CHAPTER 4

ASSOCIATION BETWEEN BIOLOGICAL COMMUNITIES AND PHYSICAL VARIABLES ON VICTORIAN ROCKY REEFS

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4.1 Introduction

The study is essentially an observational survey of common macroalgae and macroinvertebrate reef biota, using standard underwater techniques to quantify the association between biological community structures on subtidal rocky reefs in the vicinity of the Central Victoria bioregion. This study was commissioned by the Environment Conservation Council (ECC).

The objectives of this study were:

- to investigate reef communities associated with major rocky reef substratum types; and
- to establish which physical variables influence the distribution and composition of reef communities.

4.2 Methods

4.2.1 Sites Examined

The selection of which areas to undertake the study was based on an examination of Victorian coastal lithology to locate reef substratum types. Five areas with relatively distinct boundaries between substratum type lithologies were identified in the general vicinity of central Victoria. These areas were: Port Campbell (limestone and sandstone reefs); Cape Otway (calcarenite and sandstone reefs); Cape Schanck (basalt and calcarenite reefs); Phillip Island (basalt and granite reefs); and Wilsons Promontory (calcarenite and granite reefs). Of these areas only three were selected for this study (Cape Schanck, Phillip Island and Wilsons Promontory). For each area, sites were chosen to provide a variety of reef substratum type lithologies (Table 4.2.1).

Area	**Site**	**Substratum type lithology#**	**Coordinates (AMG)**	
A. Cape Schanck	West of lighthouse	Calcarenite	0314425	5738525
B. Cape Schanck	West of lighthouse	Basalt	0315212	5736975
C. Phillip Island	Red Bluff, Pyramid Rock	Basalt	0344040	5734098
D. Phillip Island	Cape Woolamai	Granite	0355230	5730620
E. Wilsons Promontory	Darby River	Calcarenite	0433557	5689331
F a. Wilsons Promontory	Shellback Island	Granite	0432379	5686079
F b. Wilsons Promontory	Tongue Point	Granite	0434937	5683512

Table 4.2.1 Location and map coordinates of survey sites.

The substratum type lithology examined were Quaternary dune calcarenite, Tertiary basalt and Devonian granite:

- Calcarenite is a sedimentary rock originating from dunes with a high shell content. During sedimentation and compaction, the calcium carbonate in the shell fragments partially dissolve and cement the fragments together, forming a coarsely grained (0.1-2 mm) and reasonably friable rock.
- Basalt is a fine grained igneous rock. Basalt originates from volcanic activity, and is usually found in the form of lava flows from fissures and central-type vents. The lava cools rapidly in contact with the air giving little time for crystal formation, resulting in the fine-grained structure.
- Granite is a coarsely-grained igneous rock with a high quartz component. Granite is formed from slowly cooled intrusive bodies with a high silica content. The slow cooling allows large crystals to form. These bodies then become exposed by uplifting and erosion of overlying rocks.

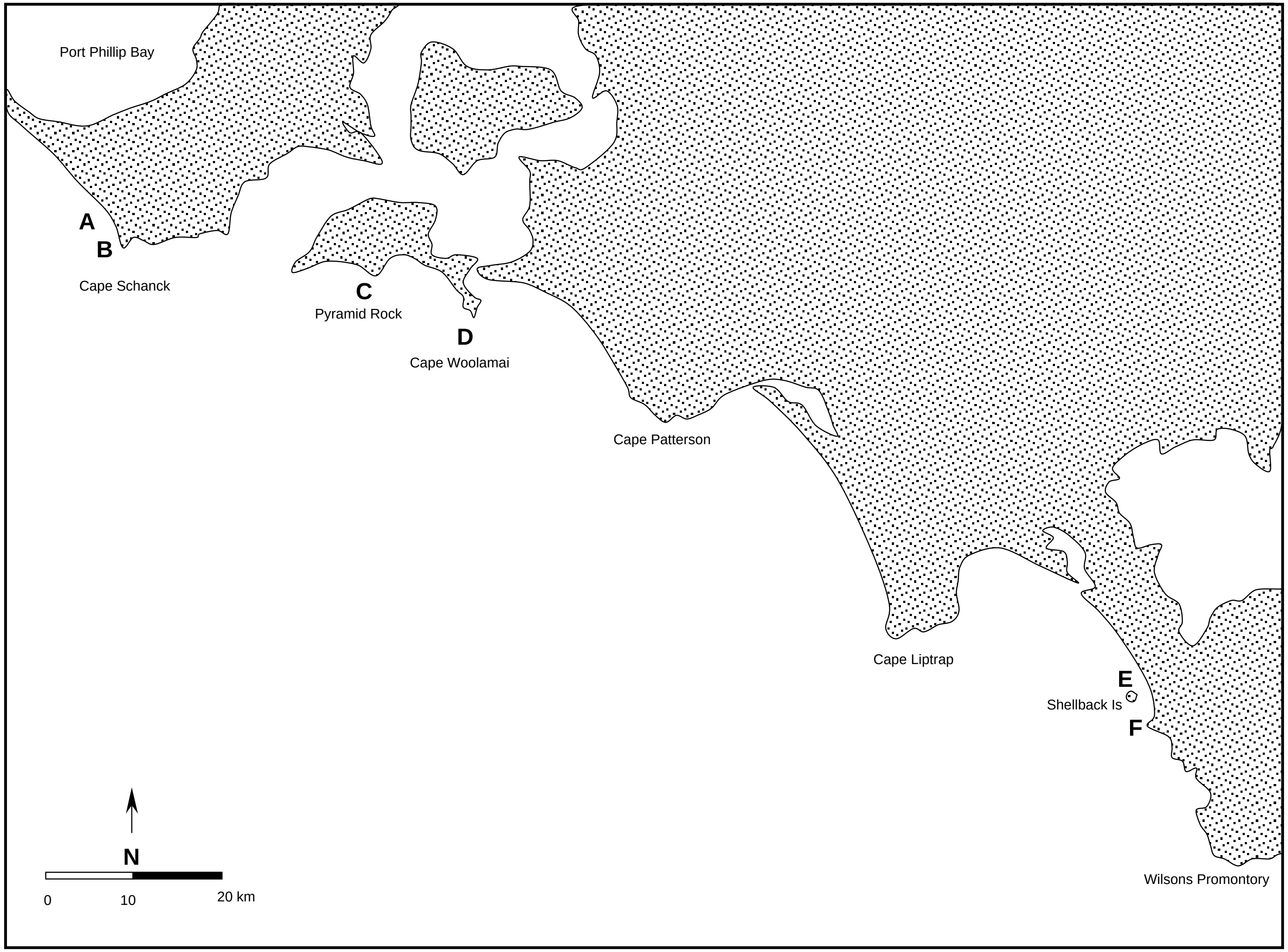

Figure 4.2.1 Location of reef survey sites. Substratum type lithology (A) calcarenite; (B) basalt; (C) basalt; (D) granite; (E) calcarenite; and (F) granite.

4.2.2 Survey Methods

Visual survey techniques widely used for studying temperate reef ecology were used (eg Australia: Edgar and Barrett 1997; Edgar *et al* 1997; Wright *et al* 1997; New Zealand: Choat and Schiel 1982; Cole *et al* 1990; Andrew and MacDiarmid 1991). These methods are efficient for collecting data where diving time is limited, and provide information comparable with other studies. Four aspects of the reef biota were quantified using these methods:

- the density of macroinvertebrates (eg abalone, lobsters, crabs and sea urchins);
- the density of canopy forming plants (predominantly kelps and other large brown algae);
- the cover of understorey macroalgae; and
- the biomass of understorey algae.

These communities were surveyed by laying a survey line along the 12 m depth contour. Replicate surveys were taken from 20 m sections of the survey line, with each replicate sampling area at least 20 m apart. Because of variations in reef structure and available reef habitat, the actual depth of each replicate ranged between 8 and 18 m.

The reef macroinvertebrates were counted within a 1 m wide swathe along one side of the 20 m transect (20 m^2). The animals counted included all sedentary invertebrates (eg large molluscs, echinoderms and crustaceans) and easily identifiable sessile species (eg the large ascidians *Herdmania momus* and *Pyura australis*). The survey included all animals visible within crevices. All animals were identified to species level. The number of replicates surveyed were 7, 4, 9, 9, 9 and 10 for sites A, B, C, D, E and F respectively. The inconsistency in sample sizes was caused by poor weather conditions at Cape Schanck and diving time limitations.

Kelps and other canopy forming seaweeds (large species of Laminariales and Fucales) were counted within 0.2 m^2 quadrats. Four quadrats were placed at 5 m intervals within each 20 m transect. The counts from these quadrats were pooled to give a total sample area of 0.8 m^2 per replicate. Ten replicate transects were surveyed at each site.

The proportions of cover of the understorey algal species were determined using photoquadrats. An underwater camera mounted on a frame was used to photograph 0.2 m^2 quadrats. The canopy species were cleared prior to each photograph. In the laboratory, each photograph was projected onto a grid of 225 points. The proportion of dots covered by each taxon was used as an index of cover. The algae were identified to species where possible, but were generally classified into functional groups (such as foliose reds, encrusting corallines and erect corallines). The quadrat locations were adjacent to the canopy-count quadrats, with 4 photoquadrats taken per replicate. The points data were pooled for each replicate, and 10 replicate areas were sampled per site.

The understorey algae were harvested from 10 randomly located 0.2 m^2 quadrats at each site. Erect algae were removed from the rock surface and placed in mesh bags. On shore, the algae were sorted, identified to species level and weighed.

Taxonomic lists for all species identified by the above survey methods is given in Appendix 4.9.2.

4.2.3 Physical Variables

Eleven physical variables were recorded for each replicate transect. These variables were:

(i) substratum type lithology (Ro);
(ii) substratum relief (Ri);
(iii) substratum interstitial space (Is);
(iv) substratum complexity (Ci);
(v) depth (Z);
(vi) exposure (wave climate) (Ex);
(vii) aspect (As);
(viii) distance from shore (Di);
(ix) slope (Sl);
(x) longitude (easting distance) (Ed); and
(xi) sediment cover (Sa).

The measurement of these variables is described below.

Substratum type lithology

(i) The substratum type lithology of each site was confirmed by chipping samples off larger reef structures.

Substratum structure measures

Three measures were used to record the substratum structure: relief; interstitial space; and complexity.

(ii) *Substratum relief*: an index of relief was calculated using depth measurements at 1 m intervals along the 20 m transect (RI_{100}; see Appendix 4.9.1).

(iii) *Substratum interstitial space*: the amount of interstitial space in the reef (such as holes, cracks and crevices) was quantified by the frequency of spaces bisected by the 20 m transect line. Only holes with an opening greater than 10 cm were counted. This interstitial space frequency index was also standardised to a 100 m sample length (ISF_{100}).

(iv) *Substratum complexity*: A complexity index (SCI) was based on the following criteria:

- flat rock substratum of low relief broken occasionally by crevices or ledges;
- boulders or rock slabs of moderate relief (0.5 m), ledges or crevices common;
- moderately high relief (1 - 2 m) with most substratum broken by ledges and crevices; and
- highly structured, high relief (> 2 m) with a large interstitial volume.

This ordinally scaled index was also used by Edgar (1981) and Edmunds (1990).

Depth

(v) The average depth of each transect replicate was determined from the relief measurements.

Exposure (wave climate)

(vi) The exposure of each site was given a ranking on a scale from 1 (most exposed) to 9 (least exposed) following the methodology by Edgar (1984). The exposure ranking scale descriptors include:

1 (maximal)
3 (submaximal)
5 (moderate)
7 (sheltered open coast)
9 (sheltered bays)

Exposure rankings were estimated a using the (vii) *aspect* of the shore near the survey sites. The (vii) *aspect* was recorded as a direction in degrees from magnetic north, with southwesterly aspects having the greatest exposures to large swells from the southern ocean. The general wave regime of the sampled reefs was also indexed using (viii) *distance from shore* (measured in m) and (ix) *slope* (calculated as function of depth and distance from the shore).

longitude

(x) The potential effect of geographic space as a variable was investigated using the longitude of the site. This value was standardised to a easting distance (in km) from the most westerly replicate.

Sediment cover

(xi) The proportion of sediment cover on each reef was estimated from the photoquadrats.

4.2.4. Analysis Strategy

The structure of biological communities between reefs of different lithologies was compared using a variety of analytical methods:

- Patterns in community structure were examined graphically using MDS ordinations.
- Differences in community structures were examined using univariate statistics (diversity statistics), bivariate plots (dominance curves) and multivariate statistics (ANOSIM and SIMPER).

The relationships between community structures and the physical environment were examined using the relatively new non-parametric methods of Clarke and Ainsworth (1993). This analysis strategy follows many of the principles summarised by Clarke (1993), and is outlined in Figure 4.2.2. Each analysis component of this strategy is presented in a separate section below (Sections 4.4 to 4.6). The analysis methods are described in detail within each section.

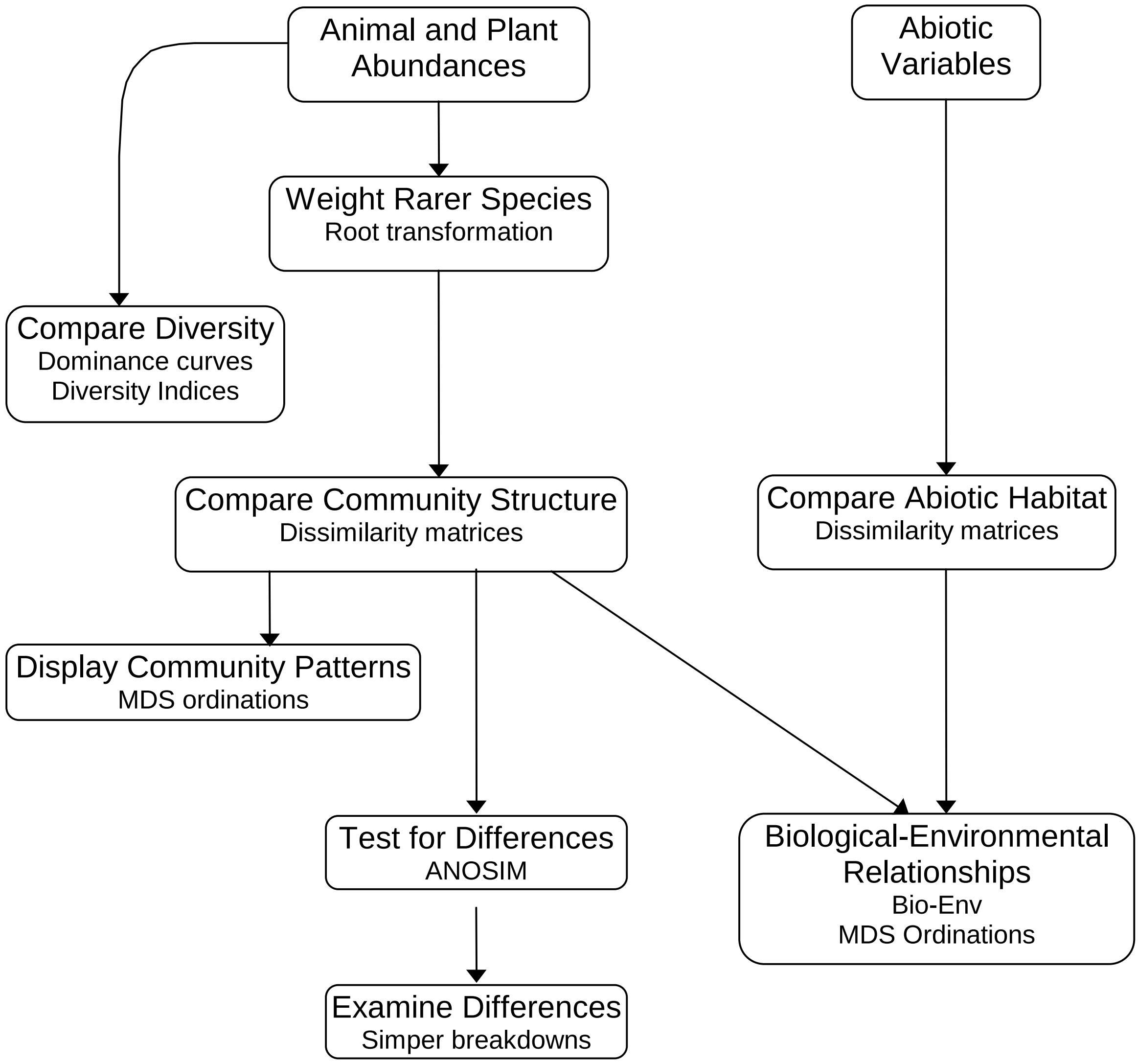

Figure 4.2.2 Analysis strategy for examining the influence of physical variables on reef communities.

