

## CHAPTER 5

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### 5. BENTHIC ECOSYSTEM STRUCTURE: SPATIAL AND TEMPORAL VARIABILITY IN ANIMAL AND PLANT DIVERSITY

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#### Executive Summary

The SRFME study found a strong seasonal signal in algal biomass in all regions, however processes underlying this pattern varied for different locations, or for particular sites within locations depending on the dominant algal habitat type. Most locations showed lowest biomass in winter (e.g. Jurien, Marmion, Two Rocks and Bunbury) but others showed summer minima where the majority of sites were dominated by *Sargassum*. The proximal factors that drive these variations also differ among locations. Erosion of biomass is most likely to be the factor driving changes in *Ecklonia* dominated sites (Marmion, Two Rocks, Perth) while light limitation is likely to be a major factor at Bunbury. Where *Sargassum* dominates sites (Green Head) algal phenology can explain changes in biomass. In contrast to the pattern for biomass, algal community structure showed no seasonal trend which was also the case for invertebrates.

Spatial trends in the data were apparent with both algae and invertebrates showing the highest number of species recorded at Jurien. Perth had the lowest numbers of species although

numbers were only marginally greater at Geographe Bay. Four new species of invertebrates were collected during the SRFME study. Algal community structure showed significant variation at the regional and location level, although much of this variation may be explained by site level variation within locations. Similar patterns were apparent for the invertebrates both for algal associated fauna and benthic fauna. Fish showed a contrasting pattern with a high level of variation among assemblages at the regional level and virtually none at the location level. However at site level there was once again significant variation in fish assemblages. We attribute this consistent variation in assemblages at the site level to definable algal habitat types that tend to dominate at particular sites. While assemblages dominated by canopy-forming large brown algae occurred at just over half the sites, nearly as many sites were instead characterised by diverse assemblages of foliose and filamentous red and brown algae.

The distribution of the different algal species assemblages is correlated with a range of environmental variables, but the relative importance of different variables differs from one region to the next. At Jurien 69% of the variation in assemblage structure was explained by a combination of bottom topography and wave-generated water motion at the sea floor. At other sites the explanatory power of environmental variables was lower, between 30% and 56% and a range of water quality parameters (nutrients and suspended sediments) were most highly correlated with assemblage structure. The distribution of invertebrates was in turn linked to the nature of the algal assemblages, with species number varying according to the algal habitat type. Total numbers of invertebrates also varied according to algal habitat with an inverse relationship being found between *Ecklonia* density and the density of both mobile invertebrates, and large sessile invertebrates, particularly sponges and corals.

## Introduction

Western Australia is unusual in possessing high-biomass, high-productivity benthic ecosystems despite the relatively low-nutrient waters of this coastal region that result from the low-rainfall environment as well as the influence of the Leeuwin current. The drivers of productivity and spatial distribution of WA's coastal ecosystems are poorly understood, and there is increasing need for improved information on fundamental aspects of benthic community structure and variability in the wake of increasing pressures resulting from population growth and development (Department of Environmental Protection 1998). Improved understanding of benthic ecosystems can support efforts to manage growing human impacts, will better enable us to determine their likely response to human influences, and will help ensure their future health and sustainability.

The SRFME study focused on improving understanding of one major habitat type –coastal rocky reefs – that had previously received relatively little attention. Rocky reefs are an important habitat type in nearshore coastal waters, supporting a diverse assemblage of benthic macroalgae (Huisman & Walker 1990, Phillips *et al.* 1997) and associated fish and invertebrates. Aside from the biodiversity associated with rocky reef communities, they are also a key component of coastal productivity, provide habitat and food for marine fauna, contribute to biogeochemical cycles, and can exert influence over nearby habitats such as seagrass meadows (Van Elven *et al.* 2004). Despite their recognised importance, comparatively little is known of the ecology of rocky reef habitats along the lower west coast of Western Australia. As a consequence, the SRFME study sought to address this gap in current knowledge of the mechanisms structuring rocky reef communities.

The approach taken in the SRFME study followed the only sound basis for future research which was to have a clear understanding of the distribution and abundance of major ecological components in the coastal ecosystem. The description of these patterns and their inter-correlations in space and time is the primary focus of Chapter 5. The dynamics of interactions between physical and biological processes, and of ecological interactions, is the focus of Chapter 6. The understanding of both pattern and process is essential to the achieving the ultimate goal of modelling the coastal ecosystem and gaining the ability to predict ecosystem behaviour.

## Aims, objectives

Building meaningful ecosystem models, whether they are conceptual or ultimately numerical, is a complex process that must draw on many different areas of expertise. Within such a program, the task of ecology is particularly complex since it must deal with a sometimes bewildering array of biological complexity and attempt to distil this down to tractable concepts that can be dealt with in a cost effective manner. The usual approach applied to this problem, especially where there is relatively little prior research on the ecosystem, is to conduct a series of systematic observations in such a way that the patterns of variation in marine communities over space and time would inform us of the key processes and environmental factors influencing the structure and dynamics of the system. For this reason sampling was designed to cover as wide a range of coastal reef habitats as possible, in order to encompass the full range of variability in physical and biological variables, improving our ability to correlate physical parameters with biological responses. The study areas were replicated throughout the SRFME region between Jurien Bay and Geographe Bay in order to ensure that results would be representative of the region, rather than specific to just one location.

Additionally assemblages of plants and animals are patchy in space and time, complicating the process of discerning patterns in structure or process. Because ecologists' perception of the nature of patchiness is that it is not a nuisance but an important component of ecology influencing many processes from population abundances and rates of change to interactions among species and overall species diversity (Underwood *et al.* 2000). Sampling to investigate the scale and nature of variability in ecological systems usually employed a nested design, incorporating sites in a hierarchical structure. In our case there was both spatial and temporal nesting. Spatially, sampling was nested at scales of meters, kilometres, tens of kilometres and hundreds of kilometres (quadrats, sites, locations and regions – Fig. 5.2). Temporal sampling was structured to incorporate seasonal and annual variation. Thus all of this hierarchical or nested sampling was done at the same set of “core sites”. This design also allowed us to establish baselines against which we will be able to assess whether trends or variation observed in the future are outside the range of spatial or temporal variation normally expected. Our ultimate goal was to lay the groundwork, with this reductionist approach, for scaling up estimates of distribution, abundance, biodiversity and so on, to broad scale synoptic evaluation of ecosystem values at a landscape scale. In order to do this we explored the use of remote sensing approaches to map and evaluate these ecosystem values.

The goal of the SRFME study was to characterise and understand the mechanisms underlying natural variability in diversity and dynamics of benthic community assemblages in selected southwestern Australian coastal marine ecosystems. The project focused mainly on reef habitats since these have been less intensively studied than the seagrass habitats of southwestern Australia. The geographic scope of the work included areas between Green Head in the north and Cape Naturaliste to the south. The range was not greater due in part to logistical constraints but also since all the sites fell within the temperate west coast region. At the same time they afforded a set of gradients in physical (latitude, temperature, bathymetry, fluvial inputs) as well as anthropogenic gradients (proximity to large urban centres, marine protected areas).

The specific SRFME goals addressed in this chapter were to:

- Characterise and quantify seasonal-scale temporal variation in algal and invertebrate assemblages
- Characterise and quantify region-, location- and site-level variation in algal, fish and invertebrate assemblages
- Characterise algal and invertebrate biodiversity and define identifiable algal community types
- Explore and identify environmental factors correlated with algal community structure variation at cross-shore, within location and within site levels
- Characterise and quantify correlations between algal community type and invertebrate assemblage structure and abundance
- Evaluate the use of remote sensing approaches for the mapping of shallow water habitats

## Methods

### Sampling sites

Sites for the SRFME project were chosen based upon representing spatial scales of meters, kilometres, tens of kilometres and hundreds of kilometres (as mentioned above). At the largest scale (hundreds of kilometres) three main 'regions' were selected, Perth in the centre of the project area, Jurien approximately 200 km to the north and Geographe Bay approximately 200 km to the south of Perth (Fig. 5.2). Within each region, 'locations' were selected at the northern and southern extent to represent a scale of tens of kilometres. The locations selected in the Jurien region are Green head and Jurien Bay, in the Perth region Two Rocks and Marmion and in the Geographe Bay region Bunbury and Cape Naturaliste. Nested within each location, 'sites' were chosen at a spatial scale of kilometres to represent a range of reefs in the area. At each site, a variety of sampling methods including quadrat samples, and transects represent the smallest spatial scale.

Sites from the SRFME regions of Jurien, Perth and Geographe Bay were sampled during the period winter 2003 to winter 2005. Within each location two 'core' sites were sampled each season in order to assess temporal variation. The core sites were chosen to be reasonably accessible during the expected range of seasonal weather conditions and were thus located on inshore reef, approximately 500m to 3 km from shore and within 12 km from the nearest safe boat launching ramp. Where possible, core sites were selected both inside and outside a marine reserve area.

Additional sites in each location were selected to address questions of spatial variability relating to variation in physical environment such as cross-shore position and depth. These sites were located on a variety of inshore, mid and offshore reefs in both exposed and sheltered aspects of the reef and due to limited accessibility were generally sampled only once during the summer or autumn seasons.

Fifty one sites were studied in the SRFME study; 9 sites from Green Head, 19 from Jurien Bay, 2 from Two Rocks, 9 from Marmion, 10 from Bunbury and 2 from Cape Naturaliste (Fig. 5.2 & Table 5.1). The average depth of reefs sampled ranged from 2.2 m at North Essex in Jurien Bay to 15.9 m at BBY15M at Geographe Bay. Most of the reefs sampled were less than 7 m but at least one deeper (>10 m) site was sampled in each region. The core sites were all inshore reefs of less than 7 m depth.

At a regional scale the sampling sites are spread over approximately 400 km of coastline from north to south and there are inherent differences in the physical influences on the three regions. Average sea surface temperatures (SST) for the regions range by approximately 1.5°C, with maximum temperatures during March to April from 21.8°C at Jurien, 21.6°C at Perth, 21.2°C at Eagle Bay and the lowest of 20.3°C at Bunbury. Minimum SST during September to October ranged from 18.5°C at Jurien, 18.4°C at Perth, 17.7°C at Eagle Bay and again the lowest average of 17.0°C at Bunbury (ref: SRFME DIVE database).

Human influences on water quality in the three regions are mainly dominated by proximity to large centres of population particularly at sites in the Marmion location and sites close to the Jurien, Bunbury and to a lesser extent Eagle Bay.

Influences on water quality in the three regions also include input from estuarine and river systems. In the Jurien region the only river system is the Hill River which is closest to sites at Booka Valley, however this river is only seasonally open and usually only for a few days or weeks (Brearley 2005). In the Perth region the nearest river inputs are the Swan River, 25 km south of sites at Marmion and the More River which is 12km north of sites at Two Rocks and only seasonally open to the sea (Brearley 2005). Sites in the Geographe Bay region are possibly influenced more by riverine input particularly at Bunbury with the Leschenault Inlet and Collie River only 6 km to the north and the Capel River and Wonnerup Inlet to the south. Sites in the Cape Naturaliste location may be influenced by the numerous small inlets to Geographe Bay such as Toby Inlet, and the Vasse diversion drain (Brearley 2005). The closest site to these inlets is at Eagle Bay approximately 13 km from Toby Inlet.

The Jurien and Perth regions share similar topographic features of complex limestone reef systems with a range of offshore, midshore and nearshore reefs and islands although with a greater number of islands at Jurien. These complex systems present a range of sites with varying degrees of influence by wave action from highly exposed outer reef to very sheltered reef inshore and inside the islands. The topography was quite different in the Geographe Bay region with a mix of granite and limestone reef and lacking the complex offshore reef and islands. The west facing coast at the Bunbury location with no offshore reef is very exposed to wind and wave influence whereas at Cape Naturaliste, the sites face further to the north and although still very exposed, seemed to be more influenced by surge from large swell.

The majority of the reefs sampled were limestone; the exceptions to this are granite reefs located at Cape Naturaliste (Eagle Bay and Quarries) and basaltic reef at one Bunbury site (BBY08). The relief of core sites range from low relief limestone reefs at the Bunbury sites (South Bunbury and Dalyellup), through medium relief reefs at the Marmion sites (South Lumps and Whitford Rock) and Julia Rocks at Green Head, to high relief reefs at the remaining Jurien sites (Fisherman Island Sanctuary Zone 3, Wire Reef and Booka Valley Rocks) and the Two Rocks sites (Cook Lump and Map Reef). The Cape Naturaliste sites were medium to high relief granite boulders and cobbles interspersed with low relief sand covered patches of reef.

### **Sampling methods – environmental**

Two measures of the physical characteristics of reefs were made; namely reef relief and rugosity (Table 5.1). The subjective measure of reef relief considered the elevation of the reef above the surrounding seabed, while the quantitative rugosity code measured the topography of the horizontal reef surface where sampling took place.

Chlorophyll *a*, total suspended solids (TSS), water column nutrients and light attenuation were measured at each site. Although the sampling frequency only provided a 'snapshot' of local environmental with no integration of temporal variability, measurements were useful for making relative comparisons between sites within seasons. Filtered water samples were analysed according to standard methods for chlorophyll *a*, TSS, N, P and Si. Available nitrogen was measured in the form of ammonium (NH<sub>4</sub>) and total oxidised nitrogen (NO<sub>x</sub>), which is the combination of nitrate (NO<sub>3</sub>) and nitrite (NO<sub>2</sub>). Light levels throughout the water column were measured using a Li-Cor LI 250 meter with 2-Pi sensor.

Carbon and nitrogen isotopes and content in the tissue of the kelp *Ecklonia radiata* were determined from reefs throughout the SRFME study area, to provide an indication of past nutrient availability and sources. Replicate plants were sampled from a number of reefs and samples were analysed using an ANCA-NT/20-20 stable isotope ratio mass spectrometer (Europa Scientific, Crewe, UK).

### **Sampling methods - biological**

At each site sampling was conducted at both 1 m<sup>2</sup> and 0.25 m<sup>2</sup> scales using randomly placed 1 x 1 m quadrats which had a 0.5 x 0.5 m quadrat fixed in one corner. Sampling of the 1 m<sup>2</sup> quadrats included solitary or mobile invertebrates >10 mm in size, with the 0.25 m<sup>2</sup> quadrat typically providing data on invertebrates <10 mm in size. Algae were sampled by hand-collecting all macroalgae within the 0.25 m<sup>2</sup> quadrat. These were bagged for later identification and weighing. Invertebrates sampled incidentally with the algal collections were also identified in the lab. This fauna tended to be largely epifaunal, or associated with algal holdfasts. A photograph of each quadrat was then taken for later analysis of benthic cover, including various algal forms but also categories such as bare rock and sand. Photos were analysed using the JEHP (v 1.0.0.1, © James Wise, UWA/CoastalCRC), using a point intercept method. Fifty points were randomly selected by JEHP and assigned to benthic categories by an expert observer. Pilot analysis of data revealed little further gain in precision was achieved by sampling more than 40-50 points. Data were converted to the % cover of primary space occupied by various benthos components.

Where possible, specimens were identified to species level. Those that were not identified in the field were collected for follow up verification. An invertebrate reference collection for the

SRMFE region has also been established. Individuals in the 1 m<sup>2</sup> quadrat were counted and measured (max length and/or width in mm). Smaller individuals from the 0.25 m<sup>2</sup> quadrat were measured in a similar way and weighed.

Fish assemblages were characterised using underwater visual census (UVC) conducted by divers on SCUBA. Censuses were conducted within 25 x 5 m transects; three or four transects were conducted at each reef in the summer of 2005/2006. Multivariate analyses focussed on spatial patterns in fish assemblages. Patterns were visualised using non-metric multidimensional scaling (NMDS) ordination, and the significance of spatial patterns was tested using ANOSIM, with both analyses based on binomial deviance dissimilarity calculated from untransformed counts (Anderson & Millar 2004).

Abundance data from 0.25 m<sup>2</sup> and 1 m<sup>2</sup> quadrats recorded from the SRFME regions of Jurien, Perth and Geographe Bay was extracted from the SRFME ACCESS database. Only species with confirmed identity were used in analyses. Data were analysed using the software package PRIMER 6 (Plymouth Routines In Multivariate Ecological Research). The effect of physical factors including depth, relief, cross-shore position of the sampling site (inshore/offshore), algal habitat type and brown algal biomass were used in qualitative comparisons with invertebrate distribution within the SRFME region, in order to identify any patterns if present.

Overall square root transformation was applied to algae abundance (biomass) data and fourth root transformations were used for invertebrate abundance (count) data. A Bray-Curtis similarity resemblance matrix was then generated and data analysed through ordination by non-metric multidimensional scaling, with a restart value of 25. The factors of region, location, site, cross-shore position, depth, relief and algae habitat type were used in analyses with results displayed in the form of scatter plots. Analysis of Similarities (ANOSIM) was applied to these factors to test significance, and Similarity Percentages (SIMPER) used to assess contribution of species, to variation in assemblage structure between and within factors.

Habitat types were allocated to each quadrat using the % algal abundance (biomass). The species were ranked from most to least abundant and the species contributing most to overall community composition were used to assign *a posteriori* habitat types for each quadrat. Habitat categories were originally developed for use by divers to visually allocate habitat type based on algal cover. As such, the classification of individual quadrats, which were based on % biomass, may vary somewhat from classifications based on cover. However, analyses of classifications done using biomass or % cover showed close agreement between the two methods.

### Remote Sensing of Shallow Water Habitat Data

The HyMap sensor is an airborne hyperspectral digital spectrometer that records reflected sunlight in 126 spectral channels between 450nm to 2500nm over a 512 pixel swath. Spatial resolutions are usually in the range 3 to 10 m (9 m<sup>2</sup> to 100 m<sup>2</sup>). Two HyMap strips (26.1km and 23.1km by 1649m wide; 3.2m pixel width) were flown at Jurien Bay in April 2004 and processed by HyVista Corporation to correct for atmospheric absorption and scattering. These data were then processed using the shallow water reflectance model outlined below (see also Vol. 1, sec. 2.2.5).

### Optical modelling

We have implemented a simple shallow water reflectance model applicable to the optical domain present in many Australian coastal waters. The model is typically tuned to local conditions by including spectral characteristics of commonly occurring local substrates. The model is based on the work of Lee *et al.* (1999). The remote sensing spectral reflectance,  $r_{rs}$ , is given by,

$$(A) \quad r_s \approx r_s^{\theta} \left( 1 - \exp \left\{ - \left[ \frac{1}{\cos(q_w)} + \frac{D_u^C}{\cos(q)} \right] kH \right\} \right) + \frac{1}{p} r \exp \left\{ - \left[ \frac{1}{\cos(q_w)} + \frac{D_u^B}{\cos(q)} \right] kH \right\}$$

where,  $r_{rs}^{dp}$  is the remote sensing reflectance of an infinitely deep water column,  $\theta$  and  $\theta_w$

relate to the illumination and viewing geometry,  $\kappa$  and  $D_u$  are light transmission functions and  $H$  is water depth. The light transmission functions may be expanded to include coefficients related to the optical properties of water column constituents, and these in turn related to concentration values for constituents such as chlorophyll and suspended sediment. The component of interest for this work is  $\rho$ , the substrate reflectance. For a pixel area that is uniformly covered in one substrate type, sand for instance,  $\rho$  is equal to,

$$r = P R'_{sand} \quad \text{(B)}$$

where  $R'_{sand}$  is a normalised sand reflectance spectrum and  $P$  is a scaling factor. The work of Lee *et al.* (1999) was developed for a single substrate, namely sand. We have expanded the applicability of the model to include mixed pixels. In theory, many substrate classes can be combined to model the total reflectance of a pixel. For this work we have chosen three commonly occurring, and spectrally distinct, substrate classes; sand, seagrass and brown algae. When the pixel contains a mixture of substrates, the total reflectance is modelled as a sum of reflectances,

$$r = P_1 R'_{sand} + P_2 R'_{seagrass} + P_3 R'_{algae} \quad \text{(C)}$$

A constrained iterative optimisation scheme is employed to search the model space for coefficients providing the best fit to the measured reflectance spectrum. The retrieval process returns the three coefficients,  $P_1$ ,  $P_2$  and  $P_3$ †, bathymetry ( $H$  in Eqn. **A**) and water column constituent properties. The three reflectance parameters,  $P_1$ ,  $P_2$  and  $P_3$ , are taken to represent the proportion of each substrate in a particular pixel. No account is made for variations in albedo (brightness) of substrates.

