INVENTORY OF ROCK TYPES, HABITATS, AND BIODIVERSITY ON ROCKY SEASHORES IN SOUTH AUSTRALIA'S TWO SOUTH-EAST MARINE PARKS: Pilot Study

A report to the South Australian Department of Environment, Water, and Natural Resources

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Abstract

Geological, habitat, and biodiversity inventories were conducted across six rocky seashores in South Australia's (SA) two south-east marine parks during August 2014, prior to the final implementation of zoning and establishment of management plans for each marine park. These inventories revealed that the sampled rocky seashores in SA's South East Region were comprised of several rock types: a soft calcarenite, Mount Gambier limestone, and/or a harder flint. Furthermore, these inventories identified five major types of habitat across the six sampled rocky seashores, which included: emersed substrate; submerged substrate; boulders; rock pools; and sand deposits. Overall, a total of 12 marine plant species and 46 megainvertebrate species were recorded across the six sampled seashores in the Lower South East and Upper South East Marine Parks. These species richness values are considerably lower than those recorded previously for rocky seashores in other parts of SA. Low species richness may result from the type of rock that constitutes south-east rocky seashores, the interaction between rock type and strong wave action and/or large swells, or may reflect the time of year (winter) during which these inventories were conducted. The species richness and space occupancy of marine plants displayed no significant difference among sampled sites, although a significant difference in the structure of marine plant assemblages was detected among sites (*p*-value = 0.0001). Exploration of patterns within the megainvertebrate assemblage revealed very strong canonical correlations (δ_1 = 0.98 and δ_2 = 0.85) between invertebrate assemblage structure and the type of habitats that were sampled. With a megainvertebrate species richness two standard deviations greater than the regional average, Racecourse Bay West was identified as a potential hotspot for intertidal megainvertebrates. Due to the short timeframe of the current pilot project, the data presented here should be viewed as the first step in creating a baseline of the geology, habitats, and biodiversity for rocky seashores in SA's two south-east marine parks. Ideally, this report should be supplemented by a replicated sampling regime, that spans multiple seasons, a greater spread of sites, and is balanced across seashores of hard, soft, and mixed rock types, to capture data on the true variability within marine plant and megainvertebrate assemblages present on rocky seashores in SA's south-east marine parks.

Introduction

A management tool for protecting marine environments worldwide is the establishment of marine parks, which have protocols in place to govern accessibility and the nature of activities that can be undertaken within their boundaries (Agardy et al. 2003). Embracing this concept, the South Australian (SA) government established a network of nineteen multiple-use marine parks across the state to protect its iconic marine species and habitats from growing anthropogenic pressures (DEWNR 2014). Represented within this network of marine parks are rocky seashores, which constitute the areas of rocky coastline exposed to air during the lowest tides, extending up to a level on the shore that is periodically submerged underwater during the highest tides, or reached by the spray of waves (Benkendorff et al. 2008; Garcia and Smith 2013). Rocky seashores support a diverse suite of benthic marine plants and invertebrates which include, but are not limited to algae, seagrasses, lichens, molluscs, crustaceans, echinoderms, sea anemones, sponges, ascidians, polychaetes and nemerteans (Benkendorff et al. 2008). The potential biological importance of SA rocky seashores is reflected in the fact that over 90 % of the marine invertebrate fauna of southern Australia is endemic (Gowlett-Holmes 2008). Furthermore, the diversity and rate of endemism of southern Australian marine invertebrate fauna is higher than for many other temperate marine regions globally (Gowlett-Holmes 2008).

Effective conservation and management programmes preferably integrate our current understanding of how the structure of marine assemblages are influenced through the interaction of biological and physical variables, drawing upon a detailed understanding of distribution, abundance and life history of each species in response to these interactions (Brooks et al. 2004; Banks and Skilleter 2007). Regrettably, the links between biota and environment remain largely unstudied for any suite of species and their associated habitats (Davidson and Chadderton 1994; Underwood and Chapman 2001; Brooks et al. 2004; Banks and Skilleter 2007). Despite their likely biological importance, SA's rocky seashores are no exception, with the types of rock that constitute them generally unknown, and the benthic assemblages that inhabit them largely unstudied. This is problematic, as a baseline understanding of intertidal geology and biodiversity is necessary to know what is being protected, design effective management and conservation strategies, and for assessing how effective these strategies are in achieving their specified management and conservation objectives.

Consequently, the principal aim of this pilot project was to provide a preliminary assessment of six rocky seashores currently protected in the Lower South East and Upper South East Marine Parks along SA's south-east coast. Specifically, dedicated geological, habitat, and biodiversity inventories were conducted for four shores in General Managed Use Zones and two shores in Habitat Protection Zones during the austral winter of 2014. Rocky seashores in Sanctuary Zones or Restricted Access Zones were not assessed during this study due to their limited availability. Each inventory assessed the abiotic characteristics of each shore, capturing information on the type(s) of rock and habitats that dominate each site. Additionally, biological surveys were conducted for each type of identified habitat, for each sampled shore, to quantify the algal and seagrass (hereafter *marine plant*) and megainvertebrate assemblage specific to each habitat type. While these inventories should not be considered as definitive for the overall biodiversity at each site, they do mark the beginning of establishing a baseline of intertidal biodiversity for these seashores. Additional inventories that assess a greater spread of sites, with seasonal replication, are necessary to build a comprehensive baseline of intertidal biodiversity on rocky seashores throughout SA's south-east marine parks. However, these inventories can be used as the cornerstone for developing and implementing an ongoing south-east marine parks intertidal monitoring program. This would not only facilitate the development of a comprehensive baseline for south-east rocky seashore biodiversity, but could ultimately be used to evaluate and enhance the management objectives of each marine park in relation to rocky seashores.

Methods

Due to unfavourable weather and tidal conditions over winter, just six sites were selected for geological, habitat, and biodiversity inventories (Figure 1). Four of these sites were located in General Managed Use Zones, which were Lake Charro, Robe South, Racecourse Bay West, and Racecourse Bay East (Table 1). The remaining two sites were situated in Habitat Protection Zones, which were Rainbow Rocks and Nora Creina (Table 1). No sites within Sanctuary Zones or Restricted Access Zones were assessed during this study. Restricted Access Zones were not sampled because this level of marine park protection is not represented within SA's two south-east marine parks, while Sanctuary Zones were not sampled due to the difficulty in finding a suitable rocky seashore within this zone to sample during winter. In total, three sites each were located in the Upper South East and Lower South East Marine Parks, respectively (Figure 1). All inventories were undertaken during the final week of August 2014, during suitable daytime low tides (predicted low tide ≤0.70 m AHD).

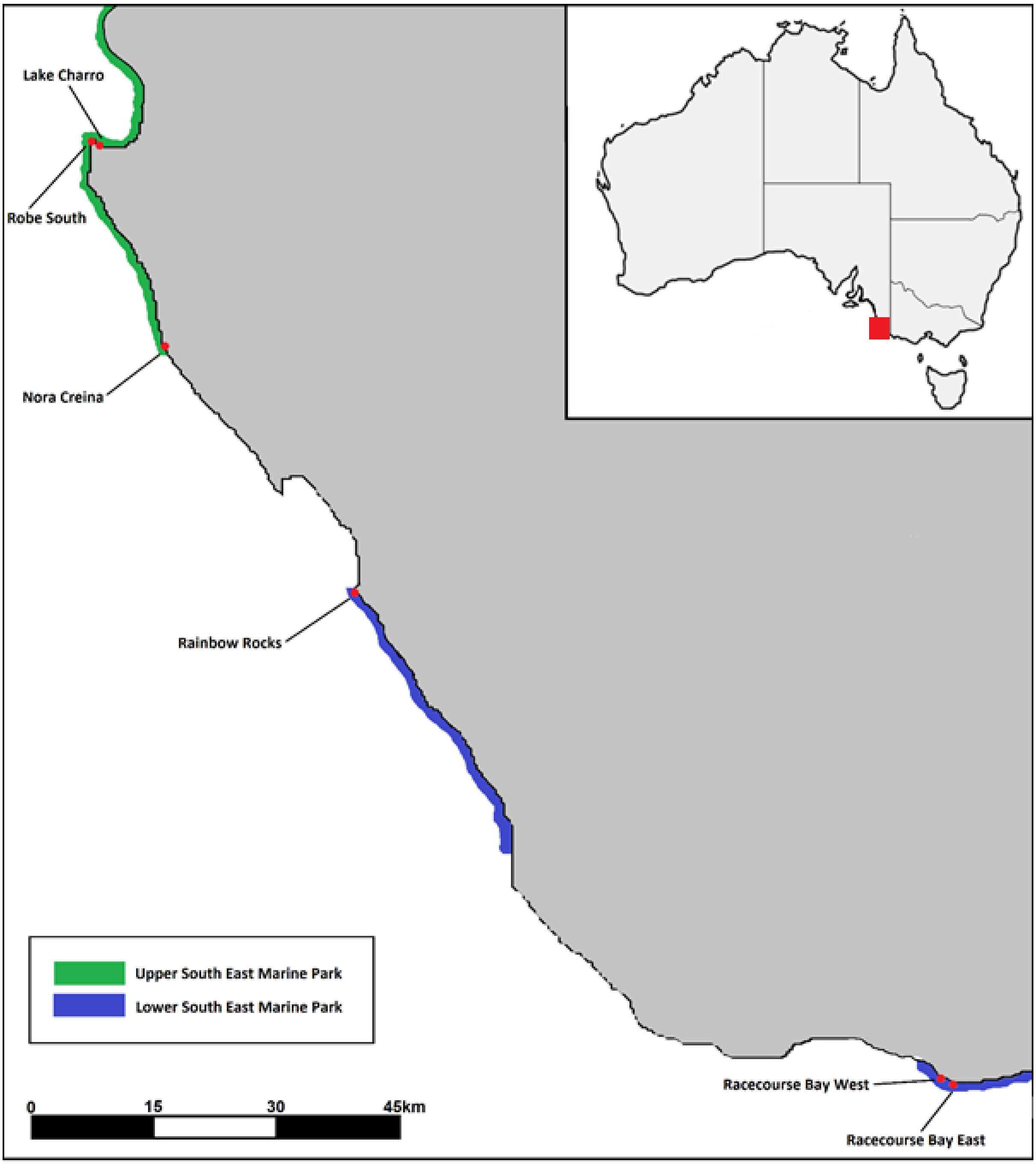

Figure 1: Map depicting sites sampled during geological, habitat, and biodiversity inventories in the Lower South East and Upper South East Marine Parks during winter 2014.

Table 1: The location, date surveyed, predicted tidal and observed weather conditions for geological, habitat, and biodiversity inventories in SA's South East Region. The aspect of each site is provided for the principal direction looking out to sea. The average slope and dominant rock types for each shore are also specified.

Site	**Latitude**	**Longitude**	**Marine park name**	**Marine park zone**	**Survey date**	**Predicted tidal height at sampling (m) AHD**	**Weather at sampling**	**Aspect of the shoreline**	**Wave exposure (DEWNR class)**	**Shore slope (%)**	**Dry substrate colour**	**Rock type(s)**
Racecourse Bay East	38°03'27.62" S	140°46'01.49"E	Lower South East	General Managed Use	28/08/2014	0.4	Sunny	South	Low	0.84	Light grey	Flint
Racecourse Bay West	38°03'31.52" S	140°44'53.94"E	Lower South East	General Managed Use	29/08/2014	0.5	Sunny	South	Low	0.68	Light grey-yellow	Mount Gambier limestone & flint
Rainbow Rocks	37°34'16.51" S	140°06'42.47"E	Lower South East	Habitat Protection	30/08/2014	0.7	Sunny	South-west	Moderate	-1.49*	Dull orange	Calcarenite
Nora Creina	37°19'46.34" S	139°50'54.97"E	Upper South East	Habitat Protection	30/08/2014	0.5	Sunny	South-west	Moderate	3.32	Light yellow	Calcarenite
Robe South	37°09'55.30" S	139°44'34.84"E	Upper South East	General Managed Use	27/08/2014	0.7	Cloudy	South-west	Low	5.61	Dull orange	Calcarenite
Lake Charro	37°09'44.29" S	139°45'51.31"E	Upper South East	General Managed Use	27/08/2014	0.4	Sunny	North-east	Low	0.8	Light brown	Calcarenite

* The negative shore slope % recorded at Rainbow Rocks is driven by this rocky seashore sloping downwards from front to back (i.e. the shore is highest closest to the sea).

Abiotic characteristics of the shore

Latitude and longitude co-ordinates were recorded via GPS from the middle of the seashore at each site, along with a summary of the date, observed weather and predicted tidal conditions at the time sampling was conducted (Table 1). The aspect of each shore, relative to the ocean, was measured with a compass (Table 1). Shore slope was quantified for each site along a minimum of three transects perpendicular to the ocean, which extended from the low tide mark at the time of sampling to the top of the rocky seashore. A clinometer and graduated staff were used to measure the slope of the shore along each transect, with an average value calculated per site (Table 1). Substrate colour was approximated by comparing the colour of apparently dry substrate samples against standardised soil colour charts (Table 1). The rock type(s) that dominated each site were determined by collecting three small representative samples of each rock type observed, and presenting these rock samples to Claudia Flaxman, a geologist at the University of Adelaide, for accurate identification. Hardness, the measure of a rock's or mineral's resistance to being scratched or indented, was measured using Moh's scale of scratch hardness, which arranges 10 minerals in increasing order of scratch hardness, ranging from talc (1 = softest) through to diamond (10 = hardest) (Tabor 1954, 1956). Using this scale, it was possible to classify all rock types into two general categories based on their hardness, soft versus hard. Soft rock encompassed rock types with a scratch hardness ≤4 using Moh's scale, while hard rock encompassed rock types with a scratch hardness >4 using Moh's scale (Liversage and Benkendorff 2013). The scratch hardness of the softest mineral capable of scratching the rock surface (as opposed to the mineral scratching off on the rock's surface) was assigned to each rock type. Additionally, the modelled wave exposure for each site was recorded using DEWNR's online GIS mapping system (Table 1).

Space occupancy of habitats

Line-intercept transects were employed to quantify the dominant types of intertidal habitat present at each site. Briefly, this method involved measuring the length of transect tape intercepted by the dominant forms of habitat (≥10 cm in length) as continuous segments (Lucas and Seber 1977; Dutton 2007). These measurements were then summed for each type of habitat, and converted into a percentage of the total tape length (Lucas and Seber 1977; Dutton 2007). Categories of habitat included: emersed substrate (i.e. dry bedrock); submerged substrate (i.e. bedrock covered by ≤10 cm of water at low tide); boulders (i.e. rock not attached to the substratum that was fist-sized or larger); rock pools (i.e. areas of the shore covered by >10 cm of water at low tide and where no water exchange occurred with the subtidal environment); and sand deposits (Benkendorff and Thomas 2007). Each transect was deployed perpendicular to the ocean, extending from the low tide mark at the time of sampling to the top of the rocky seashore (Underwood 1981). Due to the six sampled rocky seashores having vastly different alongshore lengths, three replicate transects were measured at the smaller shores (Rainbow Rocks, Nora Creina, Robe South, and Lake Charro), and five replicate transects were measured at the larger shores (Racecourse Bay East and Racecourse Bay West).

Biodiversity inventories

Each site was stratified according to the dominant types of habitat identified using line-intercept transects, with biodiversity inventories conducted separately for emersed substrate, submerged substrate, boulders, and rock pools. Previous studies have shown distinct differences in marine assemblages across these four intertidal habitats (Underwood 1981; Underwood and Chapman 2001; Smith 2005; Goodsell et al. 2007). No inventories were conducted during this study for the sand deposit habitat. The space occupancy of sessile species (algae, seagrass, tube worms, and mussels) was quantified using the same line-intercept transects employed when identifying habitat types (described above).

For the remaining intertidal invertebrate assemblage (including barnacles, which do not generally form dense aggregations on any of the six sampled seashores), 30-minute timed-search (TS) surveys were conducted. Because many intertidal species often display a patchy and over-dispersed distribution (Underwood and Chapman 2001; Chapman 2002a, b, 2005; Grayson and Chapman 2004), or have naturally low abundances on rocky seashores (Benkendorff 2003; Goodsell et al. 2007), TS surveys represent the most effective means of surveying large sections of the seashore, to ensure data is captured on the rare or over-dispersed abundances of some intertidal species (Benkendorff 2003). For TS surveys, all faunal species >5 mm (hence 'megainvertebrates') encountered within a 30-minute timeframe were recorded and ranked according to their relative abundance (Dutton 2007). Categories of abundance included: absent (0 individuals); very uncommon (1-2 individuals); moderately common (3-10 individuals); common (11-50 individuals); and abundant (≥51 individuals). Biota was identified in the field to species level wherever possible with the exception of the limpet genera *Notoacmea* and *Siphonaria*, due to the difficulty in distinguishing between each species belonging to those genera *in situ.* For the genus *Notoacmea*, a species complex including *Notoacmea flammea*, *N. mayi* and *N. alta* was acknowledged, while for *Siphonaria*, a species complex including *Siphonaria diemenensis* and *S. funiculata* was recognised. In any ambiguous cases of species identification, specimens were digitally photographed for later identification in the laboratory.