4.3 General Observations

4.3.1 Reef Structure

(A) The calcarenite at Cape Schanck was generally in the form of flat bedrock with steps of about 0.5 m in height. The reef topography is illustrated in Figure 4.3.1. The flat regions had few cracks and crevices. Relatively high outcrops (≈ 1.5 m) were present but uncommon. Caves and crevices were present at the base of these outcrops.

(B) The basalt at Cape Schanck was mostly flat with little vertical relief. The reef was relatively smooth with few cracks and crevices.

(C) The basalt at Phillip Island formed a mixture of smooth reef tops and vertical drop-offs of moderate relief (0.5 - 1.5 m). Caves and crevices were common on or near these vertical reef faces.

(D) The granite at Cape Woolamai formed a complex topography of large boulders and outcrops with moderately high relief (1 - 2 m). A moderately large interstitial volume was present in the form of vertical cracks in the rock and caves at the base of the boulders.

(E) The calcarenite at Wilsons Promontory provided a mixture of areas of high substratum complexity and areas of flat, low relief reef (with high sediment cover). The high complexity areas consisted of reef blocks 1 m high with substantial erosion and undercutting of the vertical faces, providing a high density of caves and crevices.

(F) The granite reefs at Wilsons Promontory consisted of steeply sloping sheets of relatively smooth bedrock. This bedrock was stepped, and mostly covered by fields of boulders and rubble (rocks 0.2 - 1 m across) and, to a lesser extent, massive boulders (1 - 3 m high). The boulder fields had a high density of small holes between the junctions of the rocks. Larger crevices were present at the base of the massive boulders, and at the steps of bedrock.

4.3.2 Flora and Fauna

A total of 32 invertebrate species were recorded during this study, including 9 mollusc, 15 echinoderm and 4 ascidian species. The invertebrates at the Cape Schanck and Phillip Island sites (A - D) included a predominance of the abalone *Haliotis rubra*, the periwinkle *Turbo undulatus*, the biscuit-star *Tosia australis* and the ascidians (sea squirts) *Cnemidocarpa radicosa*, *Herdmania momus* and *Pyura australis* (Table 4.3.1). The Phillip Island sites also had higher densities of other seastars such as *Nectria macrobrachia*. The Wilsons Promontory calcarenite sites (E) had a low abundance of invertebrates in general and the fauna was dominated by ascidians and the crinoid *Cenolia trichoptera*. The Wilsons Promontory granite site (F) had a very high abundance of *Cenolia*, in addition to the sea urchin *Heliocidaris erythrogramma* and ascidians (Table 4.3.1).

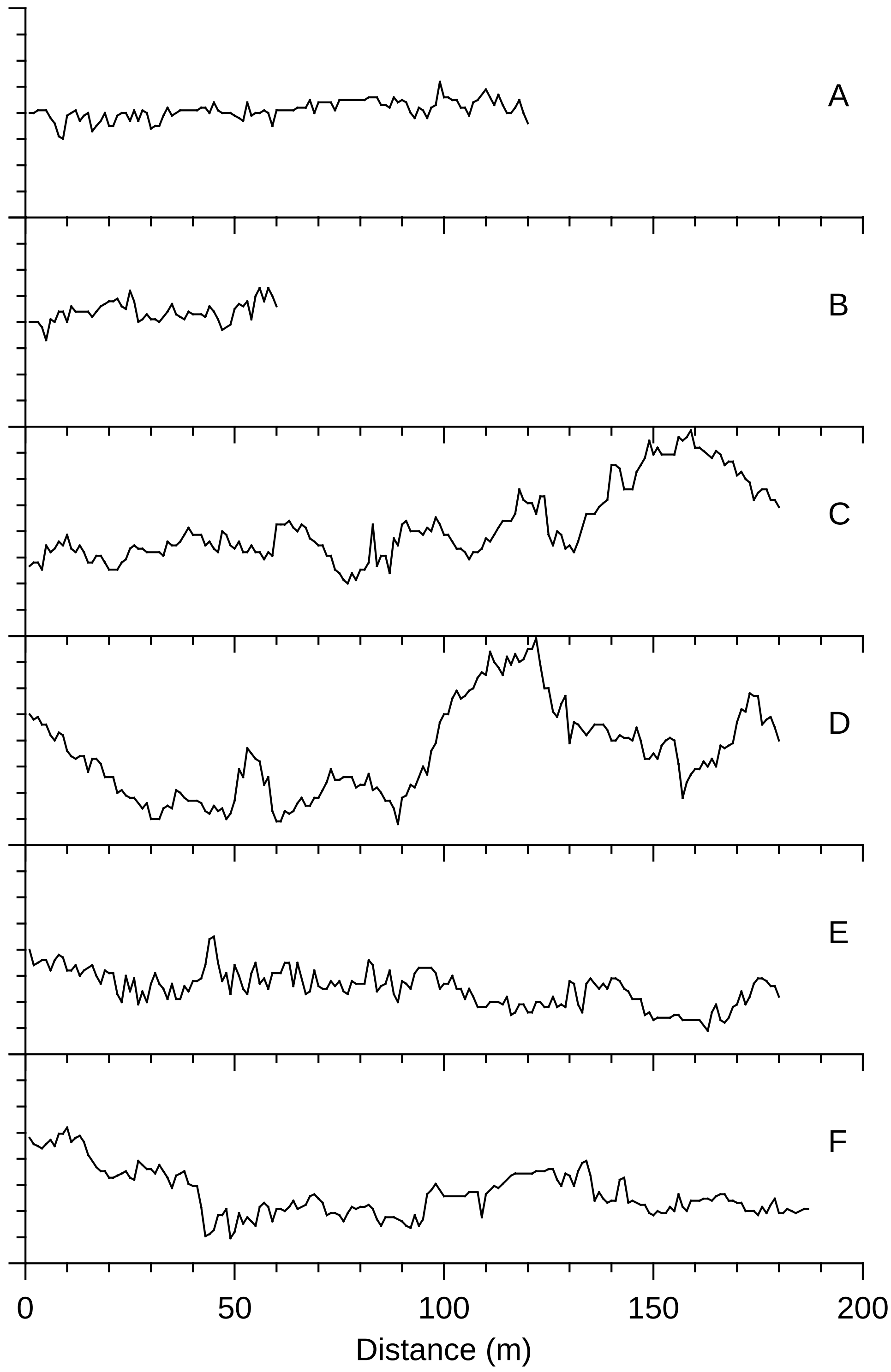

Figure 4.3.1 Reef substratum topography from relief measurements. The vertical scale is in metres. Sites: (A) Cape Schanck calcarenite; (B) Cape Schanck basalt; (C) Phillip Island basalt; (D) Phillip Island granite; (E) Wilsons Promontory calcarenite; and (F) Wilsons Promontory granite.

A total of 11 canopy forming algal species were recorded within the quadrats, however, the predominant species were *Ecklonia radiata*, *Phyllospora comosa* and *Seirococcus axillaris* (Table 4.3.2). The canopy was entirely *Ecklonia* at the two Cape Schanck sites (A and B), mostly *Phyllospora* at the two Phillip Island sites (C and D), a mixture of *Ecklonia* and *Phyllospora* at the Wilsons Promontory calcarenite site (E) and a mixture of *Ecklonia*, *Phyllospora* and *Seirococcus* at the Wilsons Promontory granite site (F; Table 4.3.2).

A total of 42 understorey algal species were recorded from the biomass collections, these being represented by 22 groups in the photoquadrat analysis (Tables 4.3.3 and 4.3.4). The general composition of the understorey algae consisted of encrusting corallines, foliose reds and turfing reds. Juvenile *Ecklonia* were also predominant in the understorey at the Cape Schanck sites (A and B). Foliose reds were particularly high in abundance at the Wilsons Promontory calcarenite site (E) and brown algae were a predominant understorey component at the Wilsons Promontory granite site (F).

4.3.3 Comparison of Sites

Some species observed during this survey occurred predominantly on one substratum type lithology (Tables 4.3.1 to 4.3.4). The ascidian *Cnemidocarpa radicosa* and brown dictyotalean algae were relatively higher in abundance on granite. The periwinkle *Turbo undulatus* and the brown alga *Halopteris* were much higher in abundance on basalt. The red alga *Pterocladia lucida* was abundant on calcarenite, but extremely scarce on basalt and granite. While these patterns may be the result of substratum type lithology, overall they do not represent substantial changes in the structure of the community (examined in more detail in following sections).

The abundances of other species appeared to be related to the geographic area along the coast. At Cape Schanck, the canopy forming kelp at both the calcarenite and basalt reef was entirely *Ecklonia radiata*. This contrasted with the Phillip Island and Wilsons Promontory reefs, where the canopy was mostly *Phyllospora comosa* and a mixture of *Ecklonia* and *Phyllospora* respectively (Table 4.3.4). The elephant snail *Scutus antipodes* and southern rock lobster *Jasus edwardsii* were observed at the Phillip Island sites, but were not seen at the Cape Schanck or Wilsons Promontory sites. The crinoid *Cenolia trichoptera* and the seastar *Plecaster decanus* were observed at Wilsons Promontory, but not at Cape Schanck or Phillip Island. The predatory snail *Dicathais orbita* was not at Wilsons Promontory, but was at all other sites. The stalked ascidian *Pyura gibbosa* was not observed at Cape Schanck, but was present at all other sites.

Few similarities were apparent between the same substratum type lithology when used as a single variable for seafloor geology at different sites. The variation in community structure between sites needed to be assessed with respect to the degree of variation within each site (ie between replicate surveys). This process involved statistical methods, which are described and used in following sections of this report. These methods incorporated the abundances of all species observed during the surveys.

Species	Site					
	A	B	C	D	E	F
Mopsella zimmeri						3.5
Acabaria sp						1.5
Jasus edwardsii			1.1	3.9		
Nectocarcinus tuberculosus				0.6	0.6	0.5
Chitons						0.5
Haliotis rubra	52.4	67.5	156.3	60.0	2.2	17.5
Haliotis laevigata				1.1		
Scutus antipodes			0.6	1.1		
Calliostoma armillata						0.5
Phasianotrochus eximius						0.5
Turbo undulatus	4.3	10.4	19.2		1.7	0.5
Astralium aureum						11.0
Dicathais orbita	0.7	3.8	1.7	2.2		
Cenolia trichoptera		1.3	3.9		10.6	99.0
Cenolia tasmaniae					0.6	2.5
Tosia magnifica						0.5
Tosia australis	3.6	5.8	3.8	1.7	1.1	1.0
Pentagonaster dubeni	0.7		0.6	0.6		
Nectria macrobrachia	0.7	2.5	6.3	6.7		3.5
Nectria multispina	1.4		4.0	2.2	1.7	1.5
Petricia vernicina				1.1	0.6	1.0
Fromia polypora				1.1	0.6	0.5
Plecaster decanus					1.7	0.5
Echinaster arcystatus		1.25	2.8	0.6		
Nepanthia troughtoni	1.2	1.3	2.8	0.6		
Patiriella gunnii				0.6		8.0
Uniophora sp			0.6			
Heliocidaris erythrogramma	0.7		1.8	1.7	1.1	95.0
Cnemidocarpa radicosa	8.8	19.2	31.1	98.9	6.1	21.0
Herdmania momus	97.1	237.5	55.28	60.2	40.0	100.0
Pyura australis	12.1	51.3	63.8	106.9	12.2	0.5
Pyura gibbosa			2.8	2.8	1.7	0.5

Table 4.3.1 Mean invertebrate densities (100 m^{-2}). Sites: (A) Cape Schanck calcarenite; (B) Cape Schanck basalt; (C) Phillip Island basalt; (D) Phillip Island granite; (E) Wilsons Promontory calcarenite; and (F) Wilsons Promontory granite.

Species			**Site**			
	A	**B**	**C**	**D**	**E**	**F**
Carpomitra costata			0.1			
Macrocystis angustifolia				0.3		
Ecklonia radiata (adult)	13.9	22.5		1.8	6.9	4.0
Ecklonia radiata (juvenile)	21.5	22.9	1.4	1.6	2.0	1.5
Xiphophora chondrophylla						0.1
Phyllospora comosa (adult)			8.5	6.8	3.5	2.4
Phyllospora comosa (juvenile)			1.9	7.1	0.8	
Phyllospora comosa (early juvenile)				5.0		
Seirococcus axillaris			0.4		0.3	4.8
Cystophora platylobium				1.5	0.3	
Cystophora moniliformis				2.0		0.4
Cystophora subfarcinata				0.5		
Acrocarpia paniculata				1.1		
Sargassum sp			0.3	1.3	0.4	0.4

Table 4.3.2 Mean canopy-forming algal densities (number per m^{-2}). Sites: (A) Cape Schanck calcarenite; (B) Cape Schanck basalt; (C) Phillip Island basalt; (D) Phillip Island granite; (E) Wilsons Promontory calcarenite; and (F) Wilsons Promontory granite.

Group			**Site**			
	A	**B**	**C**	**D**	**E**	**F**
Sand	2.8	0.1	0.7	0.6	2.6	1.6
Bare	0.6	1.4	0.2	0.1	0.3	0.2
Animals	0.2		7.5	30.3	3.5	4.1
Encrusting Coralline	32.7	40.4	20.9	5.4	11.2	17.7
Erect Coralline	4.9	1.7	2.0		1.1	2.9
Foliose Reds	32.1	19.2	40.1	36.8	64.2	19.9
Turfing Reds	9.4	6.8	11.5	8.5	9.8	4.3
Sonderopelta coriaceae	0.2	6.0	1.7	0.3	0.1	1.2
Melanthalia obtusa	1.9	0.7		1.6		0.2
Dictyotales	1.7	2.1	0.8	6.4	2.7	6.3
Acrocarpia paniculata	0.2	2.3	1.9	0.8	2.0	6.9
Ecklonia radiata (juv.)	12.6	16.8	1.1	0.9		2.1
Phyllospora comosa (juv.)	4.2		2.4	0.7	9.1	
Macrocystis angustifolia (juv.)		2.0	0.2			
Xiphophora chondrophylla			0.2	1.3		3.9
Cystophora monilifera			1.4			
Cystophora subfarcinata			2.1			0.2
Sargassum spp					0.9	3.8
Halopteris gracilescens					0.1	
Other foliose Browns						14.8
Ulva sp					0.4	
Caulerpa cactoides				0.5		0.1
Caulerpa flexilis	0.2		0.6	1.5		
Caulerpa brownii			1.6	1.2		
Caulerpa geminata						0.1
Carpoglossum					0.2	0.3
Codium fragile					0.2	

Table 4.3.3 Mean understorey algal substratum cover (% cover). Sites: (A) Cape Schanck calcarenite; (B) Cape Schanck basalt; (C) Phillip Island basalt; (D) Phillip Island granite; (E) Wilsons Promontory calcarenite; and (F) Wilsons Promontory granite.

