RAPID ASSESSMENT OF ROCKY SHORE BIODIVERSITY **IN THE BYRON BAY REGION**

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[PHOTOS FRONT COVER]

Examples of rocky shore biota from the Byron Bay region (from left to right): deep pool, Cape Byron; Notoacmaea*, Cape Byron; anemone aggregation, Cape Byron;* Onithochiton quercinus*, Flat Rock.*

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EXECUTIVE SUMMARY

This report summarises the results of a rapid assessment of the biodiversity of intertidal habitats at 4 sites with the Byron Bay region – Flat Rock, Lennox Head Reef, Broken Head and Cape Byron (the Pass eastward to the Cape). The objectives were to provide a description of intertidal habitats and communities and to: i) determine patterns of community structure and differences between habitats and sites; ii) identify the presence of rare or unusual species; iii) provide recommendations with respect to conservation zoning based on differences in community structure and species richness; and iv) to comment on conservation and management issues at the survey sites.

The study consisted of replicated 30 minute surveys of different habitat types at each site during which all species were recorded and given an abundance rating ranging from 0 (absent) to 5 (abundant). Comparisons of overall community structure and of general species richness were made within and between sites using multivariate and univariate statistical methods.

A total of 143 species were recorded for the intertidal region at Flat Rock (109 animals and 34 algal species). Of note was the relatively high cover of algae in the pools around the margin of the platform. Tropical cnidaria were represented by a single colony of zoanthid, which was the only colony of tropical cnidarian encountered during the full survey program within the region. A specimen of the tropical sea-urchin *Diadema savignyi*, the only one recorded from any locality during the surveys, was also found in the same region of the headland. The boulder habitat on the south-western margin of the platform supported a diverse community that was dominated by molluscs, 2 species of which were not encountered at other sites within the region. Although surveys of the deep-pool habitat (which is present on the north-eastern margin of the platform) were incomplete, this habitat supported algal species that were either absent or rare at other locations.

Lennox Head Reef was the largest of the sites examined and was found to support a number of discrete community types that were associated with different tidal heights and locations relative to the Moat, the lagoon occupying the majority of the reef area. Boulder fields dominate the intertidal region. A total of 187 species were recorded (158 animals and 29 plants) from the intertidal region at Lennox Head Reef with 7 additional species also present in the Moat. The highest species richness was recorded at the low tide level along the eastern margin of the reef. Pools present across the southern and south-western areas of the reef supported diverse communities which included dense aggregations of cowries and sea-cucumbers and also specimens of colourful nudibranchs. The sea-floor habitats within the Moat were dominated by algae and seagrass and animals were relatively scarce. Most rocky surfaces in the Moat were covered by a layer of sand which may limit suitable habitat for the establishment of diverse animal assemblages. Storm-water discharging over the beach from drains to the west of the Moat was observed to result in rapid changes in turbidity at adjacent intertidal sites and also to increase sedimentation which resulted in burial of reef habitat and smothering of attached biota.

Rocky intertidal areas at Broken Head and Cape Byron were found to support low species richness (61 and 48 species, respectively) which probably results from the effects of moderate wave exposure and sedimentation from adjacent beaches. Community structure was similar at these sites and was characterised by common shell species, algal assemblages in pools at lower tidal levels, and sand tolerant animals such as anemones. Despite the relatively low diversity, subsequent analysis indicated that community structure at these sites was distinct and was not represented at other sites examined during the study.

Shallow pools across the study sites supported approximately 55% of the species richness of similar locations in the Solitary Islands Marine Park (SIMP). Species richness in the boulder field habitat was also lower at the study sites than at sites within the SIMP. This is likely to be due to the differences in geology, the lack of low energy platforms in the Cape Byron region, and the effects of sedimentation which were evident at all study sites.

The results of community level analysis indicate that 7 different community types are present in the intertidal areas of the study sites. Three of these are present at Flat Rock, 1 at Broken Head/Cape Byron, and 3 at Lennox Head Reef. Lennox Head Reef also supports the Moat habitat which is unique within the region. In order to ensure that representative areas of each habitat type are included in protective zones within the Cape Byron Marine Park, we suggest that:
i) consideration should be given to extending the southern boundary to include Flat Rock;
ii) Lennox Head Reef is given maximum protection; and iii) Broken Head is also given maximum protection. Observations made during this study also indicate that stormwater needs to be more effectively managed at Lennox Head Reef if the conservation value of the site is to be adeqautely protected.

[PHOTO PAGE 1]

The rock octopus which was moderately common at some sites (Flat Rock).

[PHOTO PAGE 3]

Algal dominated substratum, the Moat, Lennox Head Reef.

CONTENTS

INTRODUCTION

The Cape Byron Marine Park (CBMP) (Fig. 1) is the most recent marine park to be declared in NSW coastal waters. Under the management of the NSW Marine Parks Authority (MPA), the CBMP will be established as a multiple-use area in which different locations are afforded different levels of protection based on their perceived value with respect to conservation and biodiversity, heritage (indigenous and European) and existing patterns of usage (MPA 2002a). Using the model that has been applied to other marine parks in NSW, protective zoning will range from Sanctuary zones, in which all destructive activities are prohibited, through to General Use zones where most activities are permitted (e.g. the Solitary Islands Marine Park – MPA 2002b). In order for this system of management to be effective, information on the values of all areas within the boundaries of the CBMP is needed so that decisions on protective zoning can be as objective as possible.

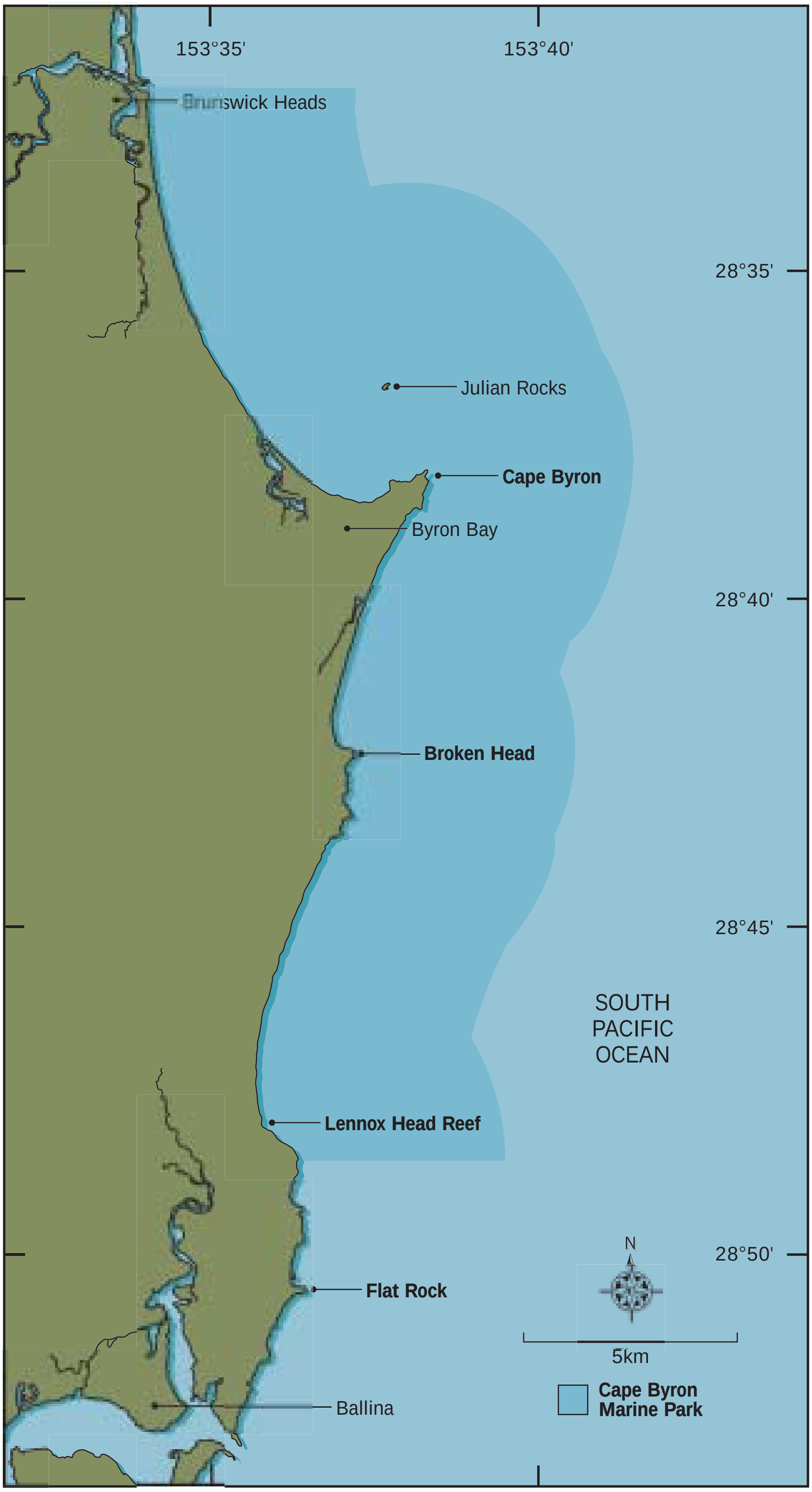
Data on community structure and biodiversity of marine benthic habitats in the Byron Bay region are currently scant (Avery 2000). This report addresses some of these gaps by providing information on the habitat diversity and biodiversity of rocky shores within the CBMP. Rocky shores are often one of the most popular marine habitats for recreational activities such as fishing, collecting and general observation; the main reason for this is their general ease of access and also their high biodiversity relative to other shore habitats (e.g. beaches and estuaries). Rocky shores are dynamic environments where community structure can change from time to time under the influence of both biological and physical factors. High wave energy can remove animals completely and may also have indirect effects through transporting large quantities of sand, and sometimes seaweed, that smother immobile organisms. Generally, where these types of disturbances occur on a regular basis, biodiversity is low and communities are made up of hardy organisms and those that can rapidly recolonise following major impacts. Biodiversity is usually highest where wave exposure is low and where there is a high diversity of physical habitats that provide for a large range of specific requirements of different organisms (Smith et al. 1997; Smith & James 1999). The importance of habitat diversity for the biodiversity of a region has been widely recognised and, where insufficient biological data are available over the spatial scale of interest, conservation planners may use habitat details to make initial recommendations on site selection for marine conservation (e.g. Banks & Skilleter 2002).