The total number of marine plant and megainvertebrate species per site (i.e. species richness) was determined by pooling the data collected from each line-intercept transect and TS survey. Sites with a species richness at least two standard deviations higher than the mean (the mean being the average species richness across the six sampled sites) were identified as potential biodiversity hotspots for marine plants and megainvertebrates, respectively, on rocky seashores in SA's south-east (Benkendorff and Davis 2002).

Data analysis and presentation

To determine whether the percentage cover or species richness of sessile species measured using line-intercept transects differed among sites, univariate analyses were conducted using the SYSTAT version 13 statistical package. Where data did not meet the assumptions for normality of distribution or homogeneity of variances, a square-root transformation was performed on the raw data. Once complete, one-factor ANOVAs were designed and run to test for differences ($\alpha = 0.05$) among sites for the total percentage cover of marine plants, the total percentage cover of marine plant divisions, and the species richness of marine plant divisions. The divisions of marine plants examined during this study included: Rhodophyta (red algae); Heterokontophyta (brown algae); Chlorophyta (green algae); and Magnoliophyta (seagrass). Histograms were prepared to compare the mean (± standard error) percentage cover or species richness of marine plants, and divisions of marine plants, among sites from replicated transects. To determine whether the sampled sessile assemblage differed among sites, univariate analyses were conducted using the PRIMER version 6 and PERMANOVA+ add-on statistical package (Anderson et al. 2008). A similarity matrix was prepared using Bray-Curtis similarity on untransformed sessile species data with the addition of a dummy variable (value = 1). From this matrix, a non-metric multidimensional scaling (nMDS) ordination plot was generated, and a one-factor PERMANOVA designed and run to test for differences ($\alpha = 0.05$) in the structure of sessile assemblages among sites. When a significant difference was detected among sites, pair-wise tests were run to distinguish which sites were significantly different ($\alpha = 0.05$) from one another, with a *p*-value from Monte Carlo tests used in place of a permutation *p*-value whenever the number of unique permutations <100 (Anderson et al. 2008). A SIMPER analysis was performed to determine which species characterised the sessile assemblage at each site, and which species contributed most to differences in assemblage structure among sites.

To examine the characteristics of the remaining intertidal invertebrate assemblage sampled using semi-quantitative abundance rankings from TS surveys, patterns within the data were explored using

PRIMER & PERMANOVA+. A CLUSTER analysis that encompassed all TS surveys for each site and habitat type was performed, as the habitats searched during TS surveys (emersed substrate, submerged substrate, boulders, and rock pools) have been shown previously (e.g. Underwood 1981; Underwood and Chapman 2001; Smith 2005; Goodsell et al. 2007) to support distinct intertidal assemblages. This group average linkage approach identified four distinct invertebrate assemblages at the 45-50 % Bray-Curtis similarity level. A constrained canonical analysis of principal coordinates (CAP) plot was generated to illustrate differences in two-dimensional ordination space among these four invertebrate assemblages (Anderson et al. 2008). Vectors corresponding to strong Spearman rank correlations (for lengths >0.8) of individual species were superimposed over this CAP plot to illustrate which species best characterised each of the four identified assemblages. This approach was supported by a SIMPER analysis, which was performed to determine which species characterised each assemblage, and which species contributed most to the dissimilarities detected among assemblages. Correlation analyses were conducted in SYSTAT, and scatterplots generated, to examine the relationship between sampled habitats and biodiversity at each site.

Results

Rock type

Three rock types were identified during geological, habitat, and biodiversity inventories in the Lower South East and Upper South East Marine Parks (Table 2). These were a softer calcarenite and Mount Gambier limestone, and a harder flint (Table 2, see Plate 2 in Appendix 1). Calcarenite was recorded at Rainbow Rocks, Nora Creina, Robe South, and Lake Charro, where it occurred as extensive platform areas or heterogeneous reef (Table 2, Plate 1 in Appendix 1). Calcarenite had a Moh’s scratch hardness value of 2.5 and consisted of coarse-grained sand particles cemented together, producing a highly friable form of rock that could be easily fractured by hand (Plate 2 in Appendix 1). Calcarenite was a light-coloured substrate, ranging from a dull orange to light brown in colour. Mount Gambier limestone was recorded at Racecourse Bay West, where it occurred as extensive platform areas (Table 2, Plate 1 in Appendix 1). Mount Gambier limestone had a Moh’s scratch hardness value of 2.0 and consisted of a matrix of fine-grained calcium carbonate particles that produced a highly friable form of rock that could be easily fractured by hand (Plate 2 in Appendix 1). It had a lighter pale-yellow colouration. Flint was recorded at both Racecourse Bay East and Racecourse Bay West, where it only occurred as small, complex boulders (Table 2, Plate 1 in Appendix 1). Flint boulders had a Moh’s scratch hardness value of 8.0 and displayed negligible friability (Table 2). Each flint boulder had a coarse-grained, rough surface texture that was a lighter grey to pale yellow in colouration. The surface conditioning of flint boulders was the result of extensive weathering (C. Flaxman pers. comm.), with un-weathered flint inside of boulders smoother in texture, and a darker black in colouration (Plate 2 in Appendix 1).

Habitats

Five types of habitat were identified using line-intercept transects during geological, habitat, and biodiversity inventories in the Lower South East and Upper South East Marine Parks. These were: emersed substrate; submerged substrate; boulders; rock pools; and sand deposits (Table 3). Emersed substrate was recorded at five of the six sampled sites, and was the dominant type of habitat at each site where it occurred, with a mean percentage cover (± standard error) ranging from 46.6 (± 7.5) % at Racecourse Bay West to 83.2 (± 3.4) % at Robe South (Table 3). Submerged substrate was only recorded at Racecourse Bay, where it had a mean percentage cover of 28.8 (± 3.6) % (Table 3). Boulders were recorded across three sampled sites, with a mean percentage cover ranging from 5.3 (± 5.3) % at Nora Creina to 100 (± 0) % at Racecourse Bay East, where boulders were observed to completely cover the shore (Table 3). Rock pools were recorded at four of the six sampled sites, with a mean percentage cover ranging from 8.7 (± 5.5) % at Racecourse Bay West to 24.1 (± 11.9) % at Nora Creina (Table 3). Although recorded at five of the six sampled sites, sand deposits generally covered only small areas of the seashore, with a mean percentage cover ranging from 0.9 (± 0.9) % at Racecourse Bay West to 16.8 (± 3.4) % at Robe South (Table 3). A graphical representation of the space occupancy of each habitat type, for each replicate transect at each site, can be found in Figures A1a-f in Appendix 2.

Table 2: The types of rock, the form in which they were observed, the Moh's scratch hardness value, the hardness category, the number of sites each rock type was recorded at, and the number of habitats observed for each rock type identified during geological, habitat and biodiversity inventories in SA's South East Region.

Rock type	**Form**	**Moh's scratch hardness value**	**Hardness category**	**Number of sites where rock was recorded**	**Number of habitats observed**
Mount Gambier limestone	Platforms	2.0	Soft	1	3
Calcarenite	Platforms & heterogeneous reef	2.5	Soft	4	3
Flint	Boulders	8.0	Hard	2	1

Table 3: Mean percent cover (± standard error) of the habitat types identified at each site using line-intercept transects during geological, habitat, and biodiversity inventories in SA's South East Region. Key: - habitat not present at sampled site, * habitat present at sampled site but not measured on transects.

Habitat	**Racecourse Bay East**	**Racecourse Bay West**	**Rainbow Rocks**	**Nora Creina**	**Robe South**	**Lake Charro**	**Total sites with that habitat observed**
Emersed substrate	-	46.6 (± 7.5)	69.0 (± 13.5)	67.3 (± 15.0)	83.2 (± 3.4)	66.1 (±14.9)	**5**
Submerged substrate	-	28.8 (± 3.6)	-	-	-	-	**1**
Boulders	100 (± 0)	15.0 (±9.7)	-	5.3 (± 5.3)	-	-	**3**
Rock pools	-	8.7 (± 5.5)	29.3 (±13.2)	24.1 (±11.9)	*	19.2 (± 10.4)	**5**
Sand deposits	-	0.9 (± 0.9)	1.7 (± 1.7)	3.4 (± 3.4)	16.8 (± 3.4)	14.7 (± 8.1)	**5**
Habitats per site	**1**	**5**	**3**	**4**	**3**	**3**	

Site descriptions at time of 2014 winter inventory

Racecourse Bay East (38°03'27.62"S, 140°46'01.49"E) is located in a General Managed Use Zone in the lower segment of the Lower South East Marine Park (Figure 1). This south-facing rocky seashore (relative to the ocean) consists of an extensive boulder/rubble field of light-grey-coloured flint boulders. These boulders are generally of a small size (majority having a major length <40 cm), with weathered and flattened surfaces (Plate 1a in Appendix 1). No underlying bedrock was observed, with multiple layers of boulders (i.e. boulders on top of boulders) often observed. This site is considered to experience a low wave exposure, has an extremely gentle average shore slope of 0.84 % (Table 1), and is sufficiently elevated to make sampling possible during suitable daytime winter low tides (<0.60 m AHD). Significant sedimentation was observed over the lower two-thirds of the flint boulder field at the time of winter inventories.

Racecourse Bay West (38°03'31.52"S**,** 140°44'53.94"E) is located in a General Managed Use Zone in the lower segment of the Lower South East Marine Park (Figure 1). This south-facing rocky seashore (relative to the ocean) consists of an extensive, pale yellow-coloured Mount Gambier limestone platform, which is interspersed throughout by large rock pools and areas of submerged substrate (Plate 1b in Appendix 1). Small light-grey-coloured flint boulders (majority having a major length <40 cm) with weathered and flattened surfaces dominated the mid-upper levels of the eastern side of this shore, with these boulders forming a single layer (i.e. no boulders on top of boulders) on the limestone platform. This site is considered to experience a low wave exposure, has an extremely gentle average shore slope of 0.68 % (Table 1), and is sufficiently elevated to make sampling possible during suitable daytime winter low tides (<0.60 m AHD). Significant sedimentation was observed across the entirety of the limestone platform and flint boulder field at the time of winter inventories.

Rainbow Rocks (37°34'16.51"S, 140°06'42.47"E) is located in a Habitat Protection Zone in the upper segment of the Lower South East Marine Park (Figure 1). This south-west-facing rocky seashore (relative to the ocean) consists of a small, elevated segment of dull-orange-coloured calcarenite platform, which is interspersed throughout by a number of small, yet very deep (average water depth >1 m) rock pools (Plate 1c in Appendix 1). As this platform slopes gently (average 1.49 %) downwards from east at west, and from front to back (i.e. the shore is highest closest to the sea), when waves wash over the seaward extremities of this platform at high tide, water trickles down the platform, flowing from one rock pool to another. This site is considered to experience a moderate wave exposure (Table 1) and is sufficiently elevated to make sampling possible during suitable daytime winter low tides (<0.60 m AHD).

Nora Creina (37°19'46.34"S, 139°50'54.97"E) is located in a Habitat Protection Zone at the southern-most extreme of the Upper South East Marine Park (Figure 1). This south-west-facing rocky seashore (relative to the ocean) consists of a small, highly complex and friable, light-yellow-coloured calcarenite platform, which is interspersed in several places by large, deep rock pools (Plate 1d in Appendix 1). This site is considered to experience a moderate wave exposure, has a steeper average shore slope (when compared against the other sampled sites) of 3.32 % (Table 1), and is sufficiently elevated to make sampling possible during suitable daytime winter low tides (<0.60 m AHD).

Robe South (37°09'55.30"S, 139°44'34.84"E) is located in a General Managed Use Zone towards the northern end of the Upper South East Marine Park (Figure 1). This south-west-facing rocky seashore (relative to the ocean) is dominated by two dull-orange-coloured calcarenite platforms, each located at different heights on the shore (Plate 1e in Appendix 1). The lower calcarenite platform appears to only be emersed during the lowest tides, being rapidly washed over by waves shortly after low tide. This lower platform is interspersed by several large, deep rock pools (water depth >2 m) that were unable to be sampled during winter inventories due to the height of the incoming tide. The upper calcarenite platform appears to be almost permanently emersed, with waves only washing over the seaward extremities of this platform at high tide (N. Janetzki pers. obs.). A small area of vertical shore marks the transition between the upper and lower platforms, giving this shore the steepest average slope (5.61 %) of the six sampled sites. This site is considered to experience a low wave exposure (Table 1), with the lower rock platform having an elevation that makes winter sampling challenging, even during suitable low tides (<0.60 m AHD).

Lake Charro (37°09'44.29"S, 139°45'51.31"E) is located in a General Managed Use Zone towards the northern end of the Upper South East Marine Park (Figure 1). This north-east-facing rocky seashore (relative to the ocean) consists of a small segment of very flat, light-brown-coloured calcarenite platform, which is divided into distinct sections by several very deep rock pools (Plate 1f in Appendix 1). This site is considered to experience a low wave exposure, has an extremely gentle average shore slope of 0.80 % (Table 1), and has a low elevation that makes winter sampling challenging, even during suitable daytime low tides (<0.60 m AHD). Substantial sedimentation was recorded at the time of winter inventories on the mid-lower levels of this calcarenite platform.

Biological observations

The sessile assemblage measured using line-intercept transects consisted of marine algae and seagrass only, with no sessile filter-feeding invertebrates recorded along transects at any of the six sampled sites. A graphical representation of the space occupancy of each sessile species, for each replicate transect at each site, can be found in Figures A1a-f in Appendix 2. While sessile filter-feeding invertebrate species such as the tube-worms *Galeolaria caespitosa* and members of the spirorbid subfamily, plus the barnacle *Tetraclitella purpurascens* were observed under boulders during TS surveys, they were never recorded along transects. Likewise, the mussel *Xenostrobus pulex* was only recorded in several locations at Lake Charro during TS surveys, with no ascidians or sponges recorded at any of the six sampled sites.

A total of 12 marine plant species were recorded across the six sampled sites using line-intercept transects (Table 4). Overall, three species of green algae, four species of brown algae, four species of red algae, and one species of seagrass constituted the 12 recorded plant species (Table 4). Of these species, the green alga *Ulva rigida* was recorded at all six sites, while the brown alga *Hormosira banksii* was recorded at five sites (Table 4). Two species of red algae recorded the fewest observations, with *Amphiroa anceps* and *Laurencia* spp. observed at just one site each (Table 4). For the six sites sampled across SA's South East Region, the mean marine plant species richness per site was 5.67 species, with a standard deviation (SD) = ±2.49 species (Figure 2a). Racecourse Bay West recorded the highest marine pant species richness with nine species, while the lowest species richness of marine plants was recorded at Robe South with two species (Figure 2a). None of the six sampled sites were identified as potential biodiversity hotspots for marine plants, as no site had a marine plant species richness two standard deviations higher than the regional mean (Figure 2a).

The species richness for each division of marine algae was variable among sites, with Racecourse Bay East recording the highest species richness of four for brown algae (Heterokontophyta). Racecourse Bay West had the highest species richness of three for red algae (Rhodophyta), and Racecourse Bay West and Rainbow Rocks the highest species richness of two for green algae (Chlorophyta) (Figure 2b). Similarity percentages were generated to characterise the marine plant assemblage sampled using line-intercept transects for each site (Table A1 in Appendix 3). Nora Creina, Lake Charro, and Racecourse Bay East were all dominated by the green alga *U. rigida*, a coralline red-algal turf dominated Robe South, the green alga *Ulva compressa* dominated Racecourse Bay West, while the brown alga *Scytosiphon lomentaria* dominated Rainbow Rocks (Table A1 in Appendix 3).

For the remaining megainvertebrate assemblage sampled using semi-quantitative abundance rankings during TS surveys, a total of 46 megainvertebrate species were recorded across the six sampled sites (Table 5). Of these species, only the air-breathing limpet *Siphonaria* spp. and the snails *Lunella undulata* and *Cominella lineolata* were recorded at all six sampled sites (Table 5). A further eight invertebrate species were recorded at five of the six sampled sites (Table 5). Eighteen species of invertebrate were only recorded at one site (Table 5). For the six sites sampled across SA's South East Region, the mean megainvertebrate species richness per site was 21.0 species, with a SD = ±5.51 species (Figure 2c). Racecourse Bay West recorded the highest megainvertebrate species richness with 33 species, while the lowest species richness of megainvertebrates was recorded at Rainbow Rocks with 17 species (Figure 2c). Racecourse Bay West was identified as a potential biodiversity hotspot for megainvertebrates, as it had a megainvertebrate species richness more than two standard deviations higher than the regional mean (Figure 2c). The species richness for specific intertidal invertebrate phyla was generally highest at Racecourse Bay West, with the highest species richness of molluscs (20 species), arthropods (7 species) and cnidarians (2 species) all recorded there (Figure 2d). Two species of cnidarians were recorded at Lake Charro, which also had the highest species richness of Echinodermata, with two species recorded (Figure 2d).