Species			**Site**			
	A	**B**	**C**	**D**	**E**	**F**
Division Phaeophyta						
Carpomitra costata		0.4				
Sporochnus comosus			0.8	5.6		
Perithalia caudata				4	15.2	
Macrocystis angustifolia (juv.)	0.8	4.8				
Ecklonia radiata (juv.)	56	45.6	2.8	1.6	1.2	1.6
Xiphophora chondrophylla						28.8
Phyllospora comosa (juv.)				4.4	0.8	1.2
Seirococcus axillaris						277.6
Carpoglossum confluens		0.4				
Cystophora sp						28.4
Acrocarpia paniculata		0.4	2			51.6
Sargassum sp			0.8			211.6
Halopteris gracilescens	21.2	179.2	139.2	0.4	4.8	44.4
Zonaria angusta	3.6	16.4	11.6		0.4	
Zonaria spiralis	0.4	9.6				
Dictyota dichotoma	1.6	0.4	3.2	11.6	18.8	
Homeostichus olsenii				30.6	19.6	17.2
Lobospira bicuspida						207.2
Division Rhodophyta						
Halyptilon roseum	40.4	18.8	10.4		3.6	13.6
Cheilosporum sagittatum			4			
Metagonialithon stelliperum			4			20.4
Synarthrophyton patena						3.6
Pterocladia lucida	132.2	22.4			289.6	.8
Pterocladia capillacea				30.4		
Sonderopelta coriacea	1.2	59.2	26	10.4		4
Halymenia plana		3.6				
Hypnea ramentacea						10
Phacelocarpus peperocarpus	44	313.6	139.2	205.6	484.4	26.8
Plocamium sp		19.2	32			10
Plocamium mertensii			48.4		12	
Plocamium angustum			55.6		69.4	20.4
Plocamium dilatatum			236	126	132.8	6.8
Nizymenia australis	0.4	2		14.4	1.6	
Melanthalia obtusata	39.8	27.2		284.4		8.4
Delisea pulchra	0.4				0.8	
Ballia callitricha	52.8	44	20.4	105.2	6.4	0.8
Wrangelia nobilis				36.48		
Euptilota articulata	1.8				2.8	0.4
Haloplegma preisii					8	
Heterosiphonia gunniana			3.2		8.4	
Rhodymenia australis	7.6	26	77.6	40.8	1.6	79.2
Champia viridis						48.8

Table 4.3.4 Mean algal biomass (g.m^{-2}). Sites: (A) Cape Schanck calcarenite; (B) Cape Schanck basalt; (C) Phillip Island basalt; (D) Phillip Island granite; (E) Wilsons Promontory calcarenite; and (F) Wilsons Promontory granite.

Species	Site					
	A	B	C	D	E	F
Callophyllis lampertii	1.6	33.6		228.8		
Polyopes constrictus						3.6
Dictymenia harveyana			10			8.4
Laurencia clavata						1.6
Red 1						59.6
Red 2						18.4
Red 3						24.4
Red 4						0.8
Division Chlorophyta						
Caulerpa flexilis	20		4.4	25.2		88.4
Caulerpa cactioides			10.8	9.6		
Caulerpa geminata						14.4

Table 4.3.4 (continued) Mean algal biomass ($g.m^{-2}$). Sites: (A) Cape Schanck calcarenite; (B) Cape Schanck basalt; (C) Phillip Island basalt; (D) Phillip Island granite; (E) Wilsons Promontory calcarenite; and (F) Wilsons Promontory granite.

4.4 Diversity and Dominance

4.4.1 Introduction to Diversity

Species diversity is a measure of the distribution of individuals among species comprising a community. A biological community is considered to have a low diversity where most of the individuals belong to a few species. Conversely, a community with higher species diversity has a more even distribution of individuals among species. The diversity aspect of community structure can be quantitatively described using a variety of univariate diversity measures. These measures provide a convenient means of comparing community structures between different sites or times. However, a limitation of diversity indices is that a substantial amount of information about the community structure is lost in the reduction to a single summary statistic.

A more elaborate method for examining diversity in community structure is the use of bivariate species dominance curves. Dominance curves are an intermediate method of summarising and comparing community structure, between univariate diversity indices and full multivariate analysis such as clustering and ordination (this study uses ordination in later sections). Although diversity indices and dominance curves do not retain specific species information, they are still considered useful in extracting universal features of community structure (Clarke 1990).

4.4.2 Methods

Diversity indices

The species diversity of the invertebrate counts was examined using Shannon *H*', Pielou's Evenness *J*' and the Warwick-Clarke taxonomic diversity Δ.. These indices are described in the Appendix. Diversity of the algal canopy was not examined as the canopy usually consisted of only two or three species.

A non-species diversity related index, taxonomic distinctness Δ*, was calculated for invertebrate species counts and algal biomass. This index is a measure of the distribution of species among higher taxonomic levels (ignoring abundances within species), and is described in Appendix 4.9.1 (equation 4.9.6). Taxonomic distinctness was not calculated for algal cover as classifications were into non-hierarchical functional groups.

Dominance curves

Dominance curves were constructed for each replicate of the invertebrate species counts and understorey algal cover. This involved plotting cumulative percentage abundance against the relevant log-species rank (*k*-dominance curves). The shapes of the curves were then compared using a difference statistic (*d*': see Appendix 4.9.1). The *d*' statistic was tested for differences in dominance structure between sites using analysis of similarities (ANOSIM: described in Section 4.5.1). Dominance curves of data pooled across all replicates for each site were constructed for invertebrate counts, algal substratum cover and algal biomass.

4.4.3 Results

There were slight variations in the means of univariate diversity indices for invertebrates between sites (Table 4.4.1). However, this variation was not statistically significant. Similarly there were no significant differences in taxonomic distinctness between sites (Table 4.4.2).

For invertebrates, the pooled *k*-dominance curves were similar for the two Cape Schanck sites (A and B: Figure 4.4.1a). However, these two curves showed a higher dominance of fewer species than at the other sites (C - F), indicating a lower diversity. The Phillip Island sites and the Wilsons Promontory calcarenite site (C - E) had very similar dominance structures, intermediate to those of A-B and F. The Wilsons Promontory granite site (F) had a slightly higher diversity of invertebrates with a more even dominance structure (Figure 4.4.1a). Dominance structure was not significantly different between sites (R = -0.03; p = 0.26).

For algal cover and algal biomass (see Figures 4.4.1b and 4.4.1c), very similar *k*-dominance curves were observed for the Cape Schanck and Phillip Island sites (A-D). In comparison, the diversity was lower on the Wilsons Promontory calcarenite (E) and higher on the Wilsons Promontory granite (F). The algal biomass analysis found a significant difference in the dominance curves between the Wilsons Promontory calcarenite and granite sites (E and F: R = 0.38; p = 0.0013), but no differences were detected between the other sites.

Parameter	**Cape Schanck**		**Phillip Island**		**Wilsons Prom**	
	A	B	C	D	E	F
Species *S*	5.9	6.3	7.8	7.3	5.0	8.2
Individuals *N*	37.3	80.3	71.2	64.7	16.4	74.4

Table 4.4.1a Mean number of invertebrate species and individuals sampled at each site.

Statistic	**Cape Schanck**		**Phillip Island**		**Wilsons Prom**		**Significance**
	A	B	C	D	E	F	
Shannon-Wiener *H'*	1.3	1.2	1.3	1.4	1.2	1.4	$F_{5,42}$ = 0.85, ns
Pielou's Evenness *J'*	0.75	0.67	0.67	0.74	0.79	0.66	$F_{5,42}$ = 2.12, ns
Clarke's Diversity Δ	2.6	1.9	2.3	2.4	2.2	2.6	$F_{5,42}$ = 1.02, ns

Table 4.4.1b Mean diversity statistics for invertebrates at each site.

Community	**Cape Schanck**		**Phillip Island**		**Wilsons Prom**		**Significance**
	A	B	C	D	E	F	
Invertebrates	3.1	2.5	2.9	2.9	2.6	3.2	$F_{5,42}$ = 1.45, ns
Algal biomass	3.1	2.6	2.6	3.1	2.4	3.2	$F_{5,54}$ = 1.58, ns

Table 4.4.2 Mean taxonomic distinctness Δ* for each site.

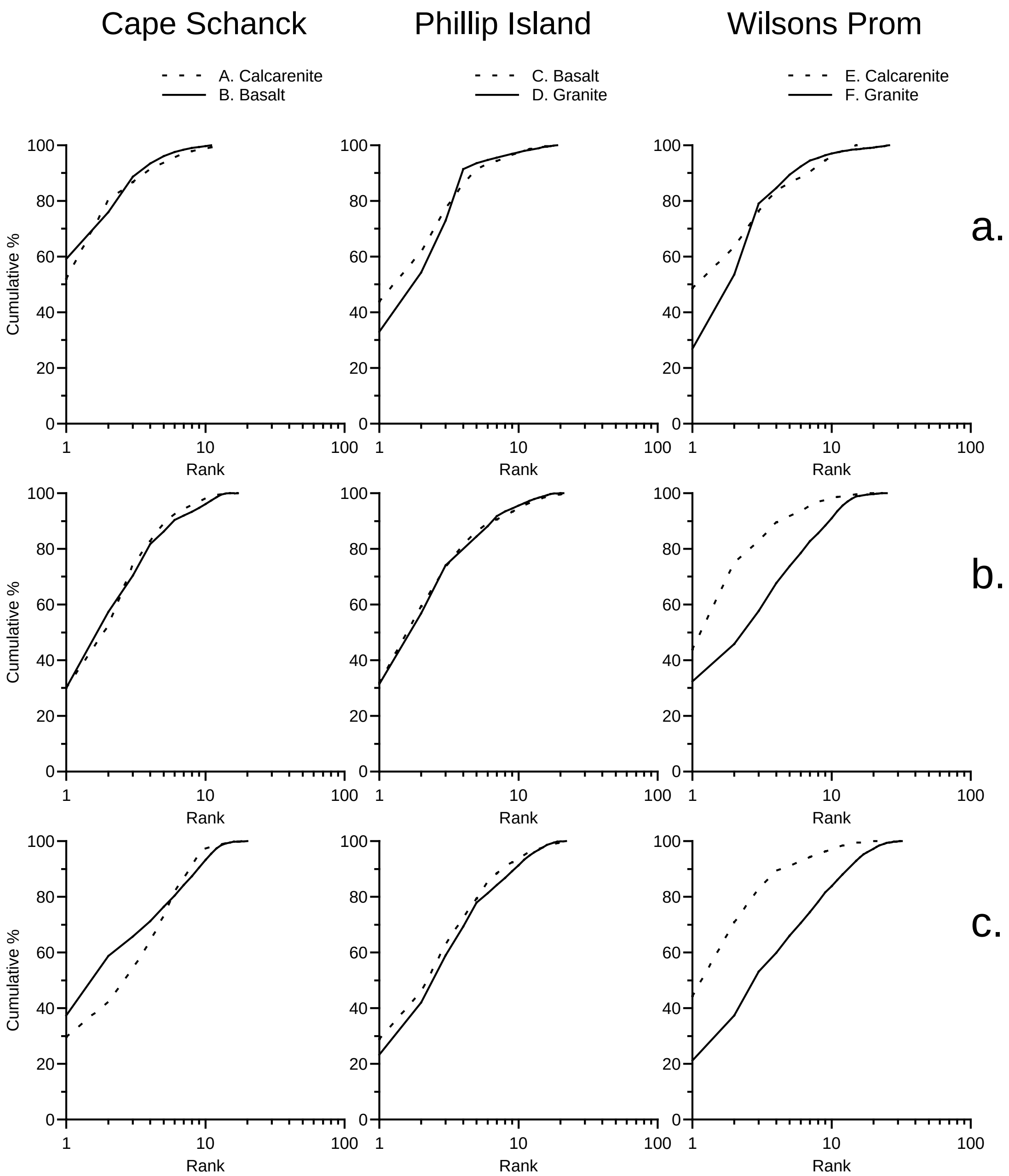

Figure 4.4.1 Dominance-diversity curves for: (a) invertebrate counts; (b) understorey algal substratum cover; and (c) algal biomass.

4.5 Comparison of Community Structure

4.5.1 Analysis of Community Structure

Display of community patterns

Community structure in this study was examined by comparing the relative the abundances of species across all sites. Multivariate analysis methods using ordination techniques were required to simultaneously examine changes in species abundances (ie the community structure) between sites. Multivariate analyses involved three main steps:

- calculating a matrix of distances among objects - in this case, the dissimilarity in community structure between each pair of sites / samples;
- reducing the dimensionality of the distance/dissimilarity matrix (where each site / sample is a dimension) to 2 or 3 dimensions which best depict the principal differences between the groups; and
- graphical display of these community patterns in these reduced dimensions.

There were 4 data sets that which were analysed separately:

- invertebrate density;
- canopy algal density;
- understorey algal cover; and
- understorey algal biomass.

Prior to analysis, the invertebrate data were fourth-root transformed, and the understorey algal cover and biomass data square-root transformed. The root transformations were used to down-weight the influence of highly abundant species in describing community structure (giving more even weighting between abundant and rarer species).

The Bray-Curtis dissimilarity index was used to calculate the difference in community structure between pairs of replicate samples and sites (described in Appendix 4.9.1, equation 4.9.8). All replicates from each site were included in the analyses for invertebrates, canopy algae and understorey algal cover. For algal biomass, it was necessary to pool the replicates for each site, such that the analysis was effectively on the total biomass for each species at each site. The comparison of all replicates with each other (or sites in the case of biomass) results in a matrix of pairwise comparisons.

The matrix of dissimilarities effectively represents differences between sites in a hyper-dimensional space (eg 59 dimensions for 60 replicates). To make the results more comprehensible, the data were reduced to two dimensions using non-metric multidimensional scaling (MDS). This ordination method finds the representation in fewer dimensions that best depicts the actual relationships in the hyper-dimensional data (ie reduces the number of dimensions while still depicting the salient relationships between the groups). The MDS results were then presented graphically to show the differences between the sites (the distance between points on the plot is representative of the difference in community structure). Kruskal stress is an indicator statistic calculated during the ordination process and indicates the degree of disparity between the reduced dimensional data set and the original hyper-dimensional data set. A Kruskal stress of < 0.05 gives an excellent representation, stress < 0.1 is a good ordination and a stress > 0.2 is considered a poor fit. The MDS ordination for invertebrates in two dimensions had a stress of 0.22, so an MDS solution was calculated for three dimensions (Kruskal stress = 0.17). All other ordinations were in two dimensions and had a stress of < 0.11.

Tests of site differences

General differences between sites were apparent from visual examinations of the MDS ordinations. Differences between the sites were examined more objectively and precisely using analysis of similarities (ANOSIM; Clarke 1993). This method is a non-parametric equivalent of multivariate analysis of variance.