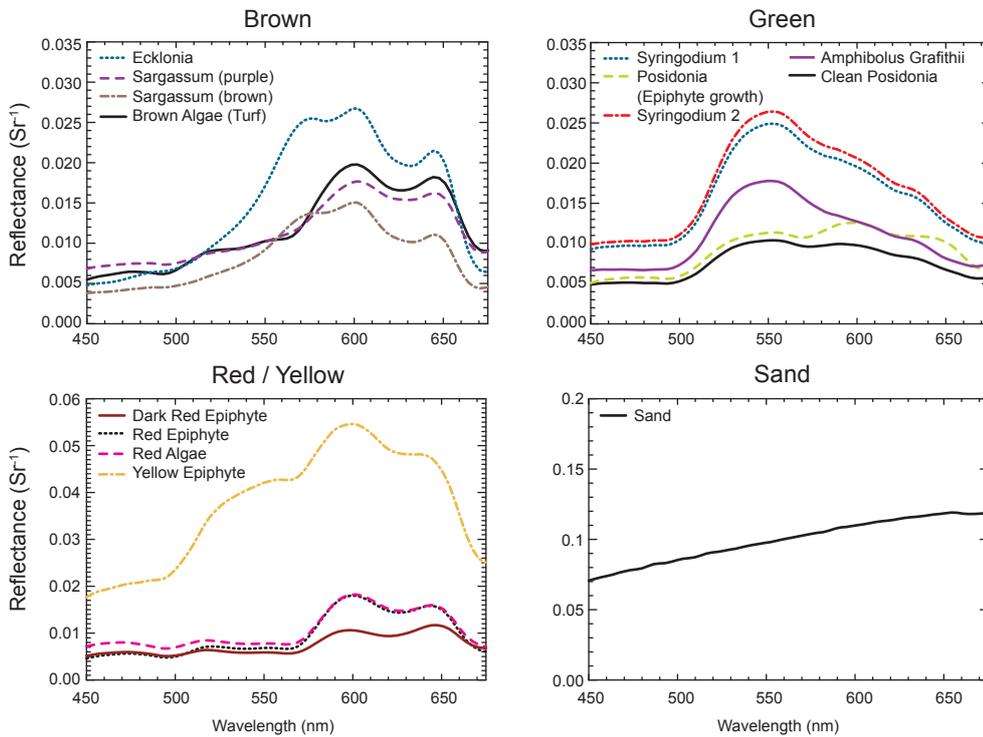
### Collection of library spectra

Classification of benthic substrates by remote sensing techniques depends upon a-priori knowledge of the spectral nature of the substrates present. Typically, spectra are selected from a spectral library. This spectral library is built up from numerous field campaigns to undertake in-situ measurements of substrate spectral properties. CMAR have been involved

in the collection of such spectra for a number of years, including campaigns measuring coral spectral properties on the Great Barrier Reef and spectral properties of numerous algae species in WA coastal waters. Reflectance spectra are measured with a dual channel Zeiss hyperspectral radiometer. The radiometer may be deployed by a diver to measure the reflectance spectrum *in situ*, or the diver may retrieve a sample of the benthic cover to measure the spectral reflectance in air. Reflectance spectra collected in Jurien Bay are shown in Figure 5.1. The spectra in each type may be normalised and averaged to create representative spectra for use in the inversion process. The sand spectrum is clearly very different to the algal spectra. The peak reflectance in the green substrate classes is around 550 nm. The peak reflectance in the brown and red/yellow algae occurs at longer wavelengths, and tends to exhibit a broader peak. For this work, the brown and red/yellow spectra have been combined to create the brown algae class. By combining and normalising spectra from a range of biotic substrate rather than treating them separately, we have opted for robust and reliable solutions for classification.

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†  $P$  values don't necessarily add up to 1.0 because they represent reflectance scaling factors, not proportion of each substrate class. However, a larger  $P$  value can be related to a greater likelihood of a given substrate dominating a pixel's reflectance.

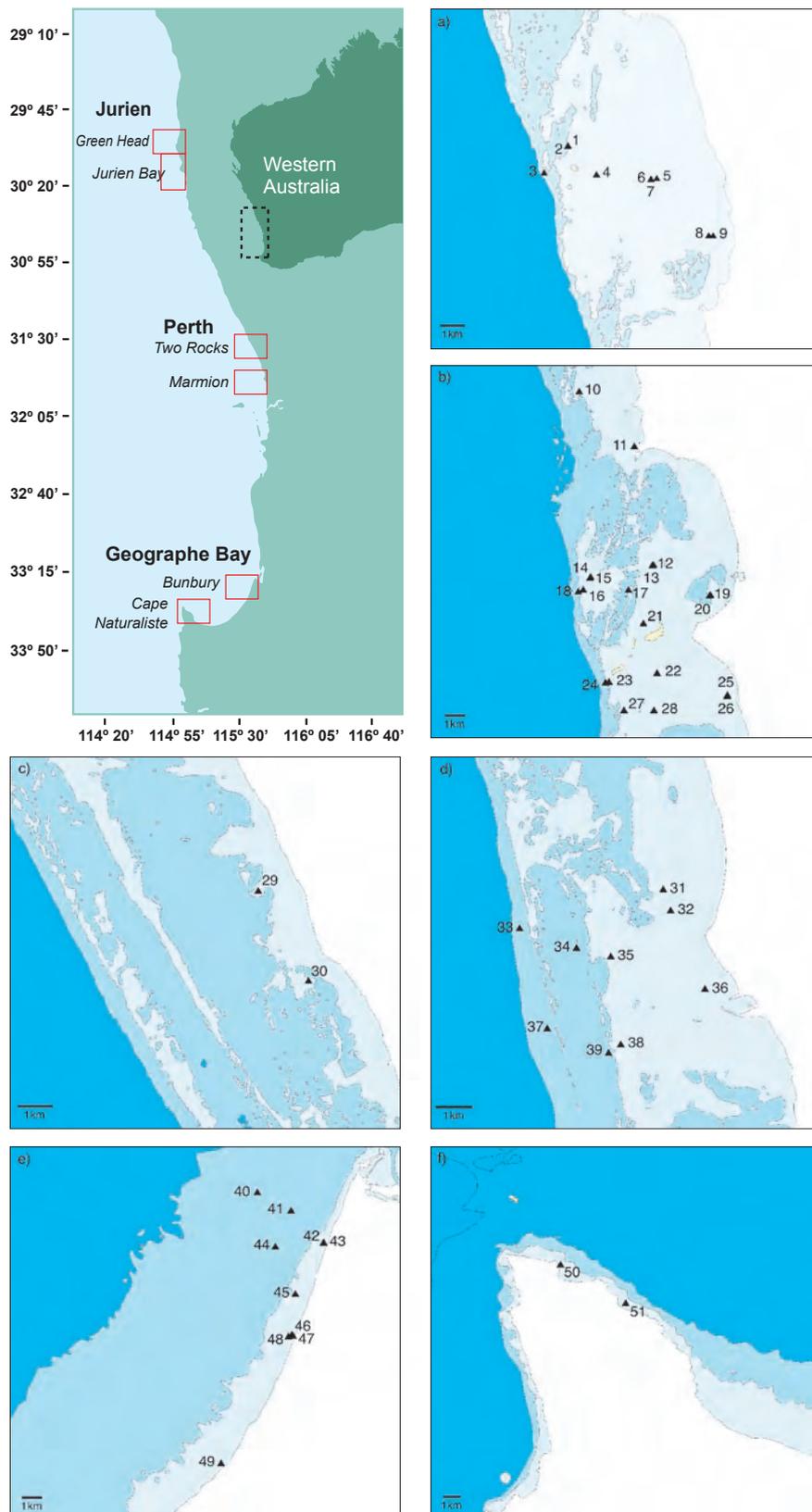


**Figure 5.1:** *In-situ* reflectance spectra of four different groups of substrate.

### Ground Truthing

Approximately three hours of video footage was obtained during October, 2004. The underwater video camera was deployed in several regions of the HyMap strips. The boat's position was geolocated with a differential Global Positioning System (GPS). The filmed benthic cover was visually classified according to a habitat classification scheme based largely on the predominant canopy macrophyte species (Table 5.6, section 5.4) as well as sand, and two classes of seagrass (*Posidonia* and *Amphibolis*). For the validation work, these habitat types were collapsed into three classes: sand, seagrass and brown algae.

The method of video camera deployment was to suspend the camera from the boat and maintain a relatively constant position. The habitat maps below (Figure 5.36) show the locations of the video data indicated by white squares. Sites were chosen based on Klonowski (Vol. 1, sec. 2.2.5) to ensure that areas representative of each of the main spectral classes was sampled at approximately the same intensity. The substrate classification based on the video data provided approximately 1800 video frames.



**Figure 5.2:** SRFME Coastal Ecosystems and Biodiversity Project study area showing the regions, locations and sites within each location a) Green Head, b) Jurien Bay, c) Two Rocks, d) Marmion, e) Bunbury and f) Cape Naturaliste. Site numbers are from Table 5.1. Colour shading on maps: white, mainland; yellow, islands; light blue, 0-10 m water depth; mid blue, 10-20 m; dark blue, 20-50 m.

**Table 5.1:** Sampling depths, reef relief and rugosity codes for all sampling sites. Core sites are indicated in bold. Reef relief, L – flat reef (0 – 10 cm above surrounding seabed), M – medium relief reef (10 – 100 cm), H – high relief reef (> 100 cm), B – boulders, C – cobbles, \* - granite reefs. Higher rugosity values indicate greater change in topography, or roughness, of reef surfaces.

No.	Site Name	Depth (metres)		Reef Relief	Rugosity			
		Mean	Range		Site Mean	Site St Dev	Quadrat Mean	Quadrat St Dev
<b>Jurien – Green Head</b>								
1	WA Museum 12	8.6	8.3 - 9.1	H	1.3	0.2	1.2	0.1
2	WA Museum 11	5.6	5.2 - 5.8	L	1.5	0.8	1.2	0.1
3	Fisherman's Island 12m	12.8	12.5 - 13.2	M	1.0	0.1	1.1	0.1
4	Fisherman's Islands Sanctuary Zone 2	3.8	3.4 - 4.2		1.3	0.2		
5	Fisherman's Islands Sanctuary Zone 1	4.8	4.2 - 5.5	M	1.2	0.1		
6	WA Museum 15	7.0	7.0 - 7.1	L	1.0	0.0	1.0	0.0
<b>7</b>	<b>Fisherman's Islands Sanctuary Zone 3</b>	<b>4.1</b>	<b>2.5 - 5.8</b>	<b>H</b>	<b>1.4</b>	<b>0.2</b>	<b>1.4</b>	<b>0.2</b>
<b>8</b>	<b>Julia Rocks</b>	<b>2.9</b>	<b>1.0 - 4.4</b>	<b>M</b>	<b>1.3</b>	<b>0.1</b>	<b>1.3</b>	<b>0.2</b>
9	WA Museum 14	5.1	5.0 - 5.5	L	1.0	0.0	1.0	0.1
<b>Jurien – Jurien Bay</b>								
10	WA Museum 9	4.8	4.7 - 5.0	M	1.6	0.3	1.2	0.1
11	North Head	4.6	4.3 - 4.9	H	1.3	0.0	1.4	0.2
12	Favourite Island	6.2	6.1 - 6.4	L				
13	WA Museum 3	5.4	4.5 - 5.9	H	1.3	0.2	1.3	0.2
14	Seaward Ledge East 06	6.5	5.8 - 6.8	LC	1.2	0.1	1.4	0.3
15	WA Museum 2	5.6	5.1 - 5.8	L	1.1	0.1	1.2	0.1
16	Seaward Ledge 6m	7.0	6.1 - 8.4	H	1.3	0.1	1.2	0.1
17	North Marker	9.7	9.0 - 10.2	L	1.3	0.1		
18	Seaward Ledge 13m	13.6	13.3 - 14.0	M	1.1	0.1	1.1	0.1
19	WA Museum 5a	7.7	7.5 - 8.0	L	1.0	0.0	1.2	0.1
<b>20</b>	<b>Wire Reef</b>	<b>5.2</b>	<b>3.8 - 6.3</b>	<b>H</b>	<b>1.6</b>	<b>0.1</b>	<b>1.6</b>	<b>0.3</b>
21	North Osprey	2.8	2.5 - 3.1	M	1.4	0.1		
22	North Essex	2.2	1.9 - 2.5	H	1.5	0.1		
23	WA Museum 7	6.8	6.3 - 7.8	M	1.4	0.1	1.2	0.1
24	WA Museum 6	11.8	11.4 - 12.0	H	1.2	0.1	1.2	0.1
25	WA Museum 4a	5.1	4.8 - 5.4	L	1.4	0.2	1.2	0.1
<b>26</b>	<b>Booka Valley Rocks</b>	<b>4.1</b>	<b>2.8 - 5.2</b>	<b>H</b>	<b>1.7</b>	<b>0.2</b>	<b>1.7</b>	<b>0.3</b>
27	WA Museum 8	7.7	7.0 - 8.6	H	1.2	0.1	1.5	0.2
28	WA Museum 1	3.1	2.6 - 3.8	H	1.4	0.1	1.4	0.3
<b>Perth – Two Rocks</b>								
<b>29</b>	<b>Cook Lump</b>	<b>6.1</b>	<b>3.5 - 8.3</b>	<b>H</b>	<b>1.3</b>	<b>0.0</b>	<b>1.4</b>	<b>0.3</b>
<b>30</b>	<b>Map Reef</b>	<b>5.9</b>	<b>3.7 - 8.3</b>	<b>H</b>	<b>1.9</b>	<b>0.3</b>	<b>1.7</b>	<b>0.4</b>
<b>Perth – Marmion</b>								
<b>31</b>	<b>South Lumps</b>	<b>5.5</b>	<b>4.4 - 7.2</b>	<b>L</b>	<b>1.2</b>	<b>0.1</b>	<b>1.4</b>	<b>0.2</b>
<b>32</b>	<b>Whitford Rock</b>	<b>4.4</b>	<b>2.9 - 5.7</b>	<b>M</b>	<b>1.5</b>	<b>0.2</b>	<b>1.6</b>	<b>0.3</b>
33	3 Mile Reef North	15.6	14.8 - 16.2	M	1.2	0.0	1.1	0.2
34	Little Island West 1	14.0	13.4 - 15.0	M	1.2	0.1		
35	Little Island	4.6	4.0 - 5.3	M	1.9	0.2		
36	Cow Rock	4.2	3.0 - 5.1	H	1.7	0.3	1.5	0.2
37	3 Mile Reef South	13.6	13.0 - 14.2	L	1.2	0.1	1.1	0.2
38	Outer Horseshoe Reef	6.5	6.2 - 6.8	L	1.1	0.0		
39	Horseshoe Reef West 1	13.8	13.4 - 14.2	L	1.1	0.0		
<b>Geographe Bay – Bunbury</b>								
40	BBY15M	15.9	15.1 - 16.2	L	1.0	0.0	1.1	0.0
41	BBY08	10.8	10.4 - 11.0	L*	1.2	0.1		
<b>42</b>	<b>South Bunbury</b>	<b>7.2</b>	<b>6.5 - 8.0</b>	<b>L</b>	<b>1.4</b>	<b>0.2</b>	<b>1.3</b>	<b>0.2</b>
43	Bunbury 4							
44	BBY14M	13.7	13.2 - 14.2	L	1.2	0.1	1.1	0.1
45	BBY10B	9.4	9.2 - 9.5	L	1.1	0.1		
<b>46</b>	<b>Dalyellup 1</b>	<b>6.8</b>	<b>6.3 - 7.3</b>	<b>L</b>	<b>1.1</b>	<b>0.4</b>	<b>1.2</b>	<b>0.1</b>
47	Dalyellup North	5.8	5.6 - 6.0	L				
48	Bunbury 3							
49	Capel 5	2.1	1.5 - 2.6	M	1.4	0.1	1.7	0.1
<b>Geographe Bay – Cape Naturaliste</b>								
<b>50</b>	<b>Quarries</b>	<b>5.2</b>	<b>3.8 - 7.4</b>	<b>L*</b>	<b>1.2</b>	<b>0.1</b>	<b>1.5</b>	<b>0.5</b>
<b>51</b>	<b>Eagle Bay</b>	<b>5.7</b>	<b>2.3 - 6.7</b>	<b>L*BC</b>	<b>1.4</b>	<b>0.2</b>	<b>1.6</b>	<b>0.2</b>

## Results

### 5.1 Environmental Parameters

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#### Nutrients

In the majority of samples  $\text{NO}_x$  made up a larger portion of available nitrogen than  $\text{NH}_4$  (Fig. 5.3). Mean levels of available nitrogen were highest at Two Rocks and Jurien Bay during autumn 2004. Mean levels at Marmion were elevated above other sites on all other occasions. Mean phosphate ( $\text{PO}_4$ ) levels at the majority of sites ranged from 0.3 to less than  $0.01 \mu\text{M}^{-1}$ , and were highest at Marmion ( $0.28 \mu\text{M}^{-1}$ ) and lowest at Bunbury ( $0.04 \mu\text{M}^{-1}$ ) (data not shown here). There was little seasonal change in phosphate levels.

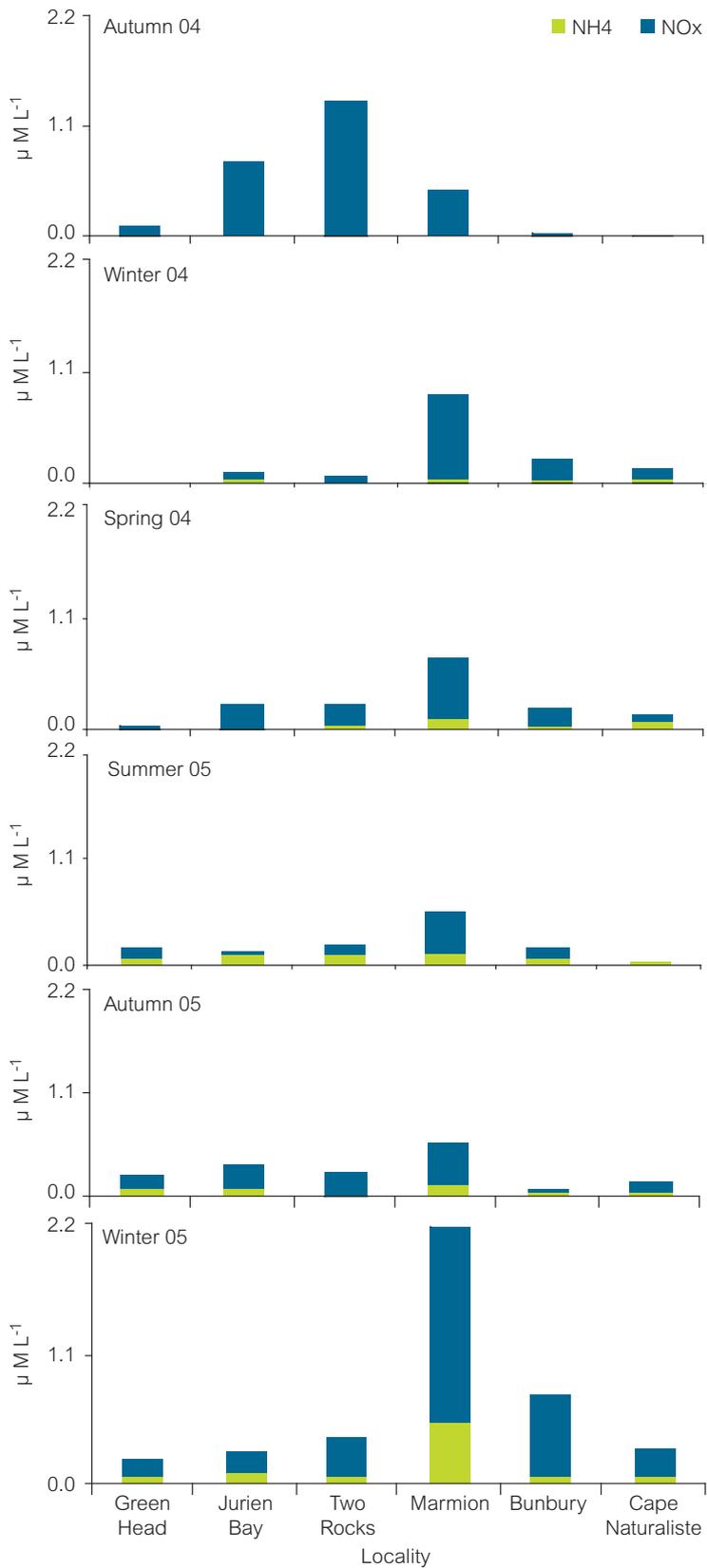
#### Chlorophyll *a*

Mean chlorophyll *a* levels were highest in Bunbury ( $5.4 \mu\text{M}^{-1}$ ) and lowest at Green Head ( $0.5 \mu\text{M}^{-1}$ ) (Fig. 5.3). Mean chlorophyll *a* levels did not vary much seasonally except at Bunbury, where they were much higher and more variable in winter compared to the other seasons. This is consistent with the trends in nutrient availability.

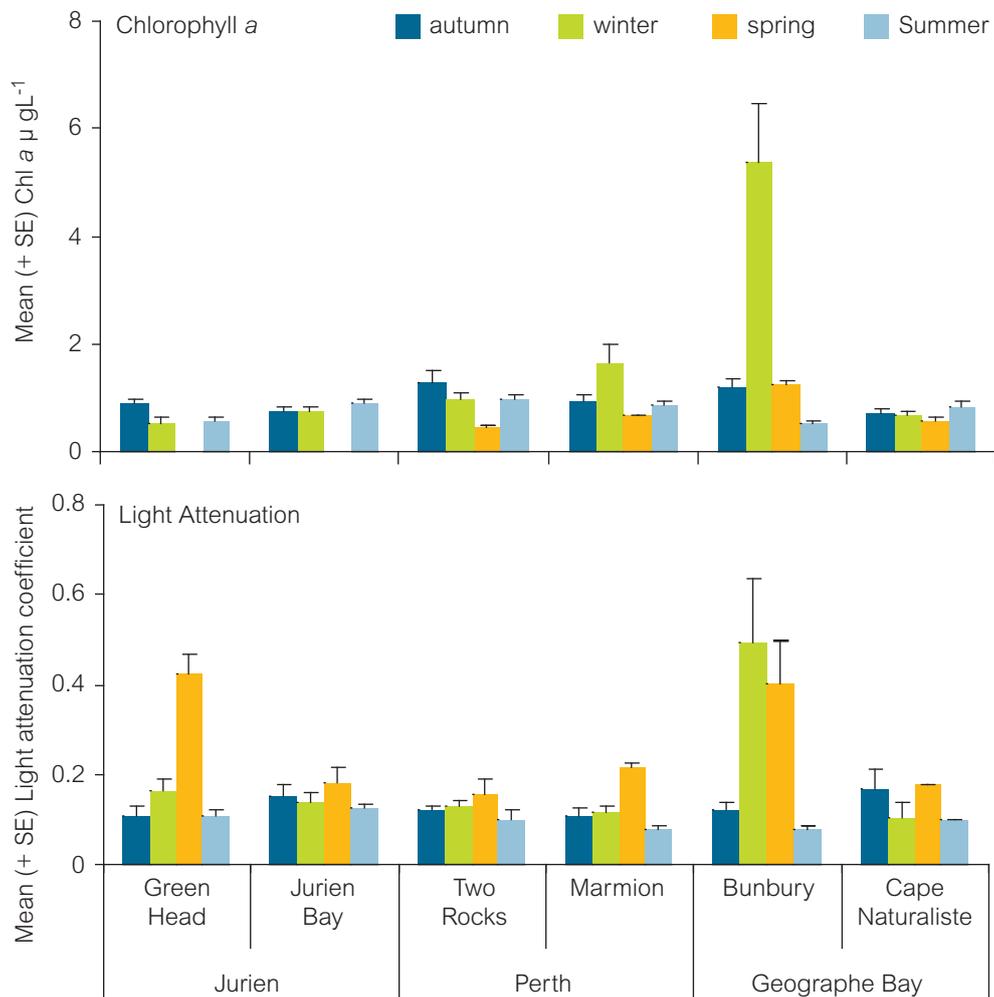
#### Light attenuation

Light attenuation coefficient showed a clear seasonal trend across most locations with attenuation increasing from autumn to winter and the highest attenuation recorded during spring then dropping off during summer (Fig. 5.4). Bunbury generally had the highest attenuation coefficient, which also corresponds to the high levels of chlorophyll *a* (and TSS, not shown here) particularly during winter and spring.