Table 4: Species list outlining the mean percent cover (± standard error) of the dominant marine algae and seagrass identified at each site using line-intercept transects during geological, habitat, and biodiversity inventories in SA's South East Region. Key: RBE = Racecourse Bay East; RBW = Racecourse Bay West; RR = Rainbow Rocks; NC = Nora Creina; RS = Robe South; LC = Lake Charro; - = not present at sampled site; and * = present at sampled site but not recorded on transects. Taxonomy checked using the World Register of Marine Species (WoRMS) and correct as of 27/04/2015 (http://marinespecies.org/).

Division	**Class**	**Family**	**Species**	**RBE**	**RBW**	**RR**	**NC**	**RS**	**LC**	**Total sites observed**
Chlorophyta	Ulvophyceae	Codiaceae	*Codium pomoides*	-	-	-	*	-	*	**2**
		Ulvaceae	*Ulva compressa*	-	23.3 (±4.3)	1.6 (±1.6)	-	-	-	**2**
			Ulva rigida	38.3 (±16.9)	8.7 (±5.3)	2.6 (±1.8)	26.8 (±14.4)	2.7 (±2.7)	17.7 (±10.2)	**6**
Heterokontophyta	Phaeophyceae	Hormosiraceae	*Hormosira banksii*	1.3 (±0.6)	11.2 (±5.0)	*	2.1 (±0.9)	-	10.5 (±6.3)	**5**
		Splachnidiaceae	*Splachnidium rugosum*	3.2 (±1.5)	0.5 (±0.3)	-	-	-	1.6 (±1.1)	**3**
		Scytosiphonaceae	*Colpomenia sinuosa*	0.3 (±0.2)	-	-	-	-	0.4 (±0.4)	**2**
			Scytosiphon lomentaria	3.2 (±1.5)	13.6 (±3.7)	15.1 (±4.5)	-	-	-	**3**
Rhodophyta	Florideophyceae	Corallinaceae	*Amphiroa anceps*	-	0.5 (±0.3)	-	-	-	-	**1**
			Mixed coralline turf	3.2 (±1.5)	4.1 (2.5)	-	-	56.5 (±8.3)	5.3 (±5.3)	**4**
		Gelidiaceae	*Capreolia implexa*	0.3 (±0.2)	1.7 (1.1)	-	5.2 (±2.3)	-	-	**3**
		Rhodomelaceae	*Laurencia* spp.	-	-	-	-	-	10.9 (9.0)	**1**
Magnoliophyta	Liliopsida	Zosteraceae	*Zostera tasmanica*	-	1.2 (±1.2)	-	-	-	4.9 (±4.9)	**2**
Marine plant species richness per site				**7**	**9**	**4**	**4**	**2**	**8**	

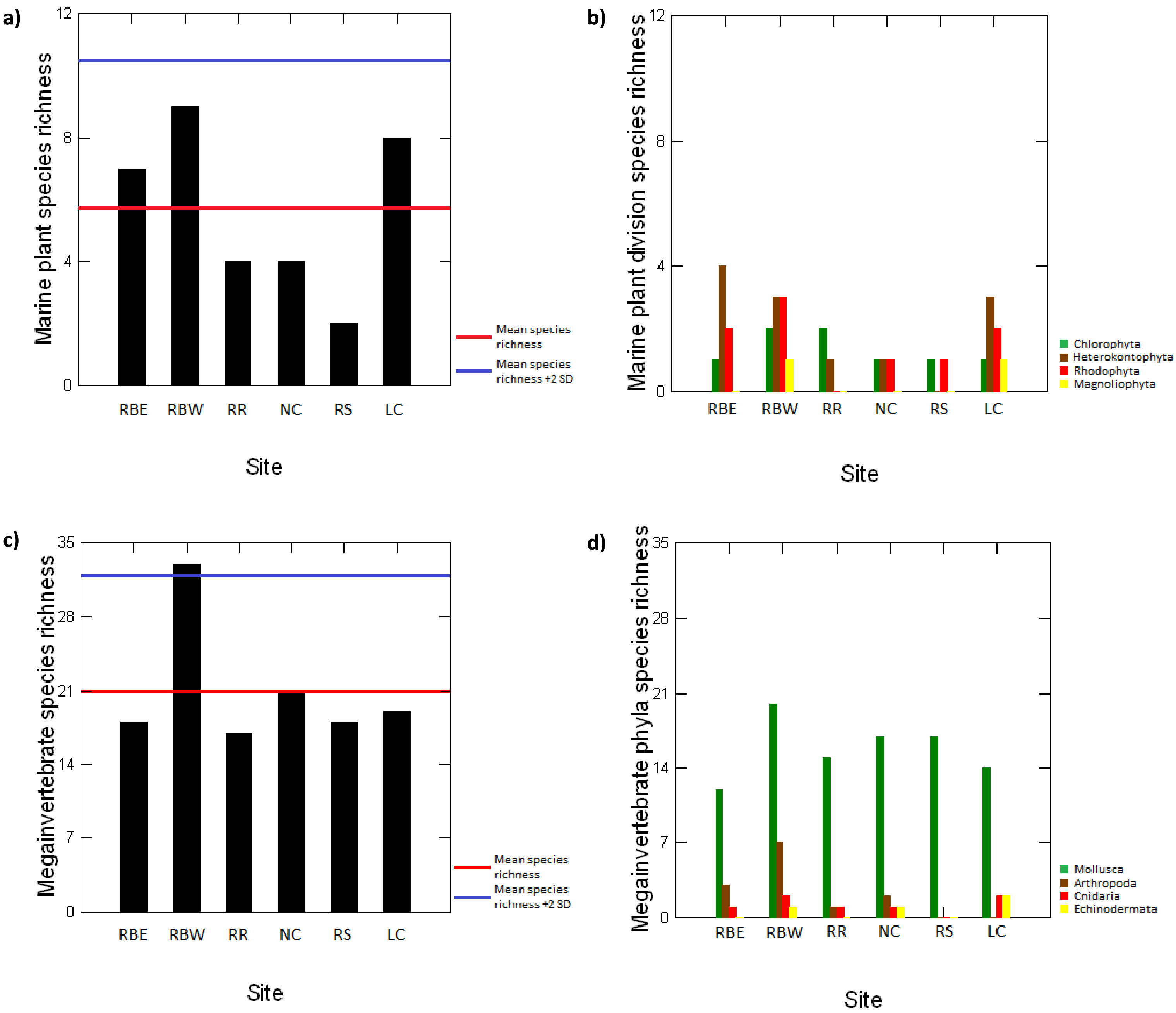

Figure 2: Species richness recorded for each site by pooling marine plant species for replicate transects and megainvertebrate species across TS surveys for: a) marine plants; b) divisions of marine plants; c) megainvertebrates; and d) phyla of megainvertebrates. Key: RBE = Racecourse Bay East; RBW = Racecourse Bay West; RR = Rainbow Rocks; NC = Nora Creina; RS = Robe South; and LC = Lake Charro.

Table 5: Species list for megainvertebrate identified at each site during geological, habitat, and biodiversity inventories in SA's south-east. The megainvertebrate assemblage column specifies which megainvertebrate assemblage(s) (from cluster analysis) that each species was found in. Key: RBE = Racecourse Bay East; RBW = Racecourse Bay West; RR = Rainbow Rocks; NC = Nora Creina; RS = Robe South; and LC = Lake Charro. Taxonomy checked using the World Register of Marine Species (WoRMS) and correct as of 27/04/2015 (http://marinespecies.org/).

Phyla	**Class**	**Family**	**Species**	**RBE**	**RBW**	**RR**	**NC**	**RS**	**LC**	**Total sites observed**	**Megainvertebrate assemblage(s)**
Cnidaria	Anthozoa	Actiniidae	*Actinia tenebrosa*		**X**	**X**	**X**		**X**	**4**	**2, 3, 4**
			Isanemonia australis	**X**	**X**				**X**	**3**	**1, 2, 3, 4**
Platyhelminthes	Rhabditophora	Notoplanidae	*Notoplana australis*		**X**					**1**	**2**
Annelida	Polychaeta	Serpulidae	*Galeolaria caespitosa*	**X**	**X**			**X**	**X**	**4**	**1**
			Spirorbid	**X**	**X**					**2**	**1**
Echinodermata	Asteroidea	Goniasteridae	*Tosia australis*						**X**	**1**	**4**
	Echinoidea	Echinometridae	*Heliocidaris erythrogramma*		**X**		**X**			**2**	**2, 4**
		Temnopleuridae	*Amblypneustes ovum*						**X**	**1**	**4**
Mollusca	Gastropoda	Nacellidae	*Cellana tramoserica*		**X**	**X**	**X**	**X**	**X**	**5**	**1, 3, 4**
		Lottidae	*Notoacmea petterdi*					**X**		**1**	**3**
			Notoacmea spp.	**X**	**X**		**X**	**X**	**X**	**5**	**1, 2, 3**
			Patelloida alticostata			**X**	**X**	**X**	**X**	**4**	**3, 4**
		Neritopsidae	*Nerita atramentosa*	**X**	**X**	**X**	**X**	**X**		**5**	**1, 3, 4**
		Haliotidae	*Haliotis laevigata*		**X**					**1**	**2**
			Haliotis rubra						**X**	**1**	**4**
		Fisurellidae	*Montfortula rugosa*	**X**	**X**					**2**	**1, 2**
		Trochidae	*Austrocochlea constricta*	**X**	**X**	**X**	**X**			**4**	**1, 2, 3, 4**
			Cantharidella balteata						**X**	**1**	**4**
			Chlorodiloma adelaidae		**X**	**X**	**X**	**X**	**X**	**5**	**2, 3, 4**
			Diloma concamerata	**X**	**X**	**X**		**X**		**4**	**1, 3**
			Phasianotrochus eximius					**X**		**1**	**3**
		Turbinidae	*Lunella undulata*	**X**	**X**	**X**	**X**	**X**	**X**	**6**	**1, 2, 3, 4**
		Littorinidae	*Afrolittorina praetermissa*		**X**	**X**	**X**	**X**	**X**	**5**	**1, 3**
			Austrolittorina unifasciata		**X**	**X**	**X**	**X**	**X**	**5**	**1, 3**
			Bembicium nanum	**X**	**X**	**X**	**X**	**X**		**5**	**1, 3**
			Bembicium vittatum			**X**		**X**		**2**	**3**

Phyla	Class	Family	Species	RBE	RBW	RR	NC	RS	LC	Total sites observed	Megainvertebrate assemblage(s)
		Buccinidae	*Cominella lineolata*	**X**	**X**	**X**	**X**	**X**	**X**	**6**	**1, 2, 3, 4**
		Fasciolariidae	*Australaria australasia*				**X**			**1**	**4**
		Batillariidae	*Eubittium lawleyanum*		**X**					**1**	**2**
		Muricidae	*Dicathais orbita*	**X**	**X**		**X**		**X**	**4**	**1, 2, 3, 4**
			Haustrum vinosum	**X**	**X**			**X**		**3**	**1, 2, 3**
		Conidae	*Conus anemone*		**X**	**X**	**X**			**3**	**2, 3, 4**
		Siphonariidae	*Siphonaria* spp.	**X**	**X**	**X**	**X**	**X**	**X**	**6**	**1, 2, 3, 4**
		Aplysiidae	*Aplysia parvula*		**X**		**X**			**2**	**1, 2, 3, 4**
	Polyplacophora		Polyplacophora sp.	**X**						**1**	**1**
		Mopalidae	*Plaxiphora albida*		**X**	**X**	**X**	**X**	**X**	**5**	**1, 2, 3, 4**
	Bivalvia	Mytilidae	*Xenostrobus pulex*						**X**	**1**	**3**
Arthropoda	Maxillopoda	Tetraclitidae	*Tetraclitella purpurascens*	**X**	**X**					**2**	**1, 2**
	Malacostraca	Grapsidae	*Leptograpsus variegatus*				**X**			**1**	**4**
		Hymenosomatidae	*Halicarcinus ovatus*		**X**					**1**	**2**
		Leucosiidae	*Bellidilia laevis*	**X**	**X**					**2**	**1, 2**
		Plagusiidae	*Guinusia chabrus*				**X**			**1**	**4**
		Varunidae	*Cyclograpsus granulosus*	**X**	**X**	**X**				**3**	**1, 2, 3**
		Sphaeromatidae	*Zuzara venosa*		**X**					**1**	**1, 2**
		Ligiidae	*Ligia australiensis*		**X**					**1**	**1**
		Palaemonidae	*Palaemon serenus*		**X**					**1**	**2**
Invertebrate species richness per site				**18**	**33**	**17**	**21**	**18**	**19**		

Percent coverage of marine plants

No significant difference in the space occupancy of marine plants, sampled using line-intercept transects, was detected among sites (Figure 3a, ANOVA *p*-value >0.05). The grand mean for marine plant percentage cover across the six sampled sites was 48.3 % cover, with a SE = 5.9 %. Racecourse Bay West was observed to have the highest percentage cover of marine plants, with a mean percentage cover of 64.7 (± 10.8) %, while Rainbow Rocks had the lowest percentage cover of marine plants, with a mean percentage cover of 19.3 (± 7.7) % (Figure 3a).

A significant difference in the percentage cover of red algae was detected among sites (Figure 3b, ANOVA *p*-value = 0.000). Pair-wise tests indicate that Robe South was significantly different from all other sampled sites, with this difference driven by the much higher percentage cover of a red algal coralline turf at Robe South (mean = 56.5 ± 8.3 %, Table 4) compared to the five other sampled sites (grand mean = 6.0 ± 1.9 %) (Figure 3b, Tables A2 & A3a in Appendix 3).

A significant difference in the percentage cover of brown algae was also detected among sites (Figure 3c, ANOVA *p*-value = 0.017). Pair-wise tests indicate that the percentage cover of brown algae at Racecourse Bay West (mean = 25.2 ± 5.9 %) was significantly different from the percentage cover of brown algae at Nora Creina (mean = 2.1 ± 0.9 %) and Robe South (zero) (Figure 3c, Tables A2 & A3b in Appendix 3). These pair-wise differences were driven by the significantly higher percentage cover of the brown alga *S. lomentaria* at Racecourse Bay West (Table 4).

No significant difference in the percentage cover of green algae was detected among sites (Figure 3d, ANOVA *p*-value >0.05). The grand mean for green algal percentage cover across the six sampled sites was 23.0 % cover, with a SE = 5.2 %. Racecourse Bay East was observed to have the highest percentage cover of green algae, with a mean percentage cover of 38.3 (± 16.9) %, while Robe South had the lowest coverage of green algae, with a mean percentage cover of 2.7 (± 2.7) % (Figure 3d).

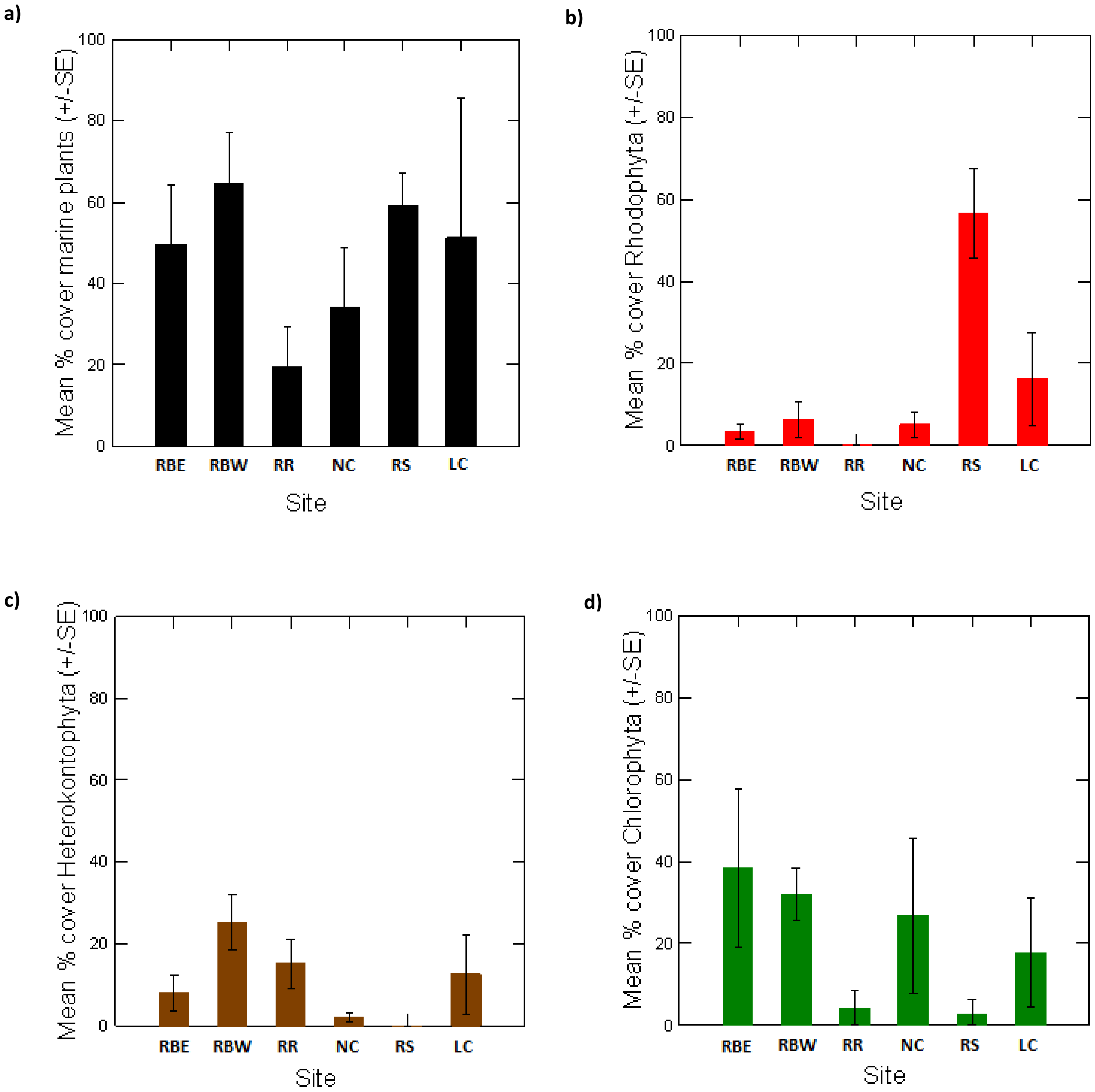

Figure 3: Mean (± standard error) percentage cover of marine plants recorded along line-intercept transects at each site for: a) the whole marine plant assemblage; b) the division Rhodophyta; c) the division Heterokontophyta; and d) the division Chlorophyta. Key: RBE = Racecourse Bay East; RBW = Racecourse Bay West; RR = Rainbow Rocks; NC = Nora Creina; RS = Robe South; and LC = Lake Charro.

