litterbag. Due to the low number of individuals (between 0 and 5 individuals per litterbag) and large number of zeros, I did not use these data further.

Statistical analyses

Litterbags Study 1

A 3-way Analysis of Variance (ANOVA) was used to assess differences in mass loss between Mesh size, Wrack types and Time. Mesh size (fine vs. coarse) and Wrack type (algal vs. seagrass) were fixed factors with 2 levels each. The factor Time was random with 6 levels (Days 0, 2, 4, 9, 23 and 43).

Litterbags Study 2

A 3-way Analysis of Variance (ANOVA) was used to assess differences in mass loss between Wrack types, Species and Time. Wrack type (algal vs. seagrass) was a fixed factor with 2 levels. The factor Species was nested within Wrack type and there were 2 Species per Wrack type. Species and Time (Days 0, 17, 27, 46 and 85) were random factors with 2 and 5 levels, respectively. For C and N content, C:N ratios and stable isotopes of C and N ($\delta^{13}C$ and $\delta^{15}N$), 3-way ANOVAs were also carried out using the same model but Time had only 3 levels (Day 0, 27 and 85).

For both litterbags studies, analyses were run on the %DW remaining. Post-hoc tests for significant effects involving the factor Time (as a main effect or interactions) were not carried out because Time was a random factor (Underwood 1997). Assumptions of ANOVA were checked by visual examination of plots and the data

were transformed to normalise distributions and homogenise variance where appropriate. Data presented are mean ± se. Analyses were carried out using SYSTAT v11.

In both litterbags studies, mass loss did not appear to follow any single curve but appeared to occur in 2 stages. Two-stage linear regressions were thus performed on the % initial DW remaining for two time periods: day 0 to the first collection and from the first collection until the end of the study.

Trophic webs: Wrack, macroinvertebrates and fish

Sampling was conducted in three regions of South Australia; metropolitan Adelaide, Fleurieu Peninsula and in the South East. Sampling was carried out in winter (July in the SE, and August in the metropolitan and Fleurieu regions) and summer (December) of 2007. Five beaches were sampled in each region (Figure 6.2). The beaches were chosen to include a variety of wrack types and covers (Chapter 2, pers. obs.). The beaches were also selected so that seine netting could be safely carried out by two people hauling the net in knee-deep water.

Field methods

Macroinvertebrates and fish were collected from the surfzone by seine netting. The net was 5 m long, 2 m tall and had a stretched mesh size of 1 cm. The area of water seined was thus 79 m^2 per haul and the maximum volume of water that could be seined was 157m^3. Seine netting was carried out in water approximately 40 cm deep and thus the actual volume of water seined was approximately only 31m^3. These areas and volumes are overestimates of the area/volume seined because individuals can escape from the edges of the seine net. Five hauls were made at each beach on each occasion. The invertebrates and fish retained were placed into aerated buckets of water, identified (Hutchins & Swainston 1986; Kuiter 1996) and counted. For each beach and occasion, a maximum of 2 individuals of each species of fish were sacrificed (as per animal ethics permission) for stable isotope analysis. Fish were euthanased by placing them in a lethal dose of anaesthetic, i.e. 250mg/L solution of benzocaine hydrochloride and seawater (Beaver *et al.* 2000; Nickum *et al.* 2004).

Any wrack retained in the net was also weighed (WW). At some beaches, a subsample of wrack from the seine net was also retained for stable isotope analysis.

Stranded wrack and beach macroinvertebrates were collected haphazardly from the beach adjacent to the location where seine netting was carried out. Wrack was collected by hand and placed into zip-lock bags. Macrofauna were collected from wrack accumulations and underlying sands. Wrack and sands were sieved over 500um mesh and the contents of the sieve were returned to the laboratory for sorting. Sampling was not carried out quantitatively due to the paucity and patchiness of fauna on the beaches (pers. obs.) and the amount of sand/wrack sieved was judged according to the quantity of visible fauna to yield enough animals to be processed for analysis. Approximately 5-10kg of sand/wrack was sieved on each beach on each occasion.

Laboratory methods

Wrack collected from the beach and from the seine net was rinsed to remove sand and any macrofauna, and sorted by species. The five most abundant species (by volume) from the beach and seine net were used for stable isotope analysis. On some occasions only one or two species of algae or seagrass were present in the wrack deposit and thus fewer species were sampled. The macrofauna retained on the sieve were sorted and only those species for which sufficient material could be obtained (depending on biomass and the number of individuals) were retained and identified. For small macrofauna, up to 300 individuals were pooled to obtain sufficient material for analysis.

Due to their small size, macrofauna from the same site and sampling date were pooled for stable isotope analysis. Fish samples consisted of white muscle tissue from individual fish. Crabs were dissected and only white flesh was analysed. Small invertebrates (e.g. amphipods, isopods and beetles) were processed whole. All tissues (wrack, invertebrates and fish) were frozen for preservation as this method does not interfere with stable isotope ratios (Bosley & Wainwright 1999). Tissues were defrosted, rinsed and blotted dry. Samples were then dried at 50ºC for 48 hours and ground to a fine powder using a mortar and pestle. Tissues suspected of containing

carbonate (i.e. fish, isopods and amphipods) were acid treated by drop-wise addition of 1M HCl until no visible CO_2 was released (Jacob *et al.* 2005). Acid-treated samples were then re-dried at 50ºC for 48 hours without rinsing (Jacob *et al.* 2005). Samples were analysed for $\delta^{13}C$ and $\delta^{15}N$ as described above.

Data analysis

Three-way ANOVA was used to assess differences in the abundance and species richness of invertebrates and fish captured in seine net hauls. The factors were Visit, Region and Beach (nested within Region). Region was a fixed factor with 3 levels (SE, Fleurieu and Metro). Visit and Beach were both random factors with 2 and 5 levels, respectively. ANCOVA was also used to assess whether the abundance and species richness were related to the amount of wrack present. The wet mass of wrack in each seine net haul was used as the covariate. Since the *F*-ratio for Region could not be calculated in the 3-way ANOVA, a two-way ANOVA for Visit and Region was also performed to assess any differences in abundance or species richness among Regions.

For each visit to a beach, the 5 seine net hauls were pooled to determine the total abundance and species richness of fish and invertebrates. The % wrack cover on the beach (estimated from photopoints) and the total mass of wrack in the 5 seine net hauls were also obtained. A linear regression between wrack cover and wrack mass was performed to determine whether these two measures of the amount of wrack present were related. Wrack cover and mass were then used as predictor variables in linear regressions with the abundance and species richness of fish and invertebrates. Wrack cover and mass and abundance were 4^{th} root-transformed (due to the large number of zeros in the data set) and species richness was √-transformed and $n = 30$ for each regression. For each of these relationships data were analysed with both Visits together ($n = 30$) and for summer and winter separately ($n = 15$).

Multivariate analyses were conducted in PRIMER v. 5 (Clarke & Warwick 1994) and analyses were run on Bray-Curtis similarities using standardised, log (x+1)-transformed data. A MDS ordination plot was produced. Two, separate 2-way crossed ANOSIMs were performed for the Factors Region x Visit or Beach x Visit.

The BIOENV routine in PRIMER was also used to match patterns among the fish and invertebrate data to environmental data; in this case only 2 variables were available, the % wrack cover on the beach and the mass of wrack caught in the seine net.

Because these data consititute a first examination of this issue for these sites, the analysis of stable isotopes data presented here will be preliminary and simplified to explore patterns in the data.

Plots of $\delta^{13}C$ vs. $\delta^{15}N$ were produced with bi-directional error bars (± se) using SigmaPlot v.10. The plots were visually inspected to attempt to identify patterns among taxonomic groups of primary producers (i.e. wrack) and consumers, and to assess any potential tracking of the wrack's stable isotopes signature by consumers. SYSTAT v.11 was used to plot $\delta^{13}C$ vs. $\delta^{15}N$ with confidence ellipses plotted for each primary producer and consumer group. Confidence ellipses were centered on the sample means (centroids) and had a confidence probability of 0.6827.

$\delta^{15}N$ can be used as an indicator of trophic level with consumers having more enriched $\delta^{15}N$ than their food sources. To determine whether there were any relationships between the size of fish and their trophic level, fish size and $\delta^{15}N$ were regressed. Two measures of fish size were used; fork length (mm) and wet weight of whole fish (g).

Results

Litterbags

Study 1

Mass loss followed similar patterns for coarse and fine mesh litterbags, and for algal and seagrass wrack, although seagrass wrack lost less mass in total than algal wrack (Figure 6.3). In each treatment, there was a rapid decrease in mass from the initial 100% on Day 0 to the first collection on day 2 (Figure 6.3). Following this, there was little change in mass until around day 43 when there was some divergence between seagrass and algal wrack, with algal wrack showing a slight increase in mass loss

(Figure 6.3). By Day 2, mean mass loss was 70 % (± 1). Mean mass loss was very similar between fine and coarse mesh bags (69 ± 1 % vs. 70 ± 1 %). Algal wrack lost more mass than seagrass wrack with mean mass loss of 78 % (± 1) and 61% (± 1), respectively. At the end of the experiment (43 days after litterbags were deployed), litterbags had lost an average of 73 % (± 3) of their original mass. This was the largest mean mass loss of any collection. Algal wrack litterbags had lost an average of 84 % (± 1) DW, whilst seagrass wrack litterbags has lost an average of 62 % (± 2) of the initial DW (Figure 6.3). The first stage of mass loss was quite rapid compared to the mass loss that occurred after Day 2. For algal wrack, the slope of the linear regressions was -163 %DWlogday^{-1} for day 0 to 2 but only -4 %DWlogday^{-1} for days 2 to 43. For seagrass wrack, slope of the linear regressions was -130 %DWlogday^{-1} for day 0 to 2 but only -1 %DWlogday^{-1} for days 2 to 43, although in the latter stages of the experiment the fine- and coarse-mesh litterbags appeared to diverge, and thus the regression was not significant (Figure 6.3).

The 3-way ANOVA for Mesh size, Wrack type and Time indicated that there were significant differences in the % DW remaining due to the interactions of Wrack type and Time, and due to the interaction of Mesh size and Time (Table 6.1). The main effects of Time and Wrack type were also significant (Table 6.1) but these significant effects were subsumed by the significant 2-way interactions. The main effect of Mesh size was not significant, nor was the 3-way interaction of Mesh size, Wrack type and Time (Table 6.1).

Study 2

Over the course of the experiment, some bags gained weight (up to 14 % of the initial DW) but this may be due to inaccuracy in the estimation of the initial DW (see Methods). Only litterbags containing *P. coriacea* gained weight. The pattern of mass loss was very similar between the two algal species, *E. radiata* and *Sarsassum* spp. (Figure 6.4). Mean mass loss was 62 % (± 2) for *E. radiata* and 59 % (± 1) for *Sarsassum* spp.. The two seagrass species showed very different decay patterns (Figure 6.4). *P. sinuosa* followed a similar pattern to the algal species, losing an average of 54 % (± 1) of the initial DW but *P. coriacea* lost very little mass during

the 85 days (only 14 ± 3 %) (Figure 6.4). The pattern of mass loss for *Sargassum* spp., *E. radiata* and *P. sinuosa* included a rapid loss of mass from day 0 to the first collection on day 17, followed by little or no mass loss until day 85 (Figure 6.4). *E. radiata* showed a slightly greater rate of mass loss from day 46 to day 85 (Figure 6.4). For *P. coriacea*, from day 0 to day 27 there was very little mass loss, with bags remaining near 100% of the initial mass. Following this, there was a slight decrease in mass until day 85 when the experiment finished (Figure 6.4). At the end of the experiment (85 days after litterbags were deployed), all litterbags had lost an average of 52 % (± 4) of their original mass. This was the largest mean mass loss of any collection. At the final collection, the brown alga *E. radiata* had lost the most DW (73 ± 2 %), followed by the other alga *Sargassum* spp. (62 ± 1 %) and the seagrass *P. sinuosa* (58 ± 1 %). *P. coriacea* lost the least DW (14 ± 3 %) after 85 days (Figure 6.4).

For the two algal species (*E. radiata* and *Sargassum* spp.) and the seagrass *P. sinuosa*, which showed similar patterns of mass loss, 2-stage linear regressions were performed. The first, from day 0 to the first collection on day 17, showed a faster rate of mass loss (slope of the regression = -3.3 %DWday^{-1}) compared with the second stage of mass loss from day 17 to the end of the experiment on day 85 (slope of the regression = -0.1 %DWday^{-1}). For *P. coriacea*, mass loss appeared to be in two different stages: no loss from day 0 to the second collection on day 27 and then slight loss at the rate of -0.259 %DWday^{-1} from day 27 to the final collection on day 85.

There was a significant difference in the % DW remaining due to the interaction of Species (nested within Wrack type) x Time (Table 6.2). The main effects of Wrack type, Species (nested within Wrack type) and Time were also all significant (Table 6.2) but the latter two were subsumed by the significant interaction. The main effect of Wrack type was that algae exceeded seagrass for % loss.

Carbon content (%C) for wrack samples ranged between 28 and 41% DW (Figure 6.5a) and the overall mean %C was 36% (± 0.4). Mean %C of algal wrack was slightly higher than for seagrass wrack (37 ± 0.7% vs. 35 ± 0.3 %) but there was also variation among the algal and seagrass species. %C was relatively stable over time for all species except for *E. radiata*, which showed a marked decrease between Day

27 and Day 85 (Figure 6.5a). In the 3-way ANOVA for Wrack type, Species (nested within Wrack type) and Time for %C there was only one significant effect; %C differed among the 4 species (Table 6.3). The main effect of Time and the interactions involving Time were not significant, indicating that there was no change in %C of wrack during the experiment.

Nitrogen content (%N) ranged between 0.5 and 1.1% DW (Figure 6.5b) with an overall mean of 0.8% (± 0.03). As for %C, mean %N was higher in algal wrack than seagrass (0.86 ± 0.04% vs. 0.70 ± 0.02 %) and there was variation between the algal and seagrass species (Figure 6.5b). %N was variable in Time but patterns differed both between Wrack types and among the 4 species (Figure 6.5b) (i.e. there did not appear to be a common pattern for either algal or seagrass wrack). This result is supported by the 3-way ANOVA. There was a significant interaction of Species (nested in Wrack type) x Time ($p < 0.05$) for the %N (Table 6.3). This was the only significant effect in this ANOVA.

The mean C:N ratio for all samples was 48:1 (± 2) and varied between 30:1 and 69:1 (Figure 6.5c). Seagrass wrack had a higher mean C:N than algae (51:1 ± 2 vs. 45:1 ± 3 for seagrass and algal wrack, respectively). The 2 seagrass species had very similar C:N ratios (*P. sinuosa*: 51:1 ± 2 vs. *P. coriacea*: 50:1 ± 2) but the 2 algal species were quite different in mean C:N (*E. radiata*: 39:1 ± 3 vs. *Sargassum* spp.: 52 ± 4). Over the 3 collections, mean C:N did not appear to differ greatly (Day 0: 48:1 ± 3; Day 27: 49:1 ± 2; and Day 85: 47:1 ± 4; Figure 6.5c). On the last collection (Day 85), the C:N ratio for the alga *E. radiata* dropped to be lower than any of the other species (Figure 6.5c). The 3-way ANOVA indicated that there were no significant differences in C:N ratio between Wrack types, Species (nested within Wrack type) or Times, or their interactions (Table 6.3).