Analysis of similarities essentially contrasts the differences between replicates within sites to the differences between replicates from different sites. The ANOSIM test statistic *R* is an indicator of the separation between sites, ranging between 0 (no difference between sites: null hypothesis true) and 1 (complete separation of site: replicates within sites more similar to each other than any replicates from different sites). The null hypothesis of no differences between sites was tested using a randomisation procedure. According to the null hypothesis, it should not matter which replicate is labelled with which site. The values that *R* can have under the null hypothesis was determined by randomly shuffling the site labels and recalculating *R*, with the null distribution determined from 10 000 random permutations. The true *R* was then compared with the null distribution, with the null hypothesis rejected at a probability level of $P = 0.05$.

The overall hypothesis of no differences between sites was tested for invertebrates, kelp canopy and algal cover using a one-way ANOSIM test. The algal biomass data was not suitable for this analysis. Where the overall test was significant, post-hoc pairwise comparisons were performed between each pair of sites (15 combinations), at the Bonferroni corrected Type I error rate of $P' = 0.05/15 = 0.0033$. Because only four replicates were surveyed for invertebrates at the Cape Schanck basalt site (B), this data was pooled with the Cape Schanck calcarenite (C) data for the post-hoc comparisons (AB vs other sites). The site groupings determined from these tests were then represented on the MDS plots.

Species responsible for site groupings

The contribution of each species to differences between site-groups was determined using similarity/dissimilarity percent breakdowns (SIMPER, Clarke 1993). The average species contribution to group dissimilarity ($\overline{\delta}_i$) was calculated for each site group versus the remaining sites.

4.5.2 Results

Invertebrates

The MDS plots for invertebrates show the variability in community structure between replicates with sites, and the variability among sites (Figure 4.5.1a and 4.5.1b). The samples for the Wilsons Promontory calcarenite (E) were clearly segregated from all other sites, although the large spread of replicates indicates there was substantial within site variability in community structure. Similarly, the invertebrate structure on the Wilsons Promontory granite (F) was also quite different from all other sites. Although there appeared to be considerable within site variation, this was largely because of the Tongue Point and Shellback Island samples clustering apart. The Shellback Island samples form the upper cluster on the MDS plot.

The Cape Schanck and Phillip Island sites (A - D) were not clearly separated on the MDS ordination. Of these sites, the Phillip Island granite site (D) appeared to have a low within-site variation and occurred at the edge of the A - D cluster (Figure 4.5.1).

There were significant differences in invertebrate composition between sites (overall $R = 0.52$; $P = 0.001$). A gradient in invertebrate changes was apparent, from the Cape Schanck sites to the Phillip Island basalt site to the Phillip Island granite site. No differences were found between the two Cape Schanck sites and the Phillip Island basalt site (A vs C, AB vs C not significant; Table 4.5.1), or between the two Phillip island sites (C vs D not significant; AB $\rightarrow$ C $\rightarrow$ D). All other site comparisons were significantly different (Table 4.5.1; Figure 4.5.2).

The ABC site-group had a consistently higher predominance of the abalone *Haliotis rubra*, the ascidian *Pyura australis*, the periwinkle *Turbo undulatus*, the ascidian *Herdmania momus* and the seastar *Tosia australis* (Table 4.5.2). *Haliotis rubra* and *Pyura australis* were also dominant at Phillip island granite (D), along with the ascidian *Cnemidocarpa radicosa*. The seastar *Nectria macrobrachia* was also a discriminating species for this site, with higher abundances than elsewhere. The Wilsons Promontory calcarenite site (E) was largely differentiated by low abundances of most species. However, the crinoid *Cenolia trichoptera* had a high dominance at this site. The Wilsons promontory granite site (F) was characterised by higher abundances of *Cnemidocarpa radicosa* (as with the other granite site, D), *Cenolia trichoptera*, the sea urchin *Heliocidaris erythrogramma*, the kelp shell *Astralium aureum* and the seastar *Patiriella gunnii*. The low abundances of *Haliotis rubra* and *Cnemidocarpa radicosa* was also a distinguishing feature (Table 4.5.2).

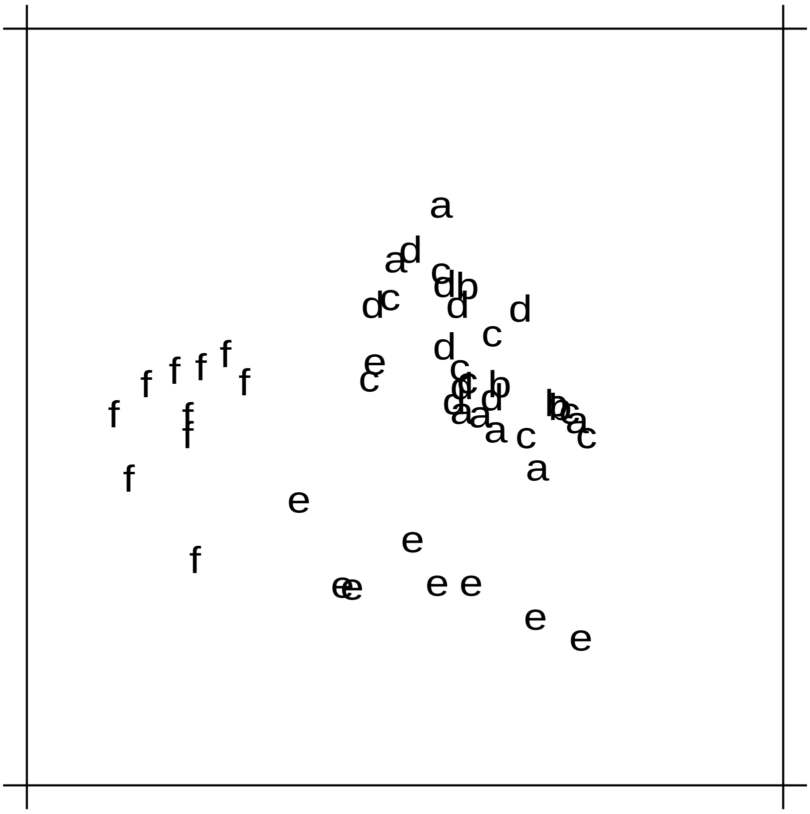

Figure 4.5.1a Invertebrate MDS ordination: first two dimensions. Legend: (a) Cape Schanck calcarenite; (b) Cape Schanck basalt; (c) Phillip Island basalt; (d) Phillip Island granite; (e) Wilsons Promontory calcarenite; and (f) Wilsons Promontory granite.

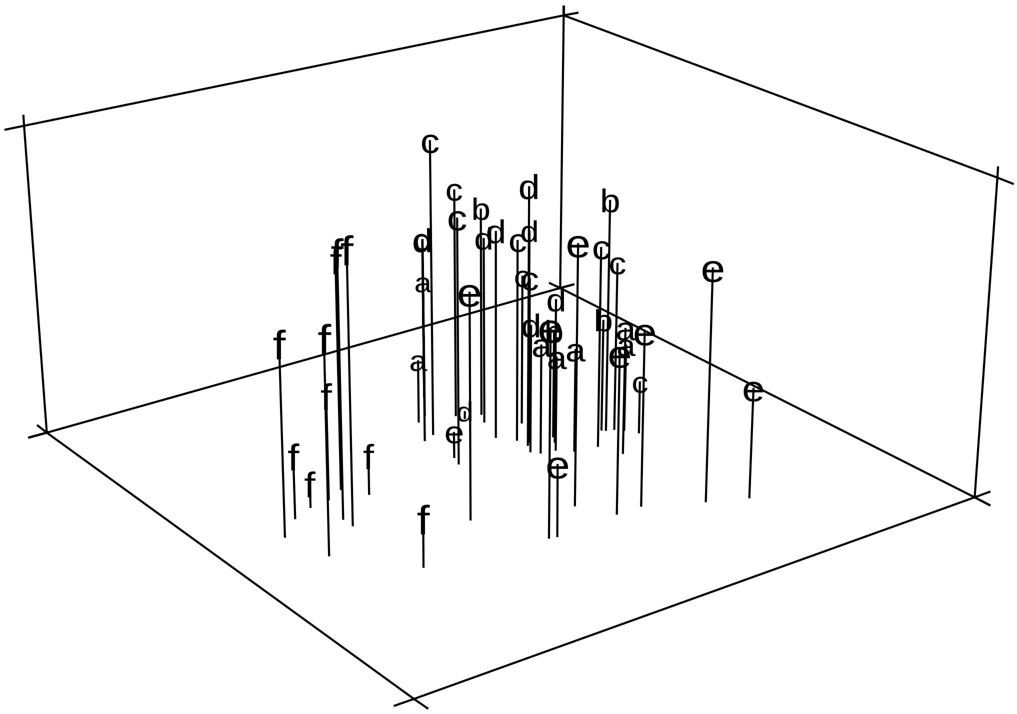

Figure 4.5.1b Invertebrate MDS ordination: all three dimensions. Legend: (a) Cape Schanck calcarenite; (b) Cape Schanck basalt; (c) Phillip Island basalt; (d) Phillip Island granite; (e) Wilsons Promontory calcarenite; and (f) Wilsons Promontory granite.

Site	A	AB	C	D	E	F
A						
AB						
C	0.19	0.19				
D	0.36*	0.32*	0.12			
E	0.40*	0.57*	0.56*	0.58*		
F	0.93*	0.95*	0.88*	0.90*	0.73*	

Table 4.5.1 Invertebrates. Summary of pairwise comparisons. ANOSIM *R* values are tabulated with significance at the Bonferroni corrected probability level: * P < 0.0033. Sites: (A) Cape Schanck calcarenite; (AB) combined data for Cape Schanck calcarenite and basalt; (C) Phillip Island basalt; (D) Phillip Island granite; (E) Wilsons Promontory calcarenite; and (F) Wilsons Promontory granite.

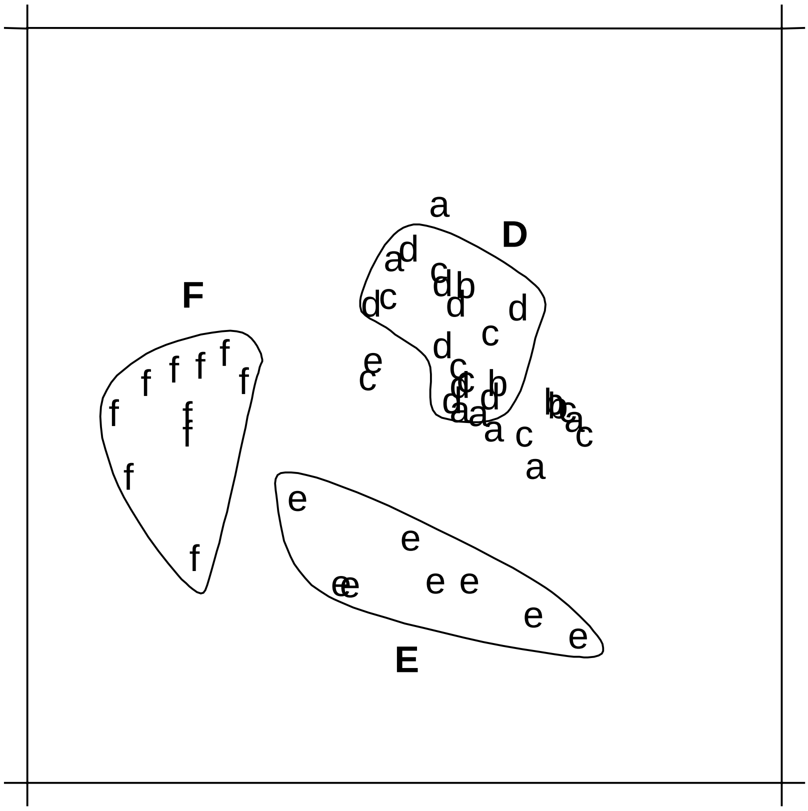

Figure 4.5.2 Invertebrates. MDS ordination (first two dimensions) with site groupings based on ANOSIM results. Sites: (a) Cape Schanck calcarenite; (b) Cape Schanck basalt; (c) Phillip Island basalt; (d) Phillip Island granite; (e) Wilsons Promontory calcarenite; and (f) Wilsons Promontory granite.

Comparison/Species	$\bar{y}_{iA}$	$\bar{y}_{iB}$	$\bar{\delta}_i$	SD(δ_i)	$\bar{\delta}_i$/SD	$\bar{\delta}_i$%
ABC vs Rest						
Haliotis rubra	2.0	0.9	6.4	5.1	1.2	12
Pyura australis	1.5	1.0	4.8	3.3	1.5	21
Cenolia trichoptera	0.2	0.9	4.3	4.3	1.0	29
Cnemidocarpa radicosa	0.9	1.3	4.2	3.5	1.2	37
Heliocidaris erythrogramma	0.2	0.8	4.0	4.2	1.0	45
Turbo undulatus	0.7	0.1	3.8	3.9	1.0	52
Herdmania momus	2.0	1.7	3.0	2.2	1.4	58
Tosia australis	0.6	0.3	2.9	3.0	1.0	63
Nectria macrobrachia	0.5	0.4	2.8	2.9	1.0	68
D vs Rest						
Pyura australis	1.9	1.0	5.5	3.8	1.5	11
Cnemidocarpa radicosa	1.8	1.0	4.6	3.7	1.2	20
Haliotis rubra	1.8	1.3	4.5	4.1	1.1	30
Cenolia trichoptera	0	0.8	3.4	4.0	0.8	36
Nectria macrobrachia	0.8	0.4	3.3	2.8	1.2	43
Heliocidaris erythrogramma	0.2	0.7	3.2	3.8	0.8	49
Herdmania momus	1.8	1.9	2.6	1.8	1.4	55
Tosia australis	0.3	0.4	2.4	2.6	0.9	59
Nectria multispina	0.4	0.3	2.3	2.7	0.9	64
Turbo undulatus	0	0.4	2.2	3.3	0.7	68
E vs Rest						
Haliotis rubra	0.3	1.7	9.0	5.1	1.8	16
Pyura australis	1.1	1.2	5.0	3.3	1.5	25
Cnemidocarpa radicosa	0.8	1.2	4.9	4.1	1.2	33
Cenolia trichoptera	0.6	0.6	4.7	4.6	1.0	51
Heliocidaris erythrogramma	0.2	0.7	4.0	4.7	0.9	48
Herdmania momus	1.6	1.9	3.1	2.3	1.4	54
Nectria macrobrachia	0	0.5	3.0	3.4	0.9	59
Turbo undulatus	0.2	0.4	3.0	4.2	0.7	64
Tosia australis	0.2	0.4	2.8	3.3	0.9	69
F vs Rest						
Heliocidaris erythrogramma	2.0	0.2	8.7	3.1	2.8	14
Cenolia trichoptera	1.9	0.3	8.0	3.6	2.2	26
Pyura australis	0.1	1.5	6.5	3.1	2.1	36
Haliotis rubra	0.8	1.6	5.4	4.0	1.3	45
Herdmania momus	1.8	1.9	3.4	2.1	1.6	50
Cnemidocarpa radicosa	1.4	1.1	3.2	2.7	1.2	55
Nectria macrobrachia	0.5	0.4	2.7	2.8	1.0	59
Patiriella gunnii	0.6	0	2.6	3.3	0.8	64
Astralium aureum	0.6	0	2.6	3.4	0.8	68

Table 4.5.2 Invertebrates. Species with the highest contribution to the average dissimilarity between sites. Statistics given are the transformed mean abundance for the comparison site-group $\bar{y}_{iA}$, mean abundance for remaining sites $\bar{y}_{iB}$, the average species contribution to differences between sites $\bar{\delta}_i$, standard deviation SD, discrimination ratio and the cumulative percent discrimination.