These trends were also quite apparent to the divers conducting sampling at each location as changes in underwater visibility. Visibility was very low at Bunbury sites during winter and spring, frequently with a distinct reduction to almost zero visibility within 1 to 2 m above the bottom. However, since water samples were collected near the surface this stratification of highly turbid water near the bottom is not fully reflected in the TSS samples.



**Figure 5.3:** Mean total oxidized nitrogen ( $\text{NO}_x$ ) and ammonium ( $\text{NH}_4$ ) recorded from sites within each location.



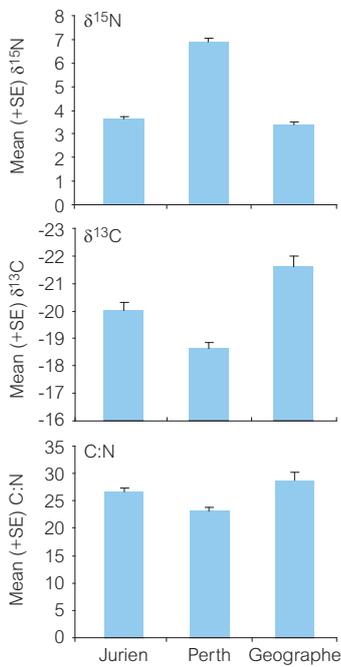
**Figure 5.4:** Seasonal variation in chlorophyll a ( $\mu\text{g L}^{-1}$ ) and light attenuation for project sites during 2004-2005.

### C and N content and isotopes

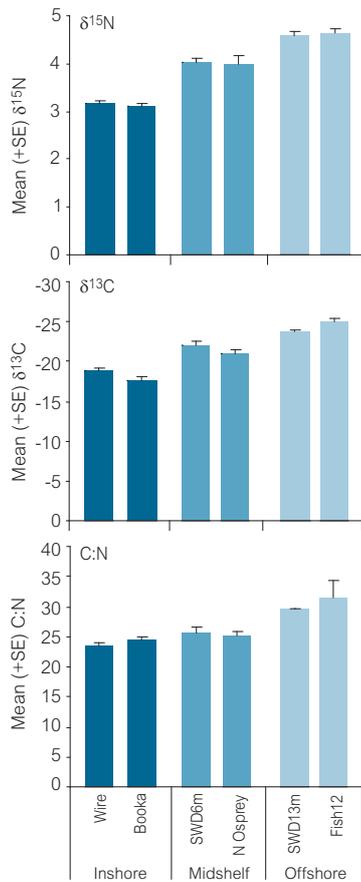
At a regional level, kelp from Perth reefs had elevated levels of  $\delta^{15}\text{N}$ , that were nearly twice as high as in kelp from Jurien and Geographe Bay ( $p < 0.001$ ), each of which had very similar levels (Fig. 5.5). The reverse was true of  $\delta^{13}\text{C}$  and C:N ratios, with lower levels in Perth kelp compared to other regions ( $p < 0.001$ ). This is indicative of higher N availability in the Perth region. The elevated  $\delta^{15}\text{N}$  signal suggests the source of this nitrogen is anthropogenic and effluent related.

Cross-shore variation in C and N isotopes and total C:N content was examined in kelps from reefs in Jurien Bay and in Marmion, in autumn 2004 and spring 2003 respectively. In Jurien Bay,  $\delta^{15}\text{N}$  levels increased with increasing distance offshore ( $p < 0.001$ ) (Fig. 5.6).  $\delta^{13}\text{C}$  was more variable among kelps across the shore, with similar levels in plants from mid and outer shore reefs ( $p > 0.05$ ). Lowest levels were in kelp plants from inner shore reefs. C:N ratios showed a general trend towards higher ratios with distance from shore and the lower levels in kelps from inner reefs ( $p < 0.001$ ) indicate a lesser degree of N-limitation compared to kelp from mid and outer reefs.

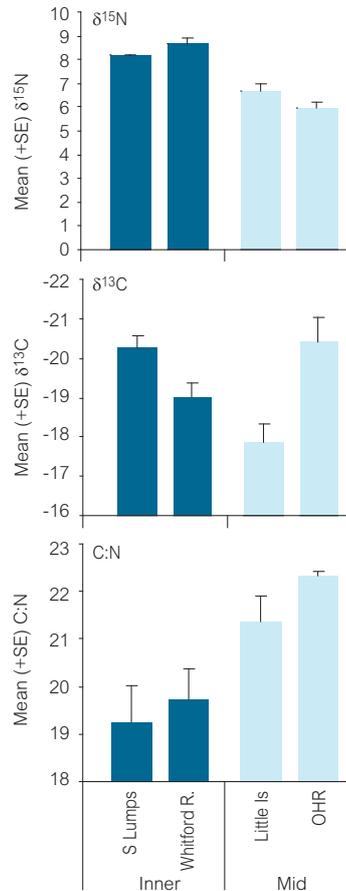
In Marmion Lagoon,  $\delta^{15}\text{N}$  was significantly higher in kelp from inner shore reefs than from mid shore reefs ( $p < 0.001$ ) (Fig. 5.7), opposite to the trend at Jurien.  $\delta^{13}\text{C}$  levels were variable and no patterns were discernible between inner and mid shore kelp populations ( $p > 0.05$ ) whereas C:N ratios were lower in inner reef kelps ( $p < 0.001$ ).



**Figure 5.5:** Regional variation in C and N isotopes and C:N ratio in the kelp *Ecklonia radiata*. n=25-80.



**Figure 5.6:** Cross-shore variation in C and N isotopes and C:N ratio in the kelp *Ecklonia radiata* from reefs in Jurien Bay during autumn 2004. n=3-8.



**Figure 5.7:** Cross-shore variation in C and N isotopes and C:N ratio in the kelp *Ecklonia radiata* from reefs in Marmion Lagoon during spring 2003. n=3.

## 5.2 Seasonal dynamics in reef algal communities

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### Abundance

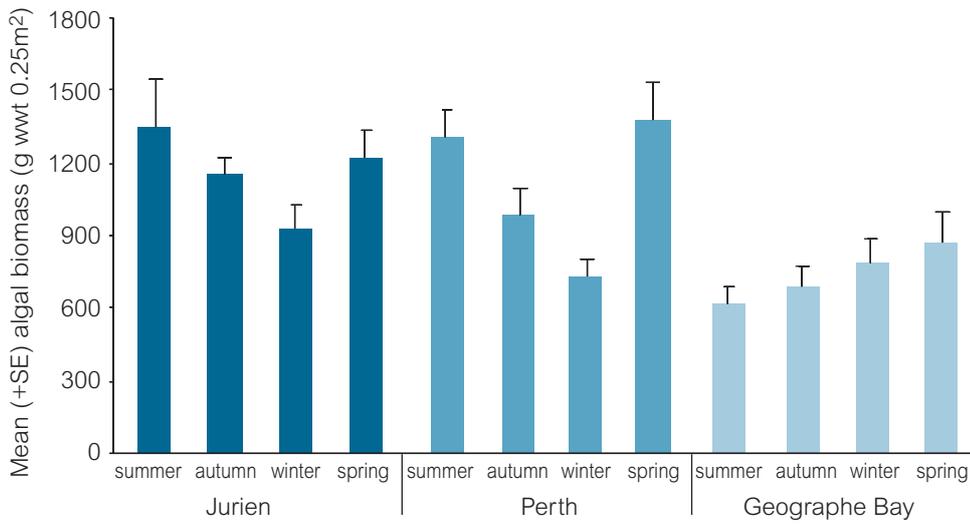
Biomass of reef algae varied significantly among regions and seasons (2-way ANOVA,  $p < 0.001$ , locations and sites pooled); furthermore, the biomass in each season differed according to the region ( $p = 0.017$ , Table 5.2). In the Jurien and Perth regions, biomass was relatively high and seasonal variation followed predictable trends (e.g. Kirkman 1989) with lower biomass during winter, increasing to a spring-summer peak. Reef algal communities in the Geographe Bay region had lower biomass and deviated from the typical annual cycle of growth and erosion seen elsewhere, instead showing a trend of increasing biomass through the year to a spring maxima (Fig. 5.8). This deviation from the typical annual cycle of algal biomass may be largely explained by the particular environmental conditions that prevailed at Bunbury during the study, namely the reduced water clarity during winter and spring (discussed further in Section 5.8).

**Table 5.2:** Results of a two-way analysis of variance testing for differences in seasonal macroalgal biomass, using the fixed factors region and season.

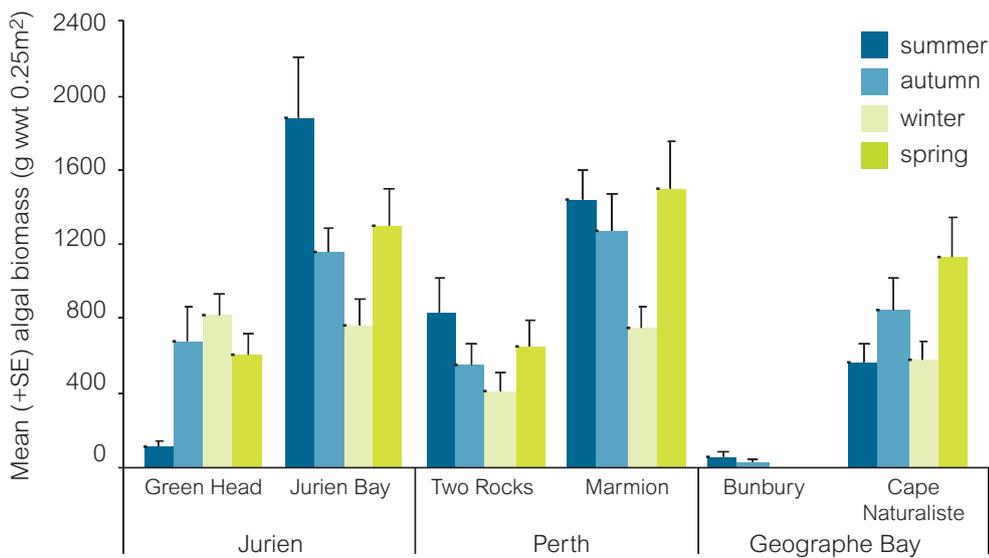
	d.f.	MS	F	P
Region	2	11224540	17.77	<0.001
Season	3	3969191	6.28	<0.001
Region*Season	6	1636723	2.59	0.017
Residual	684	631631		
Total	695	685198		

Reef algal communities can be roughly divided into the understory component and the overlying canopy, where such a canopy exists, and may have different ecological functions. The seasonal variation in understory algal biomass was similar to that reflected in the total algal biomass (as shown in Fig. 5.8) with winter minima and spring/summer maxima (data not shown). Large canopy-forming brown algal species were a conspicuous and large component of the biomass on many reefs, and as such may contribute significantly to secondary production and the export of nutrients to adjacent habitats. Seasonal variation in the biomass of canopy-forming browns (Fig. 5.9) was related to the ecology of the dominant species at each location. Reefs at Jurien Bay, Two Rocks and Marmion were dominated by the kelp *Ecklonia radiata* and seasonal changes in biomass at these locations were consistent with the annual erosion of biomass during winter storms (Kirkman 1989). *Sargassum* is the dominant canopy-forming brown alga on reefs at Green Head, the seasonal variation in abundance is explained by its particular life history (phenology). *Sargassum* produces long branches bearing reproductive structures during mid-winter and spring, and plants then die back to a basal rosette of fronds in summer and autumn following the release of spores (Womersley 1987). This seasonal phenological cycle results in dramatic fluctuations in the biomass of *Sargassum* throughout the year, which is clearly reflected in Fig. 5.9.

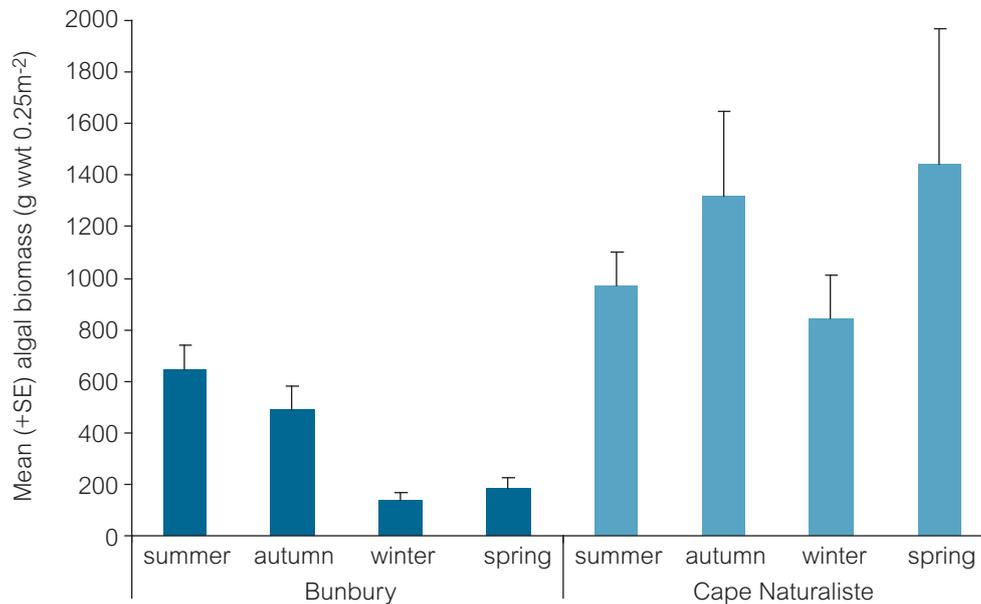
Within locations at Geographe Bay there were contrasting seasonal patterns (Fig. 5.10) in total algal biomass. At Bunbury there was significant variation among seasons ( $p = 0.002$ ) with a significantly lower biomass in winter and spring ( $p < 0.05$ ) while at Cape Naturaliste there was no significant difference among seasons ( $p = 0.46$ ). This pattern is probably related to seasonal variation in light availability to the bottom which is restricted in winter by sediment resuspension and low attenuation coefficient (Fig 5.4 and Section 5.7).



**Figure 5.8:** Seasonal variation in total biomass of reef algae within the SRFME regions.

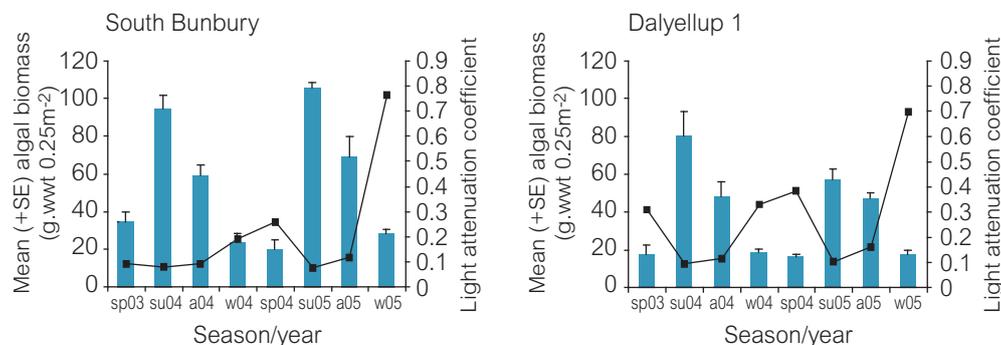


**Figure 5.9:** Seasonal variation in the biomass of large, canopy-forming brown algae on reefs in different locations within the SRFME regions.



**Figure 5.10:** Seasonal variation in total biomass of reef algae within Geographe Bay.

In Geographe Bay the biomass of reef algae at South Bunbury and Dalyellup 1 was negatively correlated with light attenuation (-0.50 and -0.76, respectively; Fig. 5.11). Light attenuation coefficients increased during winter and spring seasons when a persistent and distinct nepheloid layer close to the seafloor was observed. This may be responsible for the subsequent dieback of low-light intolerant species.



**Fig. 5.11:** Seasonal algal biomass and light attenuation coefficients at sites South Bunbury and Dalyellup 1 within the Geographe Bay region.

### Community structure

Seasonal dynamics in reef algal community structure was investigated at four sites within each region. These core sites were shallow (<7 m depth) and were sampled between two and four times in each season during the SRFME program. Overall, there was no seasonality in community structure at any of the core sites, as indicated by multivariate analyses of similarities of the communities ( $R = 0.009 - 0.339$  for all sites). The lack of seasonal trends in reef algal community structure (species composition) within the SRFME area of interest demonstrated that communities as a whole on any given reef remain relatively stable, despite variations in the biomass of key taxa such as *Ecklonia* and *Sargassum*.

### 5.3 Regional trends in reef algal community structure

Investigators / Institution

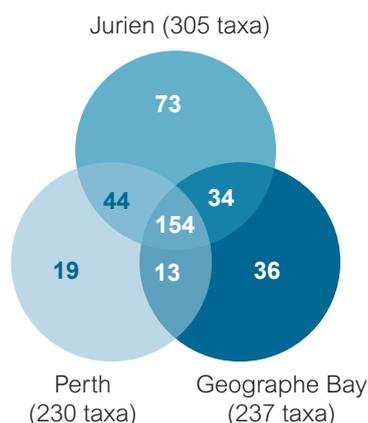
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#### Diversity and species richness

At the completion of the SRFME field program, a total of 373 marine plant taxa (macroalgae and seagrasses combined) had been identified. Over 99% of taxa have verified identifications to species level; voucher specimens have been prepared for lodgement with the Western Australian Herbarium and for inclusion on their *Naturebase* database. Numerous range extensions of species' distributions have been recorded, and the red alga *Gelidiella ramellosa* was 'rediscovered' after having not been recorded in WA for over 150 years.

The distribution of marine plant taxa among the three SRFME regions is represented in Figure 5.12. Species richness was comparable between Perth and Geographe Bay, with 230 and 237 taxa, respectively. Jurien had somewhat higher species richness (305 taxa) although it should be noted that sampling effort in terms of the number of sites visited was greater in this region and included both reef and seagrass habitats. Nevertheless, the number of species found in only one region appears high with 73 taxa recorded only at Jurien, compared with only 19 in Perth and 36 in Geographe Bay. Regional differences in the distribution of algal taxa will be driven by factors such as differences in environmental conditions (eg. water temperature) and biological constraints such as dispersal of spores, as well as sampling effort. Nevertheless, a large proportion of all taxa (over 40%, or 154 of 382 taxa) were present in all three geographic regions, indicating a broad geographic distribution along the lower west coast of Western Australia. Interestingly, although Jurien and Geographe Bay are geographically disjunct, these regions shared 34 taxa that were not found in Perth. This suggests that environmental conditions in the Perth region may be unfavourable to certain species.

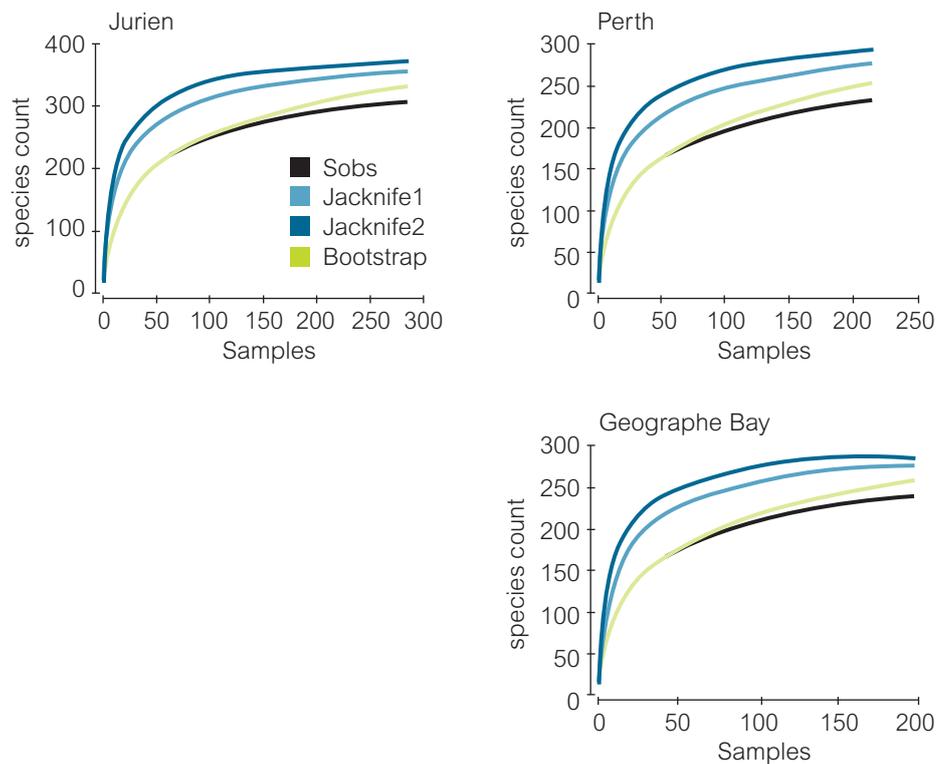


**Figure 5.12:** Distribution of marine plant taxa among the SRFME regions. Numbers in parentheses are the total number of taxa found in a region. Areas of overlap indicate the number of taxa shared between regions; the central region indicates the number that were found in all three regions.