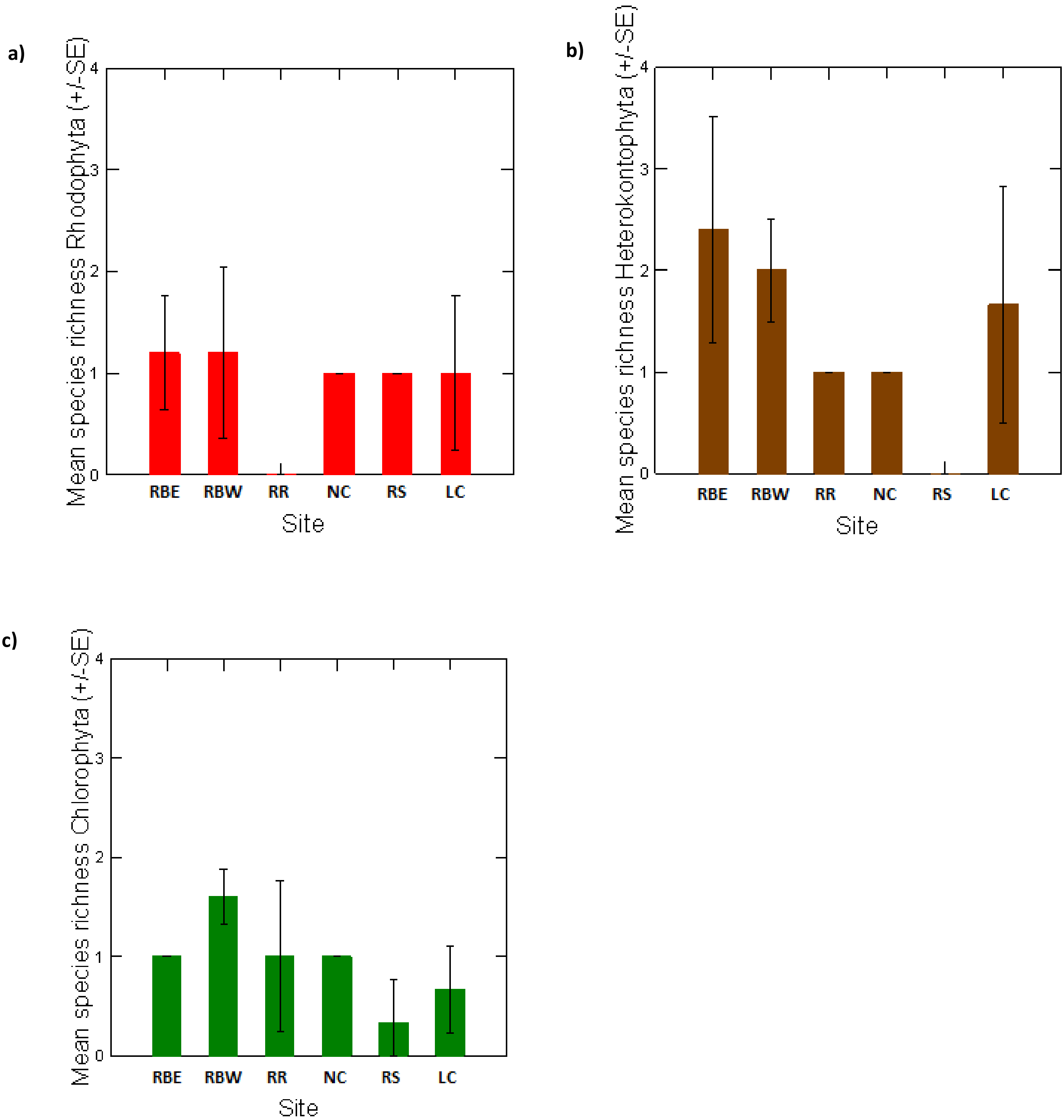

Figure 4: Mean (± standard error) species richness of algae divisions recorded along line-intercept transects at each site for: a) Rhodophyta; b) Heterokontophyta; and c) Chlorophyta Key: RBE = Racecourse Bay East; RBW = Racecourse Bay West; RR = Rainbow Rocks; NC = Nora Creina; RS = Robe South; and LC = Lake Charro.

Species richness of marine plant divisions

No significant difference in the species richness of red algae, sampled using line-intercept transects, was detected among sites (Figure 4a, ANOVA p-value >0.05). The grand mean for red algae species richness across the six sampled sites was 0.95 species, with a SE = 0.21. No significant difference in the species richness of brown algae was detected among sites (Figure 4b, ANOVA p-value >0.05). The grand mean for brown algae species richness across the six sampled sites was 1.50 species, with a SE = 0.30. No significant difference in the species richness of green algae was detected among sites (Figure 4c, ANOVA p-value >0.05). The grand mean for green algae species richness across the six sampled sites was 1.00 species, with a SE = 0.13.

Structure of the marine plant assemblage

An nMDS ordination plot (2D stress = 0.17) from the space occupancy of marine plant species sampled using line-intercept transects was created to examine assemblage structure differences among sites (Figure 5). In particular, the marine plant assemblage at Robe South was quite distinct when compared against the assemblages sampled elsewhere (Figure 5). A subsequent PERMANOVA that examined the distinctness of marine plant assemblage structure differences among sites produced a significant result (PERMANOVA p-value = 0.0001, Table A4 in Appendix 3). Pair-wise tests indicate that the structure of marine plant assemblages was significantly different between each pair of sites except Lake Charro and Racecourse Bay East, Lake Charro and Nora Creina, and Nora Creina and Racecourse Bay East (Monte Carlo test p-value >0.05, Table A5 in Appendix 3). A SIMPER analysis revealed that where a significant difference was detected, average dissimilarity in the structure of marine plant assemblages among sites ranged between 69.2 % for the comparison between Racecourse Bay West and Rainbow Rocks, and 97.8 % for the comparison between Robe South and Rainbow Rocks (Table A6 in Appendix 3). Generally, assemblage structure differences among sites were driven by the higher percentage cover of a single algal species at one of the compared sites (Table A6 in Appendix 3).

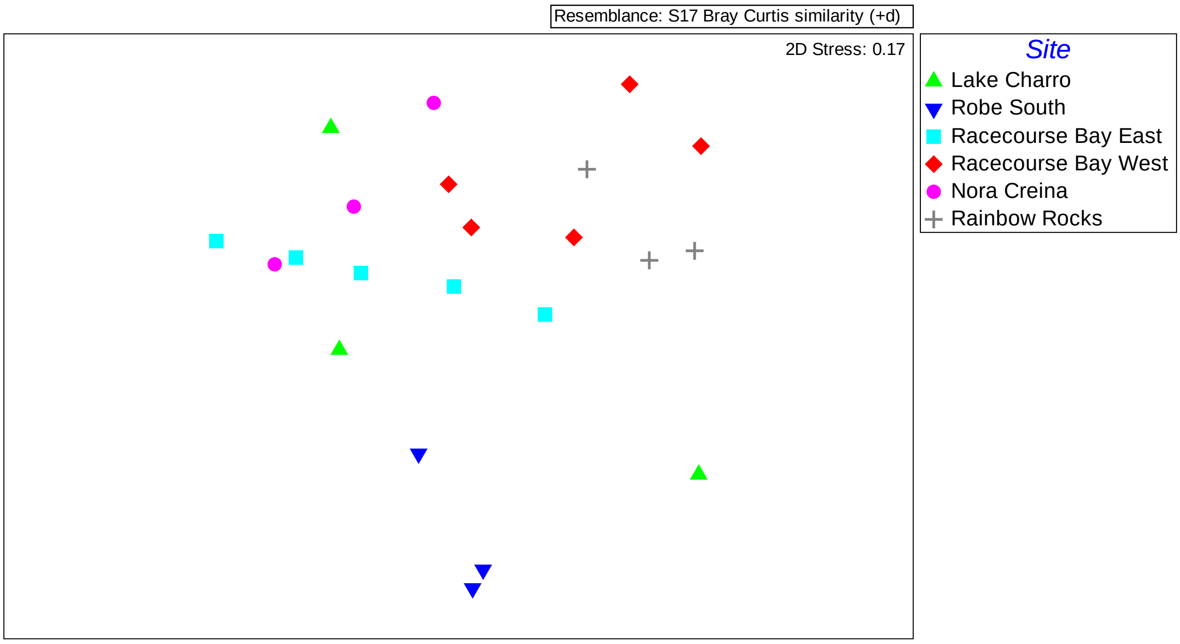

Figure 5: Two-dimensional nMDS ordination plot (based on Bray-Curtis similarity) depicting differences in the structure of marine plant assemblages among sites sampled during geological, habitat, and biodiversity inventories in SA's South East Region. Each point represents a single transect.

Structure of the intertidal megainvertebrate assemblage

A cluster analysis of the megainvertebrate assemblage sampled using semi-quantitative abundance rankings from TS surveys indicated that at approximately 45-50 % Bray-Curtis similarity, surveys clustered into four distinct groups (Figure 6). It is important to acknowledge that each of these groups does not represent a specific location, but rather a specific type of megainvertebrate assemblage (Figure 6). TS surveys from boulder habitats at Racecourse Bay (East and West) clustered into one group (first assemblage), although boulder habitats at Racecourse Bay West were different from those at Racecourse Bay East at approximately 70% Bray Curtis similarity (as indicated by the solid black line differentiating Racecourse Bay East and Racecourse Bay West in the first assemblage box in Figure 6). Surveys from submerged habitats (bedrock and pools) at Racecourse Bay clustered into another (second assemblage), all surveys from emersed habitats plus rock pools at Rainbow Rocks clustered into a third group (third assemblage), while surveys from rock pools at Lake Charro and Nora Creina formed a fourth group (fourth assemblage) (Figure 6). Patterns in the intertidal megainvertebrate data were explored further by using these four assemblages.

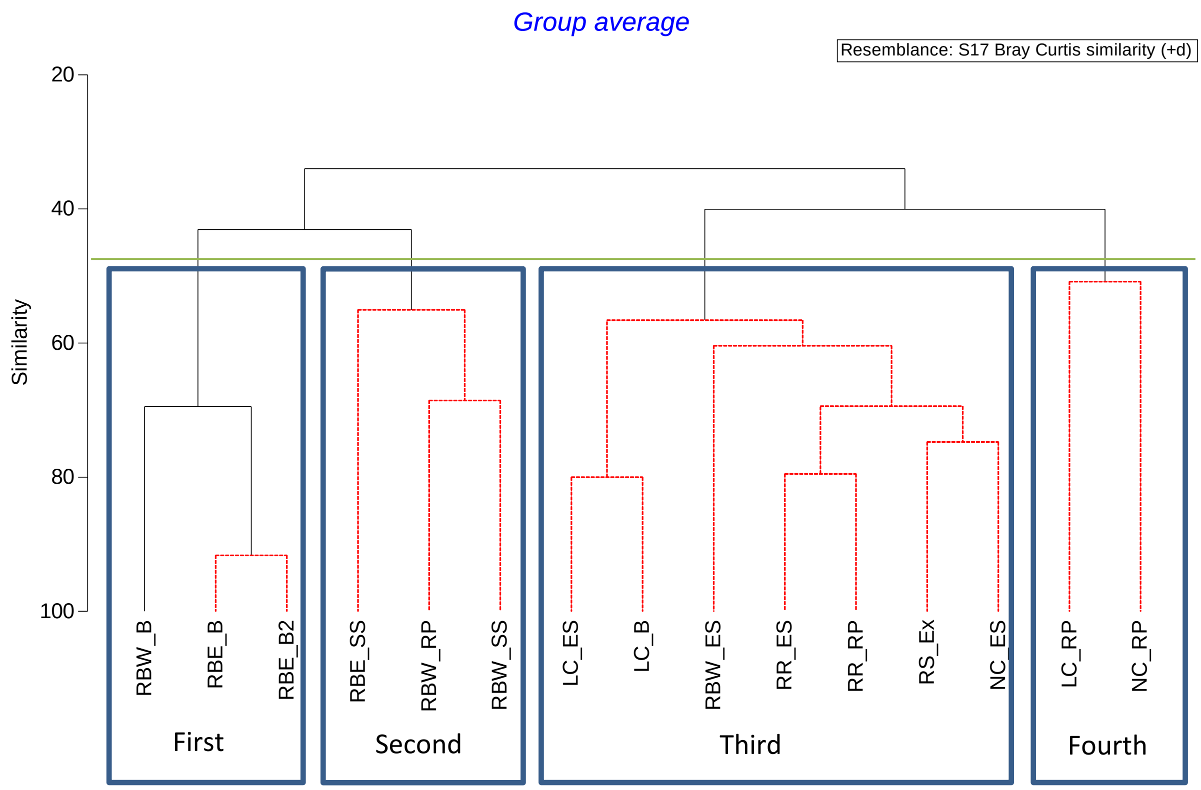

Figure 6: Cluster analysis depicting how individual TS surveys were differentiated into four distinct groups at approximately 45-50 % Bray Curtis similarity value (clear groups denoted by solid black lines but less-certain groups by red lines). Key: RBE = Racecourse Bay East; RBW = Racecourse Bay West; RR = Rainbow Rocks; NC = Nora Creina; RS = Robe South; LC = Lake Charro; _B = Boulders*; _SS = submerged substrate; _ES = emersed substrate; and _RP = rock pools. *Boulder habitats were sampled twice at Racecourse Bay East due to their extensive coverage of the intertidal shore, with the second sampling of boulders denoted by _B2.

A constrained CAP ordination produced very strong canonical correlations (δ_1 = 0.98 and δ_2 = 0.85), strongly supporting the distinction of the four assemblages identified during cluster analysis (Figure 7a). By superimposing vectors (for rho >0.8) over this CAP ordination plot (Figure 7b), and conducting a SIMPER analysis on these four assemblages, it was possible to determine which species characterised each assemblage (Table A7 in Appendix 3). The first assemblage, identified on boulder habitats at Racecourse Bay, was characterised by the relatively high abundances of the snails *N. atramentosa*, *Diloma concamerata*, and *Austrocochlea constricta*, limpet *Notoacmea* spp., and barnacle *T. purpurascens* sheltering underneath boulders (Figure 7b, Table A7 in Appendix 3). The second assemblage, associated with submerged substrate habitats at Racecourse Bay, was characterised by the relatively high abundances of the anemone *Isanemonia australis* and the snail *A. constricta* (Figure 7b, Table A7 in Appendix 3). The third assemblage, identified on emersed substrates at all sites and the small yet very deep rock pools at Rainbow Rocks, was characterised by the periwinkles *Austrolittorina unifasciata* and *Afrolittorina praetermissa*, and the limpets *Siphonaria* spp. and *Cellana tramoserica* (Figure 7b, Table A7 in Appendix 3). The fourth assemblage, identified in rock pools at Lake Charro and Nora Creina, was characterised by the relatively high abundances of the snails *Chlorodiloma adelaidae*, *Lunella undulata*, and *C. lineolata* (Figure 7b, Table A7 in Appendix 3).