Kelp canopy

The kelp canopy MDS ordination indicated a high similarity in community structure between the two Cape Schanck sites (A and B), with little within site variation. This was evidenced by a tight clustering of the replicates on the left side of the plot (Figure 4.5.3). The kelp canopy community was also similar between the two Phillip Island sites (C and D), clustering on the right side of the plot. The Wilsons Promontory sites (E and F) were intermediate in canopy structure to the Cape Schanck and Phillip Island sites, although there was a high degree of variability within the Wilsons Promontory granite community (F; Figure 4.5.3).

The MDS plot for the kelp canopy data displays a classic arch or horseshoe effect in the pattern of sites. The MDS plots represents transitions in species abundances from sites more favourable to some species, to sites more favourable to others. The ordering of sites along the arch in Figure 4.5.3 indicates the transition in species abundances (from sites AB to EF to CD) is both non-linear and non-monotonic (James and McCullock 1990).

The kelp canopy composition was significantly different between sites (overall $R = 0.58$, $P = 0.0001$). No significant differences were detected between the two Cape Schanck sites (A and B), the two Phillip Island sites (C and D) and the two Wilsons Promontory sites (E and F Table 4.5.3). These site groupings are shown in Figure 4.5.4.

The SIMPER breakdowns indicated that *Ecklonia radiata* and *Phyllospora comosa* were the predominant species associated with differences in kelp canopy (Table 4.5.4). *Ecklonia radiata* was dominant at Cape Schanck (A and B), *Phyllospora comosa* at Phillip Island (C and D) and intermediate abundances of both species at Wilsons Promontory (E and F; Table 4.5.4).

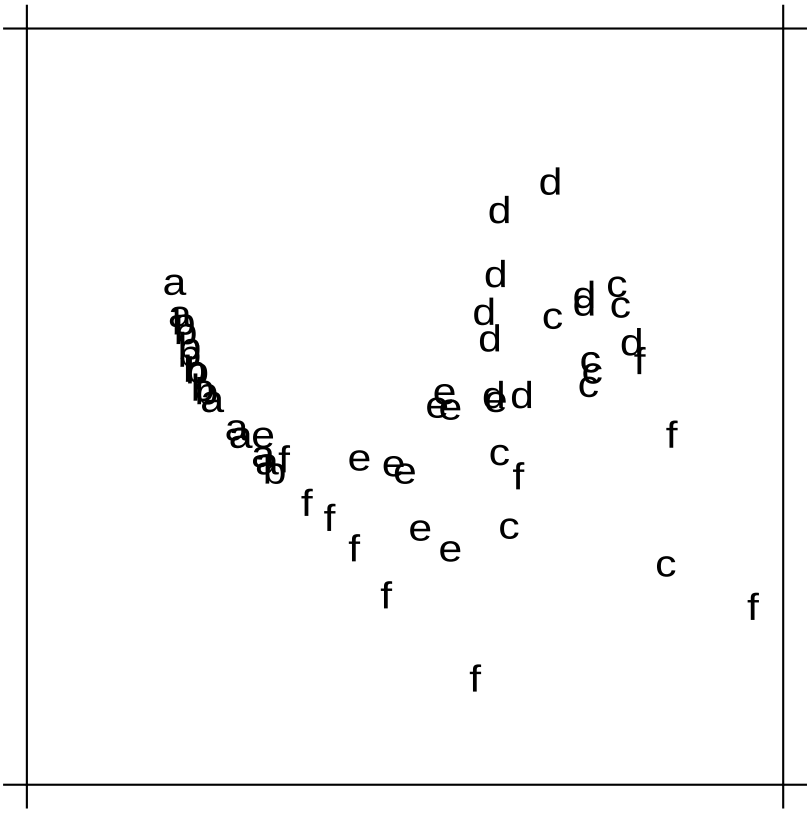

Figure 4.5.3 Kelp canopy MDS ordination. Sites: (a) Cape Schanck calcarenite; (b) Cape Schanck basalt; (c) Phillip Island basalt; (d) Phillip Island granite; (e) Wilsons Promontory calcarenite; and (f) Wilsons Promontory granite.

Site	A	B	C	D	E	F
A						
B	0.30					
C	0.99*	0.99*				
D	0.99*	0.99*	0.13			
E	0.66*	0.88*	0.48*	0.55*		
F	0.43*	0.57*	0.36*	0.42*	0.09	

Table 4.5.3 Kelp canopy. Summary of pairwise comparisons. ANOSIM *R* values are tabulated with significance at the Bonferroni corrected probability level: * P < 0.0033. Sites: (A) Cape Schanck calcarenite; (B) Cape Schanck basalt; (C) Phillip Island basalt; (D) Phillip Island granite; (E) Wilsons Promontory calcarenite; and (F) Wilsons Promontory granite.

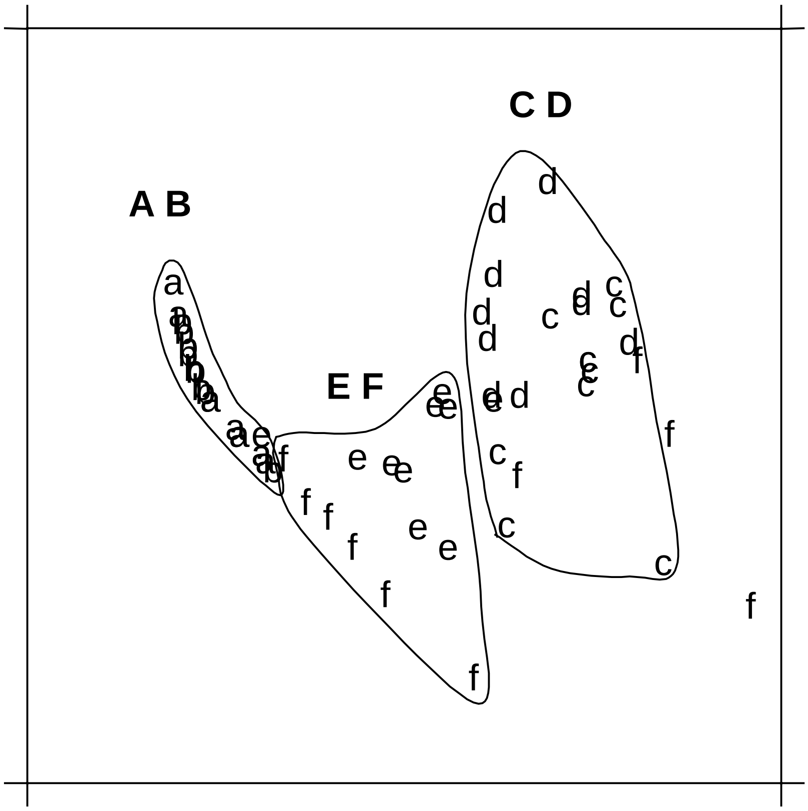

Figure 4.5.4 Kelp canopy. MDS ordination with site groupings based on ANOSIM results. Sites: (a) Cape Schanck calcarenite; (b) Cape Schanck basalt; (c) Phillip Island basalt; (d) Phillip Island granite; (e) Wilsons Promontory calcarenite; and (f) Wilsons Promontory granite.

Comparison/Species	$\bar{y}_{iA}$	$\bar{y}_{iB}$	$\bar{\delta}_i$	SD(δ_i)	$\bar{\delta}_i$/SD	$\bar{\delta}_i$%
AB vs Rest						
Ecklonia radiata	2.8	0.8	36.5	15.6	2.3	53
Phyllospora comosa	0	1.1	20.2	12.7	1.6	83
CD vs Rest						
Ecklonia radiata	0.6	1.9	26.4	17.8	1.5	39
Phyllospora comosa	1.6	0.3	24.4	12.6	1.9	74
Sargassum spp	0.2	0.1	4.3	5.2	0.8	80
EF vs Rest						
Ecklonia radiata	1.1	1.7	24.0	17.0	1.4	42
Phyllospora comosa	0.6	0.8	16.4	13.5	1.2	71
Seirococcus axillaris	0.4	0	6.7	10.3	0.7	83

Table 4.5.4 Kelp canopy. Species with the highest contribution to the average dissimilarity between sites. Statistics given are the transformed mean abundance for the comparison site-group $\bar{y}_{iA}$, mean abundance for remaining sites $\bar{y}_{iB}$, the average species contribution to differences between sites $\bar{\delta}_i$, standard deviation SD, discrimination ratio and the cumulative percent discrimination.

Algal cover

The MDS plots indicated distinct differences in the understorey communities for Wilsons Promontory granite (F), clustering to the left of the plot (Figure 4.5.5). The community for Cape Schanck basalt (B) was also clearly separated from all other sites (lower left of plot).

The other sites (A, C, D and E) appeared to be reasonably similar, clustering to the right of the plot with overlap between some site replicates. However, differences were apparent within this right hand cluster, with replicates for Phillip Island granite (D) clustering tightly together in the upper right of the plot, and the Wilsons Promontory calcarenite replicates (E) clustering in the mid-right portion of the plot.

The algal cover was significantly different between sites (overall $R = 0.51$; $P = 0.0001$). All sites were significantly different from each other except for the Cape Schanck calcarenite and Phillip Island basalt sites (A and C; Table 4.5.5; Figure 4.5.6).

The AC site group was discriminated by higher abundances of encrusting coralline algae, erect corallines and foliose red algae (Table 4.5.6). The Cape Schanck basalt (B) also had a high abundance of encrusting corallines, but a lower abundance of foliose reds. This site was also discriminated by higher abundances of *Sonderopelta coriaceae* and *Acrocarpia paniculata*.

The Phillip Island granite site had a higher dominance of foliose reds, *Caulerpa flexilis* and Dictyotales (such as the small brown *Zonaria*). The Wilsons Promontory calcarenite site (E) was distinguished by a high predominance of foliose reds and reduced abundances of other algal groups. The Wilsons Promontory granite site (F) was distinguished by a higher predominance of brown algae, including Dictyotales, *Acrocarpia paniculata* and other foliose browns (Table 4.5.6).

Algal biomass

The algal structure in terms of biomass was quite different between the Wilsons Promontory granite (F) and the other sites (Figure 4.5.7). In particular, there was a 78% dissimilarity in community structure between the two granite sites (D and F; Table 4.5.7).

The calcarenite (A and E) and basalt (B and C) had a higher similarity to each other than between the two granite sites (58% and 51% dissimilarity respectively). However, the highest similarity was between the two Cape Schanck sites (A and B), with 40% dissimilarity (Table 4.5.7).

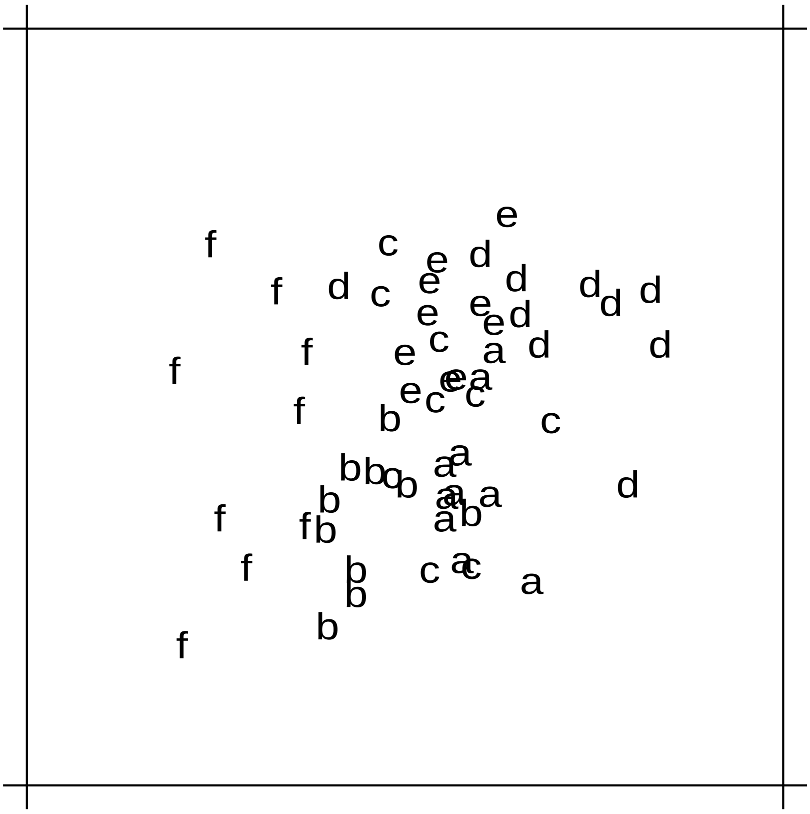

Figure 4.5.5 Algal cover MDS ordination. Sites: (a) Cape Schanck calcarenite; (b) Cape Schanck basalt; (c) Phillip Island basalt; (d) Phillip Island granite; (e) Wilsons Promontory calcarenite; and (f) Wilsons Promontory granite.

Site	A	B	C	D	E	F
A						
B	0.52*					
C	0.19	0.41*				
D	0.75*	0.92*	0.56*			
E	0.54*	0.86*	0.18*	0.57*		
F	0.57*	0.41*	0.41*	0.63*	0.59*	

Table 4.5.5 Algal cover. Summary of pairwise comparisons. ANOSIM *R* values are tabulated with significance at the Bonferroni corrected probability level: * P < 0.0033. Sites: (A) Cape Schanck calcarenite; (B) Cape Schanck basalt; (C) Phillip Island basalt; (D) Phillip Island granite; (E) Wilsons Promontory calcarenite; and (F) Wilsons Promontory granite.

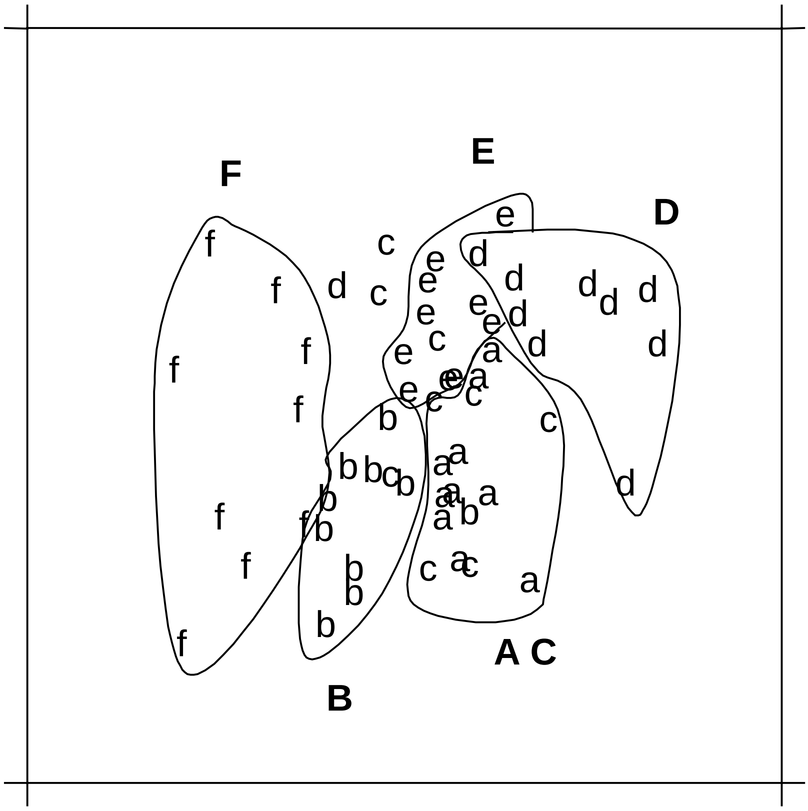

Figure 4.5.6 Algal cover. MDS ordination with site groupings based on ANOSIM results. Sites: (a) Cape Schanck calcarenite; (b) Cape Schanck basalt; (c) Phillip Island basalt; (d) Phillip Island granite; (e) Wilsons Promontory calcarenite; and (f) Wilsons Promontory granite.