$\delta^{13}C$ values ranged between -21.3 and -8.4 ‰ (Figure 6.6a). Seagrasses (*P. sinuosa* and *P. coriacea*) were more enriched in $\delta^{13}C$ than algae (*E. radiata* and *Sargassum* spp.), with mean $\delta^{13}C$ values of -9.5‰ (± 0.2) and -18.2‰ (± 0.8) for seagrass and algae, respectively. Thus there was an obvious separation of algal and seagrass species based on $\delta^{13}C$ (Figure 6.6a). $\delta^{15}N$ values ranged between -5.2 and +5.5 ‰ (Figure 6.6b). $\delta^{15}N$ for algae spanned the entire range of values but the range was

smaller for seagrass (+0.5 to +4.8 ‰). Mean $\delta^{15}N$ was slightly higher for seagrass than for algae (+2.6 ± 0.4 ‰ vs. +1.2 ± 0.8 ‰).

There was also a slight difference in $\delta^{13}C$ between species within algae or seagrass (Figure 6.6a). For algae, *Sargassum* spp. was slightly more enriched than *E. radiata* (-16.5 ± 0.3 ‰ vs. -19.9 ± 0.4 ‰) and, for seagrass, *P. coriacea* was slightly more enriched than *P. sinuosa* (-8.7 ± 0.1 ‰ vs. -10.3 ± 0.1 ‰) (Figure 6.6a). Differences between species were more pronounced for $\delta^{15}N$. *E. radiata* was more enriched than *Sargassum* spp. (+4.3 ± 0.2 ‰ vs. -2.0 ± 0.7 ‰) and *P. sinuosa* was more enriched than *P. coriacea* (+4.0 ± 0.2 ‰ vs. +1.2 ± 0.1 ‰) (Figure 6.6b). $\delta^{13}C$ did not appear to differ over time but mean $\delta^{15}N$ increased slightly from +1.5 ‰ (± 0.8) on Day 0 to +1.6 ‰ (± 0.8) after 27 days and 2.5 ‰ (± 0.8) after 85 days (Figure 6.6).

The 3-way ANOVA for the factors of Wrack type, Species (nested within Wrack type) and Time indicated that there were significant differences in both $\delta^{13}C$ and $\delta^{15}N$ between Species (nested within Wrack type) (Table 6.4). For $\delta^{15}N$ there was also a significant difference due to the factor Time (Table 6.4) with a slight increase occurring after 85 days.

Trophic webs: Wrack, macroinvertebrates and fish

Nearshore macroinvertebrates and fish

A total of 385 macroinvertebrates and fish were collected in the 150 seine net hauls. Of the 150 hauls made, only 64 (43%) contained at least one individual. Seven species of fish and three of macroinvertebrates, including 2 crab species and 1 isopod, were collected (Table 6.5). Each haul had between 0 and 44 individuals and up to 5 species. Mean abundance was only 2.6 (± 0.5) individuals per haul and mean species richness was 0.7 (±0.1) species per haul. The most abundant fish species was the smooth toadfish, *Tetractenos glaber*, with 90 individuals captured and the isopod *Paridotea ungulata* was the most abundant invertebrate, with 79 individuals (Table 6.5).

The species richness was higher in summer than in winter (0.8 ± 0.1 species per haul vs. 0.6 ± 0.1 species, respectively) and overall twice as many individuals were caught

in summer compared with the winter sampling (3.4 ± 0.9 individuals per haul vs. 1.7 ± 0.5 individuals, respectively) (Table 6.5, Figure 6.7). The SE region had the highest mean abundance (3.7 ± 1.3 individuals per haul) but the Fleurieu and Metro regions had the higher mean species richnesses (0.8 ± 0.1 species per haul in both regions). In the SE region, there was a large variation in the number of individuals captured between visits; only 4 individuals (the lowest number for any sampling event) were caught in winter but 180 individuals were caught in summer (the highest number for any sampling event) (Table 6.5).

The mass of wrack in each seine haul ranged greatly from no wrack to 14.7 kg WW of wrack in a single haul. The mean mass of wrack per haul was 0.8 (± 0.2) kg WW. Seine hauls in winter had more wrack, on average, than hauls made in summer (1.5 ± 0.3 kg vs. 0.2 ± 0.03 kg, respectively). The amount of wrack in each seine haul differed slightly between Regions (SE: 1.1 ± 0.4 kg, Fleurieu: 0.7 ± 0.3 kg and Metro: 0.6 ± 0.2 kg) but the variance (se) was quite large.

The 3-way ANOVA for Visit, Region and Beach (nested in Region) yielded significant results for the interaction of Visit x Beach (Region) for both abundance and species richness ($p < 0.001$ for both analyses, Table 6.6a). Inclusion of the covariate, the mass of wrack in each seine net haul (4^{th} root-transformed), did not change the results of the analyses and the covariate was not significant for either abundance ($p = 0.115$) or species richness ($p = 0.064$). The 2-way ANOVA for Visit and Region (which was used to assess any differences among Regions) indicated that for both abundance and species richness, the interaction of Visit and Region was significant (Table 6.6b). The main effect of Visit was also significant but there was no significant effect of Region (Table 6.6b). The inclusion of the covariate (the mass of wrack in each seine net haul (4^{th} root-transformed), did not change the results of the analyses and the covariate was not significant for either abundance or species richness.

Mean % wrack cover was 18% (± 4) for the 15 beaches sampled on 2 visits and the mean mass of wrack collected in the 5 seine net hauls was 4.1kg (± 1.5). There was no significant relationship between the cover of wrack on the beach and the mass of wrack caught in the seine net (Pearson $r = 0.317$, $p = 0.087$, $n = 30$, Figure 6.8) for

both Visits together. The linear regressions for summer and winter separately were also non-significant (Figure 6.8). There were no relationships between the cover of wrack on the beach and the abundance or species richness of fish and macroinvertebrates in the nearshore zone, nor was there any relationship between the mass of wrack caught in the seine net and the abundance or species richness (Figure 6.9). There was one exception to this; in summer, the mass of wrack caught in the seine net and the species richness of fish and macroinvertebrates was significantly and positively related.

The two-way crossed ANOSIM indicated that nearshore fish and invertebrate communities differed between Visits (Global $R = 0.153$, $p = 0.006$) and among Regions (Global $R = 0.333$, $p = 0.001$, Figure 6.10). Pairwise ANOSIM tests indicated that there were differences between each pair of Regions ($p = 0.001$ for each test) with the Fleurieu and Metro Regions being most dissimilar ($R = 0.330$), followed by the Fleurieu and SE Regions ($R = 0.296$) and Metro and SE Region ($R = 0.295$). There were also differences due to the interaction of Visits and Beaches (Global $R = 0.386$, $p = 0.001$, Figure 6.10) but due to the low number of samples, power was weak, so pairwise comparisons are not discussed here. Two species of fish were identified by SIMPER analysis as consistent indicators (i.e. Sim/SD > 1, Clarke & Warwick 1994) of Region with higher abundances of the goby *F. lateralis* in the Fleurieu Region than in either the Metro or SE and higher abundances of the smooth toadfish *T. glaber* in the Metro Region than in the Fleurieu or SE. For Visit, SIMPER indicated that more individuals of *F. lateralis* were caught in winter compared with summer. The BIOENV routine did not find a strong relationship between the patterns in the fish/macroinvertebrate community and the environmental (wrack) data. Each of the measures of the amount of wrack (% cover and mass) and both variables together yielded the same results; ρ_w was -0.009 and thus there was a very poor match between the data sets (Clarke & Warwick 1994).

Stable isotopes

A total of 246 samples including primary producers (marine algal and seagrass wrack from the beach and drifting in the nearshore waters), beach invertebrates (amphipods, beetles and flies), nearshore invertebrates (amphipods, isopods and crabs) and

nearshore fish were collected (Table 6.7, Figure 6.11). $\delta^{13}C$ values ranged between -35.5 and -7.7‰ and $\delta^{15}N$ values ranged between -2.8 and +17.1‰ (Table 6.7, Figure 6.11).

Despite the small number of samples taken for these taxa, $\delta^{13}C$ of red and green algae ranged greatly (ranges = 18.5 and 18.2 ‰, respectively) (Table 6.7). Some species of red algae (e.g. *Phacelocarpus perperocarpus*) were particularly depleted in $\delta^{13}C$ (Table 6.7). Brown algae had $\delta^{13}C$ values between -25.9 and -15.3 ‰ and kelps fell within this range (-22.9 to -12.1 ‰). $\delta^{13}C$ values of seagrasses were the highest for any taxonomic group (-11.0 ± 0.3 ‰, range = -16.1 to -7.7) (Table 6.7). The $\delta^{13}C$ of the seagrasses thus showed very little overlap with the other primary producers, particularly the red and brown algae (Figure 6.11). Several species of algae had large ranges in $\delta^{13}C$ values (e.g. *Macrocystis angustifolia* 8.8‰, *Cystophora* spp. 7.2‰ and *Acrocarpia* spp. 7.0‰) (e.g. see *Cystophora* spp. in Figure 6.12a).

$\delta^{13}C$ values of consumers ranged between -26.5 and -11.4 ‰ (Table 6.7). This was the range of values seen for the beach invertebrates, and the fish, crabs and nearshore invertebrates also fell within this range. Fish and crabs had similar values for $\delta^{13}C$ (-24.0 to -14.5 ‰ and -23.5 to -14.5 ‰, respectively). For individual species, $\delta^{13}C$ had a large range for the crab *Ovalipes australiensis* and the fish species *Leptatherina presbyeroides* and *Aldrichetta forsteri* (ranges = 9.0, 8.3 and 8.0 ‰, respectively, Table 6.7).

$\delta^{15}N$ values for primary producers (i.e. brown algae excluding kelps, kelps, green algae, red algae and seagrasses) ranged between -1.8 and +16.5 ‰ over the 123 samples (Table 6.7). The range in $\delta^{15}N$ was reasonably large for each taxonomic group, except the kelps which included only 2 species (Table 6.7). The brown algae (excluding kelps) contributed 56 samples and this group had the lowest mean $\delta^{15}N$ value (+3.7 ± 0.3 ‰) but the largest range of $\delta^{15}N$ (11.2 ‰). Kelps, red algae and green algae contributed fewer samples (16, 9 and 5 samples, respectively). Green algae had the highest $\delta^{15}N$ value (+9.5 ± 2.3 ‰), a result which is likely driven by the enriched $\delta^{15}N$ values for the green alga *Ulva lactuca* (+15.1 ± 1.4 ‰). Seagrass had an intermediate mean $\delta^{15}N$ (+5.3 ± 0.4 ‰). In cases where algae were processed

as genera including multiple species, the range of $\delta^{15}N$ was larger (Table 6.7, e.g. see *Cystophora* spp., *Sargassum* spp. and *Gracilaria* spp.), suggesting species-specfifc variation. Seagrass species also had large ranges of $\delta^{15}N$ (Table 6.7), although these were processed as individual species.

Mean $\delta^{15}N$ was highest in the predatory beach invertebrates but this group consisted of only one species, a staphylinid beetle (+11.4 ± 0.3 ‰) (Table 6.7). Crabs (+10.9 ± 0.3 ‰) and fish (+10.2 ± 0.3 ‰) also had high $\delta^{15}N$ values but the range for each of these taxonomic groups was large (Table 6.7). Invertebrates from the beach were less enriched in $\delta^{15}N$ (+6.0 ± 0.8 ‰), with values more similar to wrack, and had the greatest range in $\delta^{15}N$ values (15.2 ‰). The fish *Leptatherina presbyeroides* had the highest $\delta^{15}N$ (13.3 ± 0.7 ‰), with other species of fish also being quite enriched (Table 6.7). The goby *Favonigobius lateralis* had the lowest mean $\delta^{15}N$ (+8.7 ± 0.4 ‰) of any fish species and had the largest range in $\delta^{15}N$ values of any fish (7.5 ‰ for the 25 specimens) (Figure 6.12b). The single specimen of *Portunus pelagicus* also had a high $\delta^{15}N$ (+13.3 ‰).

Considering $\delta^{13}C$ and $\delta^{15}N$ at the same time, red and green algae did not show any distinctive signatures compared with other primary producers (Figure 6.11). Brown algae were plotted in a reasonably distinct group with kelps falling in the upper range of $\delta^{15}N$ values found for brown algae (Figure 6.11). Seagrasses had quite distinct stable isotope signatures with separation due to the more enriched $\delta^{13}C$ value (Figure 6.11). Beach invertebrates had a wide range of $\delta^{13}C$ and $\delta^{15}N$, i.e. apparently they had a range of sources of nutrition and trophic levels. Fish, crabs and staphylinid beetles showed considerable overlap in both $\delta^{13}C$ and $\delta^{15}N$ (Figure 6.11). Neither $\delta^{13}C$ or $\delta^{15}N$ appeared to differ systematically between visits, beaches or regions for individual species or taxonomic groups. For example, $\delta^{13}C$ and $\delta^{15}N$ did not show any trend due to Region for the brown alga *Cystophora* spp. and the fish *F. lateralis* (Figure 6.12). For each species of wrack (algae or seagrass) or consumer that had at least 10 samples analysed for its stable isotope signature (Table 6.7), a plot of $\delta^{13}C$ vs. $\delta^{15}N$ was produced similar to Figure 6.12. Each species showed variation in both isotopes but there were no trends by Visit or Region.

Due to the large range in $\delta^{15}N$ for both primary producers and consumers, it is difficult to assign trophic levels. Working on a mean enrichment in $\delta^{15}N$ of 3.4 ‰ per trophic level (Post 2002), fish and crabs appeared to be between 1 to 3 trophic levels higher than primary producers. Predatory beach invertebrates were 1 to 2 trophic levels higher than primary producers (Figure 6.11). The beach invertebrates group spanned 15.2 ‰ for $\delta^{15}N$ and thus may represent several trophic levels, including detritivores and/or herbivores and predators. Nearshore invertebrates were less enriched in $\delta^{15}N$ than crabs, fish and predatory invertebrates and, based on comparison with the available sources, are likely to be one trophic level higher than primary producers (Figure 6.11).

As an example, Figure 6.13a shows the data obtained from a visit to a single beach (Seacliff, in August). Seagrasses did not appear to be potential sources of nutrition but brown algae were possible food sources. Fish and crabs were more enriched in $\delta^{15}N$ than brown algae, approximately 2 to 3 trophic levels (7 to 10 ‰). A second example, from Nora Creina in December (Figure 6.13b) shows that fish, crabs and predatory beach invertebrates (staphylinoid beetles) were the most enriched in $\delta^{15}N$. Sources of nutrition for beach and seine invertebrates are not apparent but both of these taxa, as well as brown algae, appeared to be potential sources of nutrition for the fish, crabs and predatory beach invertebrates. Kelps did not appear to be a source of food for any consumers.

Fish ranged in size from 19 to 96 mm fork length (mean 55 ± 2 mm) and from 0.3 g to 13g WW (mean 2.8 ± 0.3 g) (Figure 6.14). There were no significant relationships between the size of fish (wet weight or fork length) and their trophic level (as indicated by $\delta^{15}N$) (Figure 6.14). For the goby *F. lateralis,* fork length ranged between 36 and 75 mm and wet weight ranged between 0.4 and 2.1 g (Figure 6.15). There were likewise no significant relationships between the size of fish (as either wet weight or fork length) and their trophic level (Figure 6.15).