A SIMPER analysis also revealed which species contributed most to structural differences being detected among the four megainvertebrate assemblages identified during cluster analysis (Table A8 in Appendix 3). Average dissimilarity in the structure of intertidal megainvertebrate assemblages ranged between 58.5 % for the comparison between the first (Racecourse Bay boulders) and second (Racecourse Bay submerged substrates) assemblages, and 81.9 % for the comparison between the first and fourth (rock pools at Nora Creina and Lake Charro) assemblages (Table A8). Generally, structural differences among assemblages were driven by the higher abundance of several megainvertebrate species for one assemblage when compared against the other (Table A8).

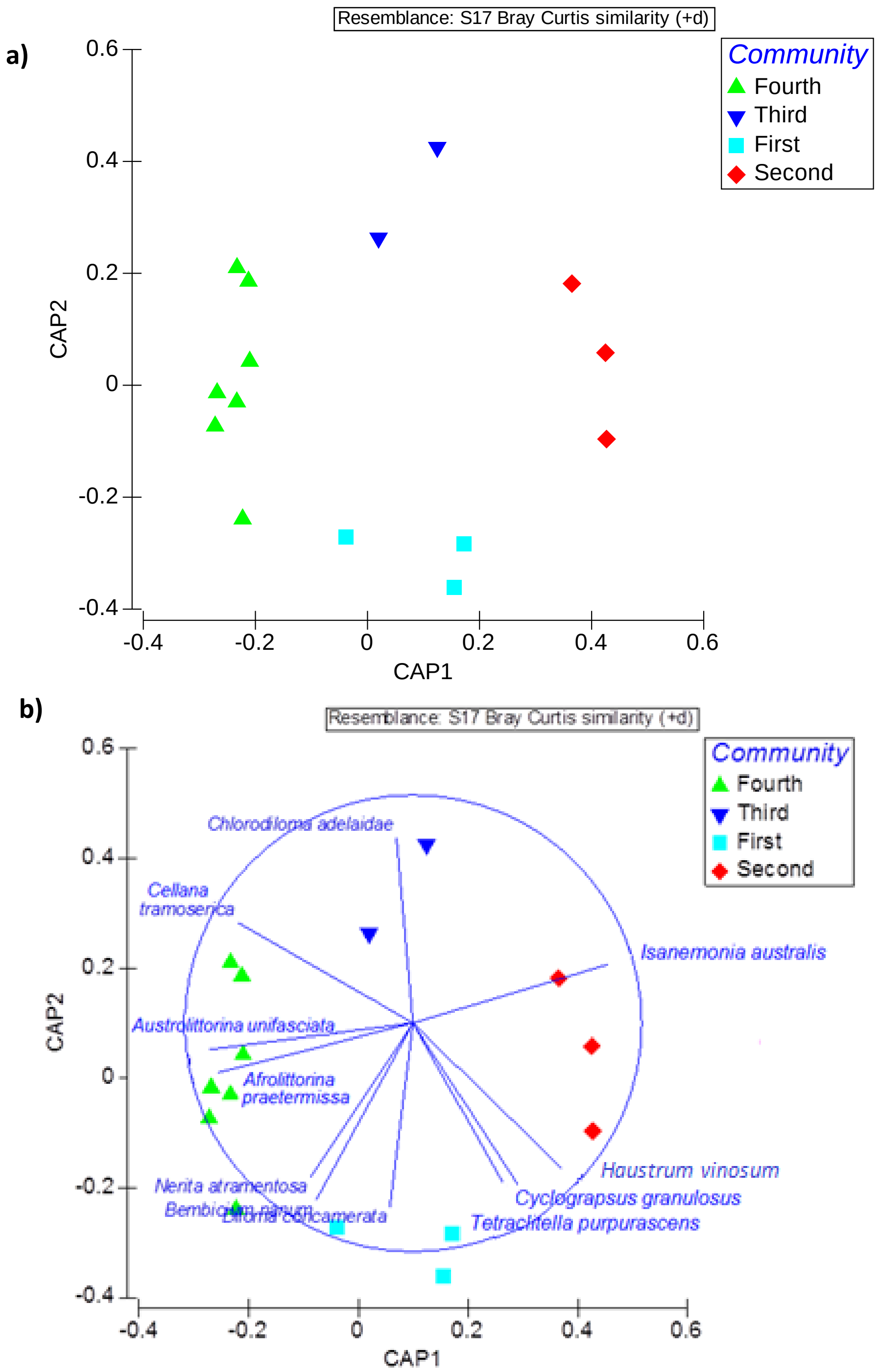

Figure 7: Constrained CAP ordination plot depicting the separation of the four assemblages identified during cluster analysis for: a) the first two canonical correlations (axes); and with b) vector overlay of Spearman rank correlations (for rho >0.8) for individual species contributing to differences in assemblage structure among the four examined groups.

Correlations between sampled habitats and biodiversity

A positive linear correlation (*r* value = 0.584) was detected between the species richness of marine plants sampled using line-intercept transects and the number of habitats sampled at each site

(Figure 8a, see Table A9 in Appendix 3). However, due to the small number of sites sampled (n = 6), this relationship was not statistically significant (p-value >0.05, Table A9 in Appendix 3). The r^2 value for this relationship was 0.34, indicating only a small proportion (approximately one-third) of the total variability in the species richness of marine plants may be accounted for by variation in the number of habitats that were sampled at each site. This indicates that the number of habitats present at a given site will not necessarily act as a strong indicator for the likely marine plant species richness at that site.

A positive linear correlation (r value = 0.766) was detected between the species richness of megainvertebrates sampled using TS surveys and the number of habitats sampled at each site (Figure 8b, Table A9 in Appendix 3). However, due to the small number of sites sampled (n = 6), this relationship was again not statistically significant (p-value >0.05, Table A9 in Appendix 3). Furthermore, this relationship was strongly influenced by the outlier Racecourse Bay West, which positively influenced the strength of the Pearson correlation (r value = 0.11) (Figure 8b). Consequently, the r^2 value of 0.59 for this relationship should be interpreted cautiously. Despite these limitations, this positive linear relationship indicates that as the number of habitats sampled at a site increases, a greater diversity of megainvertebrates may be recorded. Further sampling across a larger number of sites in the region is required to confirm the validity of this relationship. If a significant positive correlation is detected between megainvertebrate species richness and the number of habitats sampled, it may be possible to use the number of habitats present at a site as a viable surrogate to identify which rocky seashores are likely to support a greater diversity of intertidal invertebrates.

A positive linear correlation (r value = 0.594) was detected between the species richness of marine plants sampled using line-intercept transects, and the species richness of megainvertebrates sampled using TS surveys at each site (Figure 8c, Table A9 in Appendix 3). However, again due to the small number of sites sampled (n = 6), this correlation was not statistically significant (p-value >0.05, Table A9 in Appendix 3). Furthermore, this relationship was driven almost entirely by the outlier Racecourse Bay West, which positively influenced the strength of the Pearson correlation (r value = 0.52) (Figure 8c). Upon its removal, almost no correlation whatsoever was detected between marine plant and megainvertebrate species richness (r value = 0.067).This indicates that the species richness of marine plants sampled using line-intercept transects will not indicate the potential species richness of megainvertebrates sampled using TS surveys (and vice-versa) at a given site.

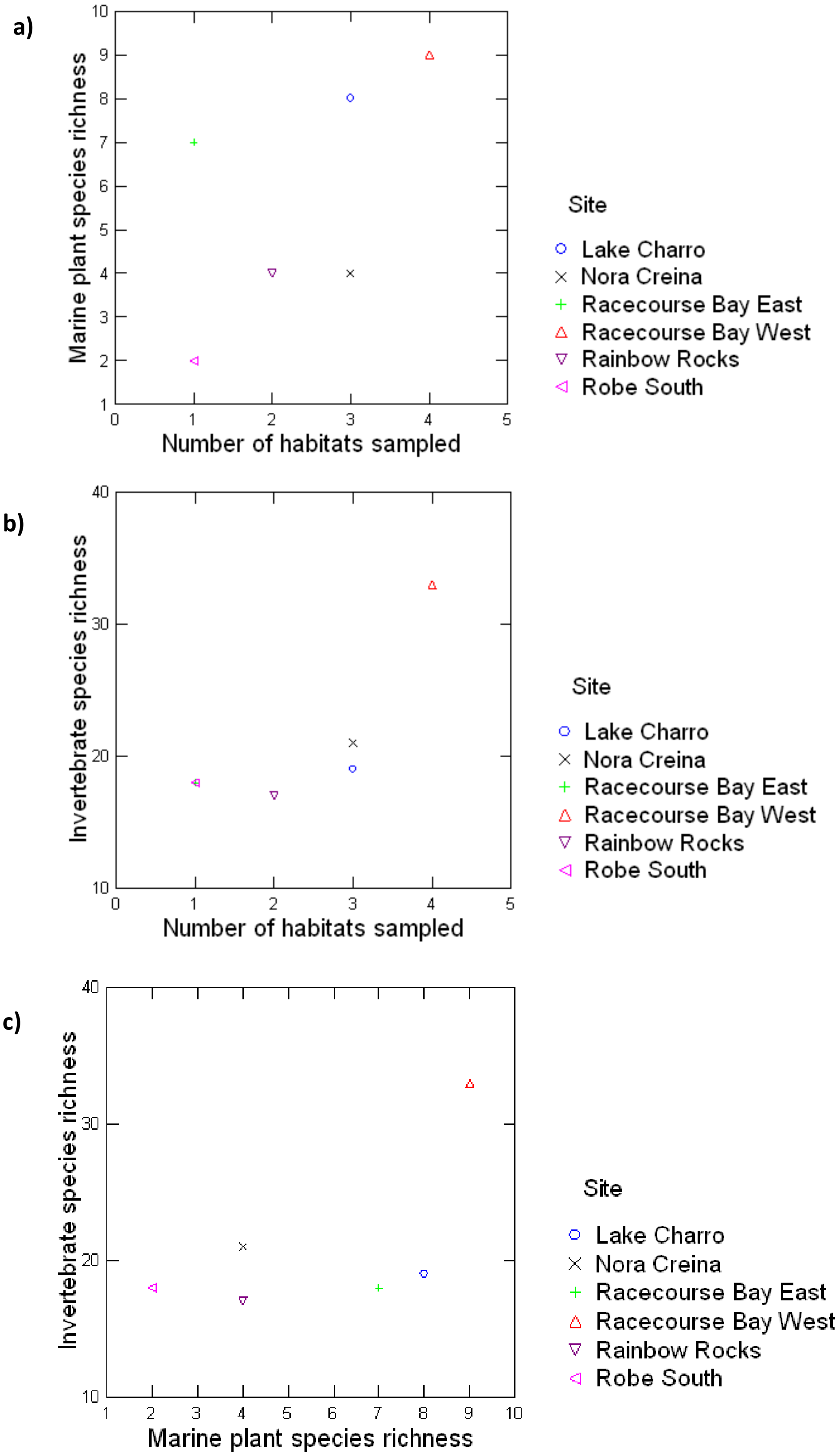

Figure 8: Scatterplots depicting the relationships between: a) marine plant species richness and the number of habitats sampled; b) invertebrate species richness and the number of habitats sampled; and c) invertebrate species richness and marine plant species richness. Racecourse Bay West is an outlier in Figures 8b and 8c, where it positively influences the strength of the Pearson correlation by 0.11 and 0.52 respectively.

Discussion

Overall, a total of 12 marine plant and 46 megainvertebrate species were recorded across six sites in the state's South East Region using line-intercept transects and TS surveys, respectively. Of these 46 megainvertebrate species, 25 mollusc and three echinoderm species were recorded (Table 5). The species richness values from these preliminary surveys are considerably lower than those recorded previously during biodiversity assessments using similar methods for rocky seashores in other locations around SA. For example, Benkendorff (2005) recorded 82 mollusc and eight echinoderm species pooled across 10 granite or limestone seashores from Althorpe Island and the Yorke Peninsula. Benkendorff et al. (2007) recorded 94 mollusc and echinoderm species and 55 marine plant species when conducting biodiversity inventories across five limestone seashores on Kangaroo Island. Furthermore, Benkendorff and Thomas (2007) recorded 141 mollusc and echinoderm species and 49 marine plant species during biodiversity assessments for 17 seashores of differing rock types along the Fleurieu Peninsula.

The comparatively low species richness of marine plants and megainvertebrates recorded during this study may be accounted for by several factors. The first of these is differences in the amount of sampling effort invested during each biodiversity inventory conducted for SA rocky seashores (Table 6). While each study employed an un-replicated sampling regime (i.e. each rocky seashore was only sampled once using TS surveys), there were differences in the number of sites sampled, the total time spent conducting TS surveys, the number of line-intercept transects sampled, and the number of habitats sampled within each study region (Table 6). For example, Benkendorff (2005) examined four habitat types across 10 rocky seashores, and spent 600 minutes conducting TS surveys for mollusc and echinoderm species on Althorpe Island and the Yorke Peninsula. Likewise, Benkendorff and Thomas (2007) examined 11 habitat types across 17 rocky seashores, and spent 1020 minutes conducting TS surveys for mollusc and echinoderm species along the Fleurieu Peninsula. In contrast, the present study examined four habitat types across only six rocky seashores, and spent just 450 minutes conducting TS surveys that encompassed the entire intertidal invertebrate assemblage (Table 6). Consequently, it is possible that the smaller sampling effort employed during this study, especially for the number of sites sampled and the total time spent conducting TS surveys, may help to account for the comparatively low species richness reported here.

Table 6: A comparison among studies for the sampling effort invested during biodiversity inventories for rocky seashores in SA. Key: N/A = not sampled in described study.

Location assessed	**Number of sites assessed**	**Region of shore assessed**	**Number of habitats assessed**	**Number of transects sampled**	**Number of TS surveys completed**	**Total sampling time (minutes)**	**Number of marine plant species recorded**	**Number of invertebrate species recorded**	**Reference**
Yorke Peninsula & Althorpe Island	10	Lower & middle only	4	0	10	600	N/A	90	Benkendorff (2005)
Kangaroo Island	5	Lower & middle only	6	0	5	195	55	94	Benkendorff et al. (2007)
Fleurieu Peninsula	17	Lower & middle only	11	85	17	1020	49	141	Benkendorff & Thomas (2007)
South-east	6	Entire shore	5	22	15	450	12	46	Present study

Another factor that may help to explain the comparatively low marine plant and megainvertebrate species richness recorded for SA's South East Region is the type of rock that constitutes each seashore. Across the six sampled rocky seashores in SA's south-east marine parks, two types of soft rock were recorded, with Mount Gambier limestone and calcarenite having Moh's scratch hardness values of 2.0 and 2.5, respectively (Table 2). One type of hard rock was recorded across this region, with flint boulders having a Moh's scratch hardness value of 8.0 (Table 2). The previously described biodiversity assessments for the Yorke and Fleurieu Peninsulas, plus several honours theses produced at Flinders University, have reported differences among intertidal assemblages inhabiting softer rock types such as limestone versus harder rock types such as granite, siltstone, gneiss, basalt, and schist (Benkendorff 2005; Benkendorff and Thomas 2007; Dutton 2007; Liversage and Benkendorff 2013; Liversage et al. 2014). Specifically, softer rock types were found to support a lower species richness of invertebrates, or abundances of individual invertebrate taxa, when compared against harder rock types (Benkendorff and Thomas 2007; Dutton 2007; Liversage and Benkendorff 2013). In the present study, the lack of a balanced sampling design across rock type (four soft-rock sites were sampled, while only one site each of hard rock and mixed rock were sampled) precludes any statistical analyses investigating how rock type may impact intertidal assemblage structure from being completed. However, given that four of the six sites sampled were comprised of the very soft, and highly friable calcarenite (Table 1), it's possible that the generally softer rock types of the South East Region (harder flint only recorded at Racecourse Bay and Carpenter Rocks, with the later location not sampled during this study as it is located outside of SA's south-east marine parks) may support megainvertebrate assemblages with a lower species richness. Moreover, while Racecourse Bay East (the only hard-rock site sampled) had a similar megainvertebrate species richness to the four soft-rock sites, the mixed hard and soft rock at Racecourse Bay West supported the highest megainvertebrate species richness recorded (Figure 2c). This observation indicates that rock type may have an additive effect on species richness, supporting previous studies (e.g. Benkendorff 2005; Benkendorff and Thomas 2007; Dutton 2007; Liversage and Benkendorff 2013; Liversage et al. 2014) that have reported invertebrate assemblage differences across different types of rock.

It has been well documented that softer rock types display faster erosion rates than harder rock, and that the fastest rates of erosion are recorded in environments with the greatest wave energy (Kirk 1977; Spencer 1985). Given the south-east coast is frequently exposed to strong waves and swell (N. Janetzki & P. Fairweather, pers. obs.), especially during winter, the soft and highly friable rock types that dominate this region are likely to be highly susceptible to weathering and erosion.