Human activities on rocky shores can have considerable, direct impacts on the communities they support, primarily from trampling, over-collecting and pollution (e.g. from littering and fishing line). Indirect effects of adjacent human activities are also important. Urbanisation and shoreline engineering works are relevant examples in the study area, affecting freshwater run-off and associated water-borne pollutants through storm-water channelling, and altering processes such as wave action and sedimentation. Human impacts are often cumulative over moderate time scales and thus relatively insidious. For all of these reasons, areas of high biodiversity need to be identified and protected using appropriate management actions. The conservation of biodiversity and ecological processes are usually the primary objectives of marine protected areas; this is also the case for the CBMP (MPA 2001, 2002a).

The objective of this study was to provide biological information on the rocky shore communities at selected sites within the Byron Bay region. In providing these data, it was also necessary to consider the habitat diversity of sites together with their exposure to various physical factors that are likely to influence biodiversity over various temporal scales. For this reason, in addition to providing the results of the field studies, the report provides a background description for each site including its geology, habitat diversity, orientation with respect to prevailing swell direction, and any evidence of impacts from either natural or anthropogenic sources (but note that comments on the latter are based on observations over a very limited period of time). Where available and appropriate, previous work has been reviewed as part of the background description for each site.

[FIGURE 1]

Map of the region showing the boundaries of the Cape Byron Marine Park and the sites surveyed for this report.



METHODS

Field methods

As the objective of this study was to provide a rapid assessment of shore communities at one point in time, species richness and the relative abundance (semi-quantitative scores) of the biota at each site were evaluated using methods developed for similar investigations of rocky shores in the Solitary Islands Marine Park (SIMP) (e.g. Smith et al. 1997; Smith & James 1999). The method involves timed surveys of intertidal rock platforms during which all visually dominant organisms (≥ 10 mm) are identified and given an abundance score (Table 1).

The first step in the process is to examine sites and allocate habitats into one of the following strata which are then surveyed separately: shallow rock-pools (<1m deep, <100m^2 in areal extent); deep rock-pools (>1m deep, <100m^2 in areal extent); boulder fields; and lagoons (>100m^2 in areal extent). Although emerged shores (i.e. rocky substrata exposed to the air at low tide) dominate on most rocky shores, these are generally associated with low species richness and high abundance of a few common taxa. Previous studies have found that most, if not all, of the species occurring in this habitat type also occur in at least one of those listed above. For this reason, this habitat was excluded from the surveys. Thirty minute searches are then conducted, repeatedly, in each habitat until all habitat of that type has been assessed for the site. This type of survey provides a species list by site, and a matrix of semi-quantitative scores for each species in each replicate 30 minute search period (Smith & James 1999).

In this study, all fauna were identified to species level wherever possible. If species could not be named, a system of codes was applied and reference material was taken, either as a specimen or a photograph, in the hope that they could be later identified from the available resource material or by a relevant taxonomic authority. Only the obvious algal species were identified and the list provided for algae is thus indicative only. It is common for algal turfs to form a complex of more than one species and consequently the process of collection and identification is time consuming and was outside the scope of this study. Filamentous and epiphytic algae were ignored and only the larger macrophytes were listed for each site.

Survey sites

A short-list of sites was prepared after consultation with the managing authority (NSW Marine Parks Authority, Cape Byron) and subsequent examination of candidate sites. These were (listed from south to north): Flat Rock, Lennox Head Reef, Broken Head and Cape Byron (The Pass east to the north-eastern point of Cape Byron) (Fig. 1).

Abundance	Descriptive Term	Score
0	Absent	0
1- 2	Very uncommon	1
3-10	Uncommon	2
11-30	Moderately common	3
31-50	Common	4
> 50	Abundant	5

[TABLE 1]

Semi-quantitative scoring system used to assess the abundance of biota during replicated 30 minute surveys.

Analysis of data

Differences in community structure within a site, and across all sites, was explored using a suite of multivariate methods. Thus, using the semi-quantitative abundance scores and all full 30 minute replicates, patterns of community structure were evaluated by calculating Bray-Curtis similarities between samples and portraying these results in a two-dimensional ordination using non-metric multidimensional scaling (nMDS). Where appropriate, these similarity data were also explored using cluster analysis. Where grouping of samples was observed, the species primarily responsible for the similarity within groups of similar samples, and dissimilarity between groups of dissimilar samples, were determined using similarity-percentages (SIMPER). One of the advantages of this type of analysis is that it identifies distinct community types within the Byron Bay region; this can therefore assist in the selection of complementary areas for protection. All multivariate analyses were performed using PRIMER (PRIMER 2001).

Comparisons between rock platforms were also made on the basis of the number of species they support and the presence of organisms considered to be of regional significance (e.g. tropically affiliated and rare species). Species richness estimates over the 30 minute replicate search periods were compared across habitats and locations using univariate statistical methods (analysis-of-variance).

To put the study into a broader spatial context, data for sites in the Byron Bay region were compared to those from rocky intertidal sites in the SIMP. Extensive surveys within the SIMP have allowed the development of a predictive model that relates total species richness of a site to its area. If sites from this study are similar to those from the SIMP in terms of species-area relationship, data points should fall within the confidence intervals of the SIMP model. In order to perform these comparisons, the total survey area at each site was extracted from the GIS database housed at the Coffs Harbour office of the MPA.

RESULTS

The geology of the Byron Bay region is such that there are few headlands that support low energy platforms. In the northern region of the park, intertidal rocky shores are derived from metamorphic rock (greywacke) and have steep, plunging profiles with little habitat conducive to the establishment of rich intertidal communities. In addition, the rocky intertidal substratum usually terminates in sandy beaches where periodic, vertical shifts in sand levels, and the effects of scour by suspended sand during periods of high wave energy, limit the development of sessile benthic communities. Flat Rock, which lies south of the current marine park boundary, has an extensive platform on which sand inundation is only limiting at the margins that are in close proximity to the adjacent beaches. Boulder habitat dominates the intertidal region in the central section of the park. While this type of habitat is often associated with high biodiversity due to the diversity of niches it offers, this usually occurs only where boulder fields are present on a platform of bedrock (e.g. see Smith & James 1999) – this situation occurs at Lennox Head Reef but not at Skennars Head immediately to the south.