Discussion

In both litterbags studies, there was a rapid initial loss of mass (DW) followed by very slow or no further decomposition. Rapid mass loss occurred before the first collection in both studies. In the first study, this was during the first 2 days. In Study 2, however, the first collection occurred on day 17 and thus it is difficult to determine whether the initial loss was as rapid (i.e. occurred over a few days as in Study 1) or occurred more gradually. The exception to the pattern of rapid initial mass loss was the seagrass *P. coriacea*. *P. coriacea* showed a slow but relatively steady loss of mass over the 85 days of the study but did not demonstrate the same initial rapid loss of mass as the other species of seagrass (*P. sinuosa*) and the algae (*E. radiata* and *Sargassum* spp.) studied. The slower loss of mass by *P. coriacea* may due to the relatively greater amount of structural components (e.g. lignin and cellulose) in *P. coriacea* compared to the other species (Gobert *et al.* 2006). Furthermore, the *P. coriacea* wrack was covered in a uniform cover of epiphytic bryozoans, which may prevent its decomposition by protecting the leaves from wetting and drying and thus reduce cell lysis and leaching (Harrison & Mann 1975).

In the first study, algal wrack lost significantly more mass than seagrass wrack, and in the second study there were differences between individual species of seagrass. Thus, rates of decomposition may be taxon- (algae vs. seagrass) and species-specific, and vary depending on the structure and chemical composition of the material. Although the first study was run over a shorter time period than the second study (43 vs. 85 days for Studies 1 and 2, respectively), the wrack in the first study reached a lower relative mass than in the second study. This suggests that decomposition rates also vary due to other factors such as differences in weather (i.e. seasonal differences, in this case summer versus autumn-winter), wetting/drying by tides, or the initial state of the wrack (since I use wrack and not freshly abscised leaves, this may have varied between studies) (Boulton & Boon 1991). Mass loss due to consumption by macrofauna appeared to be minimal. There was no significant difference in mass loss between coarse (macrofaunal access allowed) and fine (most macrofauna excluded) mesh litterbags in the first study. There were also very few macrofauna found in litter bags in both studies regardless of mesh size.

The rapid initial mass loss is most likely due to cell lysis (through wetting and then drying) and leaching (Boulton & Boon 1991). In this case, this is exacerbated by the preparation of the litterbags (rinsing of wrack to remove sand and debris) and drying following deployment. This process is similar to wrack being deposited on the shore with the highest tide and then drying during the low tide or as it remains stranded higher on the beach. Thus, after the initial deposition of wrack onto the beach causes cell lysis and leaching, there may be only a slow and small release of nutrients from wrack into the beach.

Despite the initial mass loss, carbon content (%C) for wrack samples did not differ over time, suggesting that most of the non-structural C had already been lost from the wrack prior to the start of the experiment. This result is further supported by the consistent $\delta^{13}C$ values across time. Lignin has low $\delta^{13}C$ and is decomposed very slowly. Its relative abundance increases during decomposition thus causing decrease in $\delta^{13}C$ (Machas *et al.* 2006). This trend was not seen here, suggesting that there was little loss of other material, e.g. polysaccharides. %C differed among the 4 species, probably reflecting the differing amounts of structural material in these species. %N varied due to the interaction of Species (nested in Wrack type) and Time. This result confirms the previous studies of %N during decomposition which indicated that the processes affecting %N differ among species and during decomposition (e.g. as microbial communities colonise and proliferate on the detritus) (Harrison & Mann 1975; Thayer *et al.* 1977; Walker & McComb 1985; Machas *et al.* 2006). Despite the increase in %N, there was not a significant decrease in C:N ratio over time. This may be due to the relatively high C:N ratios in the wrack used in thus study, with changes in %N having little effect on the overall ratio.

Results of the litterbag experiments in this study also indicated that $\delta^{15}N$ differs with the age of wrack, showing slight increases over time, but $\delta^{13}C$ does not change over time. Decreases in $\delta^{15}N$ during the decomposition of vascular plants have been reported by Currin *et al*. (1995), and other studies have reported no differences in $\delta^{15}N$ during the decomposition of the seagrass *Zostera noltii* (Machas *et al.* 2006). This result suggests that consumer species may have colonised the wrack, although the magnitude of the increase in $\delta^{15}N$ was small (Figure 6.6b). Presumably, whether

changes in $\delta^{15}N$ occur over time will depend on the type of plant material, the microbial communities and the surrounding environment. Given that $\delta^{15}N$ is used as an indicator of trophic level (higher trophic levels having more enriched $\delta^{15}N$), the difference in $\delta^{15}N$ over time may confound estimates of trophic level.

Examination of the data suggested that the kelp *E. radiata* may be unique among the species studied here. *E. radiata* showed an interesting series of results, which, although not formally analysed, suggest that this species underwent a unique set of processes. Between Day 27 and Day 85, *E. radiata* had a slightly faster rate of mass loss (Figure 6.4), a marked decrease in %C (Figure 6.5a), and an increase in %N, and consequently had a lower C:N ratio than any other species at the end of the experiment. This leads me to suggest that the wrack of this species contained relatively greater amounts of non-structural C (e.g. mucopolysaccharides), which was lost from the wrack between Days 27 and 85. Furthermore, this species displayed the predicted initial decrease in %N, which is due to leaching of N, followed by an increase in %N, which can be attributed to colonisation of microorganisms. This pattern has been reported by Hansen (1984) for *E. radiata* in Western Australia. Furthermore, the $\delta^{15}N$ values for *E. radiata* showed an increase between Days 27 and 85 (i.e. at the same time as an increase in %N occurred) suggesting that microbes may have colonised the wrack during this time.

Nearshore fish and macroinvertebrate communities differed between beaches, regions and visits, i.e. were variable in time and space. I encountered only 7 species of fish, which is similar to some previous reports (Kingsford & Choat 1985; in New Zealand) but is considerably lower than other studies (Lasiak 1986; Lenanton & Caputi 1989; Crawley *et al.* 2006). For example, Lasiak (1986) reported 23 species of fish off King's Beach in South Africa, Lenanton and Caputi (1989) found 37 species, and Crawley *et al*. (2006) 23 species of fish associated with surf-zone wrack accumulations in Western Australia. Each of these studies, however, used different methods from those used here; they sampled larger volumes of water and Lenanton and Caputi (1989) and Kingsford and Choat (1985) also used a boat to tow the net.

The amount of wrack on the beach and in the surf zone did not affect the abundance and species richness of fish and invertebrates. These results contrast with previous

studies which found that the abundance of fish higher in association with drift algae than open water (Kingsford & Choat 1985, in New Zealand) and that fish abundance was positively correlated with the volume of drift macrophytes (Lenanton & Caputi 1989; Crawley *et al.* 2006; both in Western Australia). To my knowledge, this is the first study to investigate whether wrack cover on the beach is correlated with abundance and species richness of fish and invertebrates in the nearshore zone.

It is important to note that not all potential food sources were sampled in this study. The most dominant wrack species were sampled and only consumers for which sufficient biomass could be harvested were sampled. Wrack is only one possible source of organic matter but consumers may derive food from fine particulate matter, other invertebrates which were not sampled in this study, or living algae, seagrass and terrestrial plants in nearby other habitats. In particular, fish, which are the most mobile, can potentially cross habitat boundaries and derive nutrition from other habitats such as nearby seagrass meadows and algae living on reefs. For this reason, analysis so far of these data was kept deliberately simple.

The $\delta^{13}C$ values for seagrasses and algae found in this study were similar to those reported in a review by Raven *et al*. (2002) for living and detached material. The values reported from Western Australia by Ince *et al*. (2007) were similar, although slightly more enriched in $\delta^{13}C$, for the seagrasses *Posidonia* spp. (-7.6 to -6.1 ‰) and *Amphibolis* spp. (-13.3 to -11.3 ‰) (Table 6.7), however the values they reported for red and brown algae (-22.3 to -19.9 ‰) fell into a narrower range than in this study, perhaps because of the lower number of beaches (only three) sampled in their study. Seagrasses were isotopically distinct from algae due to their more enriched $\delta^{13}C$ values but there was little separation algal taxa (red, green, brown algae and kelps) found in this study. This result is expected since seagrass and algae use different photosynthetic pathways (McMillan 1980).

It was interesting to note that the green alga *Ulva lactuca* had the most enriched $\delta^{15}N$ of any primary producer. This species is a known ‘weedy’ species and can bloom due to anthropogenic inputs of nitrogen (Thornber *et al.* 2008). The samples of this species were collected from sites along the metropolitan Adelaide coast where nutrient inputs from sewage treatment plants, which are more enriched than ‘natural’

marine sources of N, enter the marine environment (Bryars *et al.* 2006). Thus, the high $\delta^{15}N$ signature of *U. lactuca* also suggests that it grows in close proximity to these inputs. Anthropogenic inputs of nitrogen along the metropolitan coastline may also explain the large range in $\delta^{15}N$ values for other primary producers (Table 6.7). For example, the seagrass *Posidonia sinuosa*, which occurred in all three regions and along the entire Metropolitan coast, had a large range in $\delta^{15}N$ (Table 6.7), suggesting that it grows within a range of enrichment levels from anthropogenic sources. The values of $\delta^{15}N$ recorded for *P. sinuosa* in this study span the range reported by Bryars *et al*. (2006) and some of these plants had values in the upper range of $\delta^{15}N$ (> 9 ‰) which occurred in living plants growing around wastewater outfalls. The enrichment of $\delta^{15}N$ values of seagrasses (and potentially marine algae) due to anthropogenic inputs at point sources may present an interesting opportunity to track the movement of driftling plants from their source to the beach. For example, by mapping the $\delta^{15}N$ signature of a particular species whilst it is living *in situ* (e.g. the work done by Bryars *et al.* 2006 for *P. sinuosa*) and then sampling specimens from the beach, we may be able to determine the origins of beach-cast specimens.

Both $\delta^{13}C$ and $\delta^{15}N$ values for individual species of seagrass and algae differed in both time and space. McMillan (1980) and Raven *et al*. (2002) in their reviews also reported considerable variation between species of algae and seagrass, locations and/or dates, and parts (e.g. blades vs. stipes) of plants, but many individual studies don't sample this variation. Studies that base their conclusions on only one or a few samples may thus potentially undersample. In addition, when assessing the incorporation of wrack into trophic webs, samples should be explicitly correlated in both space and time (i.e. primary producers and consumers should be sampled at the same place and time) (Connolly *et al.* 2005; Vizzini & Mazzola 2006). Studies should thus use sufficient replication to encompass the spatial and temporal variation actually present, and the use of values from other studies and/or habitats should be regarded cautiously.

Examination of the $\delta^{13}C$ and $\delta^{15}N$ plots for primary producers and consumers (Figure 6.11) suggested that seagrasses did not provide a food source for any consumers (i.e. seagrasses were more enriched in $\delta^{13}C$ than any consumers). Algae, particularly brown algae and kelps, appeared to be potential sources of nutrition for consumers

(crabs, fish, some beach invertebrates, and especially predatory beach invertebrates). Nearshore invertebrates appeared to be less enriched in $\delta^{13}C$ than other consumers and may rely more on red and green algae rather than brown algae. Due to the relatively small number of samples from these algal taxa it is difficult to identify potential food sources (Figure 6.11).

The $\delta^{13}C$ and $\delta^{15}N$ values of consumers had a large range, reflecting the wide range of sources of organic matter available in these habitats and the range of trophic levels occupied. Individual species also varied greatly in both $\delta^{13}C$ and $\delta^{15}N$, reflecting the variety and availability of food sources, flexibility in feeding strategies and breadth of trophic niches, variability in trophic fractionation, as well as likely differences between individuals. Crabs, fish and predatory staphylinid beetles had high $\delta^{15}N$ values, reflecting their higher trophic levels compared to primary producers and other invertebrates on the beach and in the nearshore zone. In their study in Western Australia, Ince *et al*. (2007) also found that staphylinid beetles had higher $\delta^{15}N$ than other beetles, amphipods and flies, although the consumers sampled by Ince *et al*. (2007) tended to have slightly higher $\delta^{15}N$ values than those in this study. Beach invertebrates spanned multiple trophic levels including likely detritivores and/or herbivores and predators.

Examination of $\delta^{13}C$ and $\delta^{15}N$ values of primary producers and consumers suggested that seagrasses do not contribute organic matter to these trophic webs. Brown algae and kelps appear to be potential sources of nutrition for consumers. These results contrast with those of Ince *et al.* (2007), who used the IsoSource software (Phillips & Gregg 2003) to estimate contributions from primary producers to consumer diets. Their study found that seagrass (*Posidonia* spp.) contributed more to the diet of amphipods than brown and red algae (Ince *et al.* 2007). The authors, however, demonstrated that stable-isotope signatures for macroinvertebrates were most similar to those for red and brown algae. Given these apparently contradictory results, it is perhaps difficult to draw firm conclusions from their study.

The assignment of trophic levels to animals and identification of individual species of algae and seagrass as their food sources was not possible, but further analysis and examination of the data will be carried out later. Investigation into the decomposition

of wrack over longer periods of time (as attempted in the second litterbags study), other factors affecting wrack decomposition such as patch size or the location of deposits, and further research into the changes in isotopic signatures as wrack dies and decomposes should also be carried out. Additional sampling of macrofaunal communities on the beach (perhaps using pit-fall traps to capture fauna) and in the nearshore zone would also be beneficial to further assess the incorporation of wrack into trophic webs. In addition, future studies should attempt to sample a broader range of materials including living seagrass and algae to determine whether stable isotope signatures differ between living material and wrack.

Conclusion

The release of nutrients and organic matter from wrack into the beach ecosystem via decomposition appears to occur in the first few days after deposition but may be minimal after wrack dries. The incorporation of wrack into beach and nearshore ecosytems may occur primarily through consumption by herbivores such as amphipods and larval dipterans. Wrack, particularly the algal components, provides the basis of a complex trophic web, with potential pathways for the transfer of nutrients and energy into primary and secondary consumers, and further up the food chain. This flow-on effect warrants further attention.

List of Figures

P. coriacea

Stage 1: % DW remaining = - x days + 100, r = +0.079, p = 0.749, n = 12

Stage 2: % DW remaining = -0.259 x days + 109, r = -0.645, p = 0.002, n = 28

Figure 6.5. Nutrient concentrations in Study 2: Mean (± se) for a) % C, b) % N and c) C:N ratio for wrack in litterbags on Day 0 and after 27 and 85 days in study 2. Filled symbols = algae, open symbols = seagrass. ● = *E. radiata*, ■ = *Sargassum* spp., ▽ = *P. sinuosa*, ◇ = *P. coriacea*. Note that error bars (se) are smaller than the symbols in some cases. n = 3 litterbags for each species on each day.

Figure 6.6. Stable-isotope ratios in Study 2: Mean (± se) for a) $\delta^{13}C$ and b) $\delta^{15}N$ for wrack in litterbags on Day 0 and after 27 and 85 days in study 2. Filled symbols = algae, open symbols = seagrass. ● = *E. radiata*, ■ = *Sargassum* spp., ▽ = *P. sinuosa*, ◇ = *P. coriacea*. Note that error bars (se) are smaller than the symbols in some cases. n = 3 litterbags for each species on each day.

Figure 6.7. Seine netting: a) Abundance and b) species richness of fish and macroinvertebrates captured in seine net hauls at each beach on 2 visits. Data presented are the mean (± se) of 5 hauls performed at each Beach on each Visit. Black bars = summer, white bars = winter.

Figure 6.8. Seine netting: Scatterplots of % wrack cover on the beach (4^{th} root-transformed) vs. the mass of wrack (kg, 4^{th} root-transformed) in the 5 seine net hauls for each visit to each beach. Symbols are plotted by Visit: ● = summer, ○ = winter. For both Visits combined: Pearson r = 0.311, p = 0.259, n = 15. Summer: Pearson r = 0.317, p = 0.087, n = 30. Winter: Pearson r = 0.303, p = 0.272, n = 15.