Consequently, the dynamic nature of the predominantly soft-rock substratum across SA's South East Region may provide an unsuitable habitat for some intertidal species. This concept is exemplified by the almost complete absence of several sessile invertebrate species on platform areas that require a stable substratum for semi-permanent or permanent attachment including tube-worms, barnacles, and mussels. Furthermore, both calcarenite and Mount Gambier limestone are both softer than the fossiliferous limestone (Moh's scratch hardness = 3.0) found in other parts of SA including the Fleurieu Peninsula and Kangaroo Island (N. Janetzki unpublished data). Consequently, the softer rock types of the South East Region may offer less resistance to the forces of weathering and erosion than fossiliferous limestone, potentially providing a less-suitable habitat for some intertidal species. This may help to account for the low invertebrate and plant species richness recorded in the present study when compared to that recorded on Kangaroo Island (Benkendorff et al. 2007), which also examined intertidal assemblages across soft-rock seashores for a similar number of sites (Table 6).

An alternative explanation that may account for the comparatively low marine plant and invertebrate species richness recorded in the South East Region is the time of year that sampling was conducted. The biodiversity assessments conducted for rocky seashores along the Fleurieu Peninsula, Yorke Peninsula, and Kangaroo Island all conducted sampling during suitable daytime low tides over mid-spring and summer (Benkendorff 2005; Benkendorff et al. 2007; Benkendorff and Thomas 2007). The present study conducted biodiversity inventories during suitable daytime low tides during the final week of winter. While these inventories were effective in collecting baseline data for this region, they did not effectively assess intertidal biodiversity on the lower extremes of the rocky seashore. Over winter, low-pressure atmospheric cells (i.e. cold fronts), strong winds, large swells, and relatively high low-tides (low tide height never <0.40 m AHD) interact to prevent the lower-most extremes of rocky seashores from becoming emersed at low tide. This was particularly poignant at the four calcarenite-dominated sites with their apparently lower elevation, which effectively prevented the lower intertidal shore from being examined whatsoever during these winter inventories. Consequently, it is possible that any species solely living on the lower intertidal shore were not recorded in the inventories reported here (up to half the algal species and a quarter of the invertebrate species, P. Fairweather, pers. obs.).

During the final week of the 2014 winter, no significant difference in the space-occupancy or species richness of marine plants was detected among the six sampled sites. However, a significant difference was detected among sites for the assemblage structure of marine plants, except amongst Lake Charro, Racecourse Bay East and Nora Creina (see Figure 5). Racecourse Bay West, located in a

General Managed Use Zone, recorded both the greatest percentage cover (64.7 ± 10.8 %) and highest species richness (nine) of marine plants (Table 3, Figure 3a). No site recorded a marine plant species richness two standard deviations higher than the regional mean (Figure 2a). As such, no sites sampled during this study were identified as potential marine plant hotspots. The higher species richness and space-occupancy of marine plants at Racecourse Bay West may be explained by the occurrence of both hard and soft rock types at the same location, which may offer some marine plant species are greater diversity of exploitable habitats and growing conditions. This is reflected by Racecourse Bay West possessing the greatest number of habitats (five) across the six sampled sites (Table 3), ranging from water-filled depressions (i.e. both submerged substrate and rock pools) and sand deposits on the soft Mount Gambier limestone platform, to the sheltered and shaded undersides of hard flint boulders. However, the correlation between marine plant species richness and the number of habitats sampled produced a non-significant result (Table A9 in Appendix 3), although this may be driven by the small number of sites sampled (n = 6). Therefore, it would be prudent to sample a greater number of sites to better understand any relationship that may exist between marine plant species richness and the number of habitats sampled, and to determine whether the presence of multiple rock types at a single location contributes to this relationship in any way (i.e. is the greatest number of habitats generally found at sites comprised by multiple types of rock).

For the intertidal invertebrate assemblage, TS surveys were successful in establishing a baseline of the assemblages associated with each type of habitat. By exploring patterns in the invertebrate data collected during the final week of the 2014 winter, it was possible to identify four distinct megainvertebrate assemblages from the six sites sampled (Figure 6). Each assemblage was generally characterised by several dominant species that were strongly associated with a specific type of habitat. For example, flint boulders at Racecourse Bay East and West were characterised by high abundances of several megainvertebrate species sheltering under boulders, including the barnacle *T. purpurascens*. This species has been shown previously to require shaded habitats in order to survive the harsh physical stresses of the intertidal environment (Denley and Underwood 1979). The undersides of flint boulders at Racecourse Bay may afford *T. purpurascens* such a shaded intertidal habitat, helping to account for the higher abundances recorded there.

Further supporting an association between intertidal invertebrates and habitats, a positive linear relationship was detected between the species richness of megainvertebrates and the number of habitats sampled (see Figure 8b). Generally, megainvertebrate species richness increased as the number of habitats sampled increased (Figure 8b). However, intertidal invertebrate assemblages for a larger number of sites must be examined to determine the statistical validity of this relationship, as it produced a non-significant result and was strongly influenced by the outlier Racecourse Bay West (Table A9 in Appendix 3). With a megainvertebrate species richness of 33, Racecourse Bay West had a species richness that was more than two standard deviations greater than the regional mean (Figure 2c). Consequently, Racecourse Bay West may be considered a biodiversity hotspot for intertidal megainvertebrates, an observation not recorded for any of the other five sampled sites. Once again, the higher megainvertebrate species richness recorded at Racecourse Bay West may be a product of the mixed hard versus soft rock types offering a greater diversity of exploitable habitats and environmental conditions. For example, the soft Mount Gambier limestone platform was interspersed by numerous water-filled depressions providing habitat for the anemone *I. australis*, while the undersides of hard flint boulders provided a sheltered, shaded habitat for several gastropod species and the barnacle *T. purpurascens* (Figure 7b). Consequently, if only one type of rock was present at Racecourse Bay West, the habitats associated with the alternative rock type may not be available for exploitation by intertidal megainvertebrates, potentially reducing the species richness at this site. Alternatively, the higher species richness and identification of Racecourse Bay West as a potential biodiversity hotspot could simply be an artefact of the sampling design employed, in which sites with the greatest number of habitats were searched for the greatest length of time during TS surveys. Therefore, to untangle such possibilities it would be prudent to sample each site for a standardised length of time to ensure that differences in the sampling effort employed do not potentially confound the data that has been collected. Furthermore, a greater number of sites should also be sampled to better understand any relationship that may exist between megainvertebrate species richness and the number of habitats sampled, and to determine whether the presence of multiple rock types at a single location interacts with this relationship in any way.

The general observation that megainvertebrate species richness appeared to increase with the number of habitats sampled is consistent with the Habitat Diversity Hypothesis, which predicts that the greatest diversity of species will occur where the greatest diversity of habitats exists (Connor and McCoy 1979). Furthermore, this observation is consistent with biodiversity inventories conducted elsewhere for rocky seashores in SA (Benkendorff 2005). Consequently, it may be possible to use habitat counts as a viable surrogate for identifying sites that may make valuable inclusions in any ongoing south-east rocky seashore monitoring program. From the six sites sampled to date, Racecourse Bay West, with its highest space occupancy and species richness of marine plants, and potential classification as a megainvertebrate biodiversity hotspot, would be worthy of inclusion in any ongoing monitoring program. However, for any monitoring program to comprehensively evaluate the marine plant and megainvertebrate assemblages of the South East Region's rocky seashores, a sampling regime that spans multiple seasons, and encompasses a greater spread of sites balanced across rock type (soft, hard, and mixed) must be implemented.

Of the 12 marine plant and 46 megainvertebrate species recorded using line-intercept transects and TS surveys respectively, at least 11 megainvertebrate species have been identified as potentially being vulnerable to anthropogenic disturbances. In Australia, intertidal organisms are harvested by recreational fishers for bait or by some cultural groups for food (Keough et al. 1993; Underwood 1993; Alexander and Gladstone 2013). The species targeted by human harvesting can include the whole range of organisms present on the rocky seashore, although highly sought after species locally can include: the limpet *C. tramoserica* and snail *N. atramentosa* for bait and/or food; and the abalone *Haliotis* spp., and snails *L. undulata*, and *A. constricta* for food (Keough et al. 1993; Underwood 1993; Alexander and Gladstone 2013). These harvesting activities not only impact intertidal assemblages through the direct removal of individual organisms but indirectly by: 1) altering the size-structure of some invertebrate populations; 2) changing ecological interactions; 3) damaging intertidal habitats during the foraging process; and/or 4) by trampling vulnerable algae and invertebrate assemblages while accessing and/or foraging on the shore (Keough et al. 1993; Underwood 1993; Alexander and Gladstone 2013).

In SA, the harvesting of benthic organisms on rocky seashores out to a depth of two metres has been prohibited by law since January 1, 1996. Regrettably, this legislation has been largely ineffective in achieving its desired conservation outcomes, with many users of rocky seashores either unaware of or choosing to ignore the current legislative framework (pers. obs.). Accentuating this point, the three authors of this report have observed individuals and groups actively foraging for gastropods across a number of SA rocky seashores, with the heaviest foraging observed on seashores within close proximity to urban centres, despite this activity being illegal. Furthermore, a higher species diversity, abundances of individual invertebrate taxa, and larger size-classes for some mollusc species were reported from comparisons among seashores inside and outside the exclusion zone surrounding the former Port Stanvac oil refinery in metropolitan Adelaide (Dutton and Benkendorff 2008; Baring et al. 2010). It appears that the fences surrounding the refinery site prevent human intrusion onto the rocky seashore, affording the intertidal assemblages that inhabit these seashores protection from illegal harvesting (Dutton and Benkendorff 2008; Baring et al. 2010). Likewise, in

Port Phillip Bay, Victoria, the illegal harvesting of gastropods was found to reduce the size structure and abundance of several mollusc species including *C. tramoserica*, *A. constricta*, and *N. atramentosa,* when comparisons were made between rocky seashores with and without exclusion from human harvesting (Keough et al. 1993).

Given the rocky seashores of the South East Region support substantial populations that include very large individuals of the limpets *C. tramoserica* and *Patelloida alticostata*, and the snails *N. atramentosa*, *A. constricta*, *C. adelaidae*, *D. concamerata*, *L. undulata*, *Bembicium nanum*, and *Dicathais orbita*, it is highly likely that these taxa may be subjected to illegal harvesting activities in the future. This same threat is also likely to apply to the highly sought after, but far less abundant, abalone *Haliotis laevigata* and *Haliotis rubra*, which were also observed on some rocky seashores. Therefore, it is recommended that these 11 species form the basis of a targeted and longer-term monitoring program that assesses the threat that illegal harvesting activities, both directly and indirectly, may pose to populations of these taxa, and to the entire marine plant and invertebrate assemblage within these marine parks.

The marine park zones that afford the highest levels of protection, Sanctuary Zones and Restricted Access Zones (which prohibit all extractive activities and access by the general public, respectively), were not sampled during this study. Restricted Access Zones were not sampled because this level of marine park protection is not represented within SA's two south-east marine parks. In contrast, Sanctuary Zones were not sampled due to the difficulty in finding a suitable rocky seashore within this zone to sample during winter. Of the five sanctuary zones located in the two south-east marine parks, rocky seashores are only represented in the Canunda Sanctuary Zone in the Lower South East Marine Park, and the Cape Dombey Sanctuary Zone in the Upper South East Marine Park. The calcarenite rocky seashores in both of these zones are located in areas where accessibility can be problematic (i.e. access via steep cliffs, refer to photo on front cover of this report, or via 4WD through sand dunes), and are frequently subjected to strong winds, swells, and wave action. Furthermore, the rocky seashore in the Sanctuary Zone at Cape Dombey is quite small in area, making sampling with replication difficult. Consequently, finding sections of suitable rocky seashore in Sanctuary Zones that can be regularly sampled, especially during winter, was not achievable. Additionally, given these shores are comprised of flat calcarenite platforms, their generally low elevation subjects them to near permanent submersion during winter. This observation suggests that these shores may be vulnerable to permanent submersion if sea levels rise, which is predicted to be a consequence of global climate change (IPCC 2013). It is therefore possible that rocky seashores may not be adequately protected by Sanctuary Zones in the South East region if such changes were to transpire.

Future research

To adequately evaluate the potential role of rock type on marine plant and invertebrate assemblages along SA's south-east coast, it is recommended that a replicated sampling design that spans at least two sites each of hard-rock, soft-rock, and mixed rock (both hard and soft rock present) be implemented. Ideally, this sampling design would encapsulate a greater spread of sites, including several sites along the Fleurieu Peninsula (where softer fossiliferous limestone and harder siltstone, granite, and schist shores occur). Thus, it would be possible to contrast the marine plant and invertebrate assemblages between a number of different locations and rock types, to develop the emerging understanding of how the predominantly calcarenite and Mount Gambier limestone seashores of the South East region compare to rocky seashores west of this region.

Furthermore, this recommended sampling design would ideally span multiple seasons, ensuring sampling is also conducted during summer when high-pressure atmospheric cells, lighter winds, smaller swells, and lower low-tides persist. This would enable the lower-most extremes of each rocky seashore to be assessed, and new species richness values determined for the marine plant and invertebrate assemblage across the entire shore. In doing so, it would be possible to determine whether the low species richness values reported here are truly indicative of this region, or an artefact of a winter sampling regime that was unable to sample the lower extremes of the rocky seashore. A sampling approach that encapsulates aspects of this design is currently being conducted as a chapter of Nathan Janetzki's PhD thesis.

Conclusions

The inventories conducted in the two south-east marine parks during the final week of the 2014 winter have been successful in establishing a baseline of the geology, habitats, and biodiversity currently protected on rocky seashores in the Lower South East and Upper South East Marine Parks. Across the six sampled sites, three rock types (harder flint and softer calcarenite and Mount Gambier limestone) and five types of habitat (submerged substrate, emersed substrate, rock pools, boulders, and sand deposits) were identified. A total of 12 marine plant species were recorded using line-intercept transects, while 46 species of megainvertebrates were recorded during TS surveys. This sampling approach revealed a significant difference in the structure of the marine plant assemblage among sites, while the structure of the megainvertebrate assemblage was strongly correlated with the number and/or types of habitat that were sampled. A species rich hotspot for megainvertebrates was potentially identified at Racecourse Bay West. Due to the short timeframe of the current pilot survey, the data presented here should be supplemented by a replicated sampling regime, which spans multiple seasons, a greater spread of sites, and is balanced across hard, soft, and mixed rock seashores, to capture data on the true variability present within marine plant and megainvertebrate assemblages on rocky seashores in SA's south-east marine parks.

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Appendix 1: Photographic plates

Plate 1: Rocky seashores examined during geological, habitat, and biodiversity inventories in SA's South East Region: a) boulder field at Racecourse Bay East; b) boulder field and platform at Racecourse Bay West; c) platform and rock pools at Rainbow Rocks; d) platform and rock pools at Nora Creina; e) platform at Robe South; and f) platform and rock pools at Lake Charro.

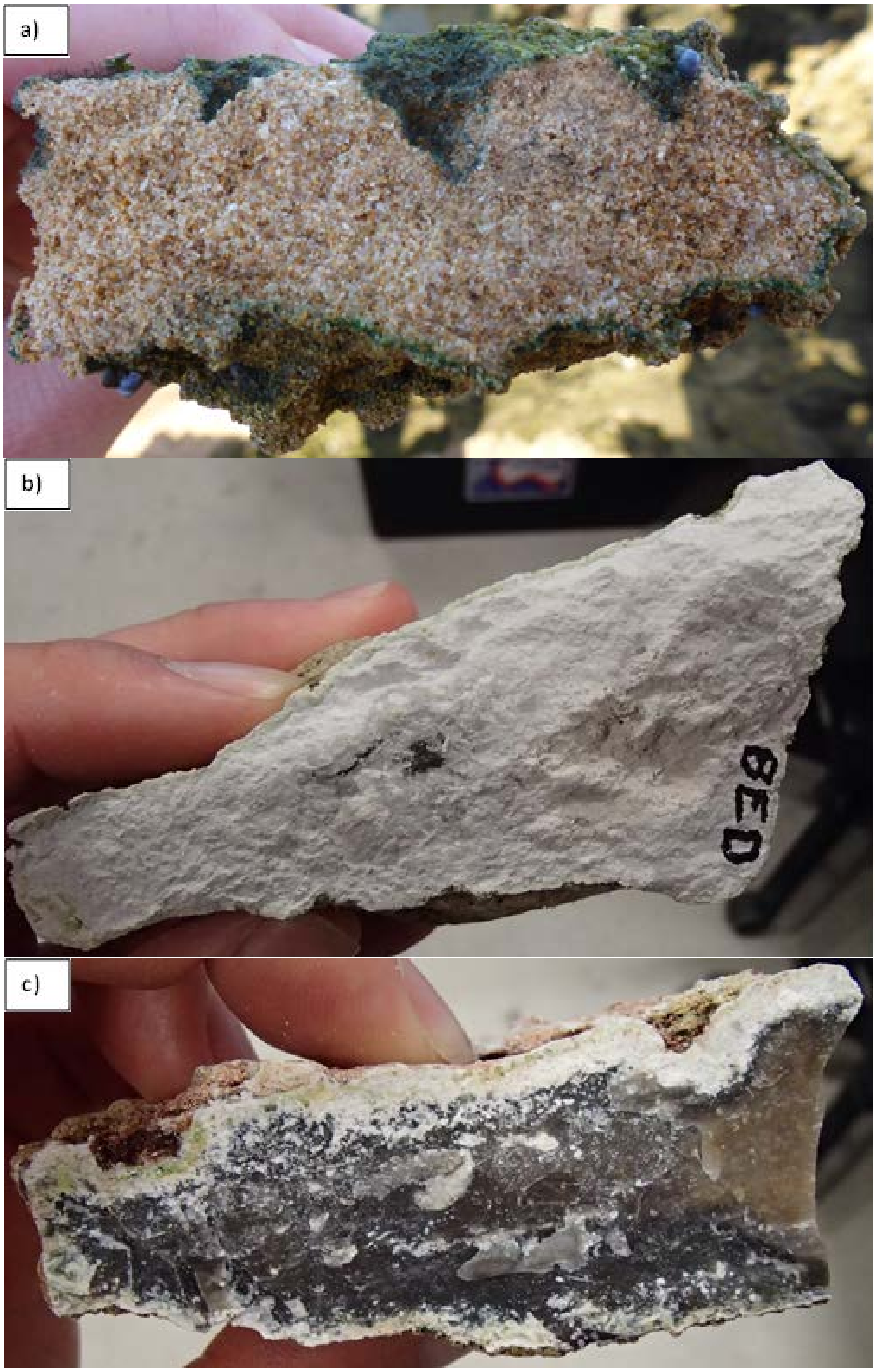

Plate 2: Rock types identified during geological, habitat, and biodiversity inventories in South Australia's South East Region: a) calcarenite; b) Mount Gambier limestone; and c) flint.