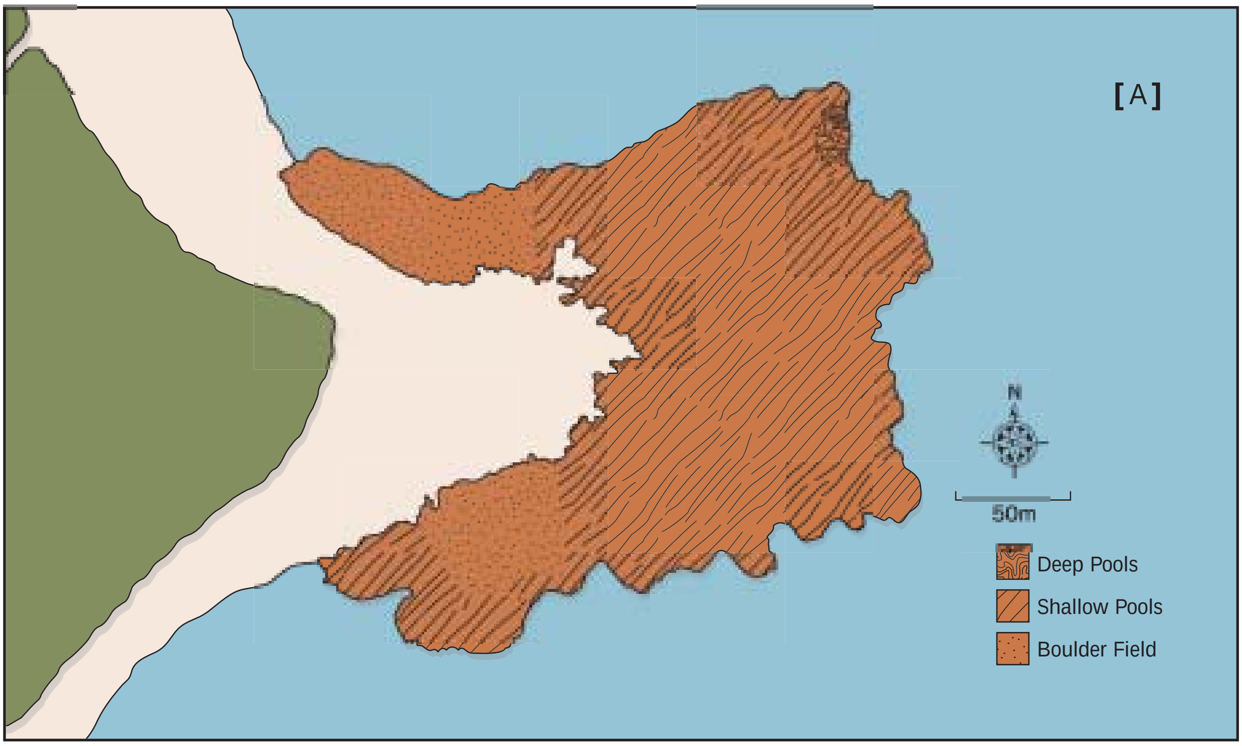
A total of 232 species of biota was recorded during the 38 replicate 30 minute searches (plus 2 incomplete replicates – see below) performed at the 4 sites during this investigation. This total comprised 184 faunal and 48 floral species; 53 of these taxa were encountered on only one occasion during the surveys (see Appendix). Specific descriptions of community structure and species complements are provided for each habitat and site, below.

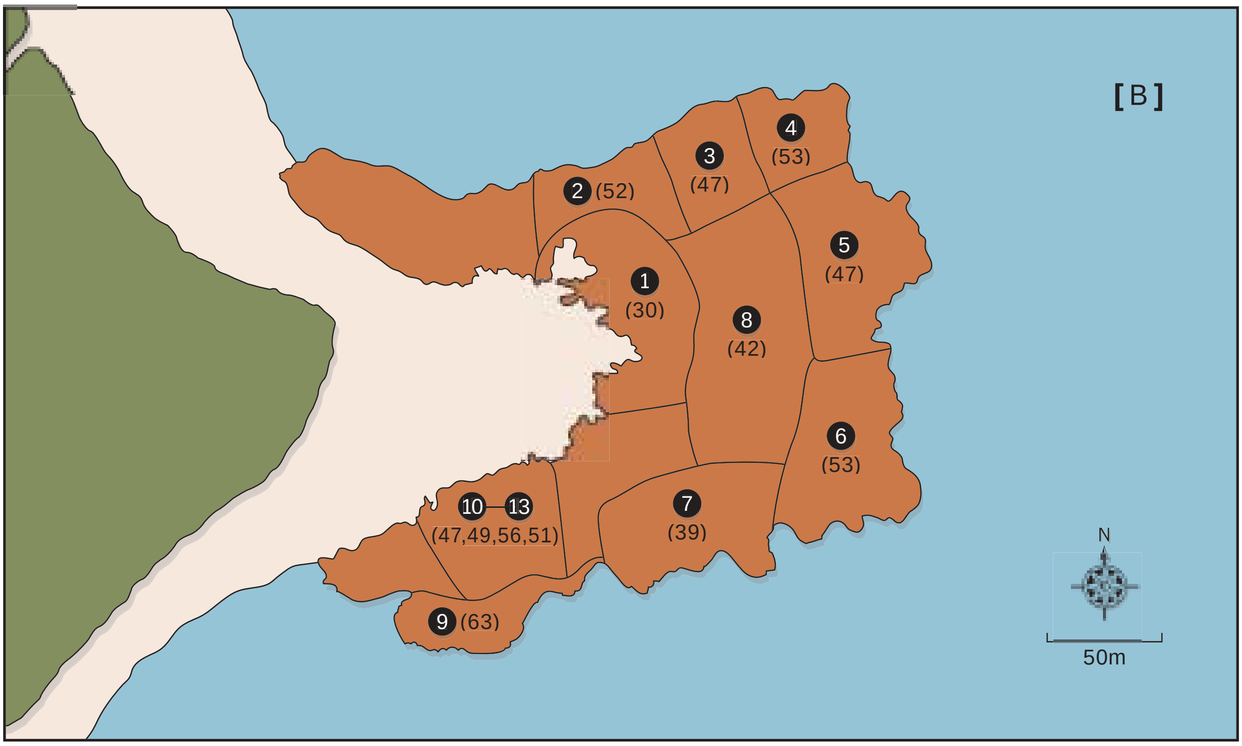
Flat Rock

Flat Rock (Fig. 1) is the southernmost location surveyed within this study. Located at the northern end of Angel's Beach, the rock platform is separated from adjacent terrestrial habitats by an elevated sand spit. The rock platform is derived from Lismore Basalts that were formed by flows of lava from the Mount Warning Shield Volcano (DLWC 2002). In other locations within this region (e.g. Skennars Head and Lennox Head) basalt pillars, eroding landward from the effects of wave action, form extensive intertidal boulder fields. However, at Flat Rock, boulder fields comprise only a small percentage of the intertidal habitat and are confined to the south-western and north-western margins (Fig. 2). Three additional habitats are present: emerged rock, shallow pools and deep pools (defined in Methods). Shallow pools are present throughout the rock platform and, with the exception of emerged rock, are the dominant habitat type (Fig. 2). Only two deep pools are present, both of which are located on the extreme north-eastern tip of the platform where they are continuously washed by waves. Sand inundation is apparent in the mid-western section of the platform as well as in both areas of boulder fields. The north-western boulder field, in particular, shows high levels of inundation with all boulders lying on sand.

Results of this study

A total of 13 replicate 30 minute surveys were conducted during the survey at Flat Rock, 9 of these in the dominant shallow pool habitat and 4 in the boulder field on the south-western margin of the platform (Fig. 2). An additional replicate was started for the deep pool habitat on the north-eastern margin of the platform but the exposure in this area, combined with the relatively high wave energy encountered during the field period, prevented this replicate from being completed. The total species count for the platform was 144 species of which 110 were fauna and 34 were algae (full species lists appear in the Appendix). Community patterns for each habitat are described below.





[FIGURE 2]

Map of Flat Rock showing: A) the approximate distribution of habitats; and B) the relative location of each of the replicate surveys. Numerals in brackets are the number of species recorded at each survey location (replicate).

Shallow pools

After initial examination of the shallow pool habitat, it was decided to stratify sampling based on what appeared to be distinct patterns of community structure associated with different sections of the platform. Thus, sampling was stratified amongst: the central platform which was closest to the beach and supported large pools with a sandy substratum (central pools); the areas on the outer margin of the platform which supported algal-dominated habitats and which appeared to differ between aspects (marginal pools) (Plate 1); and the south-western section which supported large pools in the lower tidal region below the boulder field (Fig. 2, Plate 2).

[PLATE 1]

Shallow pools on the north-eastern area of Flat Rock.

[PLATE 2]

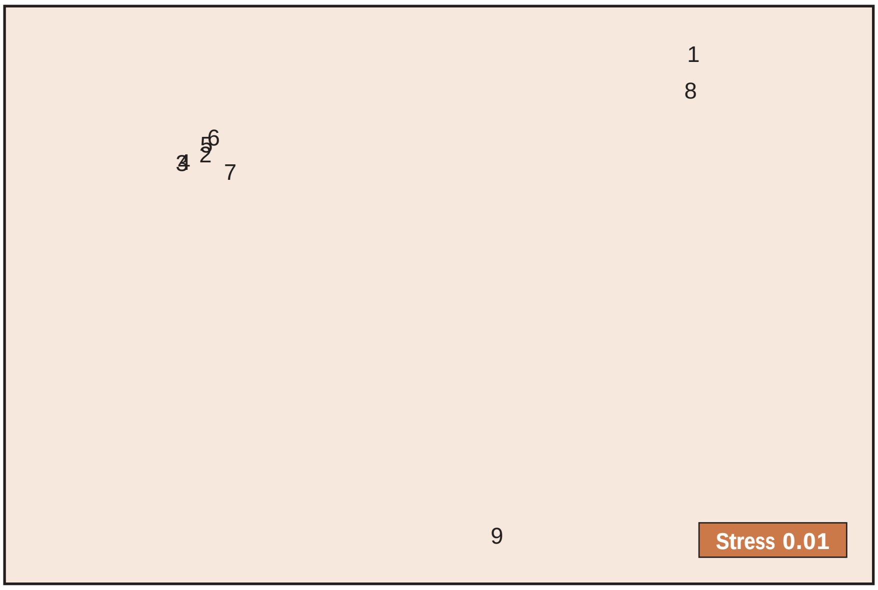
Shallow pool area in the low tide region of the south-western platform at Flat Rock.