Figure 6.9. Seine netting: Scatterplots of a) % wrack cover on the beach (4^{th} root-transformed) vs. abundance (4^{th} root-transformed), b) wrack cover on the beach (4^{th} root-transformed) vs. species richness (√-transformed), c) the mass of wrack (kg, 4^{th} root-transformed) vs. abundance (4^{th} root-transformed) and d) the mass of wrack (kg, 4^{th} root-transformed) vs. species richness (√-transformed) of nearshore fish and macroinvertebrates. Each data point represents a visit to a single beach and thus n =

30. Symbols are plotted by Visit: ● = summer, ○ = winter. Linear regressions for both Visits combined were all non-significant and $n = 30$ for each regression: a) Pearson $r = -0.027$, $p = 0.889$; b) Pearson $r = -0.082$, $p = 0.668$; c) Pearson $r = -0.155$, $p = 0.413$; and d) Pearson $r = -0.069$, $p = 0.715$. For winter, none of the regressions were significant ($p > 0.05$ in each case). For summer there was a significant linear relationship between the mass of wrack (kg, 4^{th} root-transformed) and the species richness (√-transformed) of nearshore fish and macroinvertebrates (Pearson $r = 0.516$, $p = 0.049$). The other regressions for summer were non-significant ($p > 0.05$).

Figure 6.10. Seine netting: 2-D MDS ordination plot of nearshore fish and macroinvertebrates captured from all 15 beaches on both visits. Visits: □ = winter, ○ = summer. Regions: grey = SE, white = Fleurieu, black = Metro. 2-D stress was < 0.01.

Figure 6.11. $\delta^{13}C$ vs. mean $\delta^{15}N$ for primary producers and consumers from all beaches on both visits. Symbols are plotted by taxonomic groups and each symbol represents all samples for an individual species. Open symbols represent wrack and closed symbols represent consumer taxa. Confidence ellipses centred on the sample mean for each taxonomic group are shown. Note that the confidence ellipse for green algae (green diamonds) encompasses the entire plot.

Figure 6.12. $\delta^{13}C$ vs. $\delta^{15}N$ for a) individual samples of the brown alga *Cystophora* spp. and b) the goby *Favonigobius lateralis*. Symbols are plotted by Region: ○ = Fleurieu, □ = SE, ▽ = Metro)

Figure 6.13. $\delta^{13}C$ vs. $\delta^{15}N$ for primary producers and consumers from a) Seacliff in August and b) Nora Creina in December. Symbols are plotted by taxonomic groups. ✚ = Brown algae, ◇ = Kelps, ☆ = Red algae, × = Seagrass, □ = Beach invertebrates, ▽ = *Paridotea undulata*, △ = Crabs, ○ = Fish. Each symbol represents a taxon within each group (i.e. a particular species). Error bars are the standard error of both x and y axes and are plotted only for consumer species for which multiple specimens were collected.

Figure 6.14. a) Fish fork length (mm, √-transformed) and b) fish wet weight (g, log-transformed) vs. $\delta^{15}N$ for all fish collected at the 15 beaches in 2 visits (n = 66). The linear regressions were not significant. Fork length: Pearson r = - 0.217, p = 0.079 and wet weight: Pearson r = - 0.111, p = 0.375.

Figure 6.15. a) Fish fork length (mm) and b) fish wet weight (g) vs. $\delta^{15}N$ for the goby *F. lateralis* collected at the 15 beaches in 2 visits (n = 25). The linear regressions were not significant. Fork length: Pearson r = 0.278, p = 0.178 and wet weight: Pearson r = 0.168, p = 0.422.

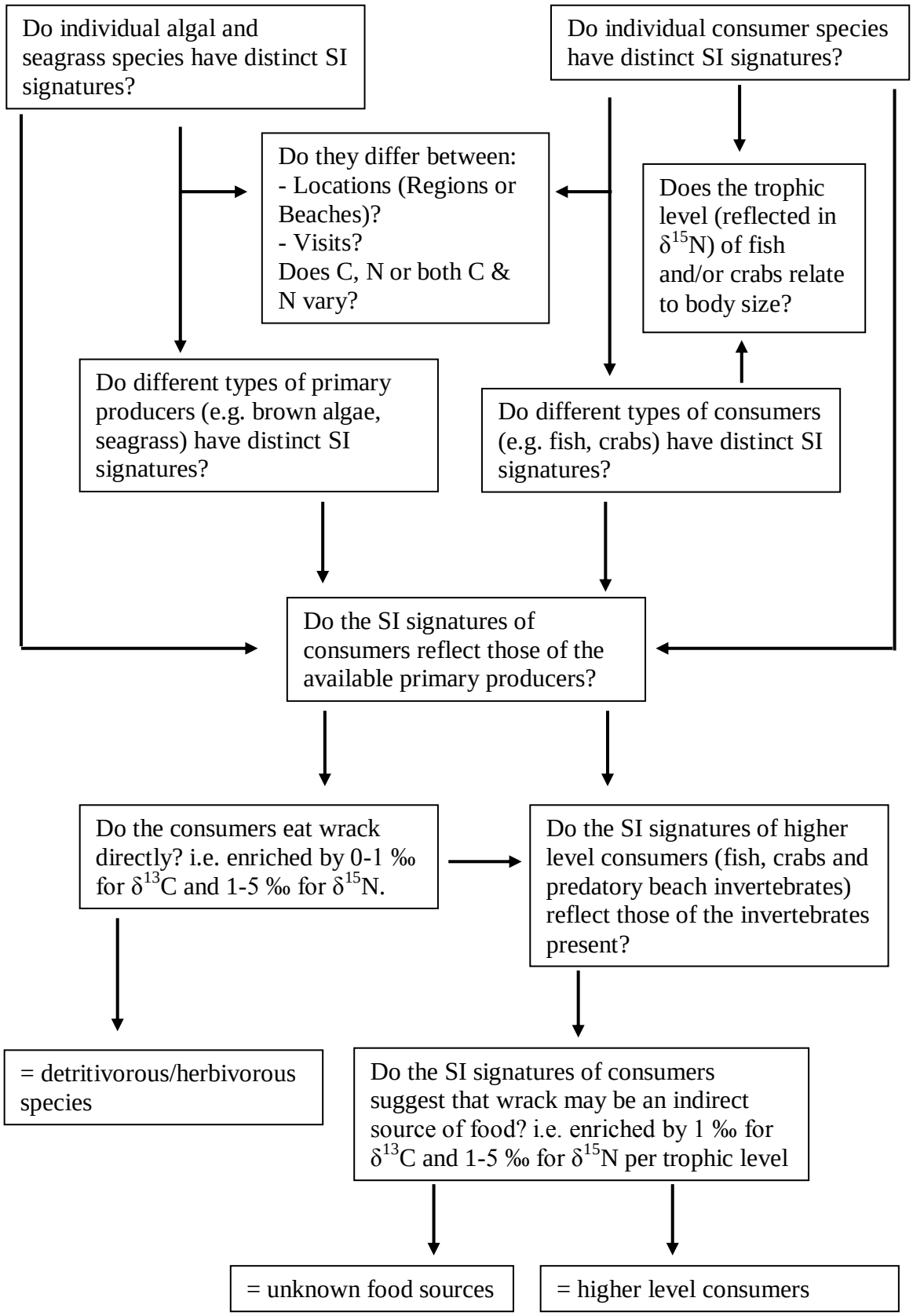

Do individual algal and seagrass species have distinct SI signatures?
Do individual consumer species have distinct SI signatures?
Do they differ between:
- Locations (Regions or Beaches)?
- Visits?
Does C, N or both C & N vary?
Does the trophic level (reflected in $\delta^{15}N$) of fish and/or crabs relate to body size?
Do different types of primary producers (e.g. brown algae, seagrass) have distinct SI signatures?
Do different types of consumers (e.g. fish, crabs) have distinct SI signatures?
Do the SI signatures of consumers reflect those of the available primary producers?
Do the consumers eat wrack directly? i.e. enriched by 0-1 ‰ for $\delta^{13}C$ and 1-5 ‰ for $\delta^{15}N$.
Do the SI signatures of higher level consumers (fish, crabs and predatory beach invertebrates) reflect those of the invertebrates present?
= detritivorous/herbivorous species
Do the SI signatures of consumers suggest that wrack may be an indirect source of food? i.e. enriched by 1 ‰ for $\delta^{13}C$ and 1-5 ‰ for $\delta^{15}N$ per trophic level
= unknown food sources
= higher level consumers

Figure 6.1

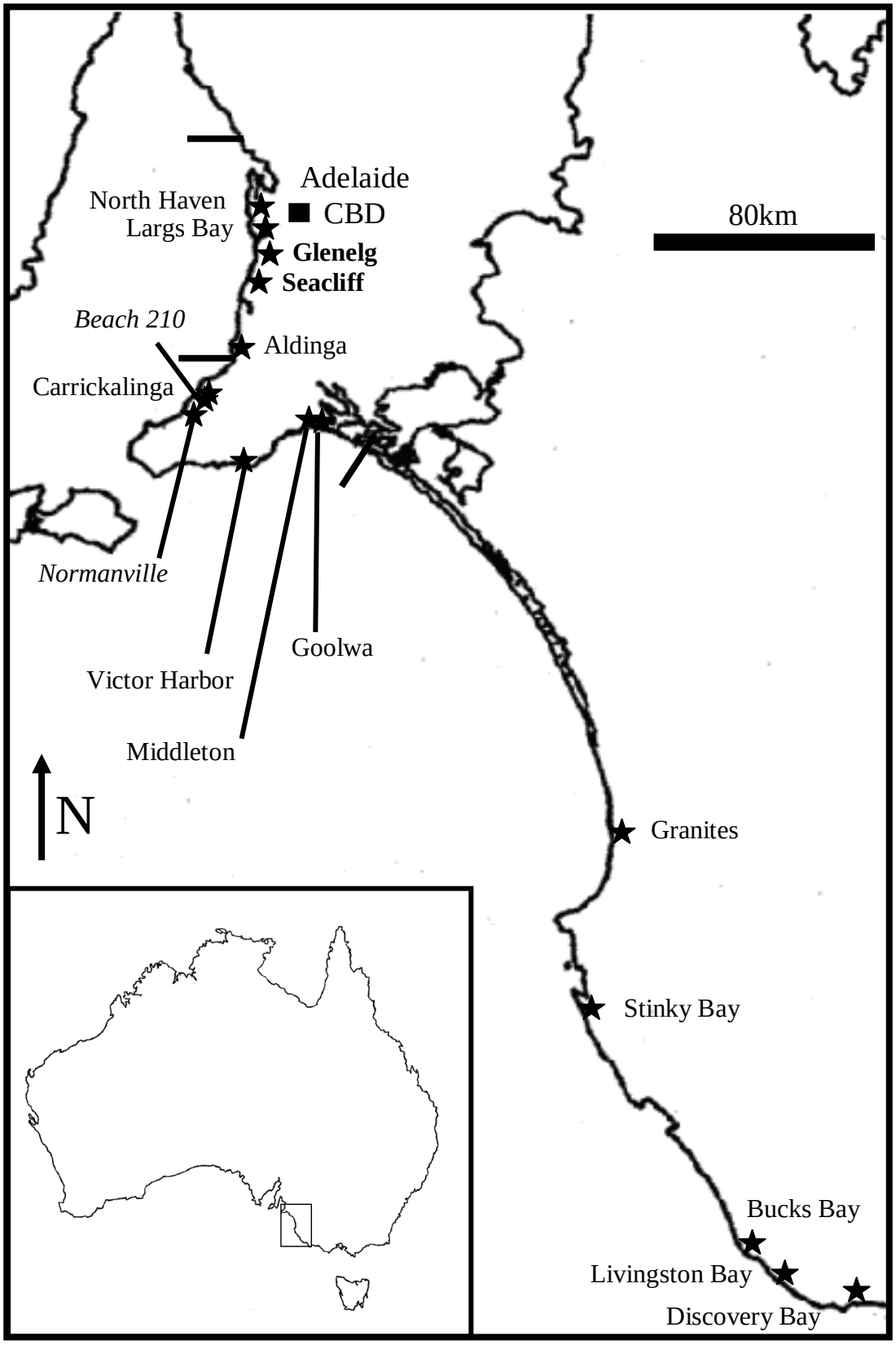

Adelaide
CBD
North Haven
Largs Bay
Glenelg
Seacliff
Beach 210
Aldinga
Carrickalinga
Normanville
Victor Harbor
Middleton
Goolwa
80km
N
Granites
Stinky Bay
Bucks Bay
Livingston Bay
Discovery Bay