Species accumulation plots were constructed for each region to determine the number of different species observed ( $S$ ) with increased sampling effort (Fig. 5.13) and assess the extent to which these trends might be merely the result of sampling artifacts. Three non-parametric estimators of  $S$  were included as predictors of the true total number of species that would be observed in each region as the number of samples reaches infinity (Clarke & Gorley 2006). The jackknife technique depends on the number of samples seen only in 1 or 2 samples (Clarke & Gorley 2006) and reduces the bias in underestimating the true number of species in an

assemblage (Colwell & Coddington 1994). The bootstrap estimator depends on the set of proportions of samples that contain each species (Colwell & Coddington 1994).

In all regions, the observed number of species ( $S_{obs}$ ) was lower than that predicted by the  $S$  estimation techniques (Fig. 5.13), suggesting that the true number of species in each region is higher than that revealed by sampling to date. This is not entirely surprising since species-accumulation curves generated by permutations of  $S$  are typically negatively biased estimators of  $S$  due to averaging. Estimates of  $S$  for reef algae in the Perth region showed the greatest difference to  $S_{obs}$  at the maximum sample size, indicating that the biodiversity in this region is least well accounted for by the sampling effort. The  $S_{obs}$  curves for all regions also rose less steeply from the origin than either jackknife curve, indicating a high degree of heterogeneity in species composition (Colwell & Coddington 1994); again, this is to be expected given the range of reef habitats sampled. Importantly, the species accumulation plots show that variation in species richness is not simply related to sample size at the three sites. Based on the same number of samples for each region (e.g. 195 which was the total for Geographe Bay), both observed and modeled estimates of  $S$  are substantially higher at Jurien than they are at Perth and Geographe Bay, both of which had very similar estimated species counts (Table 5.3).

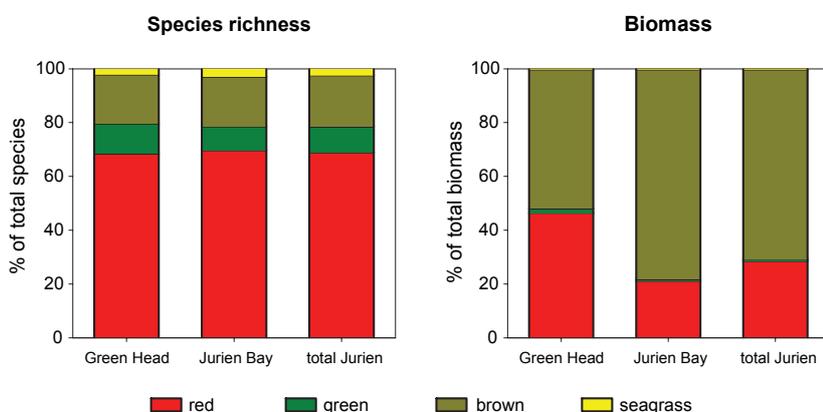


**Figure 5.13:** Species accumulation plots for algal richness in each SRFME region. Curves show the actual species observed ( $S_{obs}$ ) and three non-parametric estimators of  $S$  (Jackknife 1 and 2, Bootstrap). Jackknife techniques are based on functions of the number of species seen only in 1 or 2 samples; the Bootstrap technique depends on the set of proportions of samples that contain each species. For all curves each point is the mean of 999 randomisations of sample order.

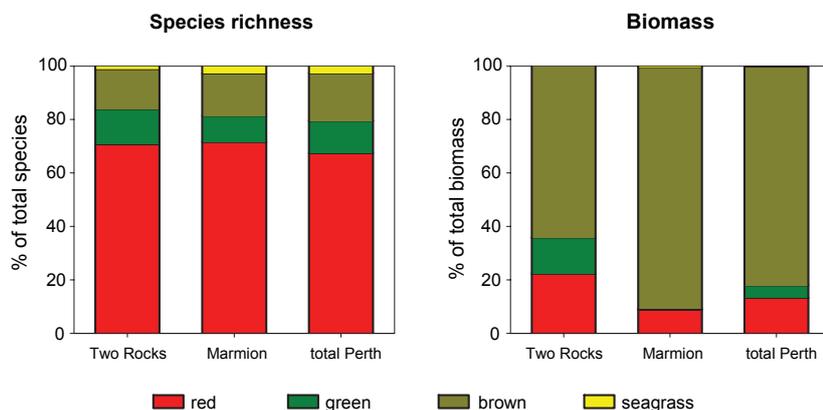
**Table 5.3** Comparisons of estimates of S for reef algae for a standard sample size using three non-parametric estimators.

	S <sub>obs</sub>	Jackknife 1	Jackknife 2	Bootstrap
Jurien	288.3	343.6	363.1	303.5
Perth	228.6	273.3	291.4	247.3
Geographe Bay	239.6	277.7	285.2	258.5

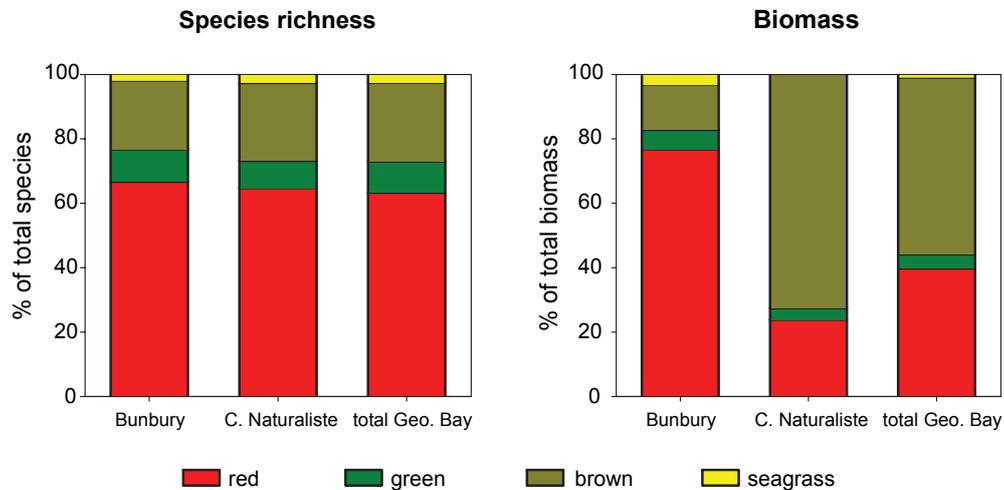
In all three regions the species richness was dominated by red algae (Division Rhodophyta), which accounted for 65-72% of all species recorded (Figs 5.14-16). This did not translate to dominance in terms of biomass (or abundance) except on reefs at Bunbury, where red algae made up 77% of the total reef algal biomass (Fig. 5.16). This can be explained by the general lack of large, canopy-forming brown algae on reefs at Bunbury where reefs are instead dominated by red foliose algae. Elsewhere, the brown algae (Division Phaeophyta) were represented by relatively few species (only 15-24% of all species in any location) yet were by far the most abundant in terms of biomass (51-91% of total biomass). This is not surprising given the large size of the fucalean (eg. *Sargassum*, *Cystophora* and *Platythalia*) and laminarian (eg. *Ecklonia*) brown algae that are common on many nearshore reefs along the lower west coast of WA. In all regions, green algae (Division Chlorophyta) were a significant component of species richness yet contributed little to total biomass. An exception to this trend was seen on reefs at Two Rocks (Fig. 5.15), where large patches of *Caulerpa* spp. are common and can replace brown algae as the dominant benthic layer.



**Figure 5.14:** Contribution of different marine plant groups to total species richness and total biomass recorded from reef habitats at two locations in the Jurien region.



**Figure 5.15:** Contribution of different marine plant groups to total species richness and total biomass recorded from reef habitats at two locations in the Perth region.



**Figure 5.16:** Contribution of different marine plant groups to total species richness and total biomass recorded from reef habitats at two locations in the Geographe Bay region.

#### 5.4 Spatial variation in reef algal community structure

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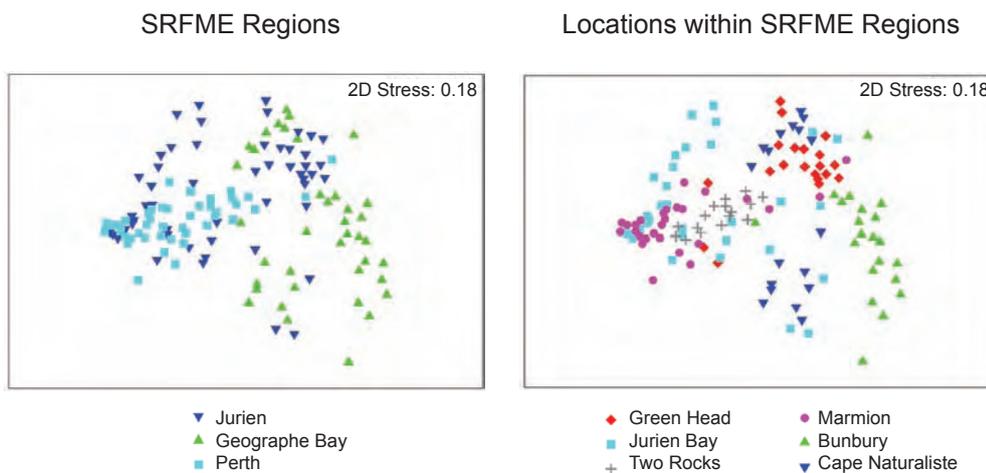
At the largest spatial scale (i.e. region), some pattern in algal community structure was evident. Although there was a substantial degree of overlap in community structure among the three regions (ANOSIM  $R = 0.348$ ,  $P = 0.001$ ), post-hoc pairwise comparisons showed Perth and Geographe Bay to have significantly different algal communities ( $R = 0.668$ ,  $P = 0.001$ ). The dissimilarity in communities was driven by abundance of the kelp, *E. radiata*; only 1.2% of samples in Geographe Bay contained *E. radiata*, compared to 24.5% in Perth (SIMPER).

*Ecklonia radiata* was also responsible for contributing to similarity between regions. As mentioned, the average abundance of *E. radiata* on Perth reefs was 24.5%, which accounted for 63.9% of the similarity between reefs in this region (SIMPER). *E. radiata* was fairly abundant in the Jurien region also (12.5% of samples and 33.5% contribution to similarity; SIMPER), and algal communities were similar in these two regions ( $R = 0.131$ ,  $P = 0.001$ ; ANOSIM).

When comparing within regions, locations in the Perth region (Fig. 5.17) had an average similarity of 27.6% in species composition (SIMPER). The similarity of species composition on reefs in the Jurien and Geographe Bay regions was considerably lower, at 17.2% and 15.2% respectively. The relatively high degree of similarity in species composition among reefs in the Perth region was again driven by the abundance of the kelp, *E. radiata*, on Perth reefs (SIMPER).

Comparison of algal communities within each location indicated statistically significant differences in algal communities between locations within Geographe Bay was large ( $R = 0.665$ ,  $p = 0.001$ ). Algal communities also varied significantly between locations within Jurien ( $R = 0.359$ ,  $p = 0.001$ ) and Perth ( $R = 0.35$ ,  $p = 0.001$ ) regions although this variation was lower than for locations in the Geographe Bay region. Algal species composition was most similar between sites within the Jurien Bay and Two Rocks ( $R = 0.027$ ,  $p = 0.285$ ), both of which have a number of sites dominated by *Ecklonia radiata* forest.

The clustering of data from Two Rocks and Marmion, and to a lesser extent Jurien Bay, in Fig. 5.17 can be explained by a common suite of species that typify algal assemblages in these areas. The brown algae *Ecklonia radiata* and *Sargassum* spp., along with several red algae including *Pterocladia lucida*, *Rhodymenia sonderi*, *Amphiroa anceps* and *Curdiea obesa*, were abundant at all locations and all species were among those with the highest contribution to the similarity in assemblage structure between reefs within these locations (SIMPER). The Cape Naturaliste data points that are clustered with those from Green Head (Fig. 5.17) were identified as being from the Eagle Bay site. These geographically separate areas both have *Sargassum* spp. (SIMPER) as the dominant canopy-forming brown algae on reefs, in contrast to *E. radiata* which dominates the canopy structure at Two Rocks and Marmion.



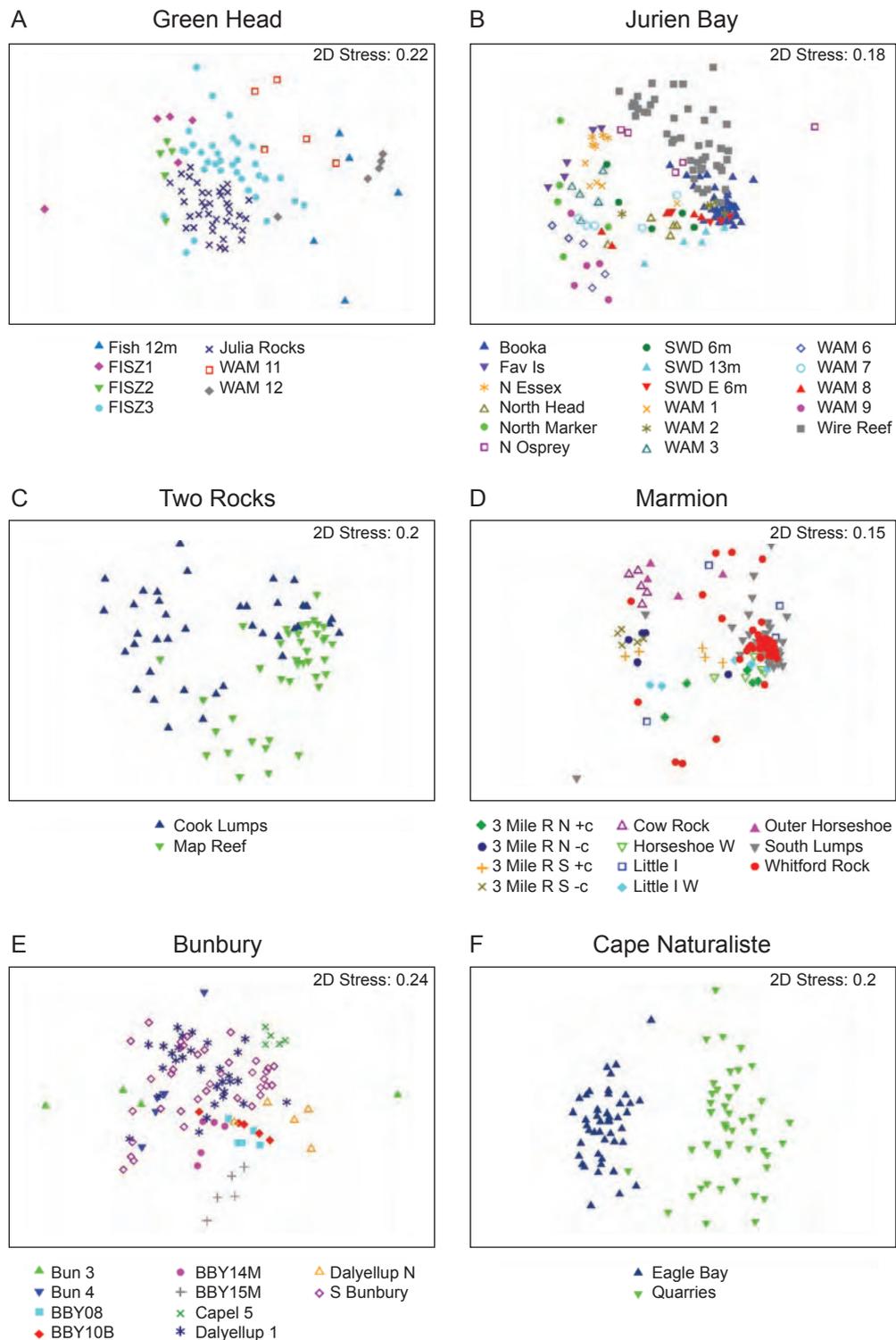
**Figure 5.17:** Regional and local variation in reef algal assemblages. Results of nMDS ordinations of mean abundance data per sampling event for sites within locations within each SRFME region.

**Table 5.4:** Results from a 1-way analysis of similarities (ANOSIM) of reef algal community structure among locations and post-hoc pairwise comparisons between locations.

	R statistic	P
<b>Global test</b>	0.467	0.001
<b>Pairwise comparisons</b>		
Bunbury vs. Cape Naturaliste	0.665	0.001
Bunbury vs. Jurien Bay	0.720	0.001
Bunbury vs. Greenhead	0.555	0.001
Bunbury vs. Marmion	0.851	0.001
Bunbury vs. Two Rocks	0.732	0.001
Cape Naturaliste vs. Jurien Bay	0.468	0.001
Cape Naturaliste vs. Greenhead	0.474	0.001
Cape Naturaliste vs. Marmion	0.791	0.001
Cape Naturaliste vs. Two Rocks	0.691	0.001
Jurien Bay vs. Greenhead	0.359	0.001
Jurien Bay vs. Marmion	0.062	0.027
Jurien Bay vs. Two Rocks	0.027	0.285
Greenhead vs. Marmion	0.724	0.001
Greenhead vs. Two Rocks	0.531	0.001
Marmion vs. Two Rocks	0.350	0.001

\* calculated from rank similarities between groups:  $R = 1$  indicates strong separation between groups;  $R \approx 0$  indicates null hypothesis is true, that there is no difference between groups.

Variation at the site level (within locations) was much clearer than at either the regional or local level, with clustering often clearly apparent (Fig. 5.18) and highly significant (Table 5.5). The greatest degree of overlap in community composition was evident between the two sites at Two Rocks, while the highest degree of dissimilarity was between the sites at Cape Naturaliste (Table 5.5).



**Figure 5.18:** Site level variation in reef algal communities. Results of nMDS ordinations for sites within locations within the three SRFME regions.

**Table 5.5:** Site-level variation in algal communities. Results of ANOSIM for sites within locations at the three SRFME regions.

Location	Global R	Significance level (%)
Green Head	0.660	0.1
Jurien	0.675	0.1
Two Rocks	0.252	0.1
Marmion	0.391	0.1
Bunbury	0.365	0.1
Cape Naturaliste	0.788	0.1

### Jurien region

The species composition of algal communities on reefs in Green Head and Jurien Bay showed only a small degree of overlap (Fig. 5.17) with an average dissimilarity of 87.8% (SIMPER). Differences were partly due to the presence of many foliose and turfing species of a more sub-tropical distribution being found on reefs at Green Head. Differences in community structure also resulted from shifts in the abundance of canopy-forming brown algal species: on reefs in Green Head, *Sargassum* spp. accounted for 19.1% of similarity between samples compared to *Ecklonia radiata* at only 1.3% of samples; in Jurien Bay *E. radiata* was the dominant canopy species and contributed 58.9% of similarity between samples while *Sargassum* spp. accounted for only 13.7% (SIMPER).

At Green Head, the algal community composition of sites grouping to the right of Fig. 5.18a are those which had an overlying canopy of large fucal and/or laminarian brown species. Those grouping to the left were characterised by *Sargassum* spp. and associated red algae, or by communities dominated by red foliose algae and devoid of an overlying canopy of large brown algae.

The clustering of sites in Jurien Bay shown in Fig. 5.18b can be broadly divided into two according to their algal assemblages. Those sites grouping to the right of the diagram are characterised by *Ecklonia radiata* being the species having the highest contribution to similarity between samples from those sites, and these sites were classified as *Ecklonia* forest habitat (see text later in this Section). The sites ranged from those with a continuous canopy of *E. radiata* (>80% contribution to similarity between sites; SIMPER) to those with a mixed *E. radiata*-fucoid canopy (*E. radiata* contribution between 23-44%; SIMPER). Sites grouped to the left side were predominantly characterised by an abundance of *Sargassum* spp., which accounted for 15-82% of similarity in algal assemblages (SIMPER). Low turfing and foliose algae were also an important component of algal assemblages on these reefs.

### Perth region

Geographic location of reefs in the Perth region did not affect species composition, with sites at Two Rocks and Marmion having similar, and overlapping, overall algal community structure (Table 5.4 and Fig. 5.17). Within locations, the Two Rocks sites of Map Reef and Cook Lump had very similar algal communities (Table 5.5) and any dissimilarity was attributed to differences in the relative abundance of *Ecklonia radiata* on each reef (SIMPER). *E. radiata* was also responsible for the tight clustering of a number of sites in the centre-right of Fig. 5.18d. Algal communities at Whitford Rock, South Lumps and Horseshoe West all had particularly high abundances of *E. radiata*, which accounted for between 67-79% of similarity of samples from these reefs (SIMPER).

### Geographe Bay region

Algal communities at different locations in the Geographe Bay region showed a reasonable degree of separation, with communities from Bunbury reefs differing from those found on Cape Naturaliste reefs ( $R = 0.665$ ,  $P = 0.01$ ; Fig. 5.17). Unlike other locations in the SRFME study area, *E. radiata* was uncommon and instead red algae were the most important components of

community structure on reefs in Bunbury, with individual species (eg. *Husseyia rubra*, *Spyridia dasyoides*, *Vidalia spiralis*, *Dictyomenia tridens* and *Amphiroa anceps*) contributing as much as 69% to the similarity within a reef (SIMPER).

The two reefs sampled within the Cape Naturaliste location were well separated (Fig. 5.18F and Table 5.5) in terms of their algal communities. The Quarries site was characterised by the abundance of large brown algae belonging to the Cystoseiraceae (eg. *Platythalia*, *Cystophora*), which was unique among all reefs in the entire SRMFE study area (SIMPER). At Eagle Bay, the most common species were *Sargassum* spp., *Lobophora variegata*, *Cystophora monilifera* and *Botryocladia sonderi* although all these species occurred in less than 8% of all samples (SIMPER). The remaining component of the algal community at Eagle Bay was characterised by a suite of low-stature, mainly red algal species with uniformly low abundances.