The nMDS for the shallow pools data (Fig. 3) confirms these initial observations. In this type of analysis, samples that are similar in community composition group closely together and those that are dissimilar are separated by greater distances. In the nMDS plot for shallow pools at Flat Rock, samples from the northern, eastern and southern margins of the platform show strong grouping indicating considerable similarity in community structure - this cluster can be seen in the upper left of the plot. The 2 samples from the central areas also show strong similarity, grouping together in the top right of the plot. The sample from the lower shore on the south-western margin of the headland is distinct in community structure from all other samples and is represented by the single point at the bottom of the plot.

Using SIMPER analysis, it was possible to determine which species were characteristic of the different sample groups, and also those species that were mainly responsible for differences between them. Summaries of these results are presented in Tables 2 and 3. High abundances of common mollusc and algal species were characteristic of both the central and marginal pools. Species richness was generally lower in the central pools, however a number of species were found in this area that did not occur elsewhere. These included a tropical cnidarian (an unidentified zoanthid – Plate 3) and a tropical sea urchin (*Diadema savignyi*), neither of which were found at any other site during the study. Moderate populations of the sea urchin *Echinometra mathaei* (Plate 4) were also characteristic of these pools. In the marginal pools, upper surfaces tended to be dominated by a mix of turfing and canopy-forming algal species while vertical surfaces were dominated by sessile fauna such as the anemone *Actinia australis* (Plate 5). The small starfish *Patiriella calcar* was abundant in many pools where individuals formed dense aggregations in cracks and crevices and also at the bottom of pools. The large, herbivorous mollusc *Turbo undulatus* was also abundant in the cracks and crevices within these pools (Plate 6). From Table 2 it can be seen that the high abundances of the ascidian *Pyura stolonifera*, the starfish *Patiriella calcar*, two species of aggregation-forming polychaete (*Galeolaria caespitosa* and *Idanthyrsus pennatus*), and the shiny bait crab (*Plagusia glabra*) were principally characteristic of the marginal pools. Indeed, it is these taxa that were primarily responsible for differences between the sample clusters representing the marginal and central pools (Fig. 3, Table 3). The south-western pool area differed from the other two areas in that it supported higher abundances of the tropically affiliated sea-cucumber *Holothuria leucospilota*, the brown algal species *Colpomenia sinuosa* and *Padina crassa*, and the hermit crab *Clibanarius virescens*, and lower abundances of many of the species that were abundant at the other sites (Table 3).

[FIGURE 3]

Non-metric multidimensional scaling (nMDS) plot for the data from shallow pools at Flat Rock. Numbers refer to the different sampling locations shown in Fig. 2.



[PLATE 5 – PAGE 15]

The anemone Actinia australis *dominated the sides of pools in the marginal platform at Flat Rock. Also pictured, the shrimp* Alope australis *and the gastropod* Montfortula rugosa.

[TABLE 2]

List of species responsible for 75% of the similarities within the two main sample clusters shown in the nMDS (Fig. 3) for shallow pools at Flat Rock (Fig. 2). Species are listed in their order of importance. Mean scores and taxon affinities are also shown.

[A] Central pools (average similarity = 66.96%)

Species	Taxon	Score
Nerita atramentosa	Gastropod	5.00
Littorina unifasciata	Gastropod	5.00
Austrocochlea porcata	Gastropod	5.00
Bembicium nanum	Gastropod	5.00
Sargassum spp.	Brown algae	5.00
Ulva sp.	Green algae	5.00
Cladophora sp.	Green algae	5.00
Enteromorpha sp.	Green algae	5.00
Trichomya hirsutus	Bivalve	4.50
Siphonaria denticulata	Gastropod	4.50
Morula marginalba	Gastropod	4.50

[B] Marginal pools (average similarity = 73.01%)

Species	Taxon	Score
Pyura stolonifera	Ascidian	5.00
Patiriella calcar	Asteroid	5.00
Siphonaria denticulata	Gastropod	5.00
Turbo undulatus	Gastropod	5.00
Morula marginalba	Gastropod	5.00
Austrocochlea porcata	Gastropod	5.00
Cellana tramoserica	Gastropod	5.00
Galeolaria caespitosa	Polychaete	5.00
Actinia australis	Anemone	5.00
Sargassum spp.	Brown algae	5.00
Ulva sp.	Green algae	5.00
Cladophora sp.	Green algae	5.00
Oulactis muscosa	Anemone	4.83
Cnidopus verater	Anemone	3.83
Hormosira banksii	Brown algae	4.17
Plagusia glabra	Crab	3.67
Jania crassa	Red algae	4.00
Montfortula rugosa	Gastropod	4.00
Idanthyrsus pennatus	Polychaete	3.83
Lobophora variegata	Brown algae	3.83
Padina crassa	Brown algae	3.83
Dictyota dichotoma	Brown algae	3.33

[PLATE 3 & 4]

Fauna inhabiting the central pools at Flat Rock: an unidentified zoanthid which was the only colonial tropical cnidarian found during the study (top); the sea urchin Echinometra mathaei *(bottom).*

Central vs Marginal

Central	Marginal
	Pyura stolonifera (Asc)
	Patiriella calcar (Ast)
Littorina unifasciata (G)	
	Galeolaria caespitosa (P)
Oulactis muscosa (An)	
	Turbo undulatus (G)
	Actinia australis (An)
	Montfortula rugosa (G)
Nerita atramentosa (G)	
	Idanthyrsus pennatus (P)
	Lobophora variegata (BA)
	Cnidopus verater (An)

Central vs South-West

Central	South-West
	Pyura stolonifera (Asc)
Nerita atramentosa (G)	
Littorina unifasciata (G)	
	Galeolaria caespitosa (P)
	Idanthyrsus pennatus (P)
	Padina crassa (BA)
Enteromorpha sp. (GA)	
Siphonaria denticulata (G)	
	Holothuria leucospilota (H)
	Colpomenia sinuosa (BA)
	Patiriella calcar (Ast)
	Scutus antipodes (G)

Marginal vs South-West

Marginal	South-West
Siphonaria denticulata (G)	
Oulactis muscosa (An)	
	Holothuria leucospilota (H)
Actinia australis (An)	
	Colpomenia sinuosa (BA)
Montfortula rugosa (G)	
Plagusia glabra (C)	
	Clibanarius virescens (HC)
Onithochiton quercinus (Ch)	
Thais orbita (G)	
	Tripneustes gratilla (Ech)
Turbo undulatus (G)	

[TABLE 3]

Summary of the results of SIMPER analysis determining the species primarily responsible for differences between clusters of shallow pool samples at Flat Rock. The 12 highest ranked species are listed and are aligned with the cluster in which they had the higher abundance score. Taxon codes: An = anemone; Asc = ascidian; Ast = asteroid; BA = brown algae; C = crab; Ch = chiton; Ech = echinoid; G = gastropod; GA = green algae; H = holothurian; HC = hermit crab; P = polychaete.

[PLATE 6]

The starfish Patiriella calcar *and the turban shell* Turbo undulatus *are abundant in the marginal pools at Flat Rock.*

Boulder field

Four replicate surveys were conducted in the south-western boulder field at Flat Rock and revealed that this area is the most diverse on the platform, particularly for fauna. The main species contributing to the overall similarity of samples from the boulder fields are listed in Table 4. Many of these taxa are cryptic, relying on the cover provided by boulders for protection from both predation and desiccation. Molluscs are particularly abundant in this habitat (Plates 7 & 8) as are species of decapod crustacean (shrimps, hermit crabs and crabs). Because this habitat is mostly emerged at low tide, and with a few exceptions, algal species generally have lower cover than in the shallow pools. Two species of mollusc were found in this habitat that were not found at any other location during the surveys (*Maculotriton serriale* and *Cronia contracta*).

Species	Taxon	Score
Pyura stolonifera	Ascidian	5.00
Morula marginalba	Gastropod	5.00
Nerita atramentosa	Gastropod	5.00
Bembicium nanum	Gastropod	5.00
Cellana tramoserica	Gastropod	5.00
Austrocochlea porcata	Gastropod	5.00
Galeolaria caespitosa	Polychaete	5.00
Idanthyrsus pennatus	Polychaete	5.00
Actinia tenebrosa	Anemone	5.00
Cnidopus verater	Anemone	5.00
Oulactis muscosa	Anemone	5.00
Sargassum spp.	Brown algae	5.00
Cladophora sp.	Green algae	5.00
Ulva sp.	Green algae	5.00
Clibanarius virescens	Hermit crab	4.50
Leptodius exaratus	Crab	4.00
Jania crassa	Red algae	4.25
Montfortula rugosa	Gastropod	4.25
Alpheus sp.	Shrimp	4.25
Scutus antipodes	Gastropod	3.50
Patiriella calcar	Asteroid	3.25

[TABLE 4]

List of species responsible for 75% of the similarities within the samples from the south-west boulder field at Flat Rock (Fig. 2). Species are listed in their order of importance. Mean scores and taxon affinities are also shown. Average similarity = 83.1%.