Figure 6.2

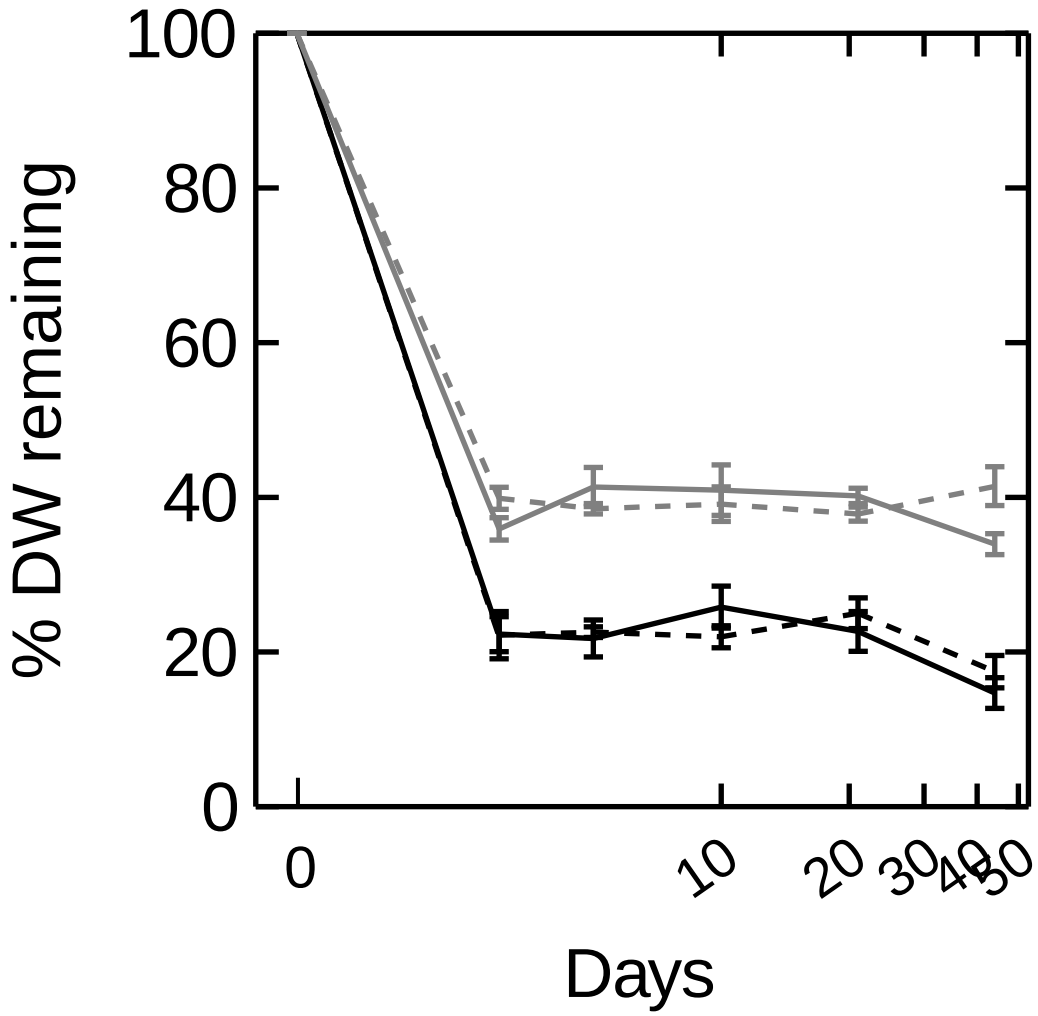


Figure 6.3

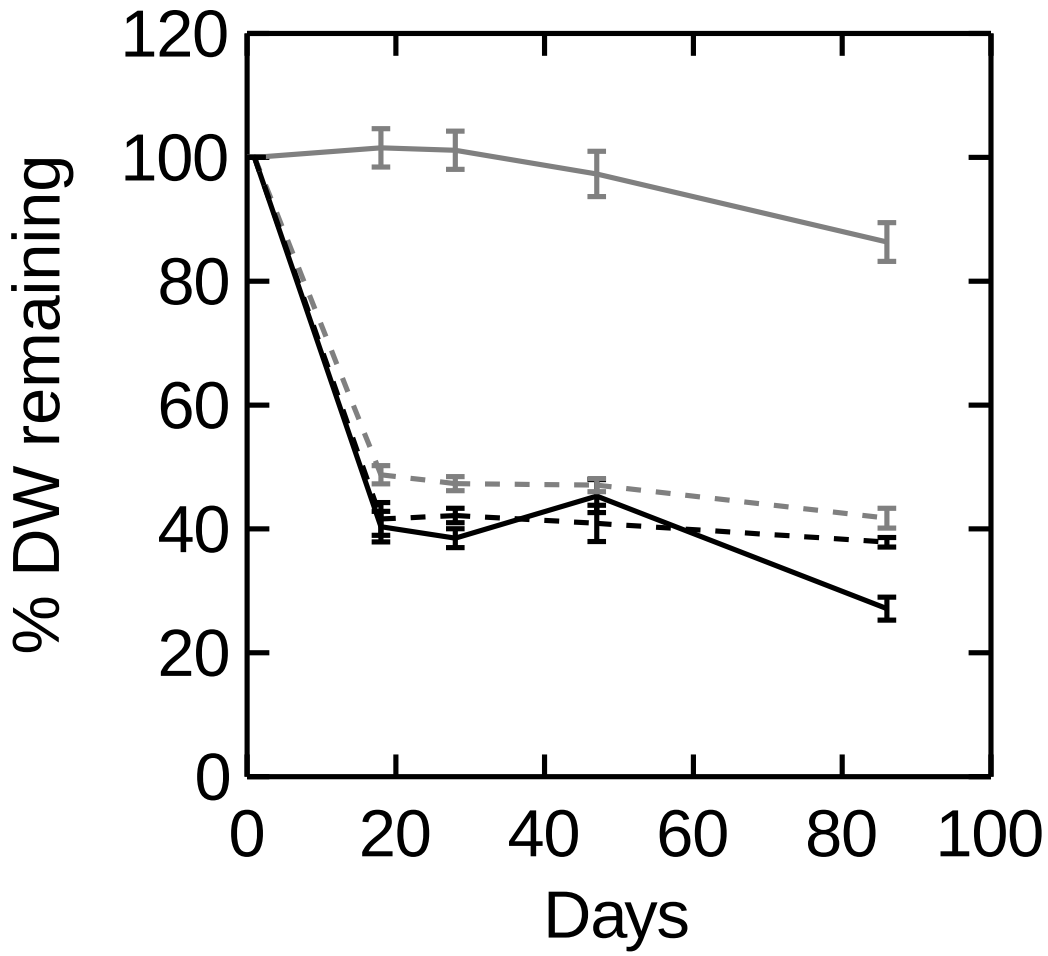
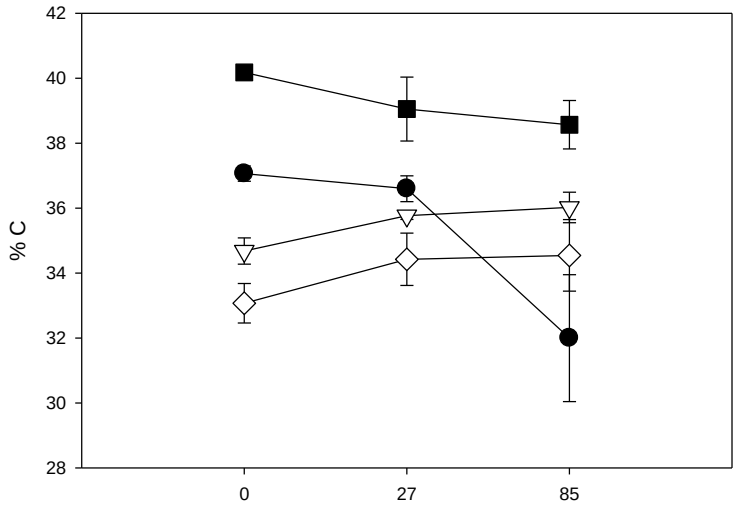


Figure 6.4

a)



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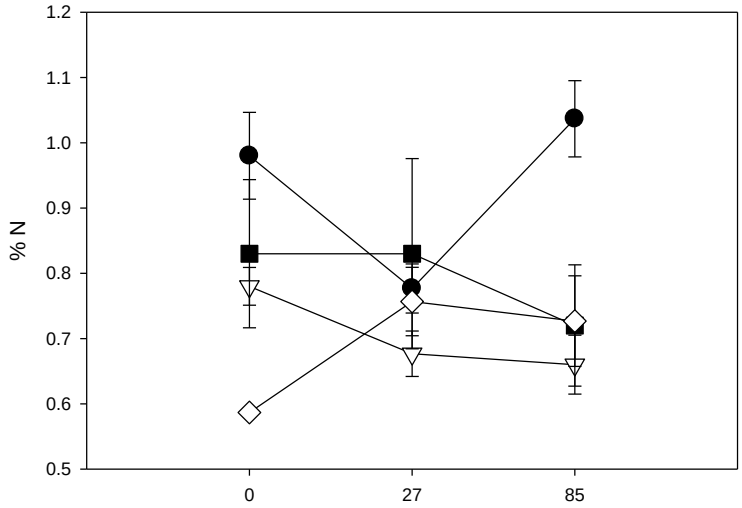

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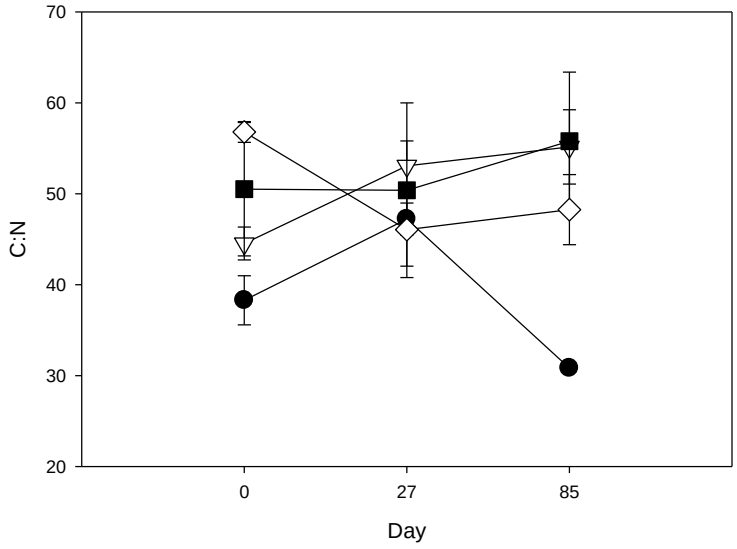
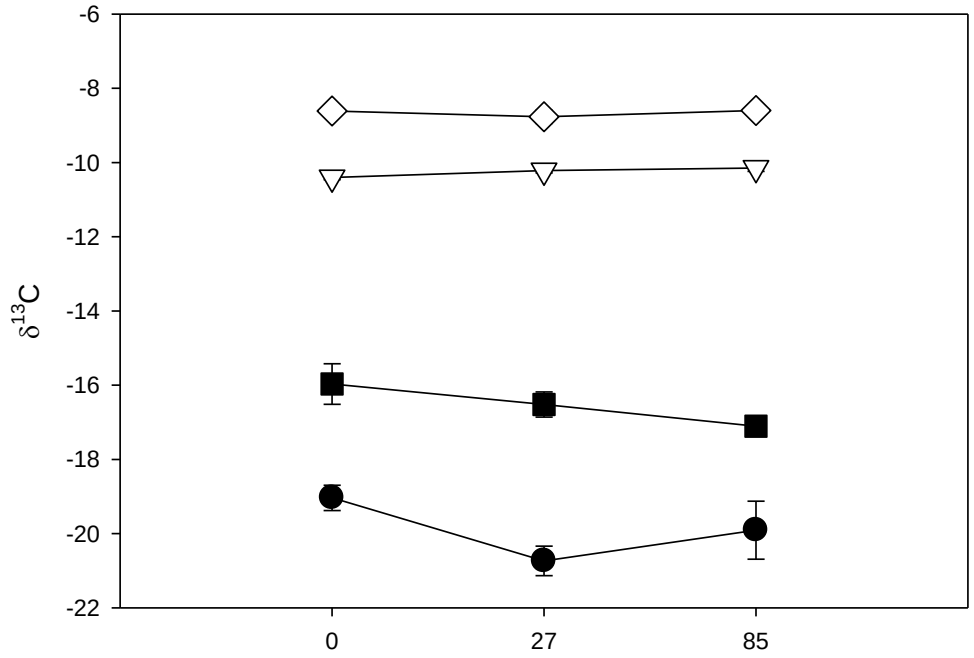


Figure 6.5

a)



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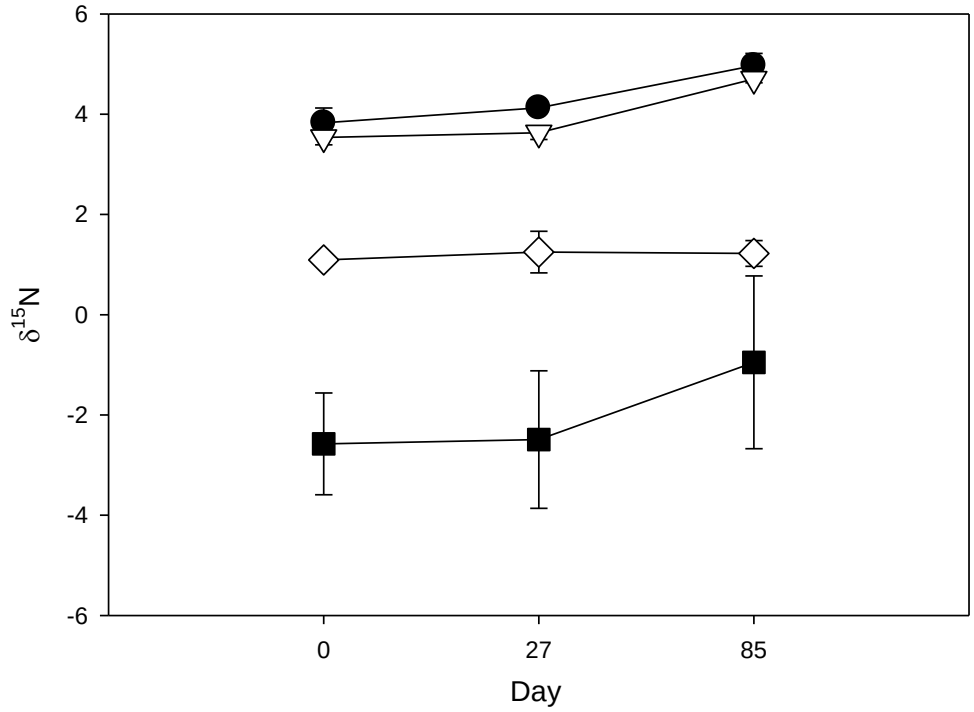
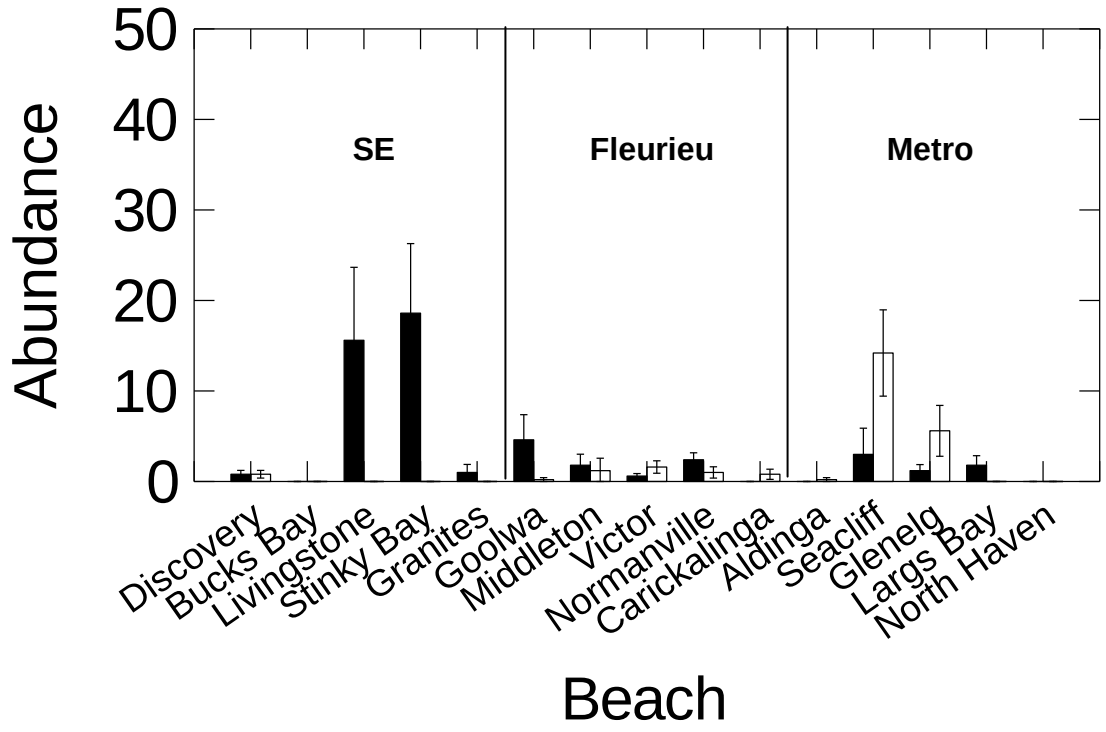


Figure 6.6

a)


Abundance
50
40
30
20
10
0
SE
Fleurieu
Metro
Discovery
Bucks Bay
Livingstone
Stinky Bay
Granites
Goolwa
Middleton
Victor
Normanville
Carickalinga
Aldinga
Seacliff
Glenelg
Largs Bay
North Haven
Beach

b)