Appendix 2: Graphical depiction of line intercept transects

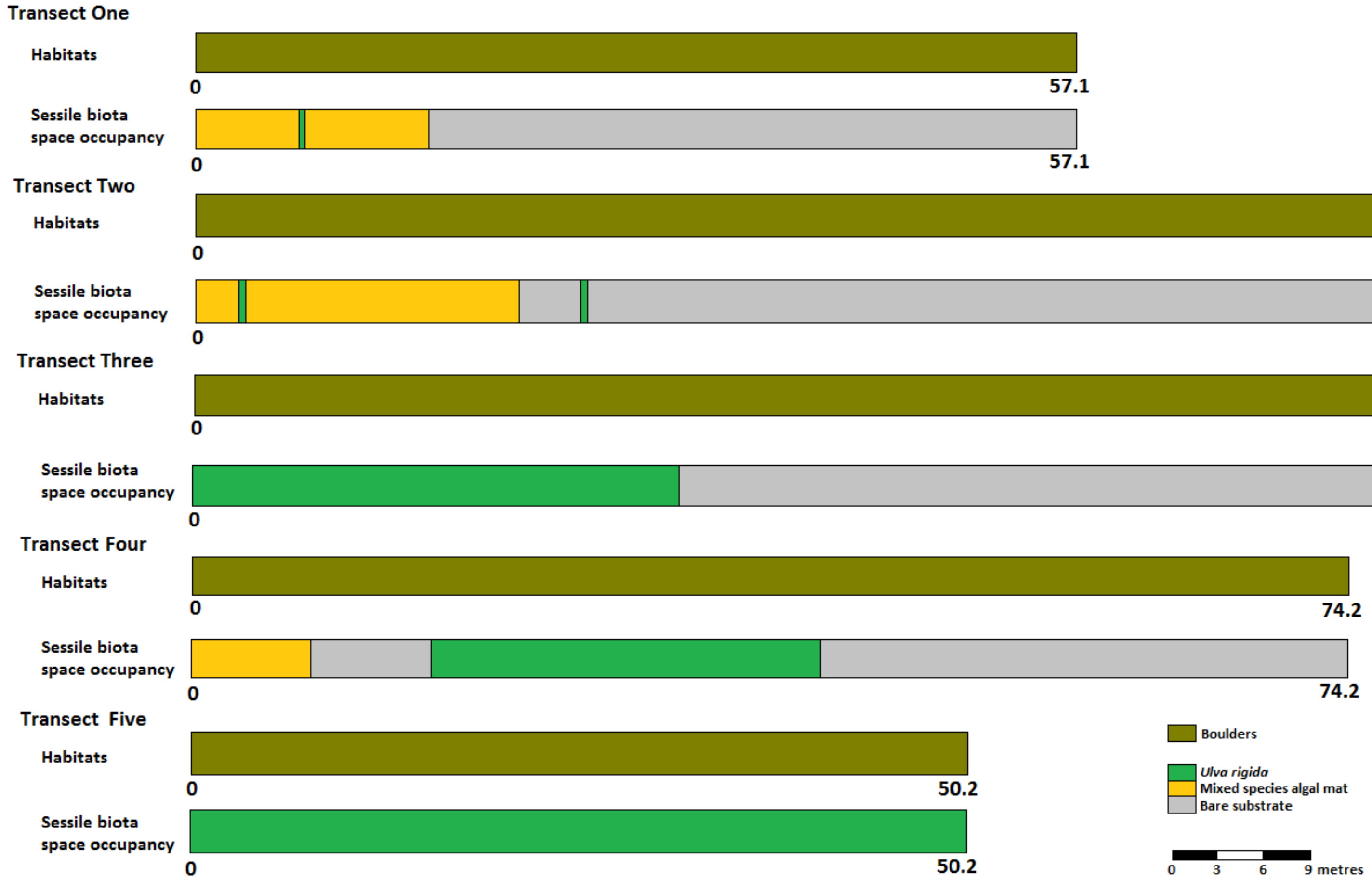

Figure A1a: Space occupancy of habitats and sessile biota recorded along line-intercept transects at Racecourse Bay East. The numbers under each transect denote its overall length (m), with each transect extending from the low tide level at the time of sampling to the top of the rocky shore. At Racecourse Bay East the mixed-species algal mat was comprised of *S. rugosum, H. banksii, S. lamentaria, C. sinuosa, C. officinalis,* and *C. implexa*.

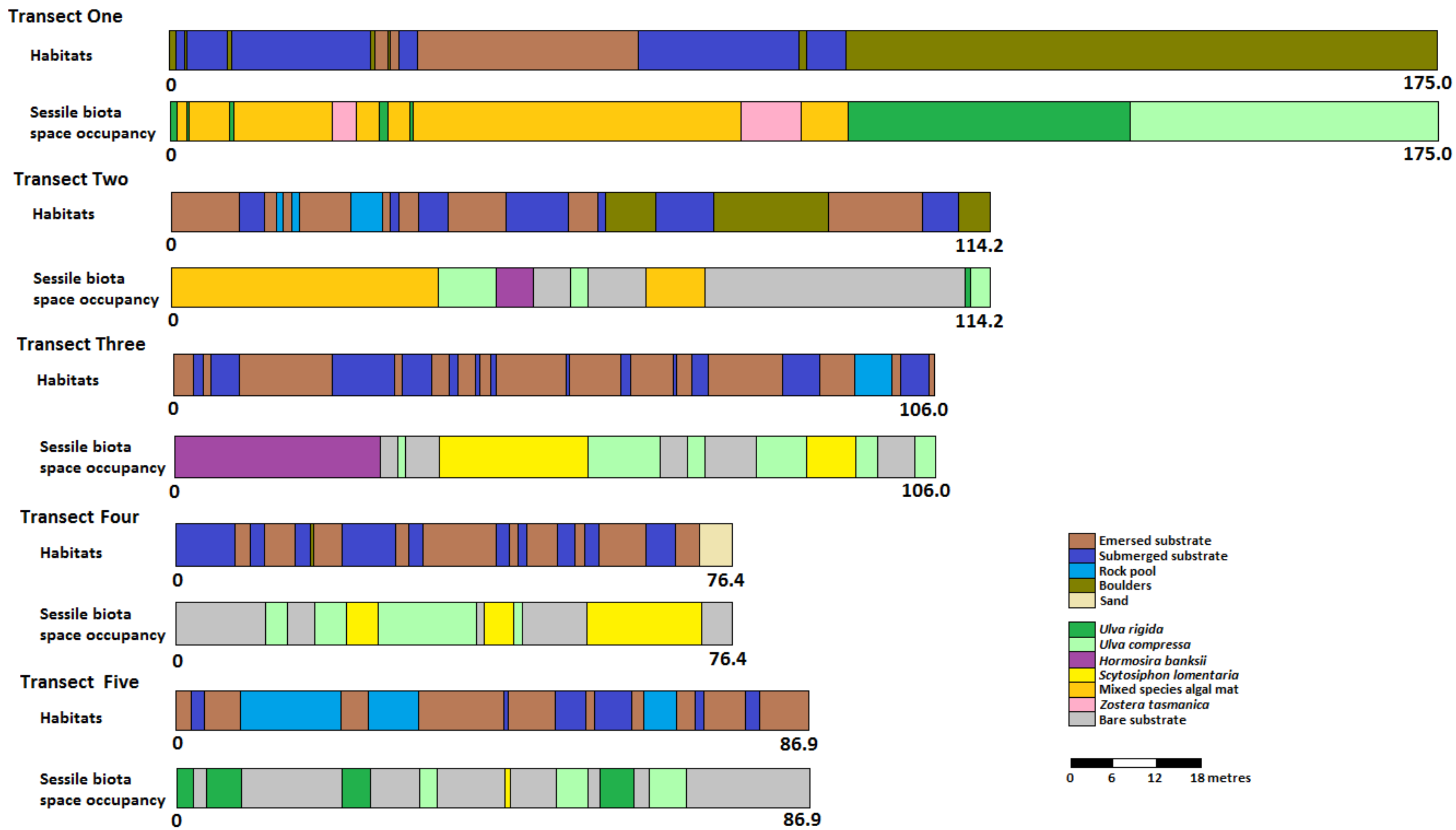

Figure A1b: Space occupancy of habitats and sessile biota recorded along line-intercept transects at Racecourse Bay West. The numbers under each transect denote its overall length (m), with each transect extending from the low tide level at the time of sampling to the top of the rocky shore. At Racecourse Bay West the mixed-species algal mat was comprised of *H. banksii, S. lamentaria, S. rugosum, C. officinalis, C. implexa*, and *A. anceps*.

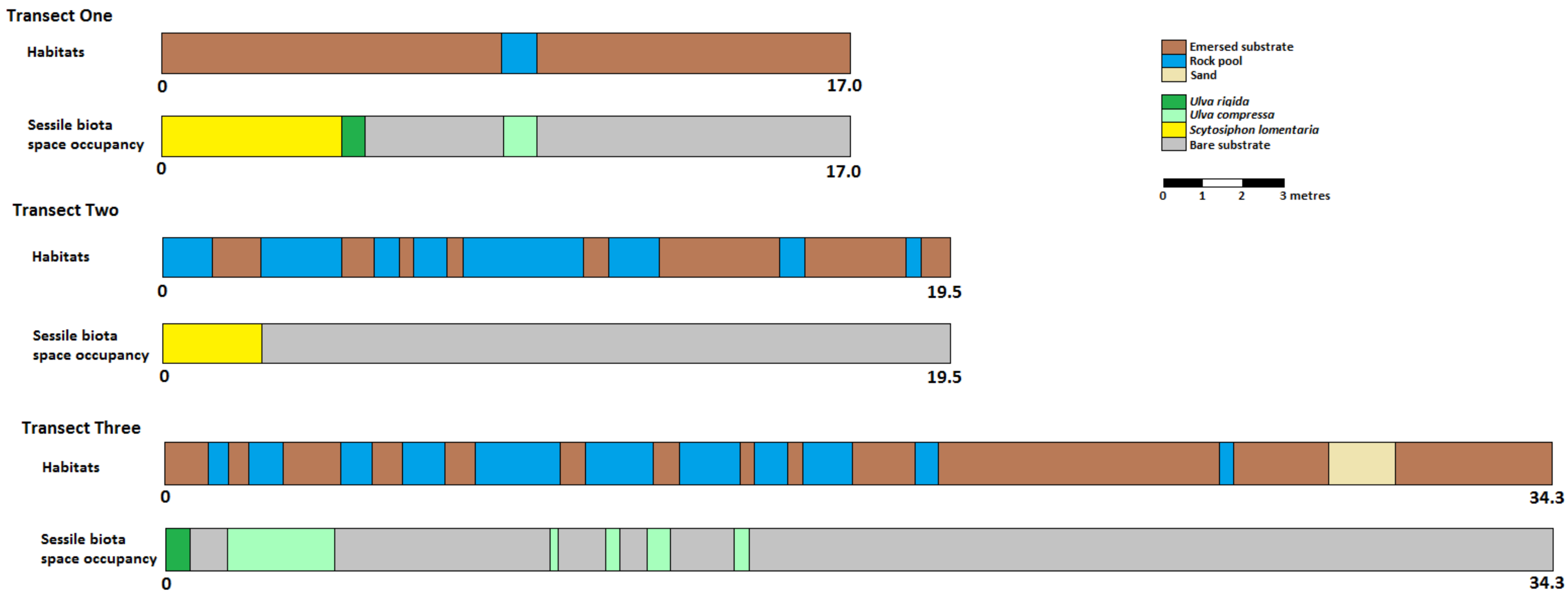

Figure A1c: Space occupancy of habitats and sessile biota recorded along line-intercept transects at Rainbow Rocks. The numbers under each transect denote its overall length (m), with each transect extending from the low tide level at the time of sampling to the top of the rocky shore.

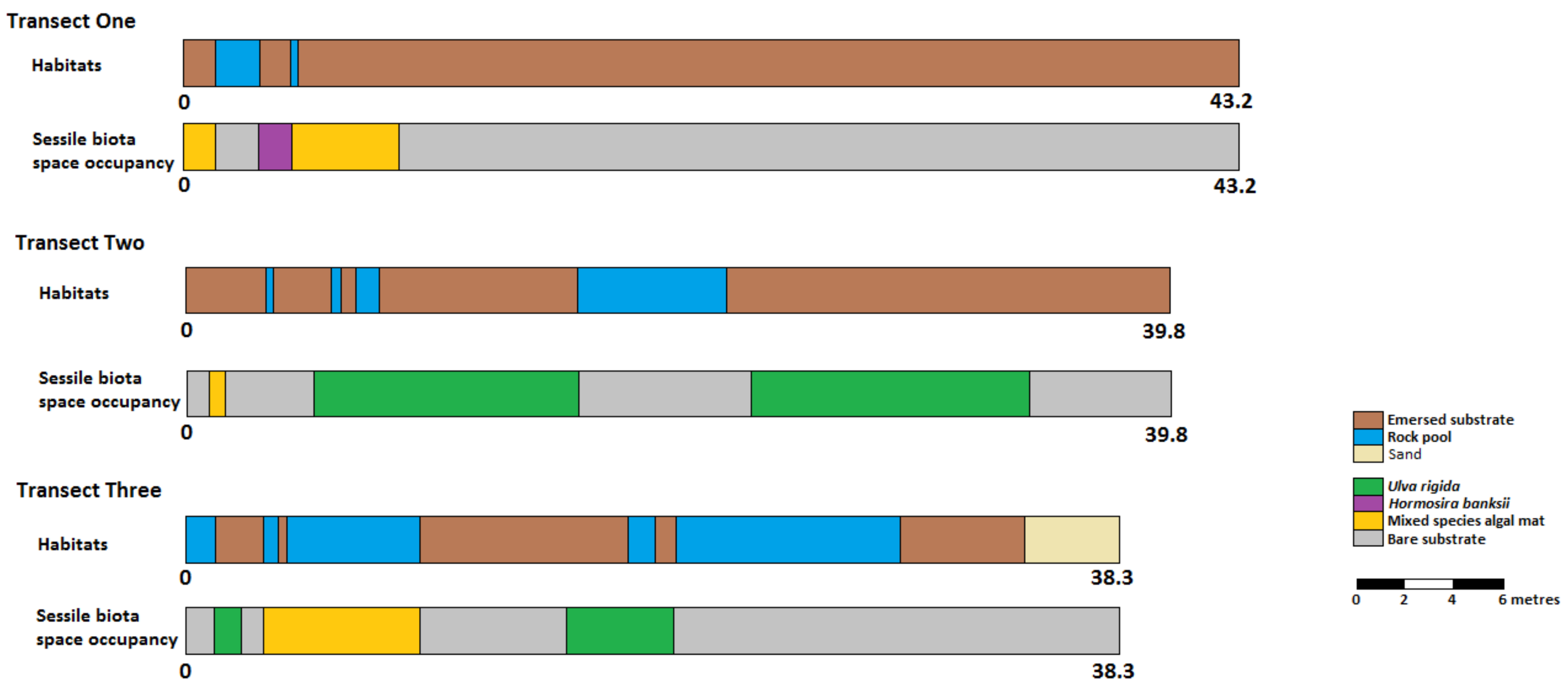

Figure A1d: Space occupancy of habitats and sessile biota recorded along line-intercept transects at Nora Creina. The numbers under each transect denote its overall length (m), with each transect extending from the low tide level at the time of sampling to the top of the rocky shore. At Nora Creina the mixed-species algal mat was comprised of *U. rigida, H. banksii*, and *C. implexa*.