[PLATE 7]

The bivalve Isognomon perna *attached to the underside of a boulder at Flat Rock.*

[PLATE 8]

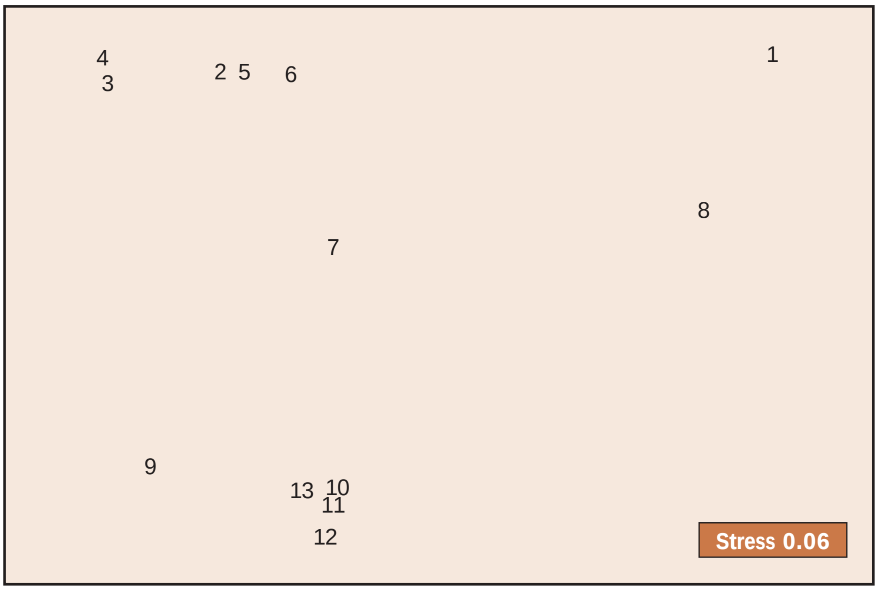
The bubble shell Hydatina physis *in the boulder field habitat at Flat Rock.*

Comparisons across habitats

The boulder field on the south-western margin of the platform was the most diverse area at Flat Rock (Fig. 2). Thus, the mean number of species encountered per 30 minutes in this area was 50.8, and the mean faunal species count was 44.5. In contrast, shallow pools supported a mean of 47.6 and 32.1 total species and fauna, respectively. Community structure was markedly different between pools in different areas of the platform as well as between the two major habitat types. In the nMDS plot comparing all full replicate 30 minute samples (Fig. 4), the samples from the boulder field form a tight cluster to the bottom of the plot.
The shallow pool sample that was noted as different to the other pool samples above (survey 9), shows considerable similarity to the samples from the boulder fields – this is almost certainly due to its very close proximity to the boulder area (Fig .2).

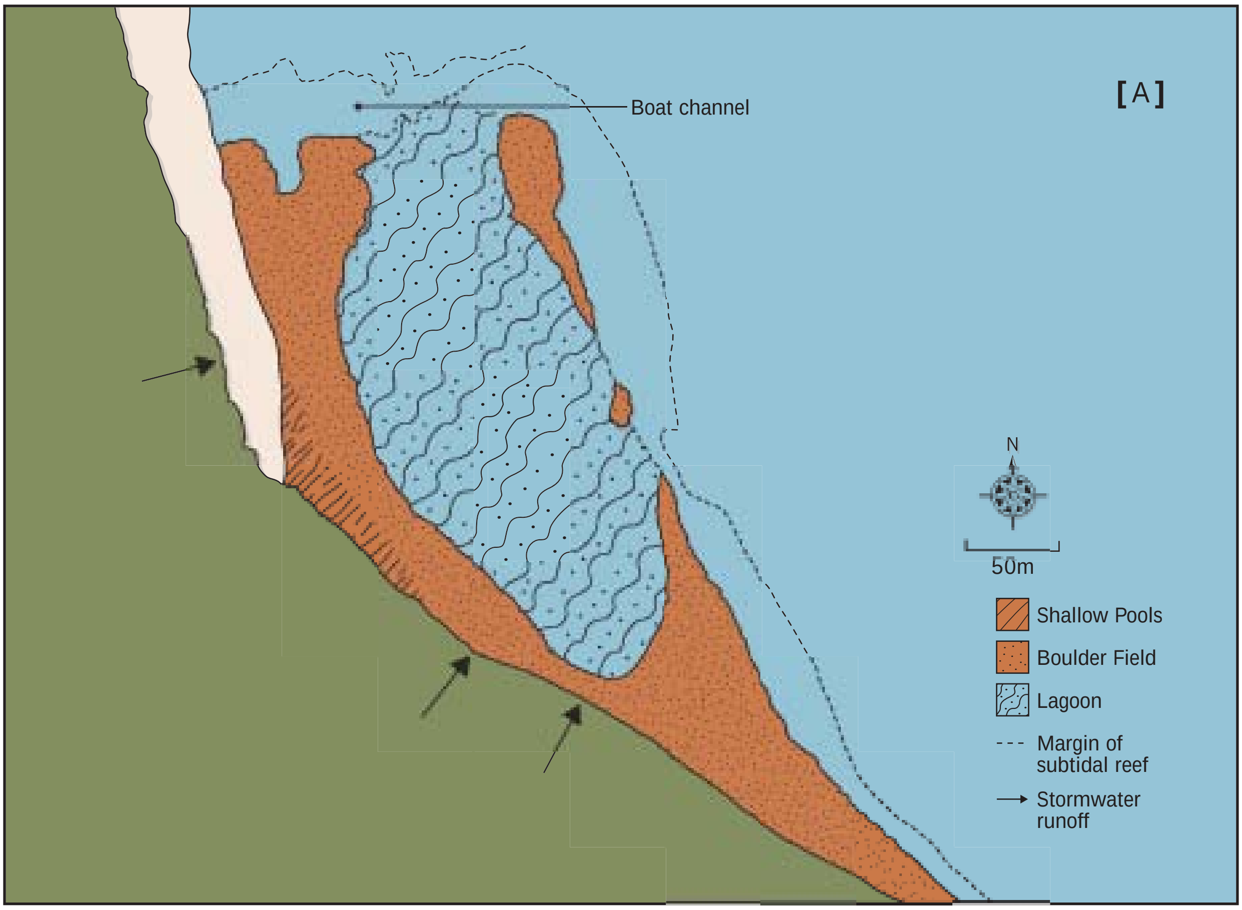
[FIGURE 4]

Non-metric multidimensional scaling (nMDS) plot for the complete data set from Flat Rock. Numbers refer to the different sampling locations shown in Fig. 2. Surveys 1-9 are from shallow pool habitats; 10-13 are from the boulder field.