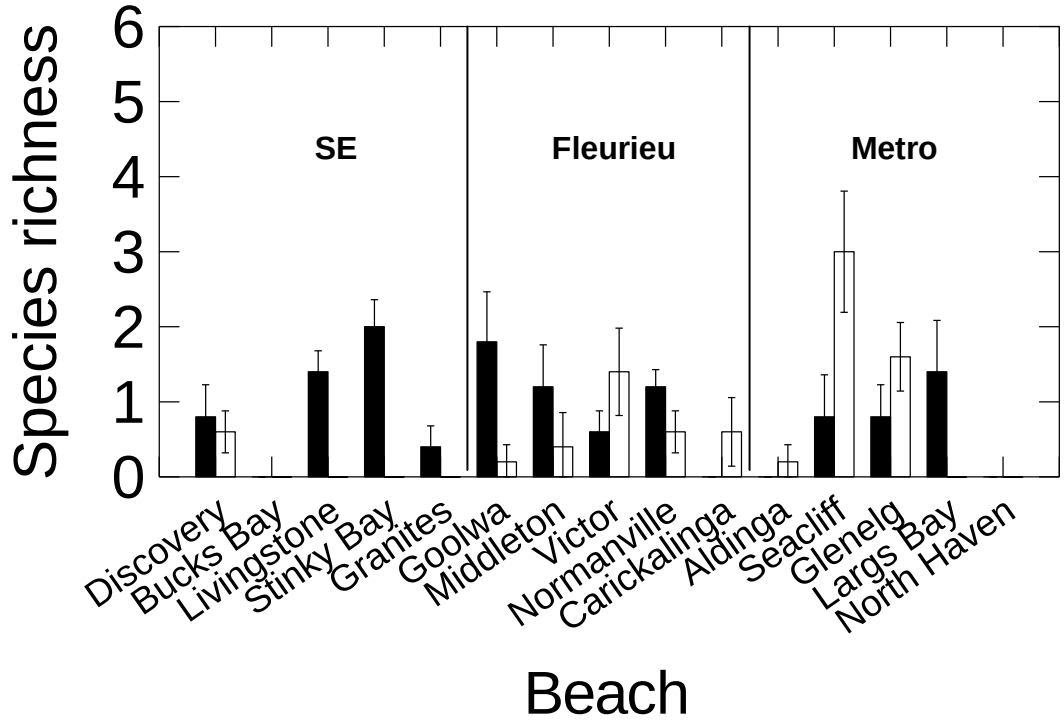

Species richness
6
5
4
3
2
1
0
SE
Fleurieu
Metro
Discovery
Bucks Bay
Livingstone
Stinky Bay
Granites
Goolwa
Middleton
Victor
Normanville
Carickalinga
Aldinga
Seacliff
Glenelg
Largs Bay
North Haven
Beach

Figure 6.7

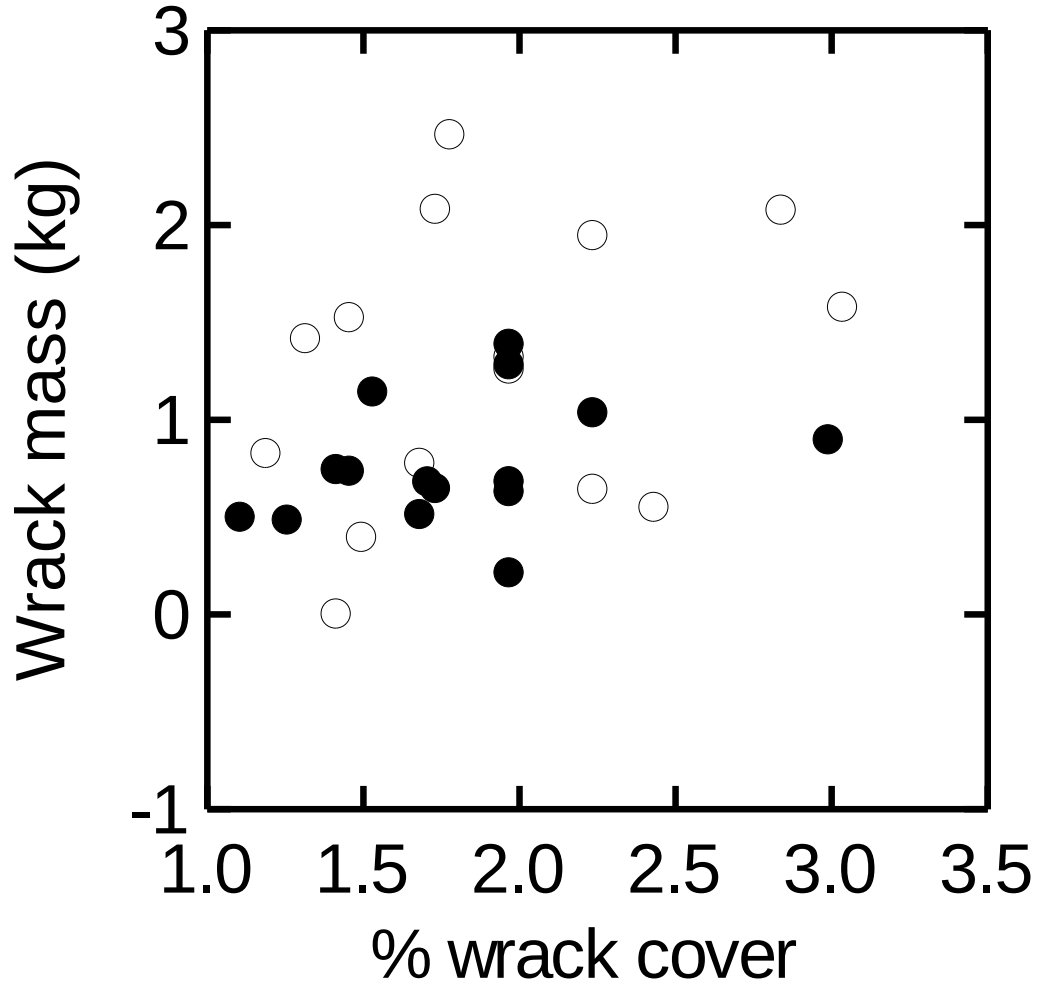


Figure 6.8

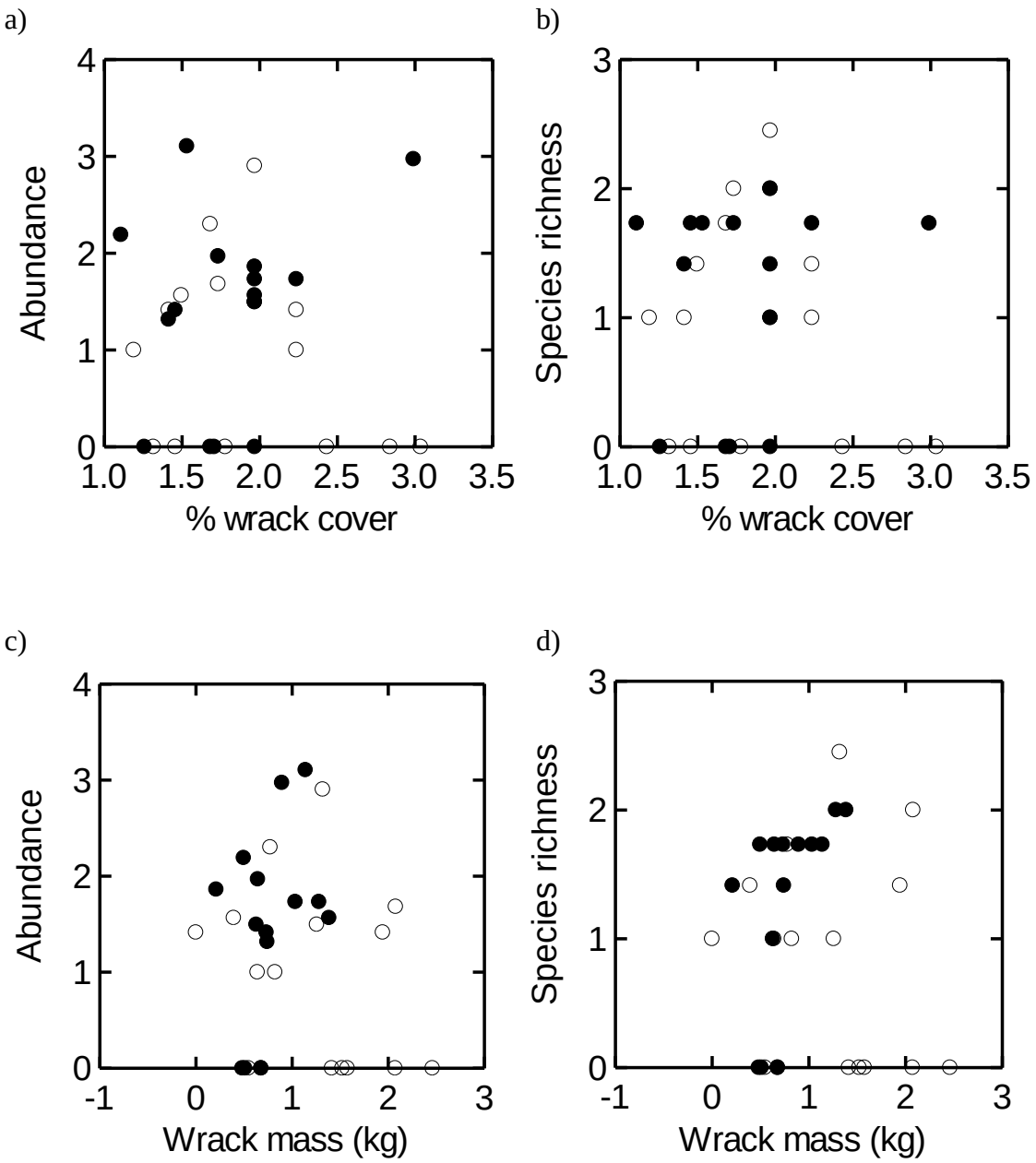

a)
b)
c)
d)
Abundance
Species richness
% wrack cover
Wrack mass (kg)
0
1
2
3
4
1.0
1.5
2.0
2.5
3.0
3.5
-1

Figure 6.9

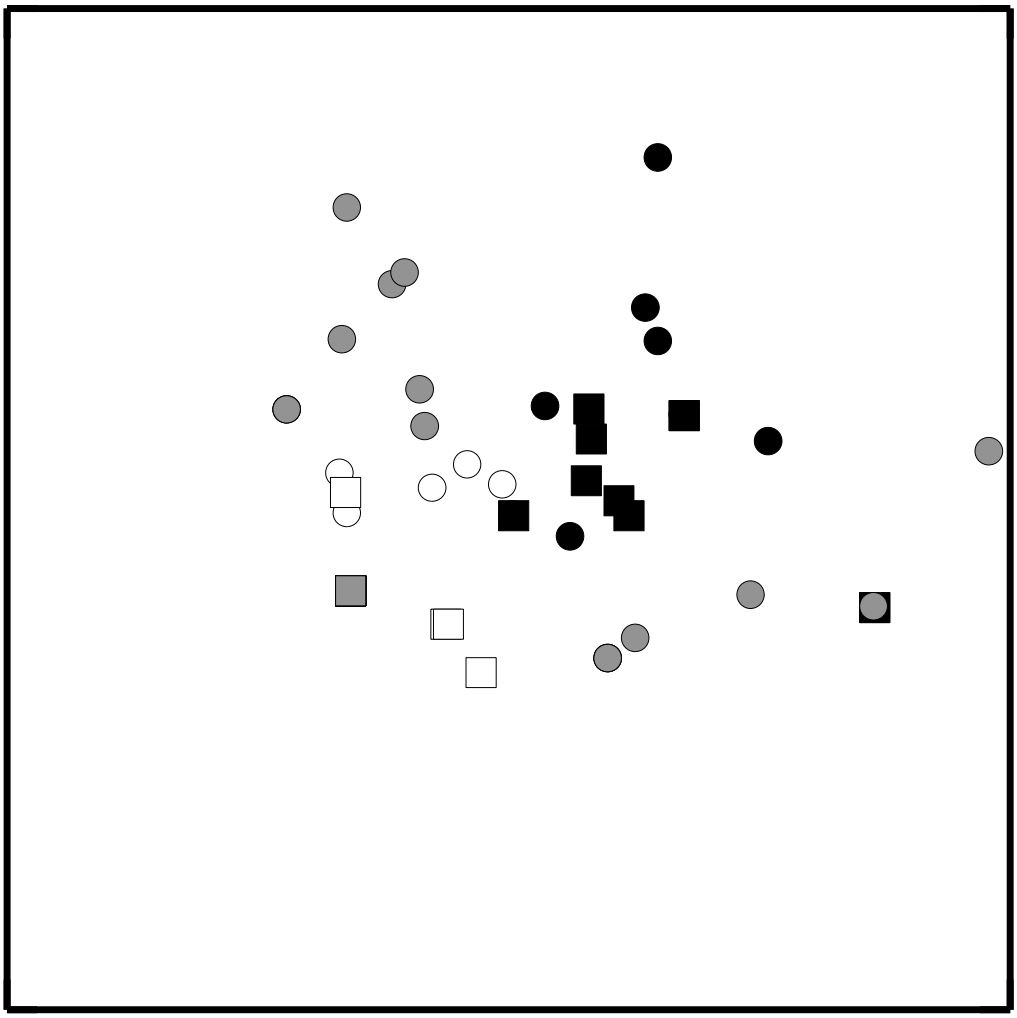


Figure 6.10

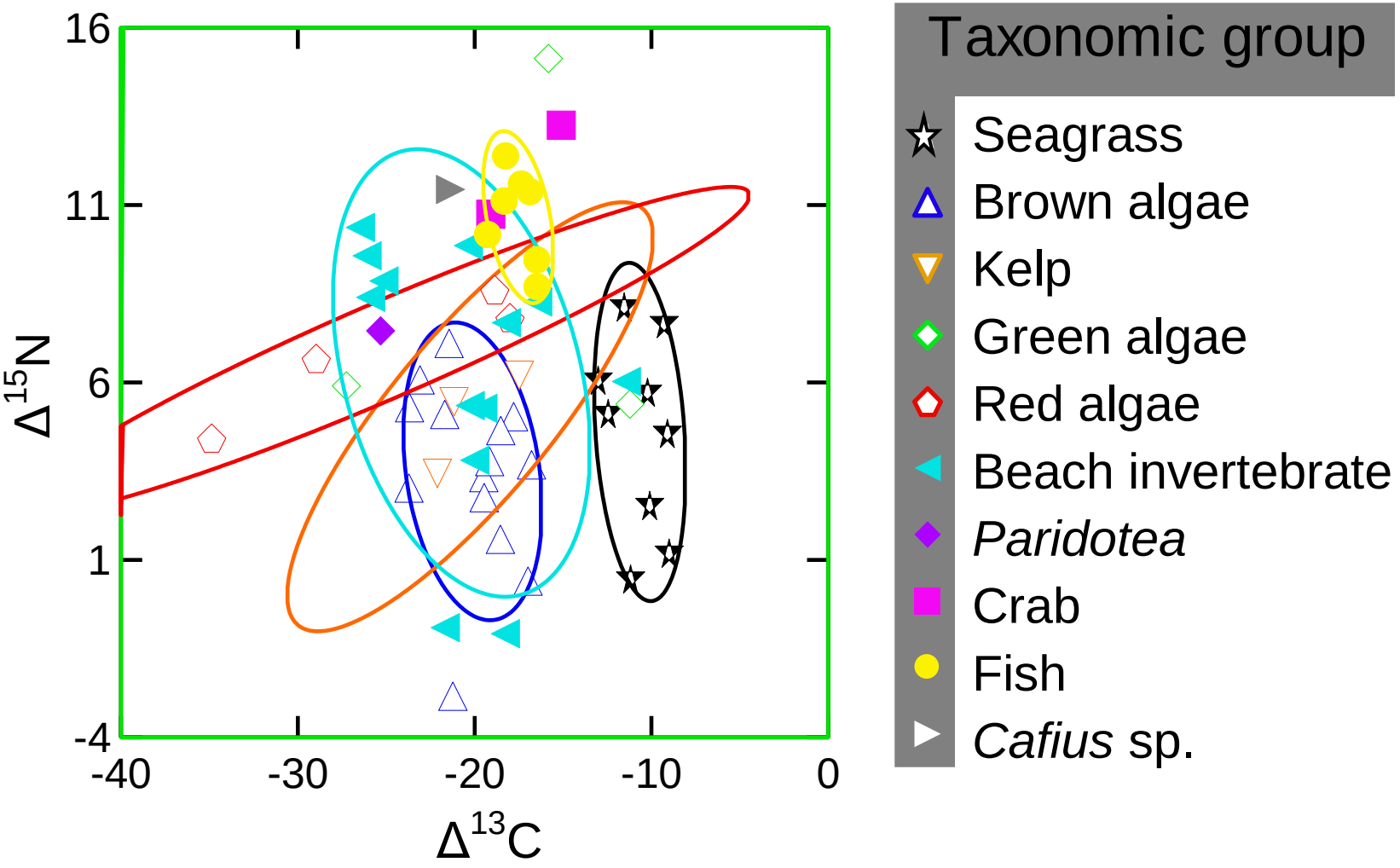
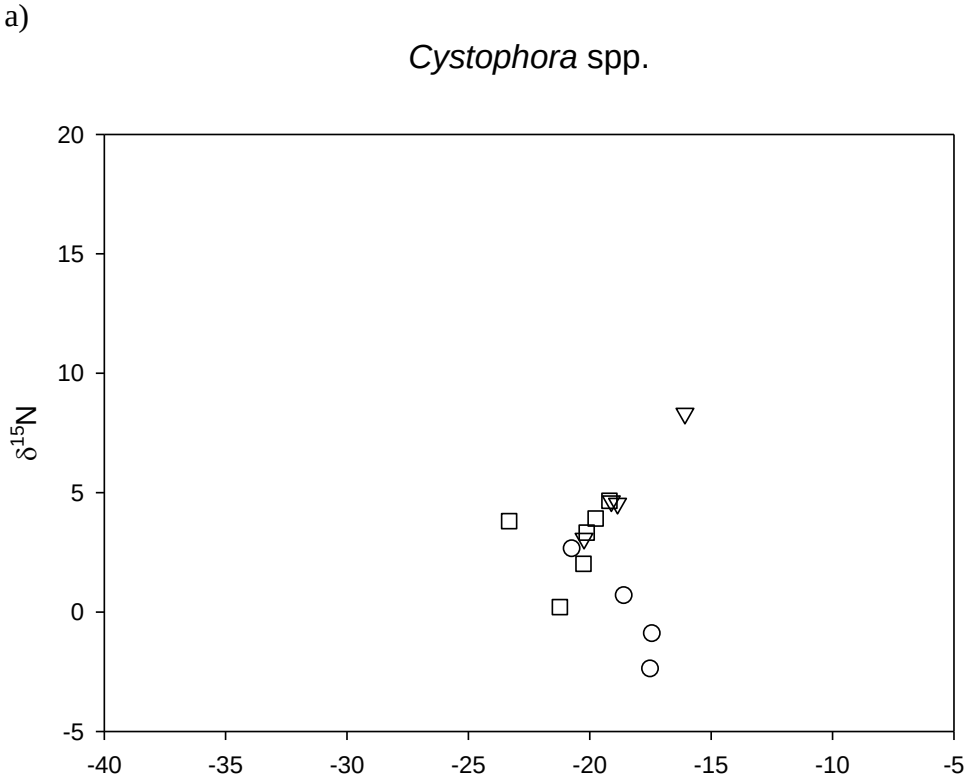