Comparison/Species	$\bar{y}_{iA}$	$\bar{y}_{iB}$	$\bar{\delta}_i$	SD(δ_i)	$\bar{\delta}_i$/SD	$\bar{\delta}_i$%
AC vs Rest						
Encrusting corallines	7.3	5.7	6.1	4.3	1.4	16
Foliose reds	8.7	8.2	6.0	4.7	1.3	33
Foliose browns	0.3	2.5	4.2	5.1	0.8	44
Dictyotales	1.3	2.8	3.5	3.6	1.0	54
Erect corallines	2.5	1.3	2.9	2.4	1.2	62
Acrocarpia paniculata	0.9	1.6	2.9	2.8	1.0	70
B vs Rest						
Encrusting corallines	9.4	5.6	7.0	4.5	1.5	19
Foliose reds	6.4	8.8	6.1	4.2	1.5	36
Sonderopelta coriaceae	3.6	0.8	4.9	2.2	2.2	50
Foliose browns	1.8	1.7	4.0	3.5	1.2	61
Acrocarpia paniculata	1.6	1.3	3.0	2.6	1.2	69
D vs Rest						
Encrusting corallines	3.4	6.8	7.0	4.3	1.7	17
Foliose reds	8.8	8.3	5.9	4.7	1.3	32
Dictyotales	3.7	2.0	4.2	2.9	1.4	42
Foliose browns	0.6	2.0	3.9	5.0	0.8	52
Erect corallines	0	2.0	3.6	2.2	1.7	61
Caulerpa flexilis	1.6	0.1	2.9	1.8	1.6	68
E vs Rest						
Foliose reds	11.9	7.6	7.9	5.6	1.4	23
Encrusting corallines	4.9	6.5	5.5	3.5	1.6	38
Foliose browns	0.7	1.9	3.6	4.6	0.8	49
Dictyotales	2.3	2.3	3	3.1	1.0	57
Acrocarpia paniculata	1.5	1.3	3.0	2.7	1.1	66
Sonderopelta coriaceae	0.2	1.4	2.4	2.4	1.0	73
F vs Rest						
Foliose browns	6.8	0.7	10.6	5.0	2.1	23
Foliose reds	5.7	8.9	7.3	6.0	1.2	39
Encrusting corallines	5.2	6.5	6.1	4.6	1.3	52
Dictyotales	3.5	2.1	4.8	3.4	0.9	63
Acrocarpia paniculata	2.5	1.1	4.2	3.7	1.1	72

Table 4.5.6 Algal cover. Species with the highest contribution to the average dissimilarity between sites. Statistics given are the transformed mean abundance for the comparison site-group $\bar{y}_{iA}$, mean abundance for remaining sites $\bar{y}_{iB}$, the average species contribution to differences between sites $\bar{\delta}_i$, standard deviation SD, discrimination ratio and the cumulative percent discrimination.

Area	Lithology	Site	A	B	C	D	E
Cape Schanck	Calcarenite	A					
	Basalt	B	40				
Phillip Island	Basalt	C	66	51			
	Granite	D	66	61	60		
Wilsons Prom.	Calcarenite	E	58	62	53	63	
	Granite	F	75	77	66	78	80

Table 4.5.7 Algal biomass Bray-Curtis dissimilarity matrix (percentages).

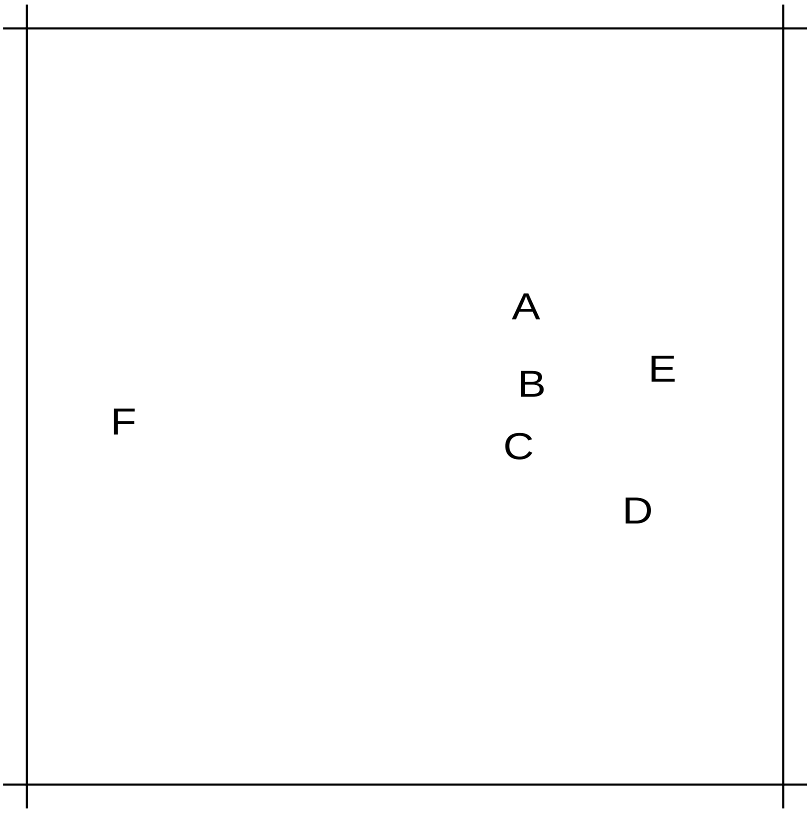

Figure 4.5.7 Algal biomass MDS ordination. Sites: (a) Cape Schanck calcarenite; (b) Cape Schanck basalt; (c) Phillip Island basalt; (d) Phillip Island granite; (e) Wilsons Promontory calcarenite; and (f) Wilsons Promontory granite.

4.6 Biological-Environmental Relationships

4.6.1 Matching Biological and Physical Parameters

For each biological survey replicate, data was also collected on the physical environment. The relationships between the biological and physical data sets was examined using BIO-ENV (a non-parametric equivalent of canonical correlation; Clarke and Ainsworth 1993; Clarke 1993). This procedure compares a biological dissimilarity matrix with a physical variable dissimilarity matrix using a harmonic rank correlation coefficient ρ_w. The best combination of abiotic variables which matches the community composition is determined by including and omitting variables from the suite of physical data. If the key physical variables are omitted, the match between the two data sets will worsen. Similarly, if irrelevant variables are included, there will be increased 'noise' in the data and the match will also worsen. The combinations of physical variables which best match the biological data (having the highest ρ_w values) are found by a systematic search of all possible combinations.

It should be noted that this observational study provides no inferences on the causality of physical variables affecting biological community structure. However, this analysis is a useful explanatory tool providing supporting evidence of which variables are likely to be influential factors.

The ranked Bray-Curtis dissimilarity matrix for invertebrates, kelp canopy and algal cover were compared with ranked Estabrook-Rogers dissimilarity matrices of the physical variable combinations. The Estabrook-Rogers coefficient was used as it incorporates categorical (multi-state), ranked ordinal and continuous-type data. Its computation is given in the Appendix 4.9.1 (equations 4.9.9 to 4.9.12). Forty-eight replicates of physical data were collected, in conjunction with the invertebrate survey. The additional 12 unmatched biological replicates for kelp canopy and algal cover were excluded from the BIO-ENV analysis.

4.6.2 Environmental Differences Between Sites

There were considerable differences in physical variables between sites. The 6 sites were located over 120 km of coastline, with exposure ranging from near-maximal at Cape Schanck to moderate at Wilsons Promontory (Table 4.6.1). Most sites had a southwesterly aspect, except for the Wilsons Promontory granite sites which had a northerly aspect. The relief was highest at the Phillip Island granite and Wilsons Promontory calcarenite sites. The reef interstitial space (crevices and holes), was low at Cape Schanck, moderate at Phillip Island and high at Wilsons Promontory (Table 4.6.1).

Multidimensional scaling of the environmental data, using a ranked Estabrook-Rogers dissimilarity matrix of all 11 variables, showed clear differences between all sites (Figure 4.6.1). The Wilsons Promontory sites (E and F) were the most different from any other site, while the four Cape Schanck and Phillip Island sites (A - D) were the most similar (Figure 4.6.1).

The relationships between all 11 physical variables was examined using scatter plots and pairwise Spearman correlation coefficients. The correlation between substratum slope and distance from shore was very high. Consequently, distance from shore was not included in further analyses. The remaining 10 variables provided 1023 (2^v - 1) combinations to be compared with the biological data sets.

Variable	Site					
	A	B	C	D	E	F
Substratum type lithology	Calcarenite	Basalt	Basalt	Granite	Calcarenite	Granite
Substratum relief	20	25	20	31	32	26
Substratum interstitial space	1.7	0.5	2.5	2.3	5.6	16.9
Substratum complexity	1.3	1.3	2.0	1.9	1.6	2.2
Depth (m)	14.6	15.6	9.9	14.2	12.7	10.7
Exposure (1 – 9 ranking)	2	2	3	3	3	4
Aspect (º True from magnetic north)	256	256	210	240	248	354
Distance from shore (m)	1000	275	120	180	1200	15
Average slope (º declin.)	0.2	6.4	1.6	1.3	0.6	37.0
Longitude (easting in km)	0	0.8	29.6	40.8	119.0	120.0
Sediment cover (%)	0.2	6.4	1.6	1.3	5.9	3.7

Table 4.6.1 Physical variable values for each site (refer to section 4.2.3 for detailed descriptions of each variable).

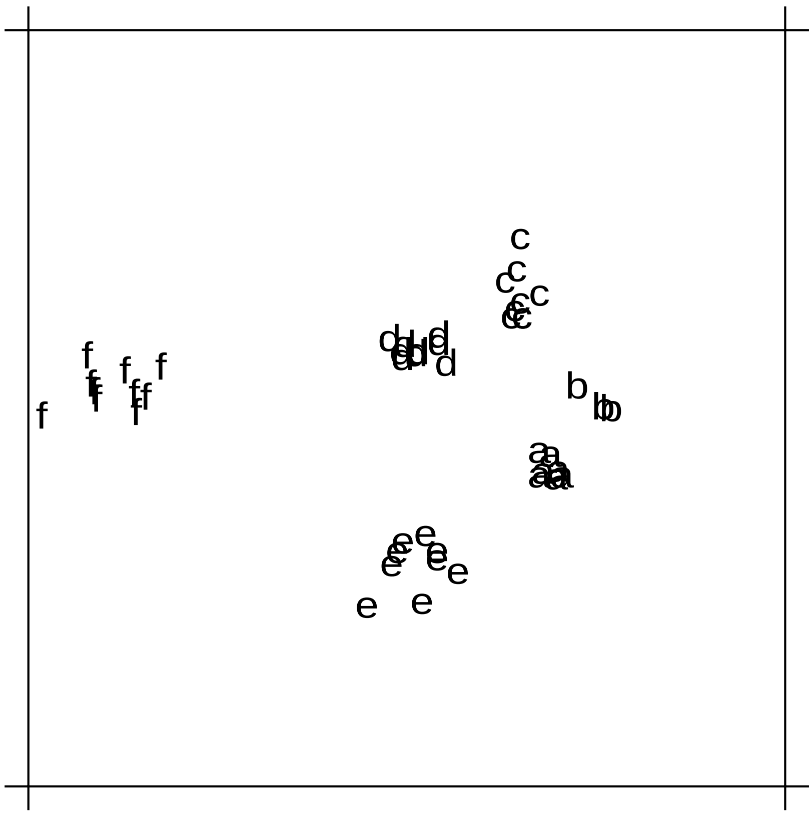

Figure 4.6.1 MDS ordination of all recorded physical variables.

4.6.3 *Biological and Environmental Correspondence*

Invertebrates

The best physical variable combinations which match the invertebrate community pattern are given in Table 4.6.2. The complexity of the environmental description increases with each row of the table, as the number of included variables increases. The best variable combination was a 5 variable subset of interstitial space, complexity index, depth, slope and easting distance. The concordance between invertebrates and these 5 variables was considerably high, with ρ_w = 0.65 (Table 4.6.2). The MDS plots also show a reasonable match between the biological and physical variables (Figure 4.6.2). Aspect and exposure also appeared to contribute to an increased correlation between the biological and physical pattern, although to a lesser extent.

k	**Best variable combinations (ρ_w)**						
1	Sl (.47)	As (.45)	Is (.42)	Ed (.40)	…	…	Ro (0.21)
2	Sl, Ed (.59)	As, Ed (.58)	Is, Ed (.54)	Is, Sl (.53)			
3	Ci, Sl, Ed (.63)	Is, Sl, Ed (.62)	Is, As, Ed (.62)	Z, Sl, Ed (.61)			
4	Is, Ci, Sl, Ed (.65)	Is, Z, Sl, Ed (.64)	Is, As, Sl, Ed (.63)	Ci, Z, Sl, Ed (.63)			
5	**Is, Ci, Z, Sl, Ed (.65)**	Is, Ci, As, Sl, Ed (.64)	Is, Ci, Ex, Sl, Ed (.64)	Is, Z, Ex, Sl, Ed (.64)			
6	Ri, Is, Ci, Z, Sl, Ed (.64)	Is, Ci, Z, Ex, Sl, Ed (.64)	Is, Ci, Z, As, Sl, Ed (.63)				
7	Ri, Is, Ci, Z, Ex, Sl, Ed (.63)	Ri, Is, Ci, Z, As, Sl, Ed (.63)	Ri, Is, Ci, Ex, As, Sl, Ed (.62)				
8	Ri, Is, Ci, Z, Ex, As, Sl, Ed (.62)	Ri, Is, Ci, Z, As, Sl, Ed, Sa (.61)	Is, Ci, Z, Ex, As, Sl, Ed, Sa (.61)				
9	Ri, Is, Ci, Z, Ex, As, Sl, Ed, Sa (.61)						
10	Ro, Ri, Is, Ci, Z, Ex, As, Sl, Ed, Sa (.60)						

Table 4.6.2 Invertebrates. Combinations of physical variables, *k* at a time, giving the largest rank correlations ρ_w between biotic and environmental similarity matrices; bold type indicates the best combination overall. Abbreviations: (Ro) lithology; (Ri) relief index; (Is) interstitial space; (Ci) complexity index; (Z) depth; (Ex) exposure; (As) aspect; (Sl) slope; (Ed) longitude; and (Sa) sediment.