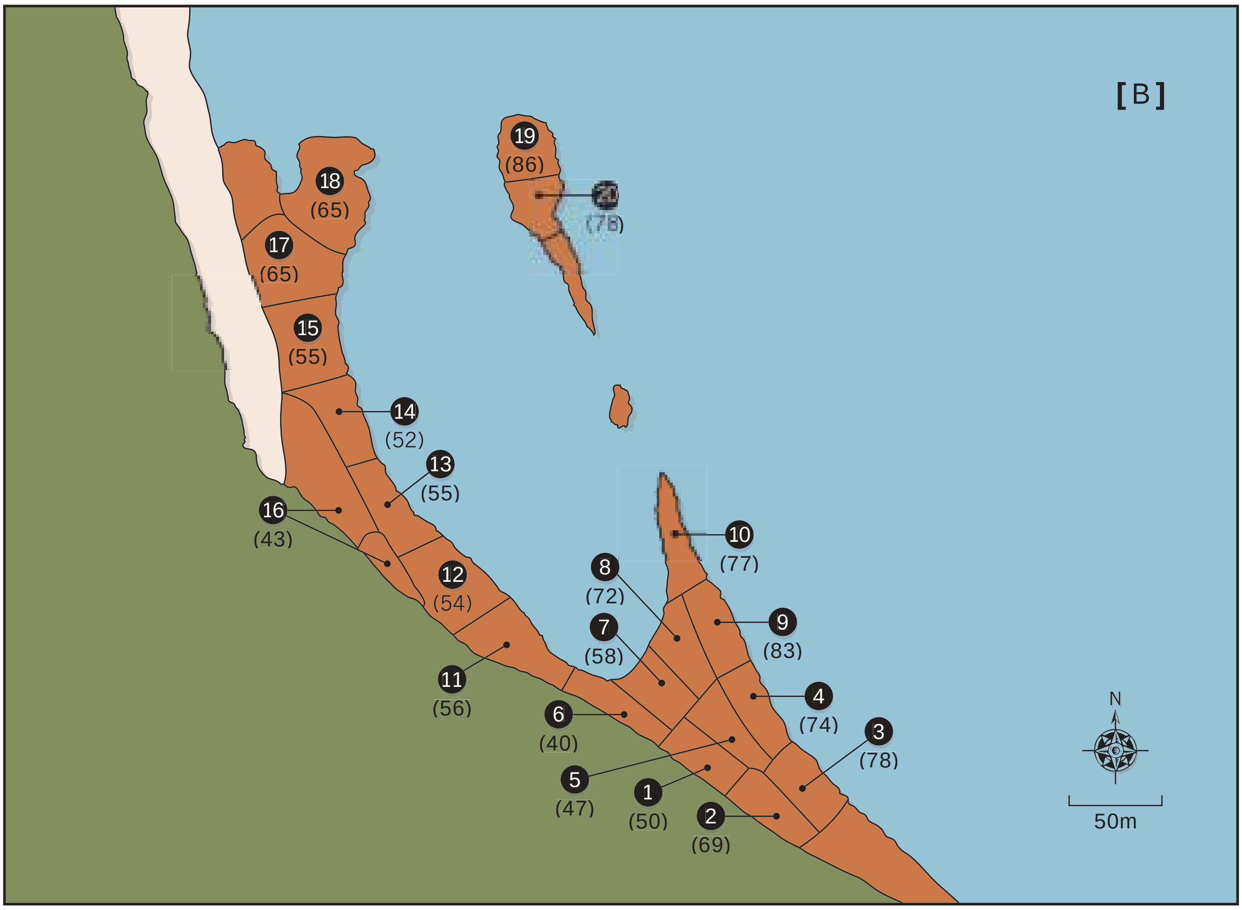
Lennox Head Reef

Lennox Head Reef (Figs. 1 & 5) is by far the most extensive of the sites surveyed during this investigation. The area south of the boat channel has been found to support the highest diversity in previous surveys (Bent 1990; Geomarine 1990; Smith 1991) and so this area was targeted in this study. The area surveyed extends 450m southward from the boat channel and reaches a maximum width of 200m from the bottom of the adjacent sandy beach to the seaward margin (Fig. 5). The reef supports a mosaic of different habitats that includes: patches of sand; boulder fields comprising basaltic boulders of various sizes; a lagoon (the Moat); and an underlying substrate of peat (Geomarine 1990). The marine communities of Lennox Head Reef have been the subject of a number of previous investigations. Three of these (Bent 1990; Geomarine 1990; Smith 1991) resulted from a proposal by Ballina Shire Council to construct rock groynes across the southern section of the reef to stabilise adjacent shorelines and halt shoreline recession. In addition to these studies, projects by third year and honours students at Southern Cross University have documented the biodiversity of the reef and commented on its regional significance (Lothian 1993; Dawes 1995; Warren 1996).



[FIGURE 5a]

Map of Lennox Head Reef showing the approximate distribution of habitats. Arrows indicate the position of the main storm-water drains and run-off areas.



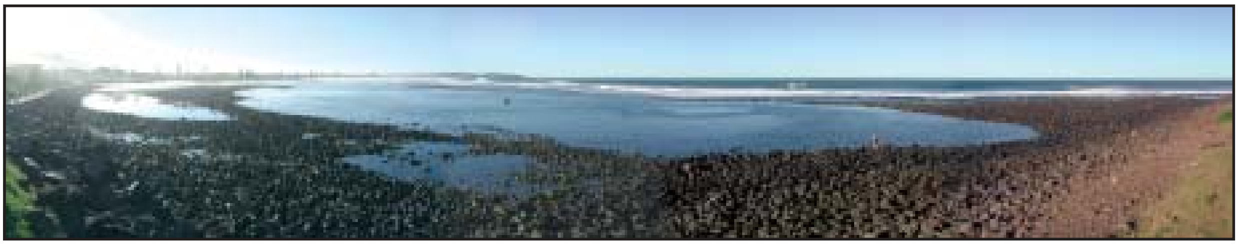
[FIGURE 5b]

Map of Lennox Head Reef showing the approximate location of each of the replicate surveys. Numerals in brackets are the number of species recorded at each survey location (replicate).

Results of this study

The extensive reef at Lennox Head is dominated by boulder fields, both intertidally and subtidally (the Moat). Indeed, although shallow pool habitat does occur, this is closely associated with boulder fields and, for the most part, is inseparable as a discrete habitat. For this reason, with the exception of one 30 minute survey, intertidal habitat at Lennox Head Reef was either classified as boulder field or lagoon (Fig. 5, Plate 9).

A total of 20 replicate 30 minute surveys were conducted in the intertidal region. Snorkelling surveys of the Moat were purely qualitative as the area was far too large to assess using the timed, semi-quantitative method applied to the more accessible intertidal region. Thus, data from the Moat comprise species lists and approximate distributions only. For convenience, the reef was stratified into different sections; these will be described separately below.



[PLATE 9]

Composite view of the section of Lennox Head Reef surveyed for this study.

Southern boulder field (surveys 1-10, Fig. 5)

The area immediately to the south of the Moat comprises an extensive boulder field which is relatively free from sand inundation. Boulders in this area are associated with extensive shallow pools most of which also contain pockets of gravel and sand providing considerable habitat heterogeneity. Broad patterns of zonation are evident across the whole area. Littorinid molluscs (*Nodilittorina pyramidalis* and *Littorina unifasciata*) dominate high on the shore occupying the boulder slope down to the high tide mark. The transition to a fully intertidal habitat is marked by a distinct change in gradient – the commencement of the intertidal platform. Broad zonation across the intertidal platform is evident by visual examination from the boulder slope. At the upper tidal level, the red alga *Porphyra* sp. coats the upper surface of boulders and the molluscs *Nerita atramentosa* and *Hinea brasiliana* form patchy, sometimes dense, aggregations beneath these boulders. At the upper tidal margin of the platform there is a rapid transition to the pool habitat where green algae (*Ulva*, *Enteromorpha* and *Cladophora*) cover the sides of most boulders; high densities of the molluscs *Austrocochlea porcata* and *Bembicium nanum* are characteristic of this zone. White encrustations of the tube worm *Galeolaria caespitosa* increase in prominence down the shore and the demarcation between the mid and lower tidal level is readily visible due to heavy growth of this species and also red coralline algae (mostly *Corallina* and *Jania*) around most boulders (Plate 10). Another habitat-forming tube-worm (*Idanthyrsus pennatus*) also increases in abundance down the shore. This species is mainly confined to the underside of boulders in the upper shore but forms extensive colonies at the lower shore where it "cements" boulders in place. In the low tide region, there is evidence of increasing sand inundation from the south of the platform to north. This is most apparent in the narrow extension of the intertidal region between the Moat and the subtidal boulder reef where sand patches are common, species richness is comparatively low and sand-tolerant biota dominate.

[PLATE 10]

The low tide region of the southern boulder field, Lennox Head Reef.

Herbivorous molluscs dominate most of the intertidal region. *Austrocochlea porcata* and *Cellana tramoserica* are abundant across the full intertidal range and *Siphonaria denticulata* is abundant on the lower shore and in most permanent pools. In the upper to mid shore region, *Bembicium nanum* is abundant on the upper surfaces of boulders while nerites (*Nerita atramentosa* and *N. albicilla*) dominate the undersides. *Montfortula rugosa*, which is also found mainly on the undersides of boulders, is present from the upper to lower shore and shows increasing abundance down the shore. Other faunal taxa that are abundant across the full intertidal range in the southern region are: the carnivorous mollusc *Morula marginalba*; the small shore crab *Pachygrapsus laevimanus*; the hermit crab *Clibanarius virescens*; the anemone *Cnidopus verater*; the bivalve *Pinctada fucata*; and the starfish *Patiriella calcar*.

There is an obvious gradient of increasing cover and diversity of algal species down the shore. The presence of permanent pools at all tidal heights provides good habitat for algae, and in particular the phaeophyta (brown algae) which provide the majority of algal cover. *Sargassum*, *Lobophora* and *Padina* are the dominant brown genera with *Dictyota* and *Dilophus* also important in pools in the mid and lower shore. Coralline algae is present from the upper-middle shore downwards with *Corallina* dominating along with species of *Jania* and *Haliptilon* (lower shore).

There were a number of features of particular note in the southern boulder field (also summarised in the Appendix). Shallow pools across the area, particularly in the mid-high tide region, supported a diverse opisthobranch assemblage (13 species) which included nudibranchs, sea-hares, side-gilled slugs and bubble shells (Plate 11). Shelled molluscs (prosobranchs) were also diverse and included a number of taxa that are popular with collectors (e.g. cowry shells) and species that, although common in death assemblages on adjacent beaches, are not often found alive (the wentletraps *Opalia australis* and *O. ballinensis*, the buccinid *Engina armillata*). In the mid-tidal region, and especially along the eastern margin of the reef, patches of *Halodule uninervis* are common and, although the blades are stunted in appearance, this seagrass covers a considerable area.
The presence of seagrass on exposed rocky shores is relatively uncommon in northern NSW (Smith and James 1999). Finally, a number of species found within the southern boulder field were not found elsewhere either at Lennox Head Reef or during the wider study of shores of CBMP. This list included two species of small, colourful nudibranchs (*Chromodoris geometrica* and *C. decora*).

[PLATE 11 – PAGE 25]

The side-gilled slug Pleurobranchus peronii *in the southern boulder field, Lennox Head Reef.*

Western boulder field (surveys 11-18, Fig. 5)

A strip on intertidal boulders runs along the western margin of the Moat terminating at the boat channel (Fig. 5). This area supports a diversity of habitats, mainly due to differences associated with the degree of sand inundation, proximity to the Moat to the east and to sand-based pools to the west, and the degree of exposure to freshwater inundation from storm-water drains that flow across the beach. Dealing with the latter first, some of the surveys were conducted during periods of moderately heavy rainfall and this provided the opportunity to observe the path, and potential effects, of freshwater run-off (the approximate position of the drains is shown in Fig. 5). All patches of reef adjacent to these drains (primarily surveys 11-15) supported lower biotic diversity than similar reef located further from sources of freshwater run-off. In addition, many of the faunal taxa found at these sites were in lower abundance that in other, similar habitats. Turbidity was also generally higher at sites adjacent to drains and there was evidence that water flow over the beach resulted in the transport of sand which smothered many sessile organisms.