16
11
6
1
-4
-40
-30
-20
-10
0
Δ15N
Δ13C
Taxonomic group
Seagrass
Brown algae
Kelp
Green algae
Red algae
Beach invertebrate
Paridotea
Crab
Fish
Cafius sp.

Figure 6.11

a)



b)

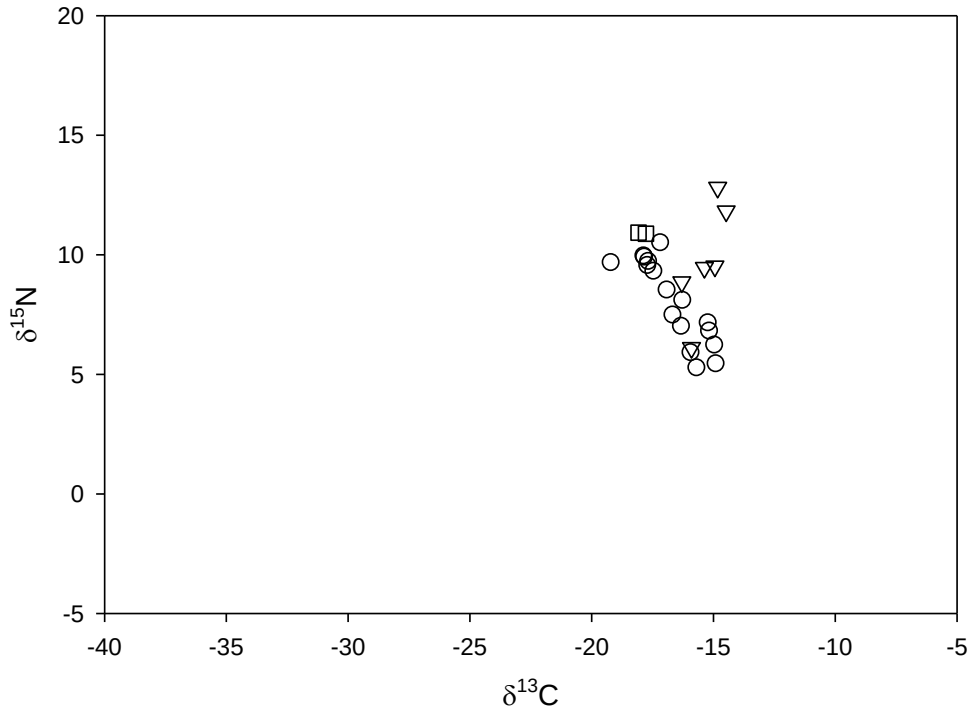
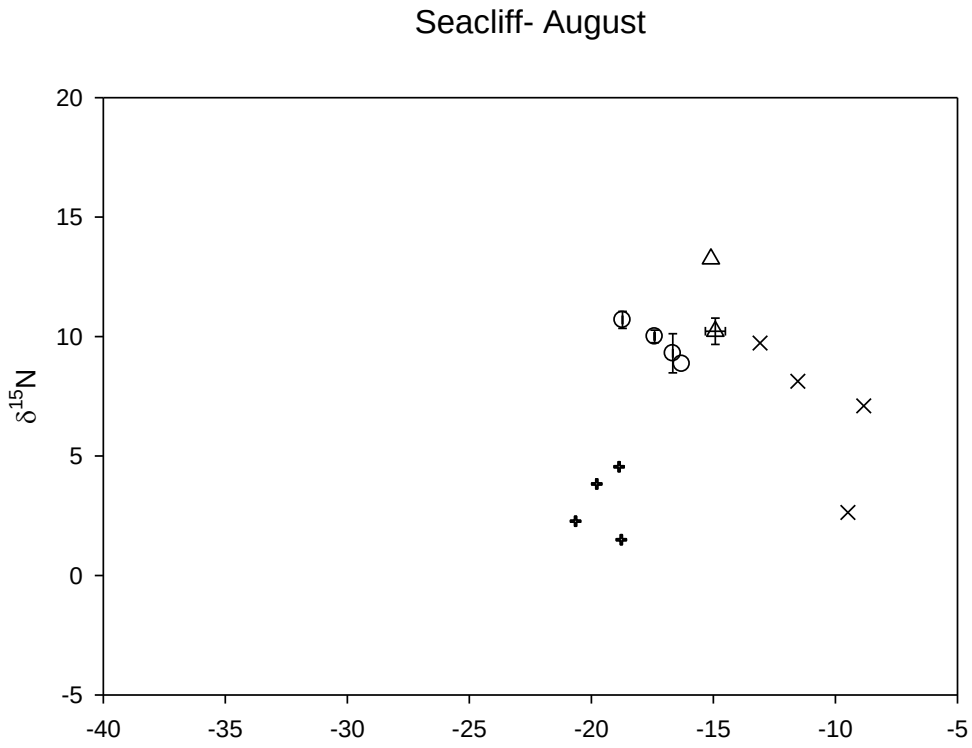


Figure 6.12

a)



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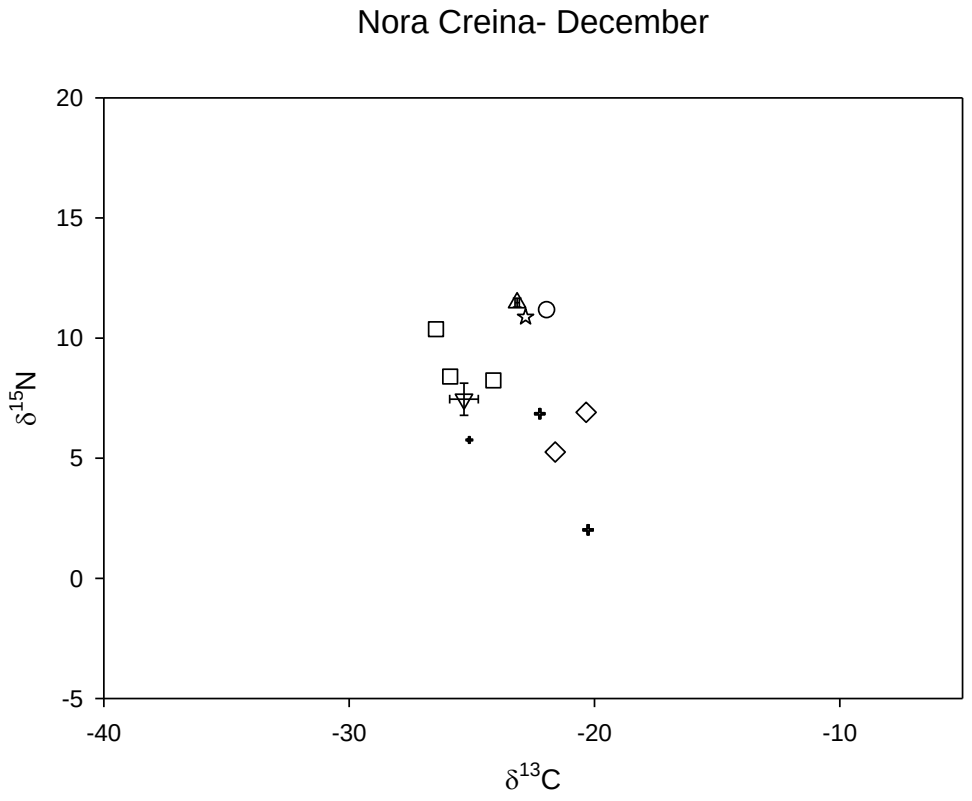
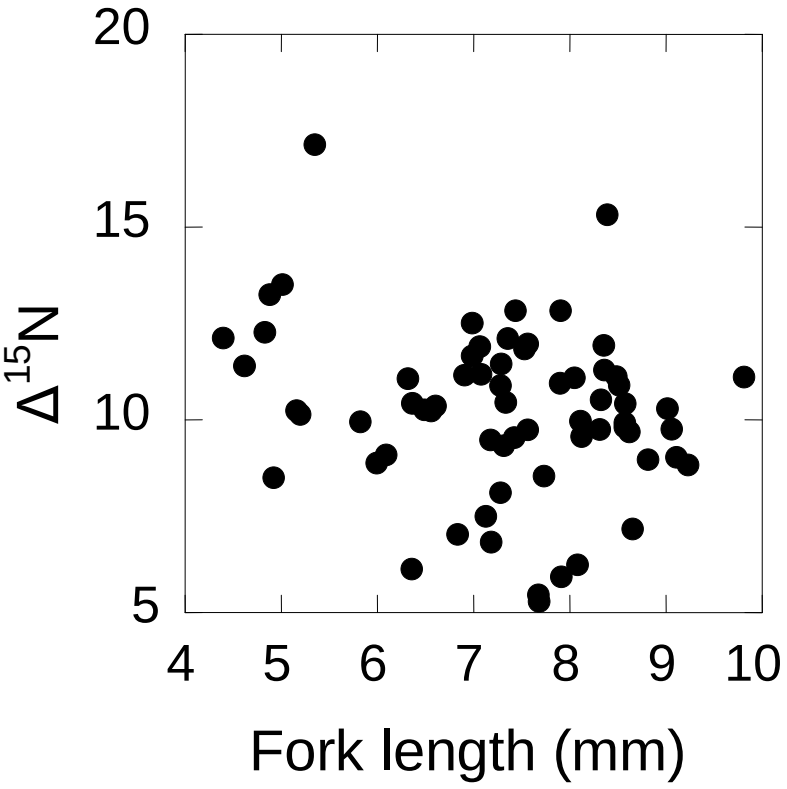


Figure 6.13

a)



b)

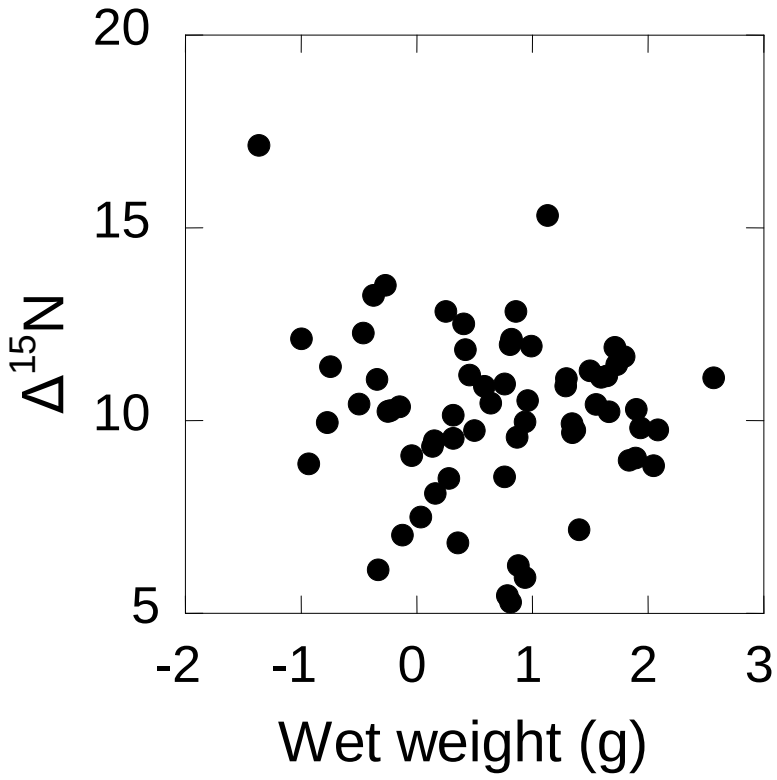
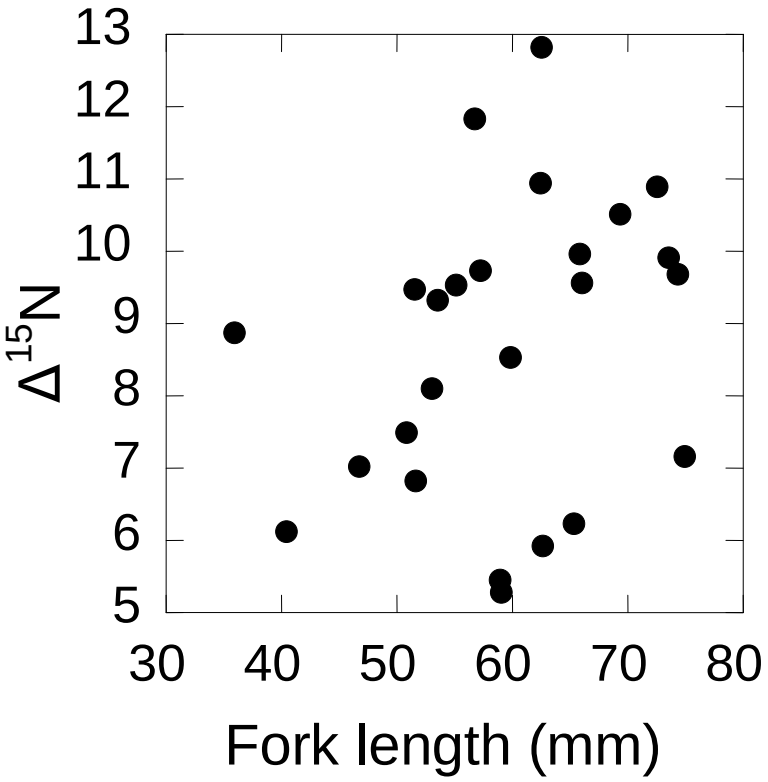