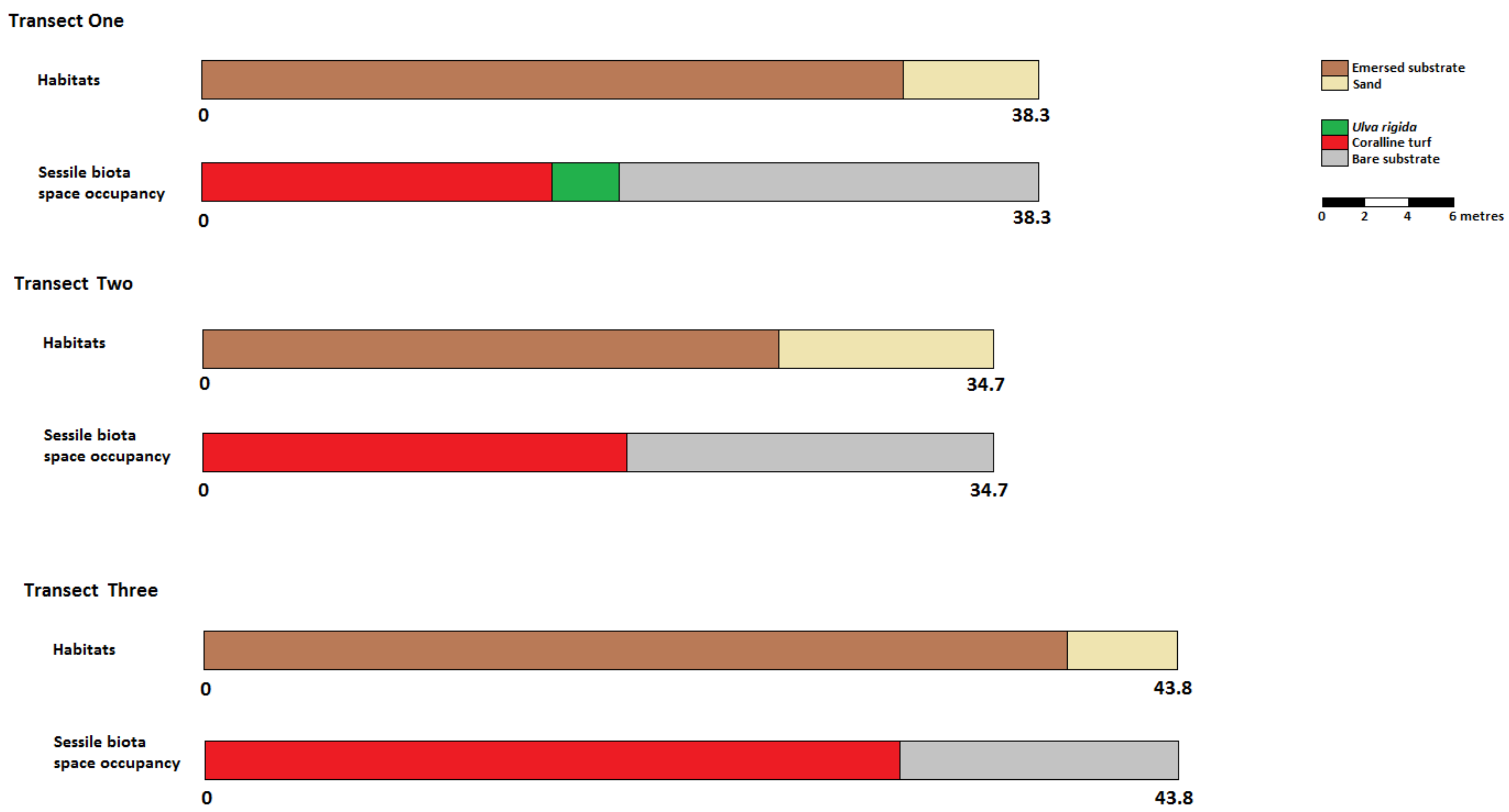

Figure A1e: Space occupancy of habitats and sessile biota recorded along line-intercept transects at Robe South. The numbers under each transect denote its overall length (m), with each transect extending from the low tide level at the time of sampling to the top of the rocky shore.

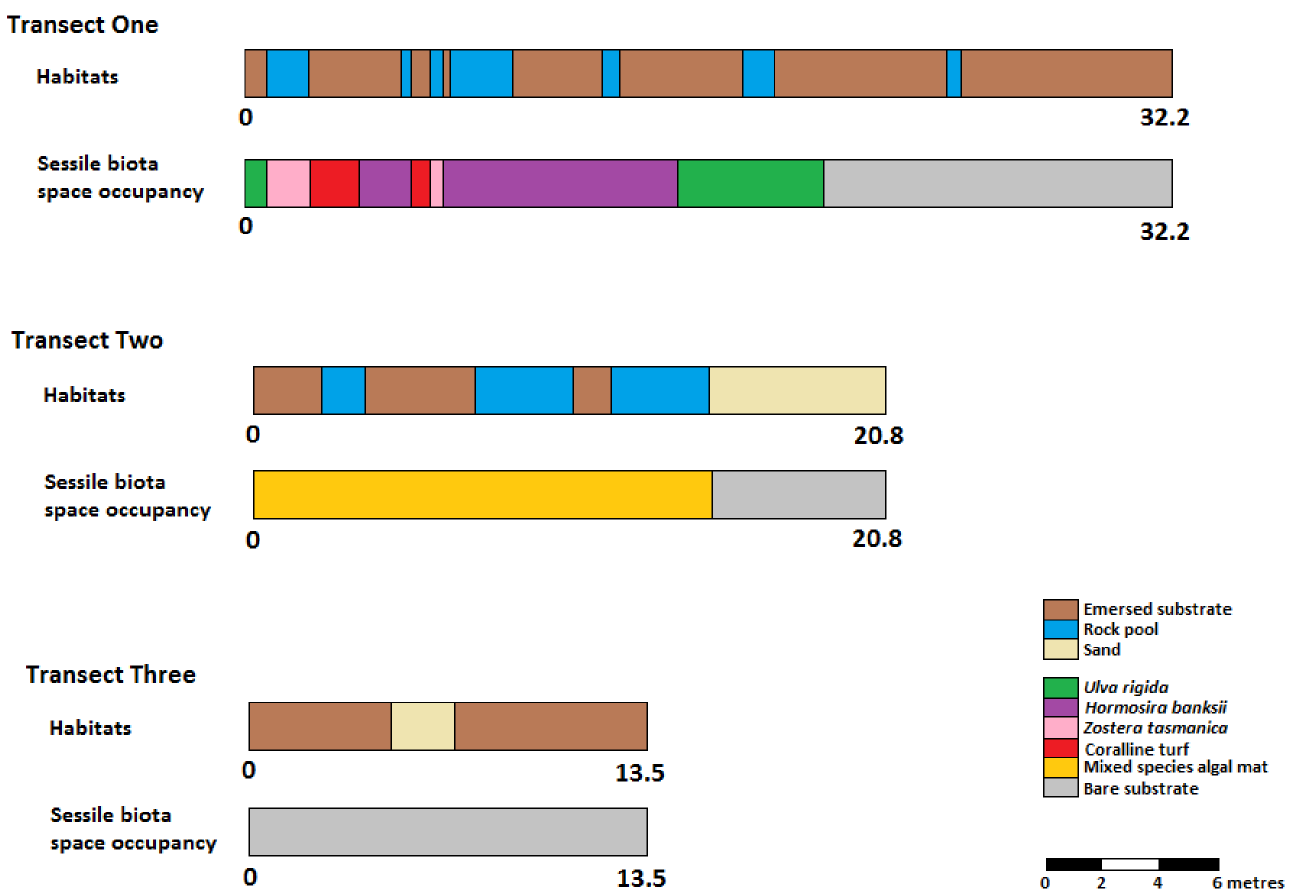

Figure A1f: Space occupancy of habitats and sessile biota recorded along line-intercept transects at Lake Charro. The numbers under each transect denote its overall length (m), with each transect extending from the low tide level at the time of sampling to the top of the rocky shore. At Lake Charro the mixed-species algal mat was comprised of *U. rigida, H. banksii*, and *Laurencia* spp.

Appendix 3: Statistical outputs discussed during report from SYSTAT version 13 or PRIMER version 6 & PERMANOVA+

Table A1: Output from SIMPER analysis done in PRIMER/PERMANOVA+ examining the average similarity among replicate line-intercept transects for each site, and the dominant species characterising this average similarity at each site.

Site	Average % similarity among transects	Characterising species	That species % contribution to average similarity
Racecourse Bay East	42.82	*Ulva rigida*	71.32
Racecourse Bay West	50.84	*Ulva compressa*	53.75
Rainbow Rocks	59.35	*Scytosiphon lamentaria*	95.68
Nora Creina	43.29	*Ulva rigida*	66.23
Robe South	79.14	Coralline turf	100
Lake Charro	14.31	*Ulva rigida*	54.49

Table A2: Output from ANOVA analyses done in SYSTAT testing for differences in the percentage cover/species richness of marine plants and marine plant divisions among sites. Significant results (α = 0.05) are shown in bold.

Parameter	Source	Type III SS	df	Mean squares	*F*-ratio	*p*-value
Total marine plants percentage cover	Site	33.785	5	6.757	1.274	0.323
	Error	84.856	16	5.304		
Red algal percentage cover	Site	7073.614	5	1414.723	18.282	**0.000**
	Error	1238.113	16	77.382		
Brown algal percentage cover	Site	54.484	5	10.897	3.904	**0.017**
	Error	44.663	16	2.791		
Green algal percentage cover	Site	72.331	5	14.466	2.643	0.063
	Error	87.569	16	5.473		
Red algal species richness	Site	2.130	5	0.426	0.966	0.467
	Error	7.057	16	0.441		
Brown algal species richness	Site	3.913	5	0.783	1.779	0.174
	Error	7.038	16	0.440		
Green algal species richness	Site	1.840	5	0.368	2.268	0.097
	Error	2.596	16	0.162		

Table A3: Output from pair-wise tests done in SYSTAT examining differences in the total percentage cover among sites for: a) red algae and b) brown algae. Significant results ($\alpha = 0.05$) are shown in bold. Key: RBE = Racecourse Bay East; RBW = Racecourse Bay West; RR = Rainbow Rocks; NC = Nora Creina; RS = Robe South; and LC = Lake Charro.

a)

Site	NC	RBE	RBW	RR	RS
LC	0.646	0.393	0.647	0.266	**0.000**
NC		1.000	1.000	0.977	**0.000**
RBE			0.995	0.993	**0.000**
RBW				0.916	**0.000**
RR					**0.000**

b)

Site	NC	RBE	RBW	RR	RS
LC	0.747	0.982	0.469	0.999	0.590
NC		0.953	**0.038**	0.552	1.000
RBE			0.090	0.894	0.853
RBW				0.687	**0.021**
RR					0.401

Table A4: Output from multivariate PERMANOVA done in PRIMER/PERMANOVA+ testing for differences in the structure of marine plant assemblages among sites. Significant results ($\alpha = 0.05$) are shown in bold.

Source	SS	df	Mean squares	F-ratio	*p*-value	Unique permutations
Site	42159	5	8431.7	5.055	**0.0001**	9909
Residual	26690	16	1668.1			
Total	68849	21				

Table A5: Output from PERMANOVA pair-wise tests done in PRIMER/PERMANOVA+ testing for differences in the structure of marine plant assemblages among sites. Significant results (α = 0.05) are shown in bold.

Sites compared	*t*	Permutation *p*-value	Unique permutations	Monte Carlo *p*-value
Lake Charro, Robe South	1.993	0.095	10	**0.046**
Lake Charro, Racecourse Bay East	1.172	0.234	56	0.271
Lake Charro, Racecourse Bay West	1.776	0.019	56	**0.046**
Lake Charro, Nora Creina	1.186	0.301	10	0.288
Lake Charro, Rainbow Rocks	1.966	0.104	10	**0.041**
Robe South, Racecourse Bay East	2.860	0.019	56	**0.006**
Robe South, Racecourse Bay West	3.856	0.020	56	**0.001**
Robe South, Nora Creina	3.350	0.099	10	**0.007**
Robe South, Rainbow Rocks	4.765	0.105	10	**0.002**
Racecourse Bay East, Racecourse Bay West	2.414	**0.015**	126	0.007
Racecourse Bay East, Nora Creina	1.166	0.323	56	0.293
Racecourse Bay East, Rainbow Rocks	2.280	0.034	56	**0.019**
Racecourse Bay West, Nora Creina	2.524	0.019	56	**0.008**
Racecourse Bay West, Rainbow Rocks	2.321	0.017	56	**0.011**
Nora Creina, Rainbow Rocks	2.701	0.096	10	**0.013**

Table A6: Output from SIMPER analysis done in PRIMER examining the average dissimilarity between pairs of sites for marine plant assemblage structure. As assemblage differences were generally driven by the higher percentage cover of a single algal species at one of the compared sites, the site which recorded a higher percentage cover of the characterising species is presented in bold. Key: NS = No significant difference detected among sites at α = 0.05.

Sites compared		Average dissimilarity %	Characterising species	That species % contribution to average dissimilarity
Lake Charro, **Robe South**		89.67	Coralline turf	61.60
Lake Charro, Racecourse Bay East	NS	75.25	*Ulva rigida*	45.64
Lake Charro, **Racecourse Bay West**		82.79	*Ulva compressa*	28.37
Lake Charro, Nora Creina	NS	77.89	*Ulva rigida*	43.00
Lake Charro, **Rainbow Rocks**		96.72	*Scytosiphon lomentaria*	39.55
Robe South, Racecourse Bay East		88.37	Coralline turf	56.93
Robe South, Racecourse Bay West		91.91	Coralline turf	47.32
Robe South, Nora Creina		94.32	Coralline turf	65.49
Robe South, Rainbow Rocks		97.80	Coralline turf	74.22
Racecourse Bay East, Racecourse Bay West		78.11	*Ulva rigida*	34.46
Racecourse Bay East, Nora Creina	NS	60.31	*Ulva rigida*	59.04
Racecourse Bay East, Rainbow Rocks		80.85	*Ulva rigida*	56.15
Racecourse Bay West, Nora Creina		82.50	*Ulva compressa*	29.65
Racecourse Bay West, Rainbow Rocks		69.21	*Ulva compressa*	39.15
Nora Creina, Rainbow Rocks		91.21	*Ulva rigida*	44.35

Table A7: Output from SIMPER analysis done in PRIMER examining the average similarity among TS surveys within each of the four intertidal invertebrate assemblages identified from cluster analysis, and the dominant species characterising this average similarity within each assemblage.

Assemblage	Average % similarity among surveys	Characterising species	That species % contribution to average similarity
First (Racecourse Bay boulders)	76.36	*Nerita atramentosa*	12.50
		Diloma concamerata	12.50
		Austrocochlea constricta	12.50
		Notoacmea spp.	12.50
		Tetraclitella purpurascens	12.50
Second (Racecourse Bay submerged substrate)	58.21	*Isanemonia australis*	22.54
		Austrocochlea constricta	18.59
Third (Lake Charro & Nora Creina rock pools)	49.12	*Chlorodiloma adelaidae*	28.57
		Cominella lineolata	21.43
		Lunella undulata	21.43
Fourth (emersed substrate & rock pools at Rainbow Rocks)	61.82	*Austrolittorina unifasciata*	17.20
		Afrolittorina praetermissa	13.49
		Siphonaria spp.	10.22
		Cellana tramoserica	9.84

Table A8: Output from SIMPER analysis done in PRIMER examining the average dissimilarity between pairs of assemblages for intertidal invertebrates sampled using semi-quantitative abundance rankings from TS surveys.

Assemblages compared	Average dissimilarity %	Characterising species	That species % contribution to average dissimilarity
Fourth, third	61.82	*Austrolittorina unifasciata*	9.82
		Afrolittorina praetermissa	8.76
		Siphonaria spp.	5.74
Fourth, first	59.32	*Tetraclitella purpurascens*	8.55
		Diloma concamerata	6.47
		Cyclograpsus granulosus	6.41
Third, first	81.94	*Diloma concamerata*	7.07
		Notoacmea spp.	7.07
		Tetraclitella purpurascens	7.07
Fourth, second	72.86	*Austrolittorina unifasciata*	8.11
		Isanemonia australis	7.79
		Afrolittorina praetermissa	7.16
Third, second	66.73	*Isanemonia australis*	7.46
		Lunella undulata	6.34
		Cellana tramoserica	6.31
First, second	58.51	*Nerita atramentosa*	9.56
		Diloma concamerata	9.56
		Bembicium nanum	8.70

Table A9: Output from correlation analyses done in SYSTAT exploring the linear relationships between sampled habitats and biodiversity.

Correlation	*r* value	*p*-value	r^2 value
Marine plant species richness, number of habitats sampled	0.584	0.227	0.34
Intertidal invertebrate species richness, number of habitats sampled	0.766	0.078	0.59
Intertidal invertebrate species richness, marine plant species richness	0.594	0.217	0.35