In the southern section of the western boulder field, the western margin is steep and supports few biota. The eastern margin is narrow, restricting the availability of habitat for intertidal taxa. A large shallow pool that borders the Moat provides suitable habitat for a number of mollusc taxa and it is here that the density of cowries is at its highest for Lennox Head Reef. The gold-ringed cowry *Cypraea annulus* is abundant in this area; specimens of the similar money cowry (*Cypraea moneta*) are also present but are relatively uncommon. In general, the habitat is dominated by the same broad taxa that occur in the southern boulder field with similar patterns of zonation. Thus, the eastern margin that adjoins the Moat supports algal-dominated communities and aggregations of the polychaetes *Galeolaria caespitosa* and *Idanthyrsus pennatus*. Crabs and molluscs predominate at higher tidal levels and moderate populations of the holothurian *Holothuria leucospilota* are also present. Sediment inundation gradually increased from survey locations 13-15 and limited the availability of suitable substratum for sessile biota. This area was also observed to be most affected by freshwater inundation from adjacent storm-water drains. Despite this, a number of taxa that were uncommon across the surveys within the CBMP were found in this area. These, included the Hebrew cone (*Conus ebraeus*) and the money cowry (*Cypraea moneta*). Shallow, sand-based pools are present between the realigned shore-line and the strip of boulders in locations 13-15. This habitat was surveyed separately (survey 16) and, although it had a low diversity, it supported a number of species that are associated with the surface of sand habitats (note that this survey did not address infauna – those animals living within soft-sediments). A single, juvenile specimen of the red-mouthed stromb (*Strombus luhuanus*) as well as an unidentified species of sand-dwelling hermit crab were found exclusively in this habitat in the intertidal surveys (although the hermit crab was also found in the Moat).

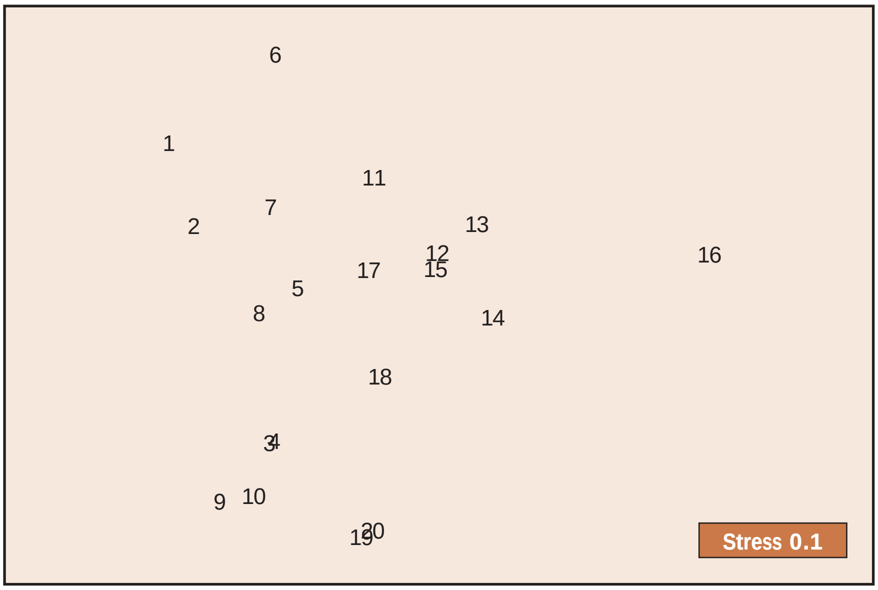
The northernmost section of boulder reef within the western region, which adjoins the boat channel (Fig. 5) was relatively free from sand and supported a moderate diversity of taxa. Of note were specimens of 3 species of cowry (*Cypraea caputserpentis*, *C. annulus* and *C. errones*), a number of opisthobranchs (including nudibranchs, sea-hares and the umbrella shell, *Umbraculum umbraculum*), 2 species of sea-urchin (*Heliocidaris erythrogramma* and *Tripneustes gratilla*), and moderate populations of the holothurian *Holothuria leucospilota*.

The north-eastern boulder field

A strip of boulders lines the eastern margin of the Moat. The intertidal section of this boulder field is narrow, discontinuous, and is confined to the southern area adjoining the southern boulder field (see Fig. 5 and description above) and to a small patch on the north-eastern margin of the Moat. The latter area emerges at low tide for a relatively short period of time but supports the highest diversity of any of the intertidal habitat at Lennox Head Reef. Boulders within this region are partially cemented in place by aggregations of tube worms and by growths of other sessile biota. However, the undersides of these boulders support diverse communities, especially of molluscs and crustaceans. One of the surveys performed in this area (survey 19, Fig. 5) returned the highest species count for any habitat within the region (85). Of note was the diversity of shells that are popular with collectors (cowries and cones); a single specimen of the Captain's cone (*Conus capitaneus*) and a number of specimens of the cowry *Cypraea gracilis*, were the only records of these species for the region. This area also supported the highest densities of the urchin *Heliocidaris erythrogramma* for the intertidal region of Lennox Head Reef.

Comparisons across areas

In order to determine the patterns of community structure across the intertidal habitats at Lennox Head Reef, a single nMDS was performed. It was anticipated that samples would fall into groups according to their relative tidal heights and that samples from adjacent to sources of freshwater inundation may separate from similar samples from elsewhere. The nMDS plot supports this prediction. Thus, in Fig. 6, there is a general trend for high tide sites to group at the top of the plot and samples from the low tide level on the eastern margin of the intertidal platform to group at the bottom of the plot. The samples in the centre of the plot are from mid-tidal heights or from mid-high tidal heights on the western margin of the Moat. Within this group there is a tendency for the samples adjacent to the beach and sources of freshwater inundation to group to the right. The sample from the shallow, sand-based pool at the top of the shore (location 16) is dissimilar to all other samples and is placed by itself to the right of the plot.



[FIGURE 6]

Non-metric multidimensional scaling (nMDS) plot for the complete data set from Lennox Head Reef. Numbers refer to the different sampling locations shown in Fig. 5.

Given these obvious patterns, SIMPER analyses were performed to determine which species: i) were characteristic of each group; and ii) were primarily responsible for differences between groups. Tables 5-7 list the species that were characteristic of each set of samples. From these lists, it can be seen that there is a suite of species that is abundant throughout the full tidal range. Thus, many of the gastropods as well as the 2 aggregation-forming polychaetes retain maximum abundance scores across the tidal gradient.

In general, the number of algal species that contribute to the core of characteristic species increases down the shore. These differences are highlighted in Table 8 which lists the taxa that are primarily responsible for the differences between the tidal levels. In this table, the taxa that, through their relative differences in abundance between tidal heights, were highest ranked as discriminators are listed. Together, these species account for 30% of the differences; smaller differences in the abundance of a range of other taxa also contribute to the overall differences in community patterns. As might be expected, taxa that have consistently high abundances across the full intertidal gradient (e.g. some of the common molluscs and polychaetes) contribute very little to the differences.

[TABLE 5]

List of species responsible for 75% of the similarities within the samples from high tide sites in the boulder field habitat at Lennox Head Reef (surveys 1, 2, 6, 7 and 11 - Fig. 5). Species are listed in their order of importance. Mean scores and taxon affinities are also shown. Average similarity = 62.05%.

Species	Taxon	Score
Morula marginalba	Gastropod	5.00
Cellana tramoserica	Gastropod	5.00
Austrocochlea porcata	Gastropod	5.00
Pachygrapsus laevimanus	Crab	5.00
Galeolaria caespitosa	Polychaete	5.00
Idanthyrsus pennatus	Polychaete	5.00
Cladophora sp.	Green algae	5.00
Ulva sp.	Green algae	5.00
Cnidopus verater	Anemone	4.83
Clibanarius virescens	Hermit crab	4.33
Bembicium nanum	Gastropod	4.17
Ritterella dispar	Ascidian	4.00
Actinia tenebrosa	Anemone	4.00
Tetraclitella purpurascens	Barnacle	4.00
Sargassum spp.	Brown algae	4.00
Montfortula rugosa	Gastropod	3.83
Nerita atramentosa	Gastropod	3.83
Patiriella calcar	Asteroid	3.33
Chthamalus antennatus	Barnacle	3.67
Pinctada fucata	Bivalve	3.67
Turbo undulatus	Gastropod	3.50
Nodilittorina pyramidalis	Gastropod	3.33

Species	Taxon	Score
Siphonaria denticulata	Gastropod	5.00
Morula marginalba	Gastropod	5.00
Bembicium nanum	Gastropod	5.00
Cellana tramoserica	Gastropod	5.00
Austrocochlea porcata	Gastropod	5.00
Clibanarius virescens	Hermit crab	5.00
Galeolaria caespitosa	Polychaete	5.00
Corallina berteri	Red algae	5.00
Cladophora sp.	Green algae	5.00
Ulva sp.	Green algae	5.00
Idanthyrsus pennatus	Polychaete	4.88
Cnidopus verater	Anemone	4.75
Sargassum spp.	Brown algae	4.75
Pachygrapsus laevimanus	Crab	4.13
Ritterella dispar	Ascidian	3.75
Thais orbita	Gastropod	3.25
Leptodius exaratus	Crab	2.88
Saccostrea cucculata	Bivalve	2.63
Ozius truncatus	Crab	2.63
Holothuria leucospilota	Holothurian	3.00
Diopatra dentata	Polychaete	2.75
Jania crassa	Red algae	3.38
Padina crassa	Brown algae	3.00
Alope australis	Shrimp	2.50
Nerita albicilla	Gastropod	2.88

[TABLE 6]

List of species responsible for 75% of the similarities within the samples from western and mid-high tide sites in the boulder field habitat at Lennox Head Reef (surveys 5, 8, 12-15, 17 and 18 - Fig. 5). Species are listed in their order of importance. Mean scores and taxon affinities are also shown. Average similarity = 70.02%.