### **Algal habitat types**

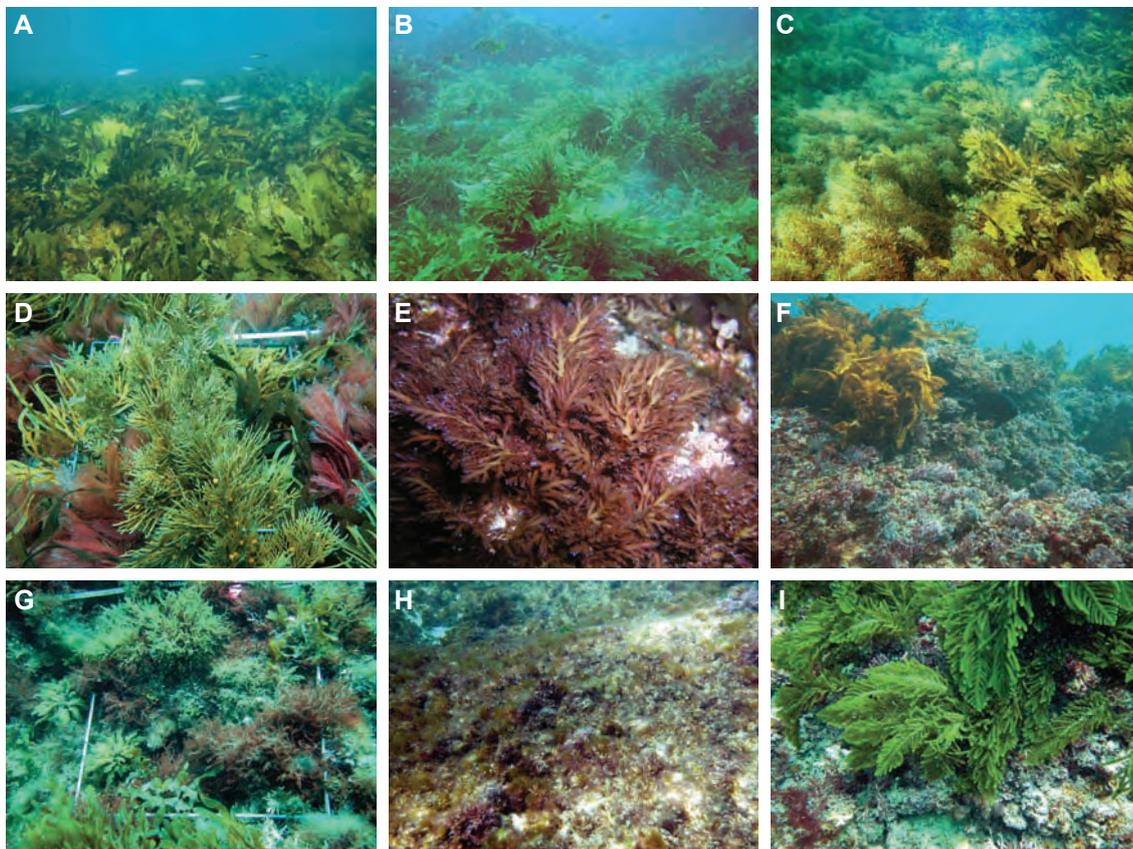
The sampling and analyses above indicated that much of the variation observed among locations, and particularly among sites within locations, was related to the presence of distinct algal habitat types which often dominated particular reefs. Therefore, moving beyond a species-level approach, sites on reefs in the SRMFE study area were classified into algal habitat types based on whole-assemblage structure and composition. A site-level classification chosen as it was the relevant scale at which data could be related to wave modelling and habitat mapping (see Chapter 6) and is the scale at which the effects of many structuring forces operate are thought to manifest themselves (eg. wave energy, nutrient availability, light regime, etc). Next, a set of habitat categories were defined based on existing knowledge and observations of broadly recognizable reef algal habitats, and are described in Table 5.6. Following this, species abundances for each site within a region were input into a similarity of percentages analysis (SIMPER) run in PRIMER, using a Bray-Curtis similarity measure. This procedure allowed the determination of the contribution of each species to the similarity of algal assemblages within a site. Using the % contribution of the highest ranking species (or suite of species) to similarity within a site, the sites were then categorised into one of the habitat types listed in Table 5.6. This classification approach can also be applied at the quadrat level, or at larger spatial scales and has the potential to be used in broad-scale visual habitat classifications.

Ordinations (nMDS) of algal communities within each region based on these *a priori* habitat categories showed fairly good clustering by habitat type, particularly in the Jurien and Perth regions (stress < 0.2, Fig. 5.20). Ordination stress was higher for Geographe Bay (stress = 0.23), yet algal communities still showed clustering by algal habitat although it should be noted that only three habitats were recognised in this region. Ordinations for all regions were not improved by using presence-absence data.

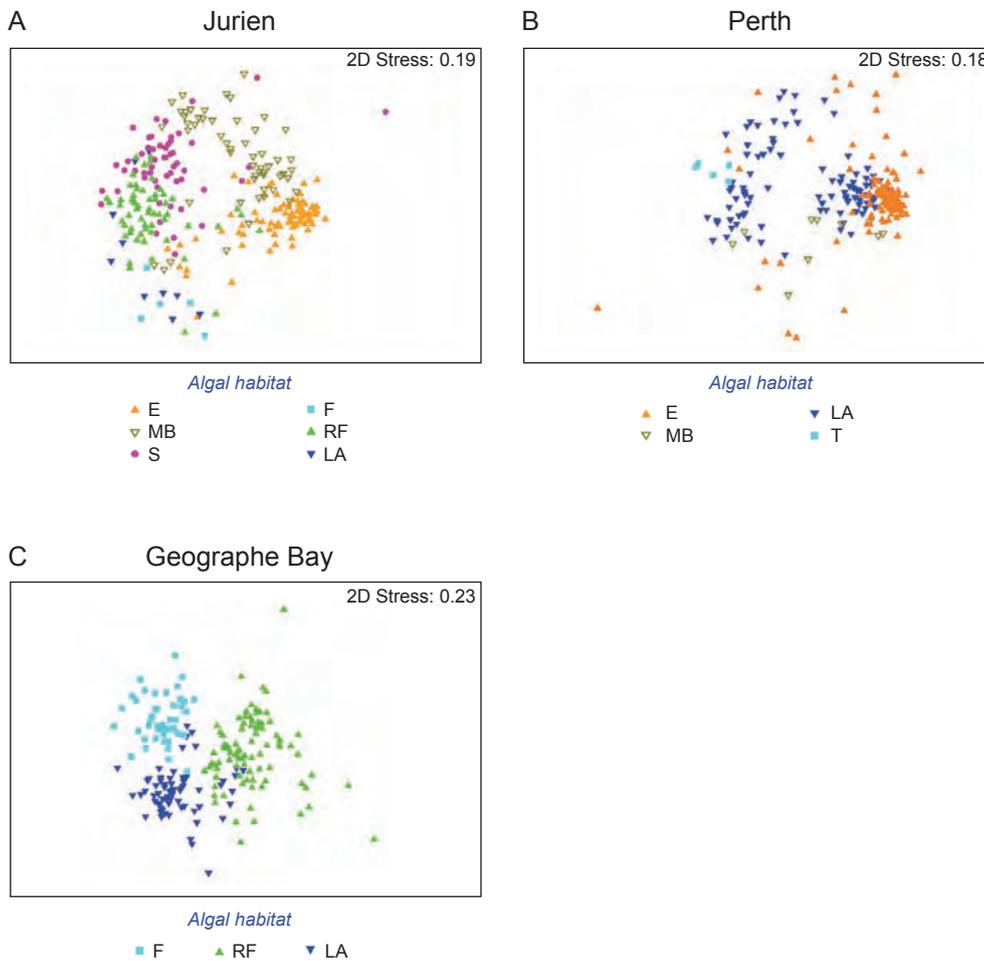
The Jurien region was most diverse in terms in number of habitats (Fig. 5.20), with reefs classified into six different algal habitats. Eight of the 25 reefs at Jurien were classified as *Ecklonia* forest habitat, with *Sargassum* and red foliose the next most common habitats (5 reefs each). Reefs in Perth and Geographe Bay regions were less diverse and could be classified into one of 3 or 4 habitat types. Both regions had a large proportion of reefs that could be classified as low algal habitats, although red foliose habitat was more common in Geographe Bay. Notably, Geographe Bay lacked any reefs that could be considered *Ecklonia* forest. It should be noted, however, that the number of reefs surveyed in Perth and Geographe Bay was around half that for Jurien, which may account for both reduced habitat complexity and apparent absence of certain habitats. Habitat dominated by green algae of the genus *Caulerpa* was commonly observed in small patches (up to ~5 m<sup>2</sup>) but not at the reef scale.

**Table 5.6:** Algal habitat types used in classification of reef habitats in the SRFME study area. Habitat types marked with an asterisk (\*) indicate those with an overlying canopy of large brown algae. Unmarked habitat types are those without an overlying canopy. Photographs showing examples of each habitat type are shown in Fig. 5.17

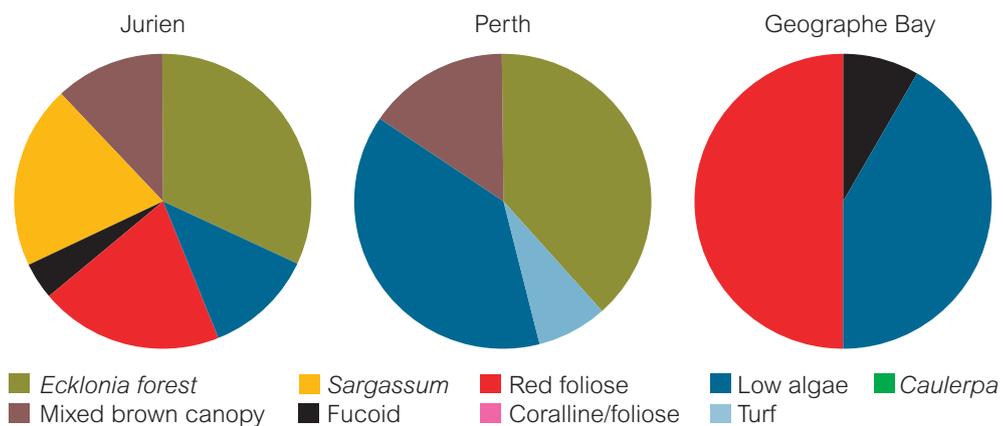
Habitat Type	Habitat Code	Description Of Habitat Structure/Composition
<i>Ecklonia</i> forest	E	Canopy consists of only <i>Ecklonia</i> , or >50% in canopy with <20% fucoids
Mixed brown canopy	MB	Mix of large brown algae comprising canopy: >20% fucoids in canopy, some <i>Ecklonia</i>
<i>Sargassum</i>	S	<i>Sargassum</i> >50% of canopy, <20% <i>Ecklonia</i> /other large brown algae
Fucoid	F	Fucoids >50%, <20% <i>Ecklonia</i>
Red foliose	RF	>70% foliose (upright) red algal species
Coralline/foliose	CF	>70% non-crustose corallines/foliose algae
Low algae	LA	>70% turf/epiphytes/foliose/cover other than algae, <30% of categories above
Turf	T	>70% turf only (algae <10 cm high)
<i>Caulerpa</i>	C	>70% <i>Caulerpa</i> spp.



**Figure 5.19:** Photographs showing examples of the algal habitat categories described in Table 5.6 and used to classify sites



**Figure 5.20:** nMDS ordination of reef algal community structure within assigned algal habitat categories



**Figure 5.21:** Proportion of each of the algal habitat categories assigned to sites on reefs in the Jurien, Perth and Geographe Bay regions using SIMPER analyses. Refer to Table 5.6 for descriptions of each algal habitat.

The success of habitat classification was independently tested using a canonical analysis of principal coordinates (CAP). The ordination was constrained using the *a priori* algal habitats assigned following SIMPER analyses, and untransformed mean species abundances at each site were randomly permuted 999 times on the basis of a Bray-Curtis dissimilarity measure.

The CAP analysis revealed an overall allocation success of 72%. Habitats with a canopy of large brown algae had a higher allocation success rate (Table 5.7) with any errors due to differences in the abundances of understory species. Habitats lacking a canopy of large browns, namely red foliose, low algae and turf habitats, were more problematic and the success of correctly distinguishing these structurally similar, low-stature habitats was relatively low. This is related to the fact that a suite of species are common across all these habitat types, thus masking the defining characteristics of each. There were very few turf and fucoid dominated sites and it was not possible to draw meaningful comparisons about classification success for these habitats. The classifications are retained for future testing as these habitat types are known to be more common in other regions of WA.

**Table 5.7:** Allocation success of algal habitat classification of reefs in the SRFME study area. Results are from a canonical analysis of principal coordinates (CAP) which uses a canonical discriminant analysis based on *a priori* habitat types assigned to each reef (site). Numbers in bold type represent correctly allocated habitat types.

Original classification	Classification by discriminant analysis							Total # of sites	% correct
	RF	LA	E	S	MB	F	T		
Red foliose (RF)	8	3	0	0	0	0	0	11	72.7
Low algae (LA)	4	7	1	0	1	0	0	13	53.8
Ecklonia forest (E)	0	0	11	0	2	0	0	13	84.6
Sargassum (S)	0	0	0	5	0	0	0	5	100
Mixed brown canopy (MB)	0	2	0	0	3	0	0	5	60
Fucoid (F)	0	2	0	0	0	0	0	2	0
Turf (T)	0	1	0	0	0	0	0	1	0

## 5.5 Spatial trends in reef invertebrate communities

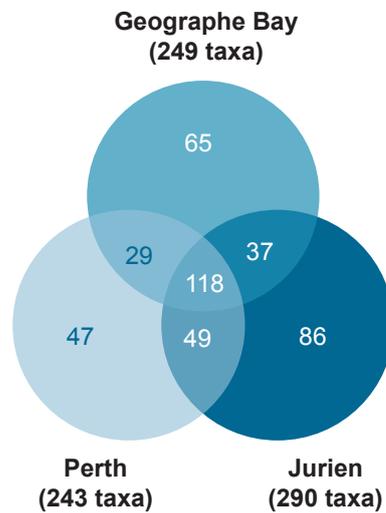
Investigators / Institution

Nicole Murphy, Geordie Clapin, Russ Babcock, Alison Sampey, Julia Phillips.

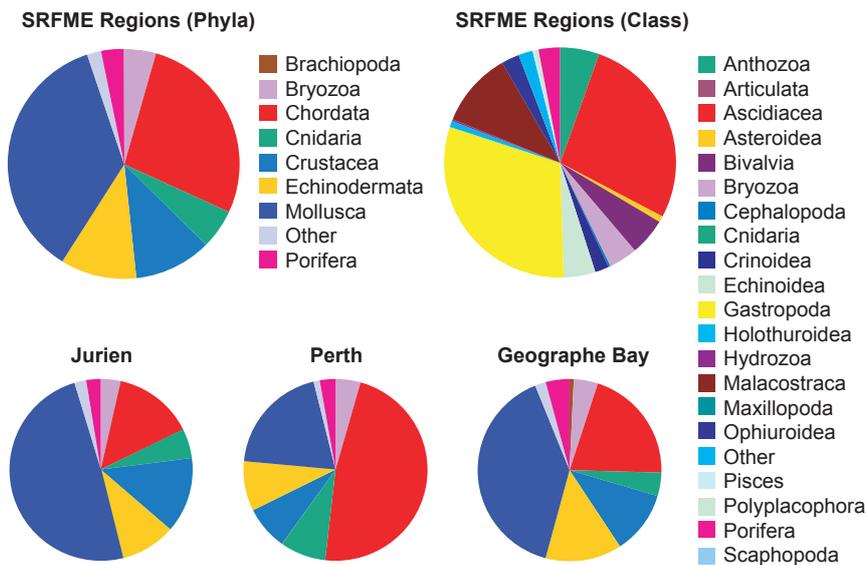
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### Overview of invertebrate assemblages from the SRFME region

A total of 431 invertebrate taxa were recorded from the SRFME regions of Jurien, Perth and Geographe Bay. Of the 431 taxa, 290 were recorded from Jurien, 243 from Perth and 249 from Geographe Bay (Fig. 5.22). Within regions, 86 taxa were only recorded for Jurien, 47 from Perth and 65 from Geographe Bay (Fig. 5.22). Between regions, 49 taxa were shared between Jurien and Perth, 37 taxa between Jurien and Geographe Bay and 29 taxa between Perth and Geographe Bay, with 118 recorded from all three regions (Fig. 5.22).



**Fig. 5.22:** Invertebrate species relationships from the SRFME regions of Jurien, Perth and Geographe Bay (782 taxa). Numbers in parentheses represent the total number of species found within a region. Areas of overlap show the number of species shared between regions, with the central region showing the number of species common to all three regions.



**Fig. 5.23:** Composition of invertebrate assemblages from the SRFME region (phylum and class level) and within the SRFME regions of Jurien, Perth and Geographe Bay (phylum).

The phyla Mollusca and Chordata were found to be the two numerically dominant taxa of invertebrate assemblages from the SRFME regions of Perth, Jurien and Geographe Bay. The Echinodermata and Crustacea, as the third and fourth dominant taxa, were roughly equal in their contribution, followed by the Cnidaria, Bryozoa, Brachiopoda and Porifera. The majority of the Chordata was comprised of the class Ascidiacea, with Gastropoda comprising the majority of the Mollusca (Fig. 5.23).

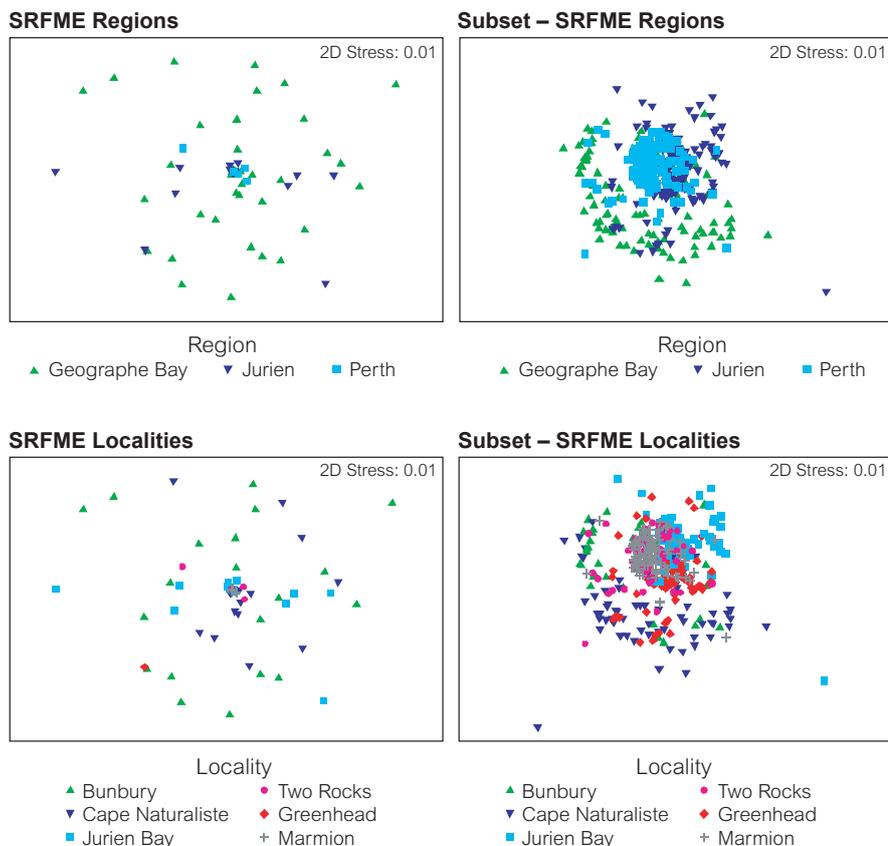
Within the SRFME regions, variation in the contribution of the Chordata (Ascidiacea) and Mollusca (Gastropoda) represented the main differences between Jurien, Perth and Geographe Bay. The Echinodermata, Crustacea, Cnidaria, Bryozoa, Brachiopoda and Porifera were found to contribute equally in each region (Fig. 5.23).

Species identification to date has recognised four new invertebrates, an ophiuroid, cf. *Ophiocomina australis* and three crustaceans, barnacle 2 – juv. cf. nov. sp. on *Sargassum*, *Hippolyte* sp. nov. and *Juleta* sp. nov. (Hale 1927, Poore 2004). Range extensions for two species have also been recorded for the ophiuroid, *Macrophiothrix spongicola*, from the Ashmore Reef (northern WA) and the crustacean, *Cryptocnemus vincentianus*, from the Gulf of St Vincent, South Australia.

The two types of sampling methods used at each quadrat targeted distinct groups of invertebrates; the 0.25m<sup>2</sup> quadrat samples were collected as part of the algal sampling procedure and were useful in sampling small (<1cm) epifauna associated with the algae. The larger 1m<sup>2</sup> samples targeted sessile or solitary fauna larger than 1cm. Consequently, within each site data were examined separately at the 0.25 m<sup>2</sup> and 1 m<sup>2</sup> levels, to examine broad scale relationships between the core sites at the SRFME regions of Jurien, Perth and Geographe Bay and their locations.

Epifauna (0.25 m<sup>2</sup> quadrat data) showed significant but weak differences among the regions of Jurien, Perth and Geographe Bay ( $R=0.16$ ,  $p=0.001$ ) and their locations ( $R=0.11$ ,  $p=0.001$ ) (ANOSIM). At the site level a similarly weak separation was found among the sites of Jurien ( $R=0.15$ ,  $p=0.001$ ), Perth ( $R=0.08$ ,  $p=0.001$ ) and Geographe Bay ( $R=0.11$ ,  $p=0.001$ ) (ANOSIM). Consequently we do not interpret these results as representing strong patterns in epifaunal distribution at these spatial scales (1, 10, 100 km). There were no seasonal trends in invertebrate assemblage structure at either for epifauna or for the larger sessile and solitary mobile fauna.

Larger sessile and solitary fauna (1 m<sup>2</sup> quadrat data) displayed a stronger separation among the regions Jurien, Perth and Geographe Bay ( $R=0.25$ ,  $p=0.001$ ) and at locations within these regions ( $R=0.29$ ,  $p=0.001$ ) (Fig. 5.24). The MDS ordination suggests a continuous, though overlapping, transition between regions and locations along a north-south gradient.



**Fig. 5.24:** MDS plots for Invertebrate assemblages examined at the level of the factors region and location (1 m<sup>2</sup> quadrat) (subset represents centre cluster from original plot).