Kelp Canopy

The best match between kelp canopy and the physical variables was with the exposure index only (Table 4.6.3). This match had a moderate coefficient of correlation (ρ_w = 0.44), with the patterns on the MDS plots reasonably similar (Figure 4.6.3). It should be noted that there was no within site variation for the exposure index, resulting in all replicates being overlayed on each other on the MDS plots. Combined with exposure, aspect and slope provided the next best matching patterns, but at substantially lower correlations (≈ 0.35).

k	**Best variable combinations (ρ_w)**						
1	**Ex (.44)**	As (.31)	Ed (.23)	Sl (.18)	…	…	Ro (0.17)
2	Ex, As (.35)	Ex, Sl (.35)	As, Sl (.27)	Ex, Ed (.26)			
3	Ex, As, Sl (.34)	Is, Ex, As (.30)	Is, Ex, Sl (.27)	Z, Ex, As (.27)			
4	Is, Ex, As, Sl (.32)	Ci, Ex, As, Sl (.29)	Z, Ex, As, Sl (.28)	Is, Ci, Ex, As (.26)			
5	Is, Ci, Ex, As, Sl (.28)	Ci, Z, Ex, As, Ed (.27)	Ci, Z, Ex, As, Sl (.27)	Is, Z, Ex, As, Sl (.26)			
6	Is, Ci, Z, Ex, As, Sl (.25)	Ci, Z, Ex, As, Sl, Ed (.25)	Is, Cl, Z, Ex, As, Ed (.25)				
7	Is, Ci, Z, Ex, As, Sl, Ed (.25)	Is, Ci, Z, Ex, As, Sl, Sa (.22)	Is, Ci, Z, Ex, As, Ed, Sa (.22)				
8	Ro, Is, Ci, Z, Ex, As, Sl, Ed (.22)	Ri, Is, Ci, Z, Ex, As, Sl, Ed (.22)	Is, Ci, Z, Ex, As, Sl, Ed, Sa (.22)				
9	Ri, Is, Ci, Z, Ex, As, Sl, Ed, Sa (.20)						
10	Ro, Ri, Is, Ci, Z, Ex, As, Sl, Ed, Sa (.18)						

Table 4.6.3 Kelp canopy. Combinations of physical variables, *k* at a time, giving the largest rank correlations ρ_w between biotic and environmental similarity matrices; bold type indicates the best combination overall. Abbreviations: (Ro) lithology; (Ri) relief index; (Is) interstitial space; (Ci) complexity index; (Z) depth; (Ex) exposure; (As) aspect; (Sl) slope; (Ed) longitude; and (Sa) sediment.

Algal Cover

The algal cover patterns were best explained by depth, exposure and reef slope (ρ_w = 0.44; Table 4.6.4). Combinations involving interstitial space and aspect also provided reasonable correspondences (Figure 4.6.4). Substratum type lithology provided some correlative information, being included in the optimal combination for 6 variables (ρ_w = 0.42).

k	**Best variable combinations (ρ_w)**			
1	As (.42)	Sl (.39)	Ex (.36)	Ro (.22)
2	Z, Sl (.42)	Ex, Sl (.40)	As, Sl (.40)	Z, As (.39)
3	**Z, Ex, Sl (.44)**	Z, As, Sl (.41)	Is, Z, Sl (.41)	Ex, As, Sl (.41)
4	Is, Z, Ex, Sl (.43)	Z, Ex, As, Sl (.43)	Is, Z, As, Sl (.42)	Ci, Z, Ex, Sl (.41)
5	Is, Z, Ex, As, Sl (.43)	Ci, Z, Ex, As, Sl (.42)	Ro, Z, Ex, As, Sl (.41)	Is, Ci, Z, Ex, Sl (.41)
6	Ro, Is, Z, Ex, As, Sl (.42)	Is, Ci, Z, Ex, As, Sl (.42)	Ro, Is, Cl, Z, As, Sl (.41)	
7	Ro, Is, Ci, Z, Ex, As, Sl (.42)	Ro, Ri, Is, Z, Ex, As, Sl (.42)	Ro, Ri, Is, Ci, Z, As, Sl (.41)	
8	Ro, Ri, Is, Ci, Z, Ex, As, Sl (.42)	Ro, Is, Ci, Z, Ex, As, Sl, Ed (.38)	Ro, Ri, Is, Ci, Z, As, Sl, Ed (.38)	
9	Ro, Ri, Is, Ci, Z, Ex, As, Sl, Ed (.38)			
10	Ro, Ri, Is, Ci, Z, Ex, As, Sl, Ed, Sa (.33)			

Table 4.6.4 Algal cover. Combinations of physical variables, *k* at a time, giving the largest rank correlations ρ_w between biotic and environmental similarity matrices; bold type indicates the best combination overall. Abbreviations: (Ro) lithology; (Ri) relief index; (Is) interstitial space; (Ci) complexity index; (Z) depth; (Ex) exposure; (As) aspect; (Sl) slope; (Ed) longitude; and (Sa) sediment.

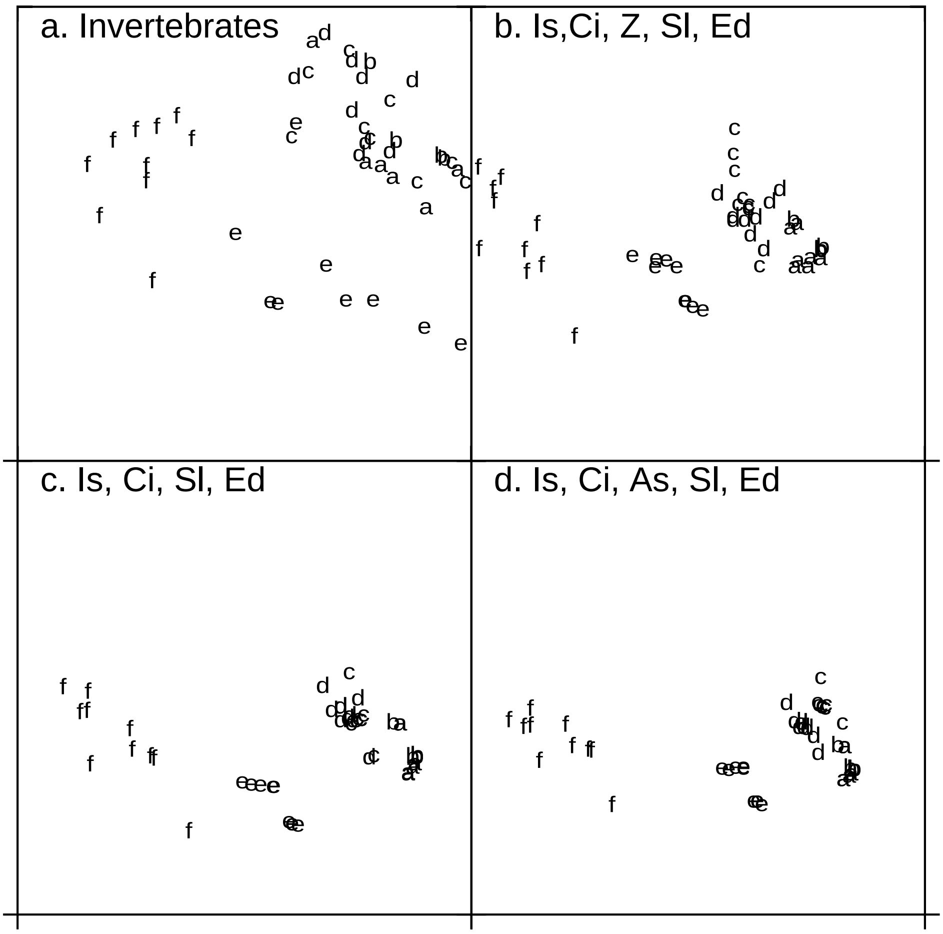

Figure 4.6.2 Invertebrates. MDS ordinations of the community composition and the three best matching combinations of physical variables. Correlation coefficients ρ_w : (b) 0.65; (c) 0.65; and (d) 0.64.

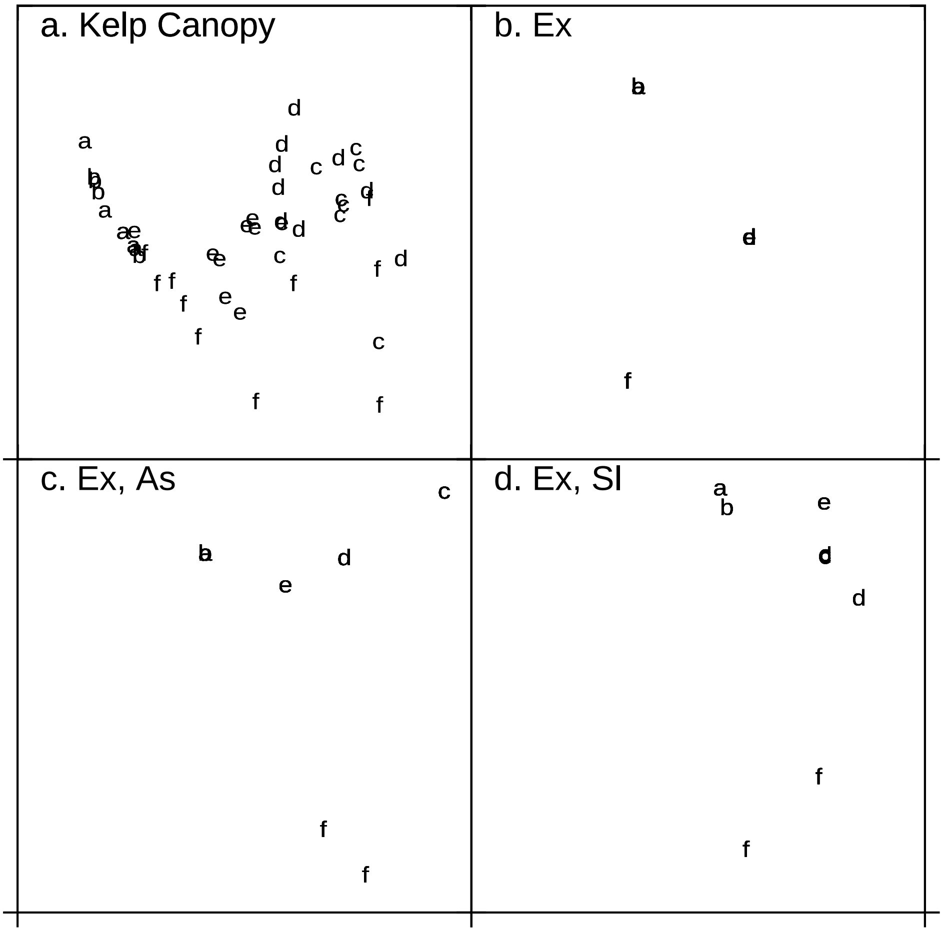

Figure 4.6.3 Kelp canopy. MDS ordinations of the community composition and the three best matching combinations of physical variables. Correlation coefficients ρ_w : (b) 0.44; (c) 0.35; and (d) 0.35.

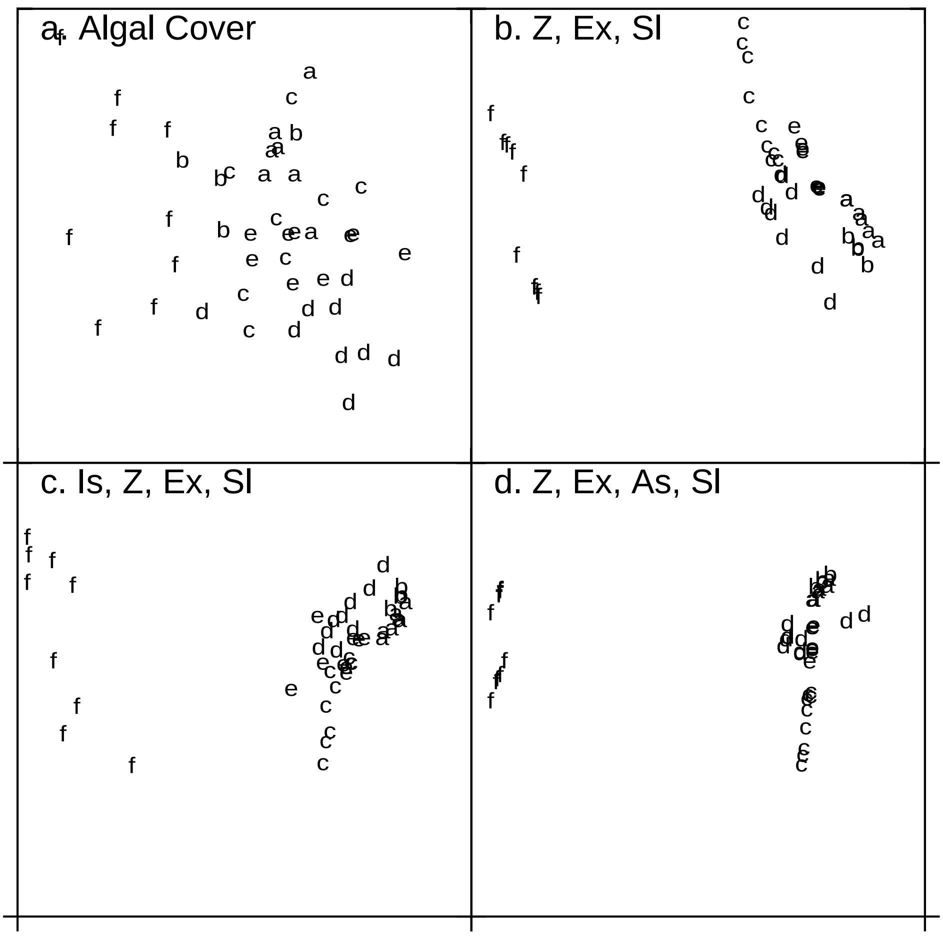

Figure 4.6.4 Algal cover. MDS ordinations of the community composition and the three best matching combinations of physical variables. Correlation coefficients ρ_w: (b) 0.44; (c) 0.44; and (d) 0.43.

4.7 Discussion

This study found that many reef inhabiting biota are closely associated with particular physical variables. This was particularly so for invertebrates, corresponding with combinations of substratum structure (ie interstitial space, complexity, slope and relief), depth and longitude. Aspect and exposure were also of some importance. There was less correspondence between the physical data and the algal communities. However, exposure (and its surrogate aspect), depth and reef slope were reasonably good explanatory variables.

These results do not imply causality between the explanatory variables and the biota, the explanatory variables possibly representing other causal factors. For example, slope is not likely to directly affect understorey algae. Instead, algal communities may be related to slope through the influence of slope on wave movements and habitat diversity. Although this study does not provide information on causal processes, the physical-biological relationships described in this study are similar to those found in other studies of reef processes (eg Choat and Schiel 1982; Choat and Ayling 1987; Edgar 1984; Edmunds 1990).

Substratum type lithology as a single variable for describing seafloor geology was not found to be a major determinant of community structure, although some species detected in this survey occurred predominantly on one substratum type. The ascidian *Cnemidocarpa radicosa* and the brown algae Dictyotales were present in relatively higher abundances on granite, while the periwinkle *Turbo undulatus* was much higher in abundance on basalt.

In addition to abiotic influences, the reef community composition is also structured by biological interactions. Predominant interactions include: the provision of biogenic habitat by kelps and other algae; competition among algae for reef space and light; grazing of algae by large invertebrate herbivores and competition for shelter resources (eg Andrew and Stocker 1986; Jones and Andrew 1993; Andrew and MacDiarmid 1991; Andrew 1993).

An overview of predominant physical and biological influences is illustrated in Figure 4.7.1. Because of this web of reef community structuring processes, physical variables alone cannot fully explain differences in biological communities between sites. Therefore, classifications of marine biodiversity based on physical data alone must therefore be used with caution. Biological information, even when restricted to a few selected taxonomic groups, provides a superior approach to explaining the distribution of marine biodiversity (see Chapters 5 and 6).