Figure 6.14

a)



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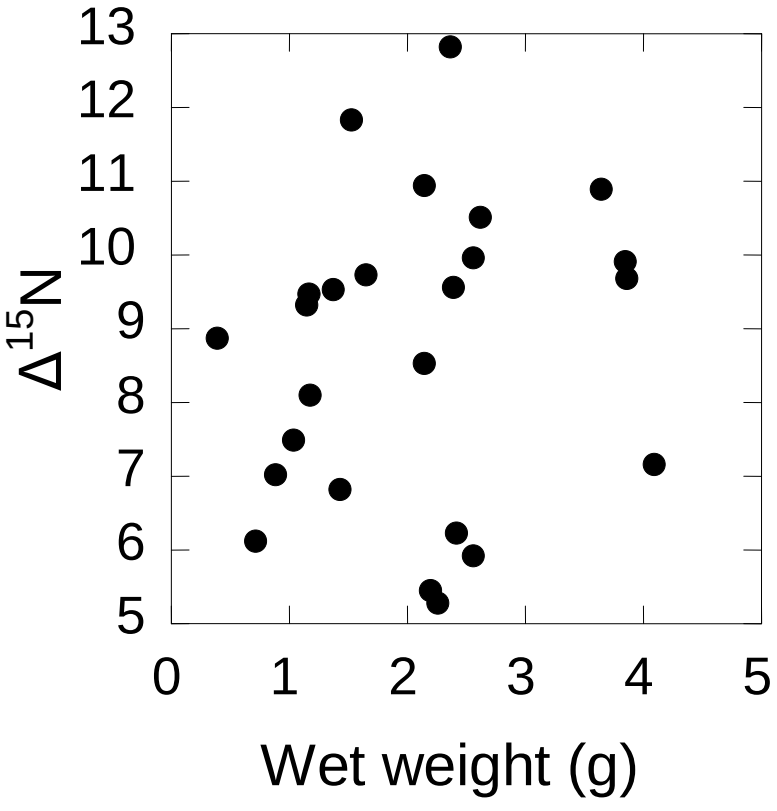

Figure 6.15

Table 6.1. Summary of the 3-way ANOVA for Mesh size, Wrack type and Time on mass loss % DW remaining of wrack material used in litterbags experiment (Study 1). NS = not statistically significant for $\alpha = 0.05$. *p*-values in **bold** indicate significance at $\alpha = 0.05$.

Source	df	MS	*F*-ratio	*p*
Mesh size	1	8.535	0.234	NS
Wrack type	1	6126.445	22.243	**< 0.01**
Time	5	16236.506	1249.398	< **0.001**
Mesh size x Wrack type	1	1.286	0.067	NS
Mesh size x Time	5	36.450	2.805	**0.021**
Wrack type x Time	5	275.432	21.194	< **0.001**
Mesh size x Wrack type x Time	5	19.238	1.480	0.203
Error	95	12.995		

Table 6.2. Summary of the 3-way ANOVA for Wrack type, Species (nested within Wrack type) and Time on mass loss (% DW remaining) of wrack material used in litterbags experiment (Study 2). NS = not statistically significant for $\alpha = 0.05$. *p*-values in **bold** indicate significance at $\alpha = 0.05$.

Source	df	MS	*F*-ratio	*p*
Wrack type	1	21461.918	28.675	< **0.001**
Species (Wrack type)	2	13191.430	17.625	< **0.005**
Time	4	8937.814	11.942	< **0.005**
Wrack type x Time	4	1126.690	1.505	NS
Species (Wrack type) x Time	8	748.458	27.643	< **0.001**
Error	112	27.076		

Table 6.3. Summary of the 3-way ANOVA for Wrack type, Species (nested within Wrack type) and Time on % C, % N (√-transformed) and the C:N ratio of wrack material used in litterbags experiment. NS = not statistically significant for $\alpha = 0.05$. *p*-values in **bold** indicate significance at $\alpha = 0.05$.

		%C			%N (√-transformed)			C:N		
Source	df	MS	*F*-ratio	*p*	MS	*F*-ratio	*p*	MS	*F*-ratio	*p*
Wrack type	1	55.876	undefined		0.073	undefined		238.254	undefined	
Species (Wrack type)	2	41.724	11.341	< **0.05**	0.014	1.000	NS	408.012	2.238	NS
Time	2	4.726	1.285	NS	0.001	0.071	NS	11.107	0.061	NS
Wrack type x Time	2	17.024	4.627	NS	0.005	0.357	NS	46.648	0.256	NS
Species (Wrack type) x Time	4	3.679	1.786	NS	0.014	2.800	< **0.05**	182.277	2.660	NS
Error	24	2.060			0.005			68.537		

Table 6.4. Summary of the 3-way ANOVA for the factors of Wrack type, Species (nested within Wrack type) and Time on $\delta^{13}C$ and $\delta^{15}N$ of wrack material used in litterbags experiment (Study 2). NS = not statistically significant for $\alpha = 0.05$. *p*-values in **bold** indicate significance at $\alpha = 0.05$.

		$\delta^{13}C$			$\delta^{15}N$		
Source	df	MS	*F*-ratio	*p*	MS	*F*-ratio	*p*
Wrack type	1	689.938	undefined		18.190	undefined	
Species (Wrack type)	2	31.163	69.716	**< 0.001**	106.918	279.890	**< 0.001**
Time	2	1.022	2.286	NS	3.589	9.395	**< 0.05**
Wrack type x Time	2	1.302	2.913	NS	0.497	1.301	NS
Species (Wrack type) x Time	4	0.447	1.288	NS	0.382	0.242	NS
Error	24	0.347			1.581		

Table 6.5. Summary of nearshore fish and macroinvertebrate species captured in five seine net hauls at 5 beaches in each of 3 Regions on 2 occasions. W = winter, S = summer.

	SE		Fleurieu		Metro		Total
Visit	W	S	W	S	W	S	
Fish							
Tetractenos glaber (Freminville 1813)	0	0	1	7	72	10	90
Aldrichetta forsteri (Valenciennes 1836)	0	70	5	0	2	0	77
Favonigobius lateralis (Macleay 1881)	4	0	16	29	7	3	59
Leptatherina presbyeroides (Richardson 1843)	0	14	0	0	13	2	29
Myxus elongates (Gunther 1861)	0	0	0	0	0	13	13
Ammotretis rostratus (Gunther 1862)	0	2	0	0	0	1	3
Acanthopagrus butcheri (Munro 1949)	0	0	1	0	0	0	1
Macroinvertebrates							
Paridotea ungulata (Pallas 1172)	0	79	0	0	0	0	79
Ovalipes australiensis (Stephenson & Rees 1968)	0	15	1	11	5	1	33
Portunus pelagicus (L. 1766)	0	0	0	0	1	0	1
Number of individuals	4	180	24	47	100	30	385
Number of species	1	5	5	3	6	6	10

Table 6.6. Summary of a) the 3-way ANOVA for the factors of Visits, Regions and Beaches (nested within Regions) and b) the 2-way ANOVA for Visits and Regions on the abundance (4^{th} root-transformed) and species richness (√-transformed) of fish and macroinvertebrates caught in seine netting. NS = not statistically significant for $\alpha = 0.05$. *p*-values in **bold** indicate significance at $\alpha = 0.05$.

a)

		Abundance (4^{th} root-transformed)			Species richness (√-transformed)		
Source	df	MS	*F*-ratio	*p*	MS	*F*-ratio	*p*
Visit	1	2.950	1.864	NS	1.824	1.564	NS
Region	2	0.147	undefined		0.582	undefined	
Beach (Region)	12	1.862	1.176	NS	1.344	1.153	NS
Visit x Region	2	3.931	2.483	NS	1.993	1.709	NS
Visit x Beach (Region)	12	1.583	6.913	< **0.001**	1.166	5.489	< **0.001**
Error	120	0.229			0.214		

b)

		Abundance (4^{th} root-transformed)			Species richness (√-transformed)		
Source	df	MS	*F*-ratio	*p*	MS	*F*-ratio	*p*
Visit	1	2.950	6.169	**0.014**	1.824	4.704	**0.032**
Region	2	0.147	0.037	NS	0.582	0.292	0.227
Visit x Region	2	3.931	8.223	< **0.001**	1.993	5.139	**0.007**
Error	144	0.478			0.388		

Table 6.7. Summary of samples taken for stable isotope analyses: taxonomic group, species, number of samples processed (*n*), $\delta^{13}C$ and $\delta^{15}N$ values in ‰. See Appendix B for taxonomy and taxonomic authorities of algae and seagrasses. A blank indicates that the minimum, maximum and se are not necessary because only one sample of that species was analysed.

			$\delta^{13}C$				$\delta^{15}N$			
	Species	*n*	Min	Max	Mean	se	Min	Max	Mean	se
Brown algae	*Acrocarpia* spp.	5	-25.8	-18.8	-23.7	1.3	0.8	3.9	3.0	0.6
	Carpoglossum confluens	1			-21.2				-2.8	
	Caulocystis spp.	3	-19.9	-16.8	-17.9	1.0	3.7	5.0	4.3	0.4
	Cladostephus spongiosus	1			-21.7				5.1	
	Cystophora spp.	14	-23.3	-16.1	-19.5	0.5	-2.4	8.3	2.8	0.7
	Perithalia caudata	4	-25.9	-21.2	-23.2	1.0	5.3	6.9	5.9	0.3
	Phyllospora comosa	3	-22.8	-20.1	-21.4	0.8	6.4	7.9	7.1	0.4
	Platythalia angustifolia	1			-18.5				1.6	
	Sargassum spp.	13	-21.1	-16.0	-18.7	0.5	-1.8	5.9	3.0	0.6
	Scaberia agardhii	10	-20.7	-15.3	-17.8	0.5	3.2	7.2	5.0	0.4
	Scytothalia doryocarpa	1			-19.5				3.3	
	All non-kelp brown algae	56	-25.9	-15.3	-19.7	0.3	-2.8	8.3	3.7	0.3
Kelps	*Ecklonia radiata*	10	-22.9	-19.7	-21.3	0.3	3.4	7.5	5.3	0.4
	Macrocystis angustifolia	6	-20.9	-12.1	-17.5	1.3	5.2	6.9	6.2	0.3
	All kelps	16	-22.9	-12.1	-19.8	0.7	3.4	7.5	5.6	0.3
Green algae	*Caulerpa brownii*	2	-29.4	-25.1	-27.3	2.2	5.8	6.1	5.9	0.1
	Halimeda cylindracea	1			-11.2				5.4	
	Ulva lactuca	2	-16.0	-15.7	-15.8	0.1	13.7	16.5	15.1	1.4
	All green algae	5	-29.4	-11.2	-19.5	3.4	5.4	16.5	9.5	2.3

	Species	*n*	$\delta^{13}C$ Min	Max	Mean	se	$\delta^{15}N$ Min	Max	Mean	se
Red algae	*Gracilaria* spp.	6	-22.9	-17.1	-18.7	0.9	4.6	11.4	8.5	1.1
	Phacelocarpus peperocarpus	2	-35.5	-34.2	-34.9	0.7	4.2	4.6	4.4	0.2
	Plocamium mertensii	1			-29.0				6.7	
	All red algae	9	-35.5	-17.1	-23.4	2.5	4.2	11.4	7.4	0.9
Seagrass	*Amphibolis antarctica*	11	-16.1	-10.7	-12.9	0.5	1.5	9.7	6.3	0.7
	Posidonia australis	7	-11.2	-7.7	-9.4	0.4	0.5	6.7	4.0	1.0
	Posidonia coriacea	3	-11.0	-9.0	-9.7	0.6	1.2	3.6	2.1	0.8
	Posidonia sinuosa	12	-12.2	-8.3	-10.1	0.3	3.0	9.1	6.0	0.6
	Zostera sp.	4	-13.8	-11.7	-12.4	0.5	2.4	10.7	5.1	1.9
	All seagrasses	37	-16.1	-7.7	-11.0	0.3	0.5	10.7	5.3	0.4
Beach invertebrates	*Actaecia pallida*	1			-18.3				-1.1	
	Talorchestia quadrimana	4	-21.0	-18.3	-19.5	0.6	2.2	9.5	5.3	1.6
	T. quadrimana- Female	3	-21.2	-19.2	-20.0	0.6	-0.5	9.7	3.8	3.1
	T. quadrimana- Male	4	-22.0	-18.8	-20.2	0.8	1.6	11.2	5.4	2.1
	Curculionidae larva	1			-11.4				6.0	
	Elmidae	2	-18.6	-14.3	-16.4	2.1	8.0	8.6	8.3	0.3
	Staphylinidae	3	-22.8	-20.2	-21.4	0.8	10.9	12.1	11.4	0.3
	Julidae	2	-22.4	-21.0	-21.7	0.7	-2.7	0.9	-0.9	1.8
	Fly sp.	1			-20.4				9.9	
	Fly larvae	1			-26.1				9.6	
	Fly pupae	2	-26.1	-24.1	-25.1	1.0	8.2	9.5	8.9	0.6
	Sciomyzidae larva	1			-25.9				8.4	
	Trichoptera larva	1			-26.5				10.4	
	Paphies angusta	5	-19.2	-17.4	-18.2	0.3	2.0	12.5	7.7	1.7
	All beach invertebrates	31	-26.5	-11.4	-20.3	0.6	-2.7	12.5	6.5	0.8

	Species	*n*	$\delta^{13}C$ Min	Max	Mean	se	$\delta^{15}N$ Min	Max	Mean	se
Nearshore invertebrates	*Paridotea ungulata*	4	-26.3	-23.7	-25.3	0.6	5.5	8.4	7.5	0.7
	Ovalipes australiensis	21	-23.5	-14.5	-19.1	0.7	7.5	13.7	10.7	0.3
	Portunus pelagicus	1	-	-	-15.1	-	-	-	13.3	-
	All nearshore invertebrates	26	-26.3	-14.5	-19.9	0.8	5.5	13.7	10.3	0.4
Fish	*Acanthopagrus butcheri*	1	-	-	-18.3	-	-	-	11.1	-
	Aldrichetta forsteri	12	-24.0	-16.0	-19.2	0.7	8.8	11.3	10.1	0.3
	Ammotretis rostratus	2	-17.6	-15.2	-16.4	1.2	9.1	9.8	9.4	0.4
	Favonigobius lateralis	25	-19.2	-14.5	-16.4	0.3	5.3	12.8	8.7	0.4
	Leptatherina presbyeroides	8	-23.4	-15.1	-19.2	1.2	11.6	17.1	13.3	0.7
	Myxus elongatus	5	-17.6	-16.6	-17.3	0.2	10.4	12.5	11.6	0.4
	Tetractenos glaber	13	-19.3	-15.2	-16.8	0.4	8.5	13.5	11.4	0.4
	All fish	66	-24.0	-14.5	-17.3	0.2	5.3	17.1	10.2	0.3
	All taxa	248	-35.5	-7.7	-18.0	0.3	-2.8	17.1	7.1	0.2