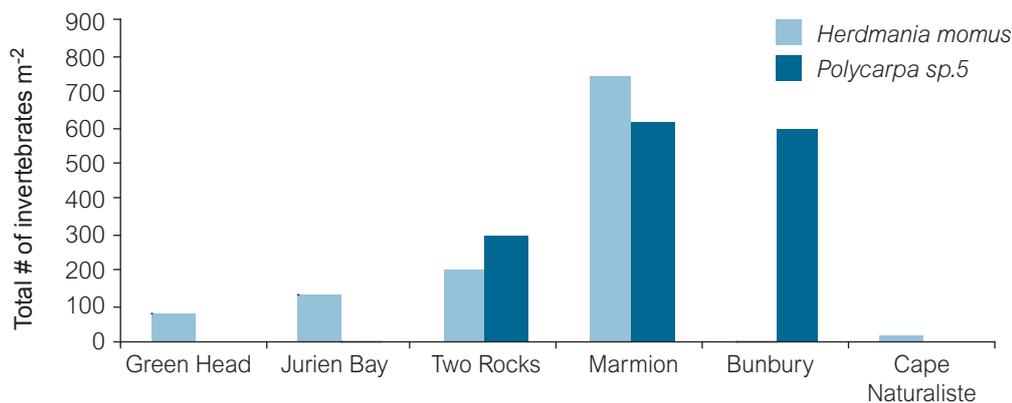
Ascidians were found to dominate sessile faunal assemblages in all three regions, with *Polycarpa* sp. 5 (blue and yellow throated), dominating assemblages in Geographe Bay and *Herdmania momus*, dominating assemblages in Jurien and Perth (SIMPER) (Table 5.8).

**Table 5.8.** Dominant invertebrate species at core SRFME sites. Species listed represent top ranking species from SIMPER analysis and their contribution to within site sample similarity (%) (1 m<sup>2</sup> quadrat).

Region	Location	Site	Species	Average Abundance (% of samples)	Contribution (% similarity between samples)
Jurien	-	-	<i>Herdmania momus</i>	0.76	44.37
Perth	-	-	<i>H. momus</i>	1.89	52.94
Geographe Bay	-	-	<i>Polycarpa</i> sp. 5	0.78	24.24
Jurien	Green Head	FISZ3	<i>H. momus</i>	0.84	30.62
		Julia Rocks	<i>Serpulorbis</i> sp.	0.93	28.50
	Jurien Bay	Booka	<i>H. momus</i>	0.97	45.04
		Wire Reef	<i>Serpulorbis</i> sp.	0.79	41.76
Perth	Two Rocks	Cook Lump	<i>Polycarpa</i> sp. 5	2.12	43.10
		Map Reef	<i>H. momus</i>	0.93	63.03
	Marmion	Whitford Rock	<i>H. momus</i>	3.17	69.05
		South Lumps	<i>Polycarpa</i> sp. 5	2.54	42.28

Region	Location	Site	Species	Average Abundance (% of samples)	Contribution (% similarity between samples)
Geographe Bay	Bunbury	Dalyellup 1	<i>Plesiastrea versipora</i>	0.27	41.96
		South Bunbury	<i>Polycarpa</i> sp. 5	3.08	83.20
	Cape Naturaliste	Eagle Bay	<i>P. versipora</i>	0.48	25.59
		Quarries	<i>Polycarpa</i> sp. 5	0.71	71.81

The species influencing dissimilarity in assemblages, varied between pairs of locations. Numbers of the ascidian, *Polycarpa* sp. 5, were found to drive dissimilarity between the locations of Bunbury and Cape Naturaliste, Bunbury and Jurien Bay, Bunbury and Green Head, Jurien Bay and Marmion, Bunbury and Two Rocks, Jurien Bay and Two Rocks and Green Head and Two Rocks. Between the locations of Cape Naturaliste and Jurien Bay, Jurien Bay and Green Head, Bunbury and Marmion and Cape Naturaliste and Marmion, another ascidian, *Herdmania momus*, drove dissimilarity, with numbers of the gastropod, *Serpulorbis* sp. driving dissimilarity between Cape Naturaliste and Green Head (SIMPER) (Table 5.9, Fig. 5.26).



**Fig. 5.25:** Relative abundance of key invertebrate species found to drive dissimilarity between the SRFME locations of Jurien, Perth and Geographe Bay (1 m<sup>2</sup> quadrat).

**Table 5.9.** Contribution of invertebrate species found to drive dissimilarity between assemblages in the SRFME regions of Jurien, Perth and Geographe Bay from SIMPER analysis (%) (1m<sup>2</sup> quadrat).

Species	Location comparison	Average Dissimilarity (%)	Contribution (%)
<i>Polycarpa</i> sp. 5	Bunbury v Cape Naturaliste	19.86	20.64
	Bunbury v Jurien Bay	17.96	17.71
	Bunbury v Green Head	14.86	15.54
	Jurien Bay v Marmion	15.85	19.28
	Bunbury v Two Rocks	20.59	22.66
	Jurien Bay v Two Rocks	12.16	14.26
	Green Head v Two Rocks	10.47	12.12
	Marmion v Two Rocks	12.97	17.68
	<i>Herdmania momus</i>	Cape Naturaliste v Jurien Bay	12.69
Jurien Bay v Green Head		10.04	11.51
Bunbury v Marmion		21.75	24.82
Cape Naturaliste v Marmion		20.14	21.45
Green Head v Marmion		14.08	16.34
Cape Naturaliste v Two Rocks		14.73	15.71
<i>Serpulorbis</i> sp.	Cape Naturaliste v Green Head	10.54	11.36

Species	Site comparison - Jurien	Average Dissimilarity (%)	Contribution (%)
<i>H. momus</i>	Booka v FiSZ3	11.45	14.12
	Booka v Julia Rocks	10.57	11.67
	Booka v Wire Reef	12.17	16.19
	FiSZ3 v Wire Reef	9.20	11.18
<i>Serpulorbis</i> sp.	FiSZ3 v Julia Rocks	10.28	12.78
	Julia Rocks v Wire Reef	9.32	10.23

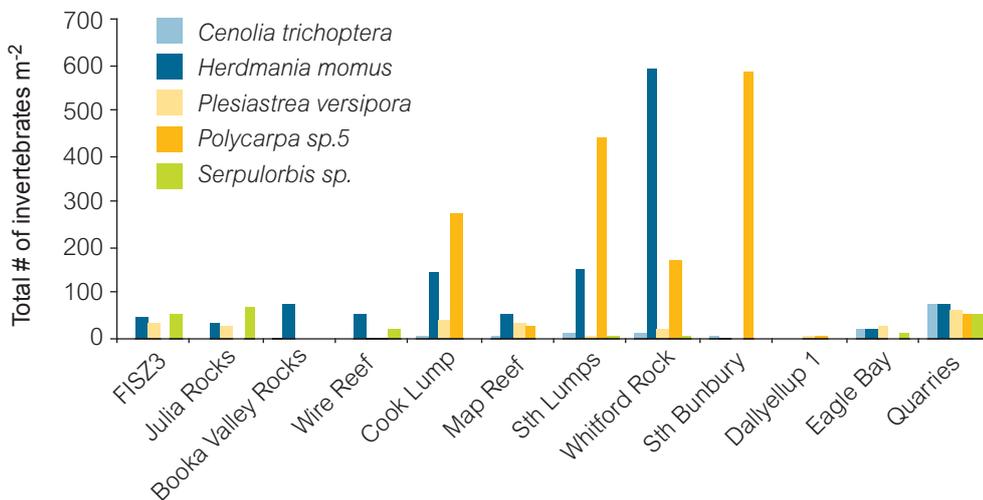
Species	Site comparison - Perth	Average Dissimilarity (%)	Contribution (%)
<i>Polycarpa</i> sp. 5	Cook Lump v Map Reef	15.36	19.86
	Cook Lump v South Lumps	12.23	18.52
	Map Reef v South Lumps	18.47	23.27
	South Lumps v Whitford Rock	12.39	18.56
<i>H. momus</i>	Cook Lump v Whitford Rock	11.98	17.30
	Map Reef v Whitford Rock	18.71	23.85

Species	Site comparison – Geographe Bay	Average Dissimilarity (%)	Contribution (%)
<i>Plesiastrea versipora</i>	Dalyellup 1 v Eagle Bay	11.15	11.74
<i>Cenolia trichoptera</i>	Dalyellup 1 v Quarries	20.93	21.11
	Eagle Bay v Quarries	13.92	14.83
<i>Polycarpa</i> sp. 5	Dalyellup 1 v South Bunbury	43.29	45.35
	Eagle Bay v South Bunbury	28.68	29.32
	Quarries v South Bunbury	35.71	36.70

Solitary and sessile invertebrates also showed significant pattern at the among-site level (Jurien,  $R=0.23$ ; Perth,  $R=0.21$ ; Geographe Bay,  $R=0.26$ ;  $p=0.001$ ) (ANOSIM), than at the location or regional level. The ascidian, *Herdmania momus*, was found to dominate species assemblages at the sites of Jurien Bay, Green Head, Marmion, Two Rocks, Bunbury and Cape Naturaliste, with another ascidian, *Polycarpa sp. 5* also dominating assemblages at Marmion, Two Rocks, Bunbury and Cape Naturaliste. The gastropod, *Serpulorbis sp.*, was found to dominate assemblages at the sites of Jurien Bay and Green Head, with the cnidarian, *Plesiastrea versipora* and the crinoid, *Cenolia trichoptera*, dominating assemblages at Bunbury and Cape Naturaliste (Table 5.8, Fig. 5.26).

Comparisons between SRFME sites, showed dissimilarity was driven by numbers of *Herdmania momus* at Jurien Bay, Green Head, Marmion, Two Rocks, Bunbury and Cape Naturaliste, with *Polycarpa sp. 5* also driving dissimilarity at Marmion, Two Rocks, Bunbury and Cape Naturaliste. The gastropod, *Serpulorbis sp.*, was found to drive dissimilarity at Jurien Bay and Green Head, with the cnidarian, *Plesiastrea versipora*, and crinoid, *Cenolia trichoptera*, driving dissimilarity at Bunbury and Cape Naturaliste (SIMPER) (Table 5.9, Fig. 5.26).



**Fig. 5.26:** Relative abundance of key invertebrate species found to drive dissimilarity between the SRFME sites of Jurien, Perth and Geographe Bay (1 m<sup>2</sup> quadrat).

## 5.6 Regional trends in fish communities

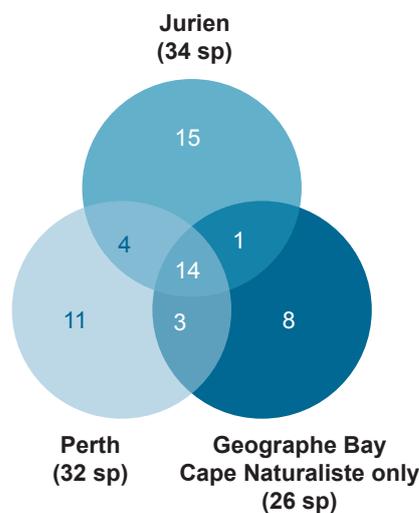
Investigator / Institution

Mat Vanderklift

CSIRO Marine and Atmospheric Research

### Overview of invertebrate assemblages from the SRFME region

A total of 56 species of reef fish were recorded during SRFME surveys. This relatively low number reflects that the fish surveys were done at a more limited number of sites than the algae and invertebrate surveys, and that fish surveys were done once only. Of the 56 species, 34 were recorded from Jurien, 32 from Perth and 26 from Cape Naturaliste (Fig. 5.27).



**Fig. 5.27:** Invertebrate species relationships from the SRMFE regions of Jurien, Perth and Geographe Bay (782 taxa). Numbers in parentheses represent the total number of species found within a region. Areas of overlap show the number of species shared between regions, with the central region showing the number of species common to all three regions.

All three regions were characterised by a similar suite of dominant species (Table 5.10). The large damselfish *Parma* spp (mainly *Parma mccullochi*) was characteristic of all three regions, but was especially abundant at Jurien and Perth. Two species of wrasses (*Notolabrus parilus* and *Halichoeres brownfieldii*) were characteristic of more than one region. The same species contributed most strongly to differences among regions. The western king wrasse *Coris auricularis* distinguished sites at Jurien from those at Cape Naturaliste and Perth: *C. auricularis* was more abundant at Jurien. The western chromis *Chromis klunzingeri* distinguished sites at Cape Naturaliste from sites at Jurien and Perth, *C. klunzingeri* being more abundant at Cape Naturaliste.

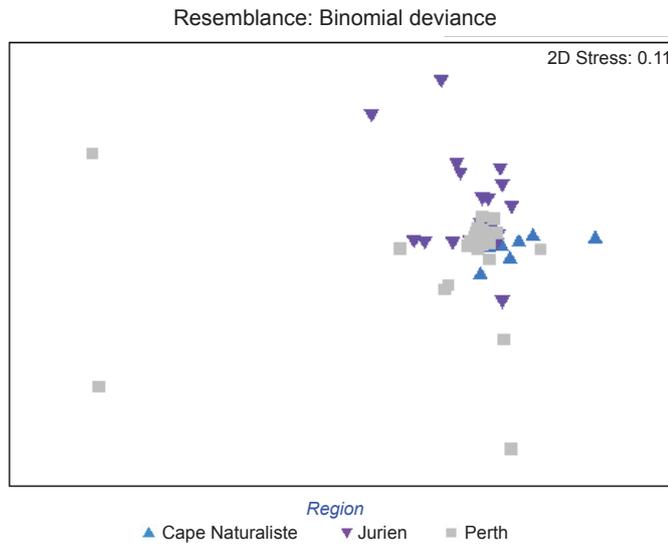
**Table 5.10.** Dominant fish species at core SRFME sites. Species listed represent top ranking species from SIMPER analysis and their contribution to within site sample similarity (%).

Region	Location	Site	Species	Average Abundance	Contribution (% similarity between samples)
Jurien	-	-	<i>Parma</i> spp	5.09	35.86
			<i>Coris auricularis</i>	7.18	32.09
			<i>Notolabrus parilus</i>	1.85	13.14
Perth	-	-	<i>Parma</i> spp	5.23	42.37
			<i>Notolabrus parilus</i>	3.19	33.78
			<i>Halichoeres brownfieldii</i>	0.61	4.07
Cape Naturaliste	-	-	<i>Chromis klunzingeri</i>	6.56	31.97
			<i>Parma</i> spp	1.11	25.02
			<i>Halichoeres brownfieldii</i>	2.44	11.11

**Table 5.11.** Contribution of fish species to dissimilarity between regions.

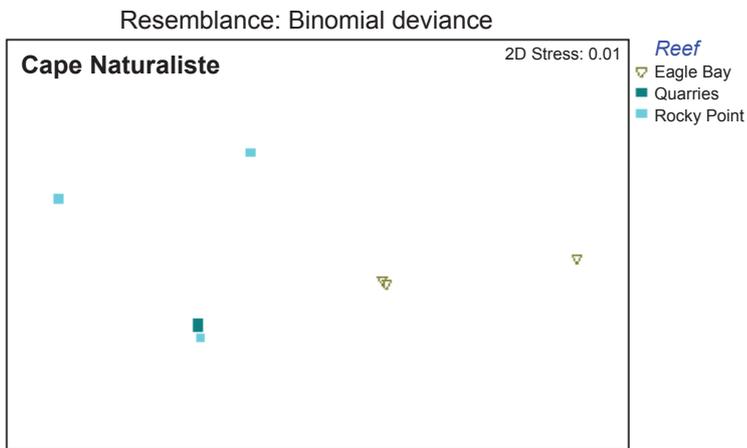
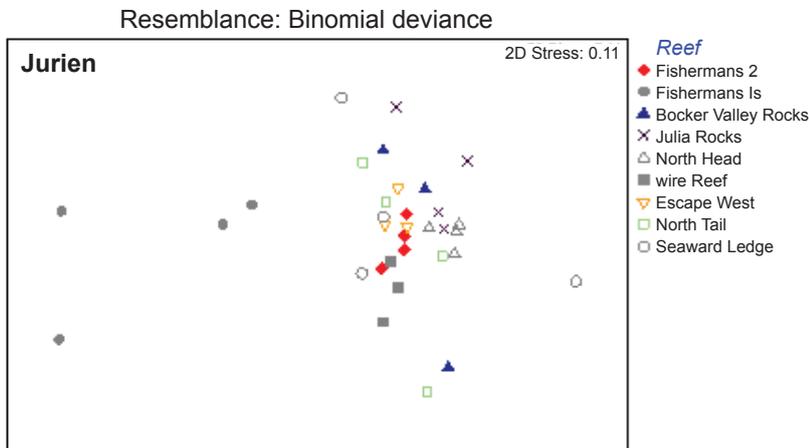
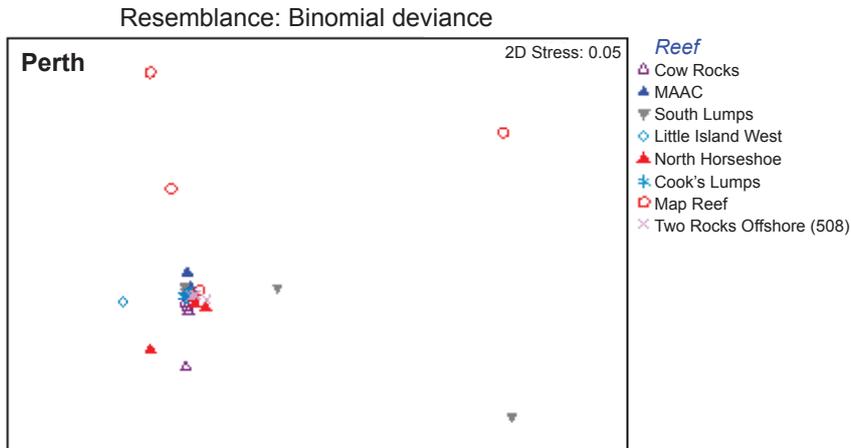
Species	Location comparison	Average Dissimilarity (%)	Contribution (%)
<i>Coris auricularis</i>	Cape Naturaliste v Jurien	13.36	15.15
<i>Chromis klunzingeri</i>	Cape Naturaliste v Jurien	10.51	11.92
<i>Parma</i> spp	Cape Naturaliste v Jurien	9.13	10.36
<i>Chromis klunzingeri</i>	Cape Naturaliste v Perth	10.74	12.34
<i>Parma</i> spp	Cape Naturaliste v Perth	9.56	10.98
<i>Notolabrus parilus</i>	Cape Naturaliste v Perth	7.33	8.42
<i>Coris auricularis</i>	Perth v Jurien	12.38	16.06
<i>Pempheris klunzingeri</i>	Perth v Jurien	8.78	11.40
<i>Parma</i> spp	Perth v Jurien	8.66	11.24

Fish assemblages showed distinct differences among the three regions studied (Fig. 5.28). Substantial differences were indicated by a large *R* statistic (0.75) from a two-way ANOSIM, although the significance of this could not be tested due to the low number of permutations possible (only 15 permutations). Differences among locations within the regions were negligible ( $R = 0.1$ ,  $P > 0.05$ ). Perth reefs were characterised by higher overall abundances of brown-spotted wrasse (*Notolabrus parilus*) and silver drummer (*Kyphosus cornellii*); Jurien reefs were characterised by higher overall abundances of western king wrasse (*Coris auricularis*) and western buffalo bream (*Kyphosus sydneyanus*); Cape Naturaliste reefs were characterised by higher overall abundances of Brownfield's wrasse (*Halichoeres brownfieldii*) and black-headed puller (*Chromis klunzingeri*).



**Figure 5.28:** Multidimensional scaling of fish assemblages found on reefs in the SRFME study area, grouped according to the three main regions studied.

Within each of the regions, there were clear differences in the fish assemblages of individual sites (Fig. 5.29), but not between locations. These patterns were reflected by ANOSIM: differences among sites were statistically significant for Perth ( $R = 0.26$ ,  $P < 0.01$ ), Jurien ( $R = 0.41$ ,  $P < 0.01$ ) and Cape Naturaliste ( $R = 0.26$ ,  $P = 0.05$ ).



**Figure 5.29:** Multidimensional scaling of fish assemblages found on reefs in the SRFME study area, grouped according to reef separately for the three main regions studied.

## 5.7 Environmental correlates of reef algal community structure

Investigators / Institution

Julia Phillips, Russ Babcock, Phillip England, Geordie Clapin,  
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CSIRO Marine and Atmospheric Research

As the largest number of sites sampled were from the Jurien region, and because Jurien was the only region from which modelled wave-driven orbital velocity at the sea floor was available, the correlation of algal community structure with environmental variables was restricted to this region. The extent to which environmental variables explained the patterns observed in reef algal community structure was investigated, as a means of better understanding and ultimately modelling important factors influencing reef ecosystems. Variables considered included nominal categories of depth of reef ( $\leq 6$  m, 6.1-10m,  $>10$  m), cross-shore position (inner, mid or outer shore) and reef relief (high, medium or low relief), while light attenuation, water column nutrients (Si,  $\text{PO}_4$ ,  $\text{NO}_x$ ,  $\text{NO}_2$ ,  $\text{NH}_4$ ), water column particulates (chl-*a*, total suspended solids (TSS)), as well as depth and rugosity of each quadrat were directly measured. Additionally, wave modelling was used to derive a number of parameters relating to the orbital motion experienced at each reef; namely cumulative, minimum, maximum and mean orbital motion (refer to Chapter 6.1).

Using square-root transformed biomass data, ordinations (nMDS) of algal communities based on depth category, cross-shore position, or reef relief, did not reveal definitive patterns in community structure that could be related to these reef properties, and plots are not included here ( $R < 0.3$ ,  $p < 0.06$ ; ANOSIM). A similar lack of patterns resulted when presence-absence species data was used instead, indicating that this suite of reef descriptors are not important in structuring algal communities, at least across the range of environmental variation encountered in this study.