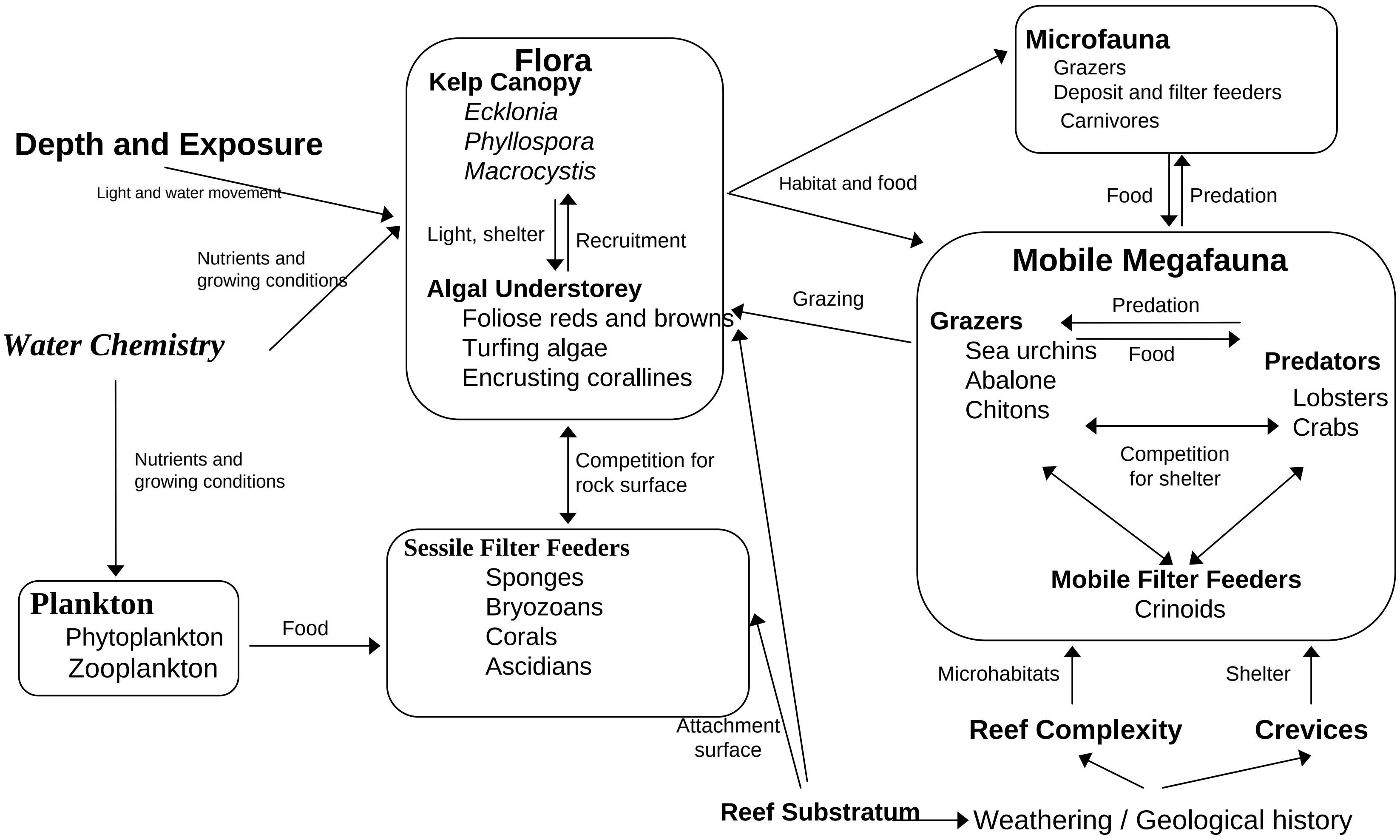

Figure 4.7.1 Conceptual summary of biological and environmental influences structuring reef communities.

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4.9 Appendix

4.9.1 Analysis statistics

Relief Index

The relief index was calculated as:

$$RI_{100} = \frac{100}{(k-1)} \bullet \sum_{i=1}^{k} \left| x_i - x_{i-1} \right| \qquad \text{(Equation 4.9.1)}$$

where x_i-x_{i+1} is the deviation between successive depth measurements (1 m apart in this case) and *k* is the number of measurements (after Luckhurst and Luckhurst 1978; Bodkin 1988).

Shannon Diversity Index

Shannon species diversity is calculated as:

$$H' = -\sum_{i=1}^{k} p_i \log p_i \qquad \text{(Equation 4.9.2)}$$

where *k* is the number of species and p_i is the proportion of abundance observed for the *i*th species.

Pielou's Evenness

The Shannon index is affected by the number of species sampled and can be expressed as a proportion of the maximum possible diversity:

$$H'_{\max} = \log k \qquad \text{(Equation 4.9.3)}$$

and

$$J' = \frac{H'}{H'_{\max}} \qquad \text{(Equation 4.9.4)}$$

where *J'* is termed Pielou's evenness and is scaled between 0 and 1 (Pielou 1975).

Taxonomic Diversity

The taxonomic diversity index is related to Shannon species diversity *H'*, but incorporates taxonomic separation. This index discriminates between community structures where species are predominantly from the one genus (or higher taxonomic levels), compared to a more even distribution among the taxonomic hierarchy. Taxonomic diversity is defined as:

$$\Delta = \frac{\sum_{i<j} w_{ij} x_i x_j}{\sum_{i<j} x_i x_j + \sum_{i} x_i \left(x_i - 1\right)/2} \qquad \text{(Equation 4.9.5)}$$

where x_i is the abundance of the *i*th species and w_{ij} is the weighting given to the taxonomic path length linking species (following Warwick and Clarke 1995). In this case, *w* was set at 1 for species in the same genus, *w* = 2 for species in the same family (but different genera) and so on to *w* = 6 for species within different phyla. Current Linnean hierarchical taxonomic structures were used, and these are given with the species lists in Appendix 4.9.2.

Taxonomic Distinctness

Taxonomic distinctness describes the distribution of species among higher taxonomic levels, and does not include information on the distribution of individuals among species (Warwick and Clarke 1995). Taxonomic distinctness was calculated as:

$$\Delta^* = \frac{\sum_{i<j} w_{ij} x_i x_j}{\sum_{i<j} x_i x_j} \qquad \text{(Equation 4.9.6)}$$

Dominance Curve Difference

The difference in shape between two *k*-dominance curves was given by the log-weighted difference statistic:

$$d' = \sum_{i=1}^{S_{max}} \left|y_{iA} - y_{iB}\right| \log\left(1 + i^{-1}\right) \qquad \text{(Equation 4.9.7)}$$

where y_i is the cumulative proportional abundance for the *i*th species rank, and *A* and *B* are the samples being compared (Clarke 1990).

Bray-Curtis Dissimilarity Coefficient

The ecological distance in community structure between two samples was computed using the Bray-Curtis dissimilarity coefficient (Faith *et al* 1987):

$$y_{ij} = 100 \bullet \frac{\sum_{s=1}^{S} \left| abundance_{si} - abundance_{sj} \right|}{\sum_{s=1}^{S} \left(abundance_{si} + abundance_{sj} \right)} \qquad \text{(Equation 4.9.8)}$$

This coefficient computed the percentage difference in community structure based on abundances of taxa, where *i* and *j* are the pair of samples being compared using $s = 1$ to S species.

Estabrook-Rogers Dissimilarity Coefficient

The distance in physical structure between two samples was computed using the Estabrook-Rogers coefficient (Estabrook and Rogers 1966). The similarity coefficient was calculated as:

$$S_{ij} = \frac{\sum_{k=1}^{N} S(k_i, k_j)}{N} \qquad \text{(Equation 4.9.9)}$$

where N is the total number of characters (*k*) used and $S(k_i, k_j)$ depends on the character type. This was converted to dissimilarity for the analysis (D = 1- S).

For discrete, non-ordinal (multistate) characters:

$$S(k_i, k_j) = 1, \text{ if } k_i = k_j \quad \text{or} \quad S(k_i, k_j) = 0, \text{ if } k_i \neq k_j \qquad \text{(Equation 4.9.10)}$$

For discrete, ordinal (ranked) characters:

$$S(k_i, k_j) = 1 - \frac{\left| k_i - k_j \right|}{n_k - 1} \qquad \text{(Equation 4.9.11)}$$

where n_k is the number of states for that character.

For continuous variable characters:

$$S(k_i, k_j) = 1 - \frac{\left| k_i - k_j \right|}{\text{MAX}_k - \text{MIN}_k} \qquad \text{(Equation 4.9.12)}$$

4.9.2 Species lists

Taxon	Species	Common name	Database Code
Phylum Cnidaria			
Class Anthozoa			
Order Alcyonacea			
Family Melithaeidae	*Mopsella zimmeri*	Gorgonian coral	MOPZIM
	Acabaria sp	Gorgonian coral	ACASPE
Ph. Arthropoda			
C. Malacostraca			
O. Decapoda			
F. Palinuridae	*Jasus edwardsii*	Southern rock lobster	JASEDW
F. Portunidae	*Nectocarcinus tuberculatus*	Red swimmer crab	NECTUR
Ph. Mollusca			
Cl. Polyplacophora			
O. Neoloricata		Chitons	CHITON
Cl. Gastropoda			
O. Archaeogastropoda			
F. Haliotidae	*Haliotis rubra*	Blacklip abalone	HALRUB
	Haliotis laevigata	Greenlip abalone	HALLAE
F. Fissurellidae	*Scutus antipodes*	Elephant snail	SCUANT
F. Trochidae	*Calliostoma armillata*	Top shell	CALARM
	Phasianotrochus exmius		PHAEXE
F. Turbinidae	*Turbo undulatus*	Periwinkle	TURUND
	Astralium aureum	Kelp shell	ASTAUR
O. Neogastropoda			
F. Muricidae	*Dicathais orbita*	Dog whelk	DICORB
Ph. Echinodermata			
Cl. Crinoidea			
O. Comatulida			
F. Comasteridae	*Cenolia trichoptera*	Crinoid	CENTRI
	Cenolia tasmaniae	Crinoid	CENTAS
Cl. Asteroidea			
O. Paxillosida			
F. Goniasteridae	*Tosia magnifica*	Seastar	TOSMAG
	Tosia australis		TOSAUS
	Pentagonaster dubeni		PENDUB
F. Oreasteridae	*Nectria macrobrachia*		NECMAC
	Nectria multispina		NECMUL
F. Asteropseidae	*Petricia vernicina*		PETVER
F. Ophidiasteridae	*Fromia polypora*		FROPOL
O. Spinulisida			
F. Echinasteridae	*Plecaster decanus*		PLEDEC
	Echinaster arcystatus		ECHARC
F. Asterinidae	*Nepanthia troughtoni*		NEPTRO
	Patiriella gunnii		PATGUN

Table 4.9.1 Hierarchical classification of macroinvertebrates surveyed within 20 m^2 strip transects.

Taxa	Species	Common name	Database Code
Ph. Echinodermata			
Cl. Asteroidea			
O. Forcipulatida			
F. Asteriidae	Uniophora sp		UNISPE
Cl. Echinoidea			
O. Echinoida			
F. Echinometridae	Heliocidaris erythrogramma	Purple Sea Urchin	HELERY
Ph. Chordata			
Cl. Ascidiacea			
F. Ascidiidae	Cnemidocarpa radicosa	Sea squirt	CNERAD
F. Pyuridae	Herdmania momus		HERMOM
	Pyura australis		PYUAUS
	Pyura gibbosa		PYUGIB

Table 4.9.1 (continued) Hierarchical classification of megafaunal invertebrates surveyed within 20 m^2 strip transects.

Taxon	Species	Common name	Database Code
Division Phaeophyta			
Order Sporochnales			
Family Sporochnaceae	Carpomitra costata		CARCOS
Order Laminariales			
F. Lessoniaceae	Macrocystis angustifolia	String kelp	MACANG
F. Alariaceae	Ecklonia radiata	Common kelp	ECKRAD
Order Fucales			
F. Fucaceae	Xiphophora chondrophylla		XIPCHO
F. Seirococcaceae	Phyllospora comosa	Cray weed	PHYCOM
	Seirococcus axillaris		SEIAXI
	Scytothalia dorycarpa		SCYDOR
F. Cystoseiraceae	Carpoglossum confluens		CARCON
	Cystophora platylobium		CYSPLA
	Cystophora moniliformis		CYSMON
	Cystophora subfarcinata		CYSSUB
	Acrocarpia paniculata		ACRPAN
F. Sargassaceae	Sargassum sp		SARSPE

Table 4.9.2 Hierarchical classification of kelps and large brown algae surveyed within 0.2 m^2 quadrats.

Taxon			Species	Database Code
Division Phaeophyta				
	Order Sporochnales			
		Family Sporochnaceae	Sporochnus comosus	SPOCOM
			Perithalia caudata	PERCAU
	Order Laminariales			
		Family Lessoniaceae	Macrocystis angustifolia	MACANG
		F. Alariaceae	Ecklonia radiata	ECKRAD
	Order Fucales			
		F. Fucaceae	Xiphophora chondrophylla	XIPCON
		F. Seirococcaceae	Phyllospora comosa	PHYCOM
			Seirococcus axillaris	SEIAXI
		F. Cystoseiraceae	Carpoglossum confluens	CARCON
			Cystophora platylobium	CYSPLA
			Cystophora sp	CYSTSP
			Acrocarpia paniculata	ACRPAN
		F. Sargassaceae	Sargassum sp	SARGSP
	Order Sphacelariales			
		F. Stypocaulaceae	Halopteris gracilescens	HALGRA
	Order Dictyotales			
		F. Dictyotaceae	Zonaria angusta	ZONANG
			Zonaria spiralis	ZONSPI
			Dictyota dichotoma	DICDIC
			Homeostichus olsenii	HOMOLS
			Lobospira bicuspida	LOBBIC
Division Rhodophyta				
	Order Corallinaceae			
			Halyptilon roseum	HALROS
			Cheilosporum sagittatum	CHESAG
			Metagonialithon stelliperum	METSTE
			Synarthrophyton patena	SYNPAT
	Order Gelidiales			
		F. Gelidiaceae	Pterocladia lucida	PTELUC
			Pterocladia capillacea	PTECAP
	Order Gigartinales			
		F. Peyssoneliaceae	Sonderopelta coriacea	SONCOR
		F. Halymeniaceae	Halymenia plana	HALPLA
		F. Hypneacea	Hypnea ramentacea	HYPRAM
		F. Phacelocarpaceae	Phacelocarpus peperocarpus	PHAPEP
		F. Plocamiaceae	Plocamium sp	PLOCSP
			Plocamium mertensii	PLOMER
			Plocamium angustum	PLOANG
			Plocamium dilatatum	PLODIL
		F. Nizymeniaceae	Nizymenia australis	NIZAUS

Table 4.9.3 Hierarchical classification of algae harvested within 0.2 m^2 quadrats.

Taxon			Species		Database Code
Division Rhodophyta					
	Order Gigartinales				
		F. Gracilariaceae	Melanthalia obtusata		MELOBT
		F. Solieriaceae	Callophycus sp		CALTRI
	Order Ceramiales				
		F. Ceramiaceae	Balia calitricha		BALCAL
		F. Wrangelieae	Wrangelia nobilis		WRANOB
			Euptilota articulata		EUPART
			Haloplegma preisii		HALPRE
		F. Dasyaceae	Heterosiphonia gunniana		HETGUN
		F. Rhodomelaceae	Dictymenia harveyana		DICHAR
			Laurencia sp		LAUCLA
	Order Rhodymeniales				
		F. Rhodymeniaceae	Rhodymenia australis		RHOAUS
		F. Champiaceae	Champia viridis		CHAVIR
	Order Cryptonemiales				
		F. Kallymeniaceae	Callophyllis lambertii		CALLAM
			Polyopes constrictus		POLCON
	Unidentified red species			Red 1	RED1
				Red 2	RED2
				Red 3	RED3
				Red 4	RED4
Division Chlorophyta					
	Order Caulerpales				
		F. Caulerpaceae	Caulerpa flexilis		CAUFLE
			Caulerpa cactioides		CAUCAC
			Caulerpa geminata		CAUGEM

Table 4.9.3 (continued) Heirarchical classification of algae harvested within 0.2 m^2 quadrats.