For the remaining, directly measured or modelled environmental variables, the approach taken was to analyse the algal data and then determine how well the environmental variables, either singly or in combination, was correlated to algal community structure. This was achieved using the BIOENV procedure in PRIMER, whereby a Bray-Curtis dissimilarity measure among samples was used for the algal data.  $\text{Log}(0.1+x)$  transformation was applied to the phosphate and nitrogen concentrations before all environmental data was normalised prior to analysis. Euclidean distances were used as the measure of dissimilarity among environmental data and Spearman rank correlations were used as the measure of agreement between the algal and environmental resemblance matrices. Rank correlation coefficients ( $\rho$ ) were generated from 99 random permutations of the data and compared to the true value of  $\rho$  to determine the statistical significance of the BIOENV procedure. Since environmental data were missing for some sites or variables, linking of algal and environmental variables was restricted to those sampling events for which full datasets existed. The BIOENV procedure was repeated using both biomass (square-root transformed) and presence/absence algal data: in all cases, stronger correlations with environmental variables existed when presence/absence data was used and only these results are presented here.

In the Jurien region, surface complexity of reefs (ie. quadrat rugosity) and orbital motion explained a large and significant proportion ( $\rho = 0.686$ ,  $p = 0.01$ ) of the variation in reef algal communities based on the presence/absence of species (Table 5.12). The four orbital motion parameters used in this analysis – cumulative, minimum, maximum and mean orbital motion – are naturally highly auto-correlated so any attempt to identify which is more important as an algal structuring force should proceed with caution. Nevertheless, it is clear that algal communities in Jurien are strongly influenced by both reef rugosity and exposure to wave forces, since the best eight results from BIOENV contain no other environmental variables either singly or in combination (Table 5.12). At this point,  $\text{NO}_x$  was included in the combination of important environmental variables. Nitrogen is accepted as the most limiting nutrient in the

marine environment (Lobban & Harrison 1994) and further investigation into the role of N in regulating algal community structure is recommended.

**Table 5.12:** Results from linking multivariate algal community analysis to environmental variables for reefs in the Jurien region. Rank correlations ( $\rho$ ) were determined using the BIOENV procedure in PRIMER following 99 random permutations of presence/absence algal data and normalised environmental data. Global  $\rho=0.686$ ,  $p=0.01$ .

	Variables	No. of variables	Best results	
			$\rho$	Variable #'s
1	Light attenuation coeff.	3	0.686	10, 11, 13
2	Mean Si	4	0.683	10 -13
3	Mean PO <sub>4</sub>	2	0.675	10, 13
4	Mean NO <sub>x</sub>	5	0.673	10 -14
5	Mean NO <sub>2</sub>	4	0.673	10, 11, 13, 14
6	Mean NH <sub>4</sub>	4	0.671	10, 11, 13, 15
7	Mean Chl- <i>a</i>	3	0.668	10, 12, 13
8	Mean TSS	3	0.668	10, 13, 14
9	Mean quadrat depth	4	0.666	10, 12–14
10	Mean quadrat rugosity	5	0.665	10, 11, 13–15
11	Mean site rugosity			
12	Cumulative orbital motion			
13	Minimum orbital motion			
14	Mean orbital motion			
15	Maximum orbital motion			

## 5.8 Relationships between algal communities and faunal diversity and biomass

Investigators / Institution

Nicole Murphy, Geordie Clapin, Russ Babcock, Alison Sampey, Julia Phillips

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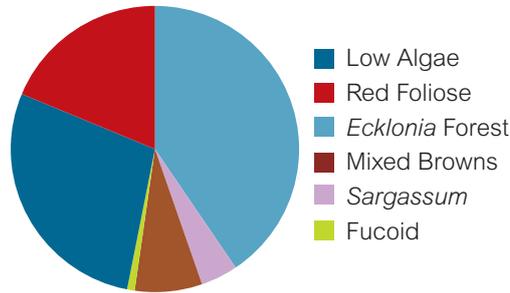
### Algal habitat type and invertebrate assemblage distribution

To measure the relationship between algal communities and their associated fauna, invertebrate assemblages were related to algal community (habitat) type (classified at the quadrat level) (Table 5.6). Comparisons included all quadrat data (0.25 m<sup>2</sup> and 1 m<sup>2</sup> separate or combined) and belt transects designed to measure larger or rarer invertebrates (25 × 1 m).

For the purposes of exploring relationships between algal communities and invertebrates, the structurally similar habitat classes of coralline/foliose (CF) and red foliose (RF) habitat were combined as were the furoid (F) and mixed brown algae (MB) habitats. Previous analyses have shown these classes to be difficult to separate (Table 5.6). In both instances the latter habitat name (i.e. red foliose and mixed brown algae) has been used hereafter.

Over the three SRFME Regions, *Ecklonia* was found to be the single most dominant algal habitat type at Jurien, Perth and Geographe Bay, with low algae comprising the second most common group (Fig. 5.30). Based on the classifications above, mixed brown algae and *Sargassum* habitats formed an equal proportion of the total quadrats to that of red foliose, with the habitat type furoid representing the smallest overall proportion (Fig. 5.30). Overall, those habitats dominated by large brown algae comprised slightly more than half of all habitats.

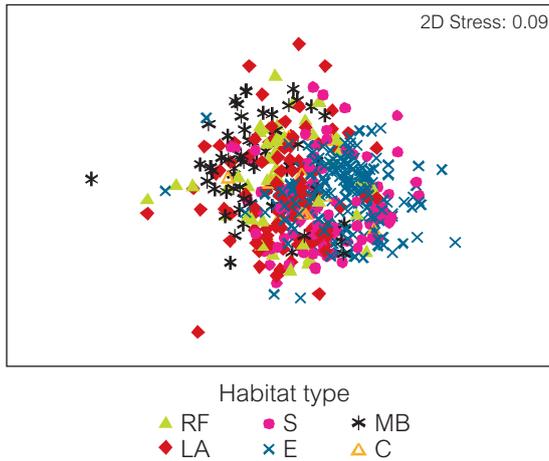
SRFME Regions – Algal Habitat Type



**Fig. 5.30:** Relative abundance of algal habitat types from the SRFME regions of Jurien, Perth and Geographe Bay.

When invertebrate density (combined 0.25m<sup>2</sup> and 1m<sup>2</sup> quadrat data) from the SRFME regions of Jurien, Perth and Geographe Bay was assessed against algal habitat type, a weak separation was found between invertebrate assemblages and algal habitat type (R=0.26, p=0.001) (ANOSIM) (Fig. 5.31).

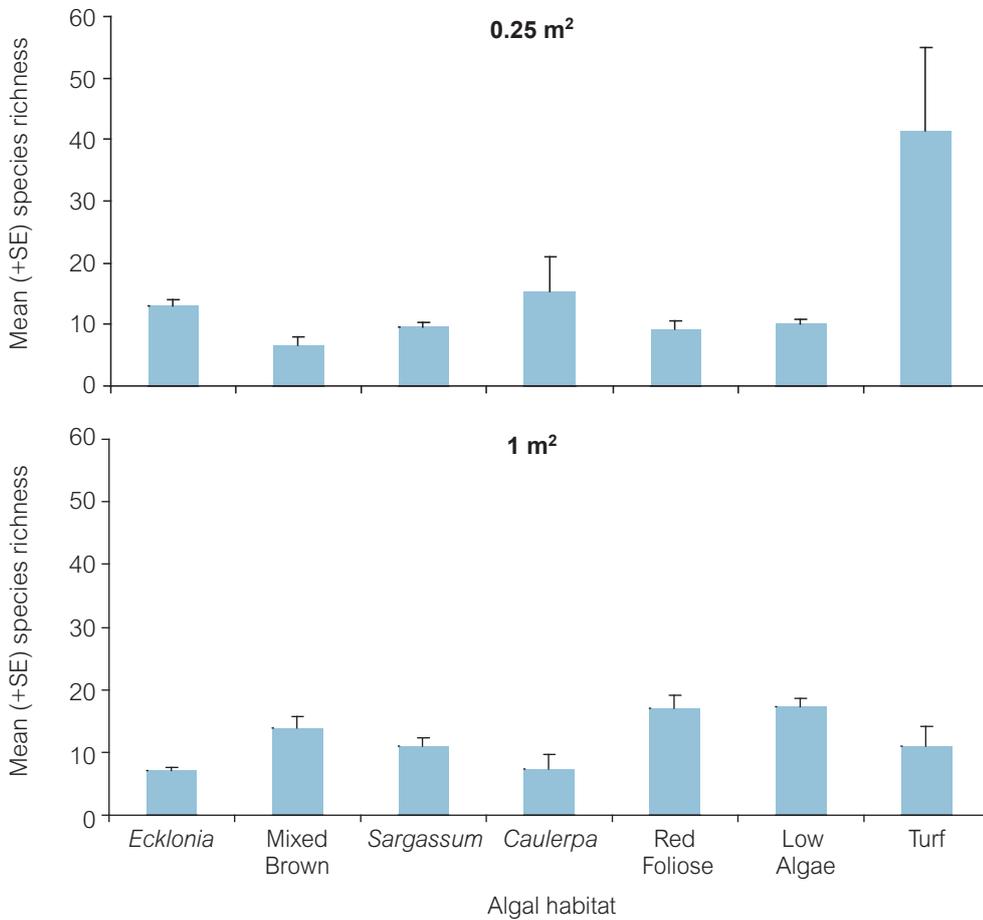
Invertebrate density – Algal habitat type



**Fig. 5.31:** Invertebrate assemblage as a function of algal habitat type. MDS plot for the SRFME regions of Jurien, Perth and Geographe Bay (combined 0.25m<sup>2</sup> and 1m<sup>2</sup> quadrat data). Refer to Table 5.6 for algal habitat definitions.

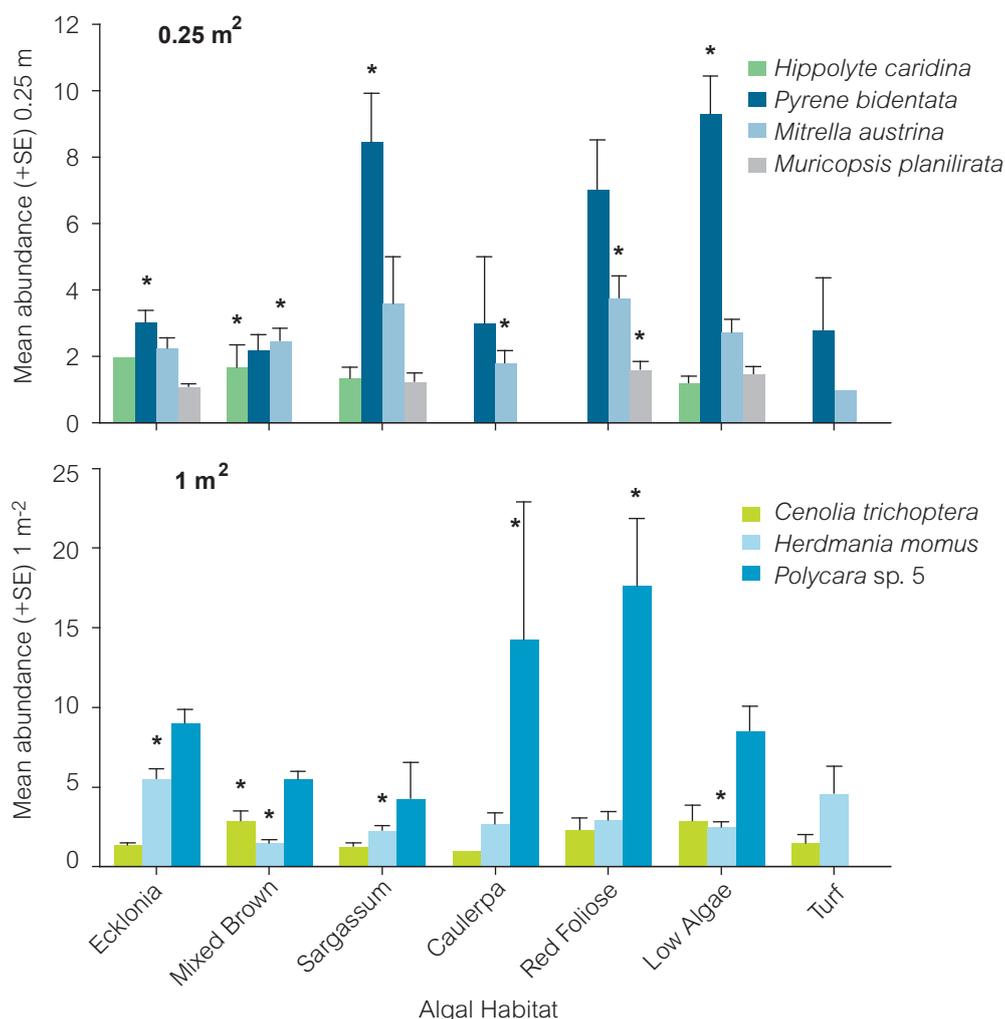
For the 0.25 m<sup>2</sup> quadrat data, a higher number of invertebrate taxa were found to be associated with turf (T) habitats, followed by *Caulerpa* (C), *Ecklonia*, *Sargassum*, low algae, red foliose and mixed brown algae (Fig 5.31). Data from the 1 m<sup>2</sup> quadrat, found a higher number of taxa associated with low algae and red foliose, followed by mixed brown algae, turf, *Sargassum*, *Ecklonia* and *Caulerpa* habitats (Fig. 5.32).

Generally, higher numbers of invertebrate taxa were identified from habitats without a canopy (*Caulerpa*, red foliose, low algae, and turf), compared to canopy dominated habitats (*Ecklonia*, mixed brown algae and *Sargassum*), with this pattern becoming stronger when invertebrates collected off the algae were examined (Fig. 5.32).



**Figure 5.32:** Species richness of invertebrates collected from 0.25 m<sup>2</sup> and 1 m<sup>2</sup> quadrats per algal habitat type.

SIMPER analysis of habitat type for the 0.25 m<sup>2</sup> quadrat data showed the top ranking species of *Pyrene bidentata* was primarily associated low algae, *Ecklonia* and *Sargassum* habitats; *Mitrella austrina* with low algae, fucoid and *Caulerpa*; *Muricopsis planilirata* with red foliose; and *Hippolyte caridina* with mixed brown algae (Fig. 5.33). For the 1 m<sup>2</sup> quadrat, data showed the top ranking species of *Herdmania momus* was primarily associated with low algae, *Ecklonia* and *Sargassum* habitats; *Polycarpa* sp. 5 with red foliose and *Caulerpa*; and *Cenolia trichoptera* with fucoid habitat (Fig. 5.33).

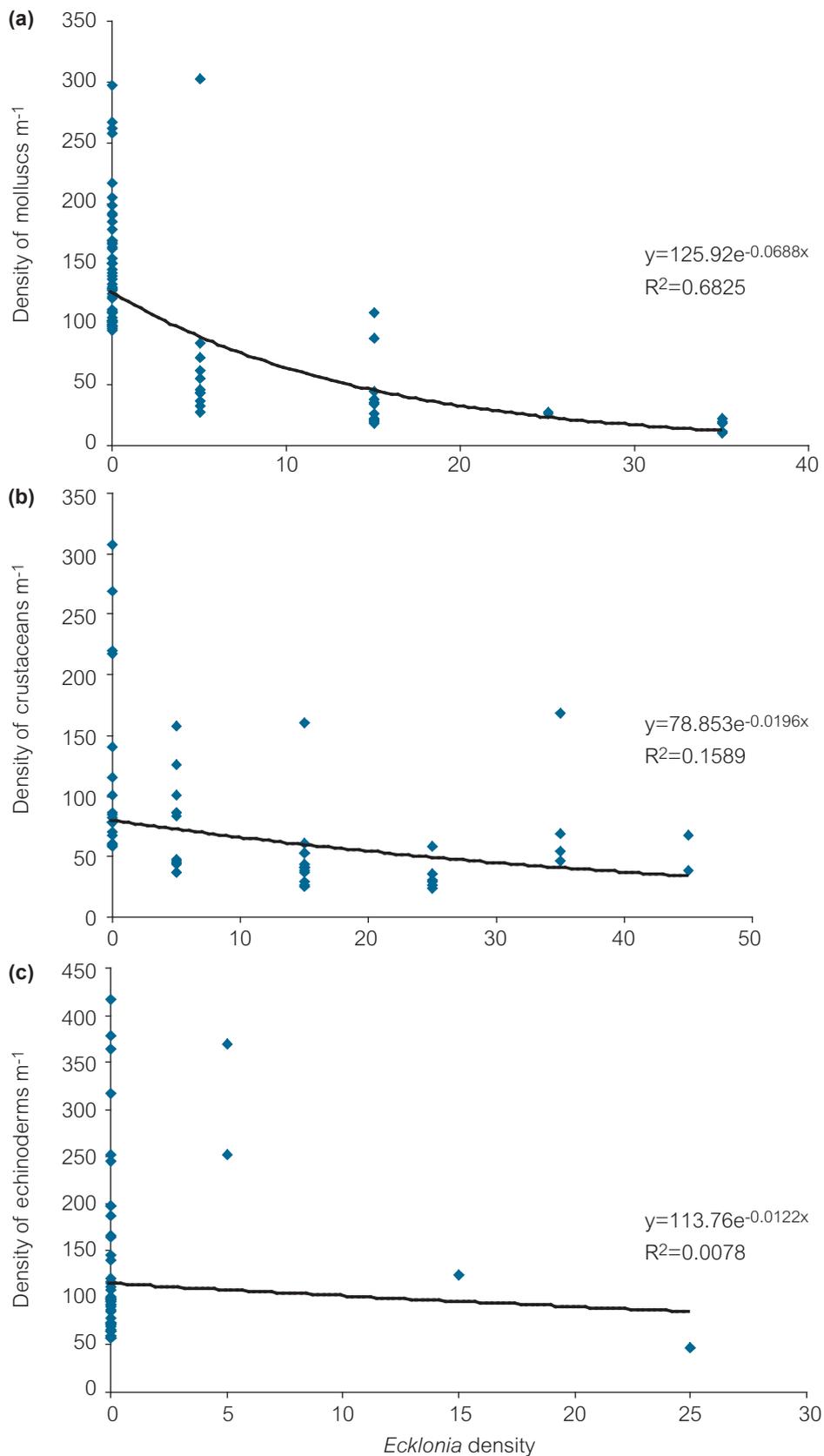


**Figure 5.33:** Mean abundance of taxa from 0.25m<sup>2</sup> and 1m<sup>2</sup> quadrats per algal habitat type (as assigned to individual quadrats). Marked taxa (\*) represent top ranked species from SIMPER analysis of algal habitat type.

The number of mobile inverts (0.25 m<sup>2</sup> and 1m<sup>2</sup> quadrats combined) from the SRFME regions of Jurien, Perth and Geographe Bay, representing the Mollusca, Echinodermata and Crustacea, was assessed in relation to those algal habitat sites classified as *Ecklonia* forest. Not only were higher numbers of taxa present in non-canopy habitats, the number of individuals was also correlated with habitat type. As kelp density increased, invertebrate number was seen to decrease across all size classes of Mollusca, Echinodermata and Crustacea (Fig. 5.34). This trend was significant at both Jurien and Perth, but not at Geographe Bay where *Ecklonia* is a relatively rare component of reef algal assemblages.

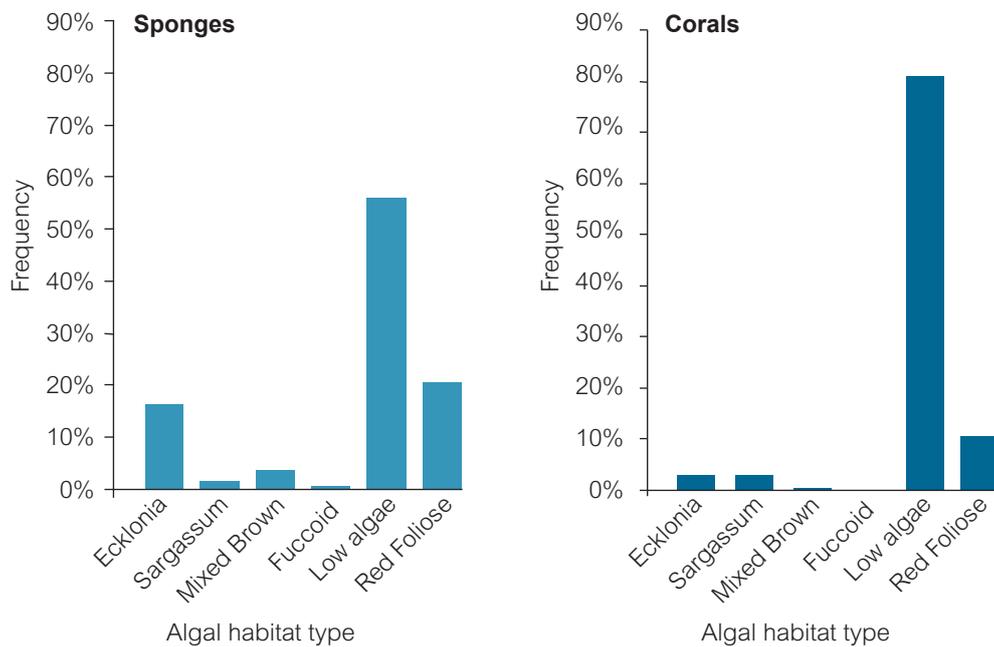
**Table 5.13.** Mobile invertebrate density as a function of *Ecklonia* canopy density. One Way ANOVA on total density of gastropods, crustaceans and echinoderms, ) (Combined 0.25 m<sup>2</sup> and 1m<sup>2</sup> quadrat data).

	<i>R</i> <sup>2</sup>	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Jurien	0.412	1.0	156874.9	156874.9	51.8	0.0
Perth	0.113	1.0	23003.1	23003.1	7.0	0.0
Geographe Bay	0.001	1.0	543.7	543.7	0.1	0.8



**Figure 5.34:** Relationship between density of *Ecklonia radiata* and a) molluscs, b) crustaceans and c) echinoderms across the SRFME study area. Data was pooled in bins of 10, with the upper quartiles plotted for regression (Combined 0.25 m<sup>2</sup> and 1m<sup>2</sup> quadrat data).

There were also strong relationships between algal community composition and the abundance of larger sessile invertebrates. Belt transects revealed strong trends among algal habitats in the abundance of corals and sponges. Brown algal dominated habitats totalled 53% of habitats covered by transects at Marmion, yet for these same transects only 22% of sponges and 7% of corals were recorded from brown algal dominated habitats (Fig. 5.35). Note that *Caulerpa* habitat was not recorded along belt transects. The transects also gave an indication of the spatial scale of the patches. Canopy and non-canopy patches were approximately the same average length (canopy  $2.4 \pm 2.1$ m, non-canopy  $2.5 \pm 2.1$ m) and the maximum patch sizes recorded were also approximately the same for canopy and non-canopy patches (9 and 11 m respectively).



**Fig. 5.35:** Algal habitat associations of sessile invertebrates (sponges and corals). The proportion of invertebrates from belt transects in six major algal habitat types at Marmion.

## 5.9 Shallow water habitat mapping

Investigators / Institution

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In SRFME we aimed to advance the science of hyperspectral remote sensing for application as a mapping and monitoring tool in shallow Western Australian coastal environments. Here we describe initial efforts to map benthic habitat in the Jurien Bay region using the airborne sensor, HyMap (Hyvista Corporation, Sydney). We present results of analysis of the northern section of one of the HyMap strips; chosen because it had good representation of each habitat type. The remote sensing-derived results are validated by comparison with video-based ground truthing information. This work represents the first of its kind undertaken in WA.

## Video data

The total number of video frames was 1807. For the HyMap validation exercise the number of classes of substrate was limited to three; sand, seagrass and brown algae. Table 5.14 shows the number of video frames for each class of substrate where at least 10% of the frame contained that class. Note that each video frame can contain more than one class of substrate, so the sum of all frames from all classes amounts to more than 1807.

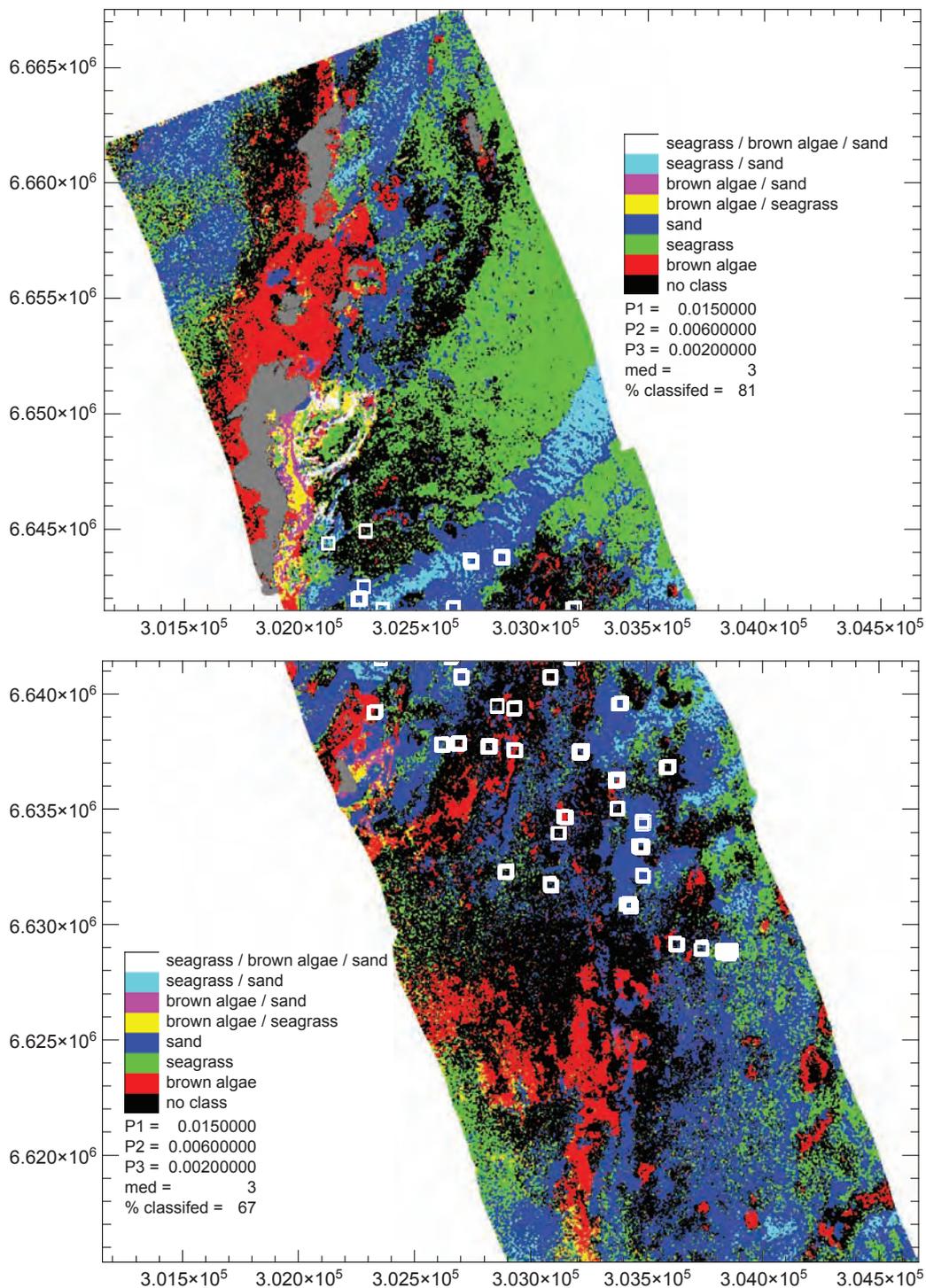
**Table 5.14.** The number of video frames that contained at least 10 percent cover for each substrate class. The total number of video frames was 1807. Some frames contained more than one substrate type and are therefore counted more than once.

Substrate class	Number of video frames
Sea grass	523
Sand	598
Algae	1111

## Comparison of video and remote sensing data

Achieving a useful outcome from hyperspectral habitat classifications is a matter of setting thresholds for reflectance parameters that result in the optimal trade-off between accurate classification of the substratum and minimize the number of cells that are not classified. For Jurien these optimal reflectance parameter values were; sand=0.015, seagrass=0.006 and brown algae=0.002. These parameters produced validation percentages of sand = 52%, seagrass = 48%, and brown algae = 88% for ground truthed sites which were judged to have at least 10% cover of one of these habitat types. Validation percentages were calculated as the percentage of video-classified pixels of a particular class for all pixels that were classified by HyMap at the chosen threshold.

Judging where to set the balance between accuracy and coverage will in part be determined by the intended application of the habitat map as some uses will require higher levels of certainty than others. Brown algae was the most accurately classified of the three habitat types as this category achieved the highest reliability with respect to the pixels for which ground truth data were available. This seems counter-intuitive as sand appears to be the brightest and most distinctive bottom type in remote images of shallow water. This result may be related to the problems associated with accurately identifying sand when seagrass is present at low to medium densities, as it often is at Jurien Bay. It may also be related to water depth, which is lowest over raised reef where algae mostly occur, reducing water column effects on the bottom reflectance and thereby improving accuracy for this habitat class.



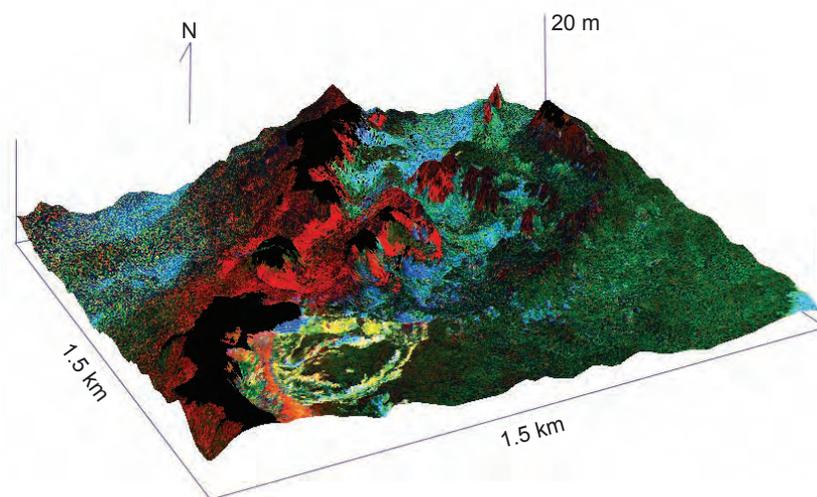
**Fig. 5.36:** Habitat map of the Fishermans Island area of Jurien Bay Marine Park using optimised reflectance thresholds.

Benthic plant communities at Jurien Bay are highly biodiverse (Section 5.4) and there is likely to be a corresponding diversity of spectral signatures among the dominant species represented in the bottom reflectance signal. Furthermore, the conspicuous spatial patchiness in reef habitats occurs on a scale which corresponds closely to that of HyMap (~1-5m). Continued field campaigns to build the spectral library of substrates should lead to better understanding of the spectral variability of substrates, and therefore improved estimates of substrate cover from remote sensing data.

One can envisage a classification technique based on statistical information related to such factors as spatio-temporal variations in spectral nature, patch scale dynamics, depth, rugosity, wave exposure, local and historical knowledge. The output of the model outlined here lends itself to such probabilistic methods, where products are delivered at every pixel in an image, and each pixel also contains information which may be interpreted as a confidence estimate.

A key to the difference between *in situ* ecological data collection and remote sensing methods is that *in situ* methods are often assessed by some form of statistical sampling theory. *In situ* results are analysed with the understanding that a small sample (a number of quadrats) of a population (a complete reef structure) is being measured. The results might be analysed using ANOVA techniques to report, say, the ability to classify a particular characteristic (such as 10% change in coral cover) with a high (> 90%) statistical power. However, remote sensing methods sample the complete population (the complete reef). The power of the remote sensing data is therefore in its spatial coverage.

One of the products determined from the remote sensing data is water depth. Figure 2.20 in Vol. 1, sec. 2.2.5 shows model-derived bathymetry compared to hydro-acoustical bathymetry data (WA Department of Planning and Infrastructure). For 1500 data points the RMS error was less than 7%. The model-derived substrate map may be overlaid on the model-retrieved bathymetry. This provides a very powerful tool for improving the accuracy of habitat classifications, as contextual information can greatly increase classification success but these clues have usually have to be obtained through independent sources (e.g. Ong *et al* 1998). Figure 5.37 shows the habitat class data extracted from the northern (top) portion of Figure 5.36 overlaid on the retrieved bathymetry. Brown algae (red) is situated along the sides of the raised reef structure. Sand (blue) occurs in the low lying channel running across the middle of the region (and mega-ripple structures of partially vegetated sand substrata can be seen). Sea grass (green) covers the broad low lying and relatively smooth area to the right of the scene. The unclassified (black) pixels atop the mounds in Figure 5.37 are the result of breaking waves and islands. Areas of mixed algal/sand or algal/seagrass habitat form a relatively small proportion of the total area, but interestingly they are all located in a very concentrated area of the landscape, in the shallow wave sheltered area behind Fisherman Is. and its associated reefs. In general the congruence of the geomorphological aspects of the map and the biological classifications provide a significant level of validation of the overall classification success of the approach.



**Figure 5.37:** Substrate classes (red – brown algae, green – sea grass, blue – sand, yellow – algae/sand, purple – algae/seagrass, turquoise – sand/seagrass, white – sand/seagrass/algae) overlaid on model derived bathymetry. Maximum water depth is approximately 15 m. The spatial extent of the image is approximately 1.5 km x 1.5 km. The region portrayed is the northern most section of the HyMap flight line shown in Figure 5.36. The vertical resolution is exaggerated to emphasise the variability in bathymetry across the scene.

This work represents the first application of a physically based optical model to the processing of hyperspectral remote sensing data for coastal mapping undertaken in Western Australia. We are confident that hyperspectral remote sensing can be a valuable tool in monitoring and mapping shallow coastal waters in WA. Challenges include overcoming signal to noise ratio in deeper water and over dark substrates. Future advances in sensor technology will improve this state. The optical model is, we believe, valid for the range of optical conditions typically experienced in SW WA coastal waters.

While there is a perceived high cost of HyMap data, it presents significant opportunities for shallow water habitat mapping and classification since it can produce high resolution bathymetry at the same time as habitat data. While its use is limited to relatively shallow waters these are precisely the areas where hydroacoustic methods lose their power because of the reduction in acoustic swath width in shallow water. The combination of shallow water hyperspectral mapping and multibeam acoustic mapping and habitat modelling techniques in deeper waters promises to provide a seamless picture of habitats across the continental shelf. These data will form the basis for bioregional planning and more process oriented studies such as biogeochemical modeling, trophodynamic modeling.

## Discussion

The SRFME study found a strong seasonal signal in algal biomass in all regions, however processes underlying this pattern varied for different locations, or for particular sites within locations depending on the dominant algal habitat type. Most locations showed lowest biomass in winter (e.g. Jurien Bay, Marmion, Two Rocks and Bunbury) but others showed summer minima, where the majority of sites were dominated by *Sargassum*. The proximal factors that drive these variations also differ among locations. Erosion of biomass is most likely to be the factor driving changes in *Ecklonia* dominated sites (Marmion, Two Rocks, Perth) (Kirkman 1981) while light limitation is likely to be a major factor at Bunbury, most likely due to seasonal re-suspension of particulate matter and sediment in eastern Geographe Bay by winter and spring storm events and long-period swells. In the case of Bunbury these effects appear to occur across the entire algal community which is largely made up of foliose red and brown algae. Where *Sargassum* dominates sites (Green Head), algal phenology can explain reduced algal biomass in summer (Kendrick 1993). In contrast to the pattern for biomass, algal community structure showed no seasonal trend, which was also the case for invertebrates.

Among the study regions the overall number of algal species recorded was similar. While variations in number were not large, there were more species recorded at the lower latitude sites, and fewer recorded in the Perth region. In this regard it is worth noting that this may be explained by variation in the relative dominance of large brown algae in the different regions. In all the regions, by far the largest contribution to overall species diversity was made by the red algae (Figs. 5.13-5.15). The highest densities of *Ecklonia* were found at reefs in the Perth region (Fig. 5.20) and since there is an inverse relationship between *Ecklonia* biomass and that of red algae (Figs. 5.13-5.15), it is perhaps not surprising that fewer species were recorded around Perth where *Ecklonia* appears to be particularly dominant. At this point we can only speculate on the underlying cause of the dominance of *Ecklonia* at some sites in the Perth region. The potential for anthropogenic nitrogen sources (Fig 5.3) to enhance the growth of *Ecklonia* may provide one explanation worthy of further investigation. Nutrient levels seem to be elevated in the area and to carry a high level of  $\delta^{15}\text{N}$  (Fig. 5.6), a sign of terrestrial effluent origins for this nitrogen. Other Laminarian algae are known to be nitrogen limited (Davison *et al.* 1984, Brown *et al.* 1997, Hepburn & Hurd 2005) however it is not known if this is actually the case for *Ecklonia* on the WA coast.

Macroalgal community structure varied at all the spatial scales we examined, but was strongest at the site level. In fact, site level variation is likely to be largely responsible for the patterns observed at larger scales. Regional trends were due to the separation of Geographe Bay sites from more northern sites, and this difference could be attributed to a lack of sites dominated by *Ecklonia radiata*. Similarly there were even clearer differences at the location level, except between sites at Jurien and the Perth region dominated by *Ecklonia*. In fact, at the site level, the differences among sites, even within locations, was greater than the

differences between sites at the most widely separated regions. This strongly suggests that for algal community structure, processes operating or varying across relatively small scales may be responsible for much of the variation observed on west coast reefs. Assemblages not dominated by *Ecklonia* or other canopy species were most often composed of a diverse mixture of medium to small sized foliose algae, mainly red and brown algae, though green algae were occasionally dominant. Our study has shown that for the study area these habitats can on average form almost 50% of all algal communities, and are likely to be of greater importance than previously assumed in WA, although other recent studies in temperate Australia have shown that on rocky reefs algal habitats that are not dominated by a closed kelp canopy are a characteristic and important feature of reefs on the WA south coast, South Australia and southern New South Wales (Fowler-Walker and Connell 2002).

Since the nature of this variation was often associated with clear qualitative differences in community structure, e.g. presence or absence of a canopy, we developed a method to classify algal communities based on a semi-quantitative mix of structural and taxonomic attributes. The system was 75% reliable and offers a means of classifying algal assemblages for use in higher level analysis of patterns at the landscape scale and as a rapid system for visual quantification of habitats for mapping and ground truthing.

A statistical model relating algal assemblage structure to physical environmental variables in the Jurien region showed that the two factors most strongly associated with community structure were sea bed roughness at the 1 m and 10 m scales, and modelled seabed orbital velocity. Wave generated water movement across the seabed and small scale seabed topography are likely to interact very strongly, further reinforcing the conclusion that small scale variations in ecological processes are likely to be of prime importance in determining the structure of benthic reef assemblages. Processes controlled by interactions of topography and water motion include physical disturbance (dislodgement), diffusive processes (gas and nutrient exchange) and sediment transport (scour and burial) (Hurd 2000). It is important for us to understand the implications of this small scale variation in algal assemblages for several practical reasons. Ecological studies, whether long term monitoring or extensive mapping surveys, need to be explicit about what sorts of habitats they are describing. To fail to do so will create a high level of uncertainty for subsequent research.

For invertebrates weaker patterns were present, particularly for the algal-associated epifauna. Some pattern was present in the larger sessile and solitary fauna, but levels of similarity/dissimilarity did not vary markedly across scales. The lack of pattern suggests that the spatial scales encompassed in the sampling (regions, locations, sites), which was designed primarily to quantify algal assemblages, was not adequately capturing variation in the invertebrate assemblages.

When examined at different spatial scales however, informative patterns did emerge. Species number varied according to the algal habitat type with epifaunal invertebrate species richness (at the scale of 0.25 m<sup>2</sup> quadrats) higher for turf habitats, followed by *Caulerpa*, *Ecklonia* forest, *Sargassum*, low algae, red foliose and mixed brown habitats. A higher number of solitary and sessile invertebrates (1 m<sup>2</sup> quadrat) were found to be associated with low algae and red foliose habitats, followed by mixed brown, turf, *Sargassum*, *Ecklonia* forest and *Caulerpa* habitats. As for the algae, the highest number of invertebrate species was recorded at Jurien, and Perth had the lowest numbers of species although numbers were only marginally greater at Geographe Bay. While the magnitude of the differences is relatively small, it is once again interesting that the region with the most *Ecklonia* dominated sites had the lowest number of species.

For larger sessile invertebrates, belt transects revealed strong trends for coral and sponge abundance, for low algae and red foliose algal habitat types. Brown algal dominated habitats totalled 53% of habitats covered by transects at Marmion, yet for these same transects only 22% of sponges and 7% of corals were recorded in these areas. These patterns essentially reflect algal habitat structure and coverage, and its patchiness or variability not just at the site level but within sites. Interestingly one of the coral species (*Plesiastrea*) was one of the taxa most responsible for dissimilarity among sessile and solitary invertebrate assemblages at the site level (Fig. 5.25). Sessile invertebrates such as corals and sponges, may achieve a higher larval settlement rate and/or higher subsequent survival and growth, in habitat that is lower and sparser

in comparison to the typically dense, canopy forming brown algae species. Physical abrasion by kelp is a likely explanation for this since mechanical damage by large kelps is known to influence the distribution of other invertebrates. While the coral species in question are hermatypic species and do require light, which is also lower under kelp canopies, these same species are also found in nearby overhangs and walls associated with sciaphilous filter feeder assemblages (sponges, colonial ascidians, bryozoans, gorgonians; R. Babcock pers. obs.) therefore light is less likely as an explanation for their relative absence under kelp.

At the scale of individual quadrats there were significant patterns in the overall abundance of mobile invertebrates, particularly molluscs and crustaceans. Most of these animals are relatively small and likely to be key contributors to secondary production in the reef ecosystem (Edgar 1990). Interestingly this pattern resulted from a significant negative correlation between invertebrate abundance and the biomass of *Ecklonia radiata*, which in this case turns out to have a key indirect influence on invertebrate assemblages.

Fish assemblages showed a contrasting pattern to those of algae and invertebrates, with a high level of variation among assemblages at the regional level and virtually none at the location level. However at the site level there was once again significant variation in fish assemblages. We attribute this consistent variation at the site level to the association of fish assemblages with definable algal habitat types that tend to dominate at particular sites. While assemblages dominated by large brown algae dominated at just over half the sites, nearly as many were characterized by a canopy of large brown algae and were instead characterized by a diverse assemblages of foliose and filamentous red and brown algae.

Across all three major groups we have studied, algae, invertebrates and fish, we see the importance, even dominance, of processes operating at relatively small scales (meters to tens of meters) for structuring variation in benthic assemblages. This variation has important implications for ecological processes which will be explored in Chapter 6. Some aspect of wave action, coupled with the nature of the substratum, interact to determine the characteristics of the algal community. The characteristics of the algal community in turn appear to strongly determine the nature of invertebrate assemblages. For fish, these aspects of habitat also appear to be important, although in their case there may also be stronger large-scale biogeographic factors influencing distribution across the west coast region. At the regional level some locations have physical characteristics that mean larger scale processes play a more important role. Variation in water quality in eastern Geographe Bay creates conditions that result in a seasonal change in algal biomass quite distinct from other parts of the west coast. The implications of this unusual pattern merit further exploration. It is possible that elevated nitrogen levels in Perth metropolitan waters are linked in some way to the abundance of *Ecklonia* dominated habitats at Marmion. For most of the coast smaller scale studies focused on the way in which environmental factors impact at the site or even quadrat scale are likely to lead to a broader general understanding of key ecological processes. The role of such small scale processes, and of nutrients in coastal reef systems, will be explored as part of a 5 year program beginning in 2006.

This small-scale understanding will have to be applied from the bottom-up to larger scale pictures of ecological processes across the coastal ecosystem as a whole. Remotely sensed habitat mapping shows significant promise as a tool in the scaling up process to the landscape level and integrating information at a range of scales

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