[TABLE 7]

List of species responsible for 75% of the similarities within the samples from low tide sites in the boulder field habitat at Lennox Head Reef (surveys 3, 4, 9, 10, 19 and 20 - Fig. 5). Species are listed in their order of importance. Mean scores and taxon affinities are also shown. Average similarity = 72.95%.

Species	Taxon	Score
Pyura stolonifera	Ascidian	5.00
Siphonaria denticulata	Gastropod	5.00
Cellana tramoserica	Gastropod	5.00
Austrocochlea porcata	Gastropod	5.00
Galeolaria caespitosa	Polychaete	5.00
Idanthyrsus pennatus	Polychaete	5.00
Sargassum spp.	Brown algae	5.00
Corallina berteri	Red algae	5.00
Cladophora sp.	Green algae	5.00
Ulva sp.	Green algae	5.00
Morula marginalba	Gastropod	4.80
Thais orbita	Gastropod	4.60
Montfortula rugosa	Gastropod	4.60
Ritterella dispar	Ascidian	4.60
Dictyota dichotoma	Brown algae	4.40
Colpomenia sinuosa	Brown algae	4.40
Pachygrapsus laevimanus	Crab	4.40
Patiriella calcar	Asteroid	4.20
Pinctada fucata	Bivalve	4.00
Alope australis	Shrimp	4.00
Austrobalanus imperator	Barnacle	4.00
Lobophora variegata	Brown algae	4.20
Clibanarius virescens	Hermit crab	4.00
Tesseropora rosea	Barnacle	4.00
Diopatra dentata	Polychaete	3.00
Actinia australis	Anemone	3.60
Dilophus marginatus	Brown algae	3.20
Cnidopus verater	Anemone	3.20
Leptodius exaratus	Crab	3.00
Scutus antipodes	Gastropod	2.60
Haliptilon roseum	Red algae	3.40
Holothuria leucospilota	Holothurian	2.60

	Western/MidHigh	**Low**
High	Nodilittorina pyramidalis (G) Littorina unifasciata (G) Jania crassa (RA) Chthamalus antennatus (B) Tetraclitella purpurascens (B) Halodule uninervis (SG) Nerita atramentosa (G) Montfortula rugosa (G) Red algae sp. 3 (RA) Pinctada fucata (Biv) Tesseropora rosea (B) Lobophora variegata (BA) Hinea brasiliana (G) Actinia australis (An) Padina crassa (BA)	Bembicium nanum (G) Tetraclitella purpurascens (B) Nerita atramentosa (G) Chthamalus antennatus (B) Austrobalanus imperator (B) Nodilittorina pyramidalis (G) Littorina unifasciata (G) Actinia tenebrosa (An) Tesseropora rosea (B) Haliptilon roseum (RA) Nerita albicilla (G) Dilophus marginatus (BA) Alope australis (Sh) Dictyota dichotoma (BA) Actinia australis (An) Heliocidaris erythrogramma (Ech)
Western/MidHigh		Bembicium nanum (G) Austrobalanus imperator (B) Haliptilon roseum (RA) Jania crassa (RA) Dilophus marginatus (BA) Nerita albicilla (G) Pyura stolonifera (Asc) Montfortula rugosa (G) Heliocidaris erythrogramma (Ech) Ozius truncatus (C) Lobophora variegata (BA) Red algae sp. 3 (RA) Austromegabalanus nigrescens (B) Halodule uninervis (SG) Jania crassa (RA) Tesseropora rosea (B)

[TABLE 8]

Summary of the results of SIMPER analysis determining the species primarily responsible for differences between the areas of boulder field at Lennox Head Reef. The species that contribute to the first 30% of differences are listed and are aligned with the tidal level at which they had the higher abundance score. Taxon codes: An = anemone; Asc = ascidian; B = barnacle; BA = brown algae; Biv = bivalve; C = crab; Ech = echinoid; G = gastropod; RA = red algae; SG = sea grass; Sh = shrimp.

The Moat

Results of this study

The Moat area was examined on two separate occasions over a total survey time of approximately 4 hours. Surveys were conducted on snorkel which proved adequate to evaluate general cover and community structure but may have prevented some of the smaller and cryptic taxa from being observed and recorded. A species list (without abundance scores) for the Moat is presented as part of the Appendix. The area surveyed supported a mosaic of algal-covered reef and sand patches. Brown algae dominated patches of reef with most cover comprising one or more of 5 species: *Sargassum* spp., *Padina crassa*, *Lobophora variegata*, *Dictyota dichotoma* and *Dilophus marginatus* (Plate 12). Species of red and green algae were also very common and contributed to the general pattern of algal dominated substratum. Seagrass provided the main cover in some of the sand patches and also on one small area of reef in the middle section of the Moat. Two species are present, *Zostera capricorni* and *Halodule uninervis* (Plate 13). Of these species, *H. uninervis* is by far the most abundant covering extensive areas around both the margins and central sections of the Moat (but with little growth in the south and south-western areas) (Dawes 1995). As described above, this species is also very common within the southern and eastern intertidal boulder fields. *Z. capricorni* is confined to one dense patch measuring approximately 6m^2 in the centre of the Moat. The high cover of algae and seagrass, combined with the shallow water and relatively sheltered conditions, suggests that the Moat is an important area of primary production for Lennox Head Reef. Invertebrate consumers, however, are present in low abundances suggesting much of the production is either exported to adjacent habitats or consumed by herbivorous fish.

[PLATE 12]

Algal-dominated benthic habitat in the Moat, Lennox Head Reef.

[PLATE 13 – TOP & BOTTOM]

Seagrass is the dominant cover in sandy patches in the Moat, Lennox Head Reef.

In general, invertebrate fauna within the Moat were sparse. This can tentatively be explained by the very obvious sediment dynamism that was evident within the Moat. Thus, most reef surfaces were covered in a film of sand and there was considerable evidence of recent increases in sand levels (i.e. algae protruding from sand but still attached to reef below the sand surface). This situation was particularly evident in the southernmost areas of the Moat. Large invertebrates were mostly confined to the northern and north-western areas and were dominated by large turban shells (*Turbo imperialis*) and the urchins *Heliocidaris erythrogramma* and *Tripneustes gratilla* (Plate 14). The large, carnivorous mollusc *Thais orbita* was also relatively common in the mid-western and north-western area. Large aggregations of the tube-building polychaete worm *Idanthyrsus pennatus* provided habitat for moderate populations of urchins in the northern half of the Moat.

[PLATE 14]

The sea urchin Tripneustes gratilla *in the Moat, Lennox Head Reef.*

In an attempt to find more cryptic animals, boulders were turned wherever possible. In most cases, this process revealed few taxa as the sand underlying the boulders was grey-black in colour indicating reduced, anoxic conditions. Some smaller taxa were observed in other habitats within the Moat, however, and these included shrimps, crabs, hermit crabs and a number of species of mollusc including a single specimen of the sand-dwelling stromb *Strombus mutabilis*. Of note in the southern Moat were juvenile specimens of two urchins, *Salmacis* sp. and *Pseudoboletia indiana*.

In addition to recording the biota, it was also possible to make a number of basic observations on the hydrodynamics of the Moat area. The first survey occurred during a period of moderate to heavy rainfall when there was considerable run-off from the adjacent land. The fresh water entering the Moat in the south-western corner appeared to undergo little mixing with sea water and instead formed a surface, fresh-water lens. Further to the north, fresh water running over the beach increased turbidity dramatically, mixing with the sea water in the Moat and reducing underwater visibility to less than 1m in the adjacent, western area. This effect diminished eastwards. During the surveys, the maximum period during which the Moat was free from wave action was approximately 1.5 hours. As soon as the tide rose sufficiently for waves to breach the outer barrier of the Moat, a current was set up flowing northward into the boat channel. Towards the northern area of the Moat, this current was sufficient to influence algal and sediment movement.

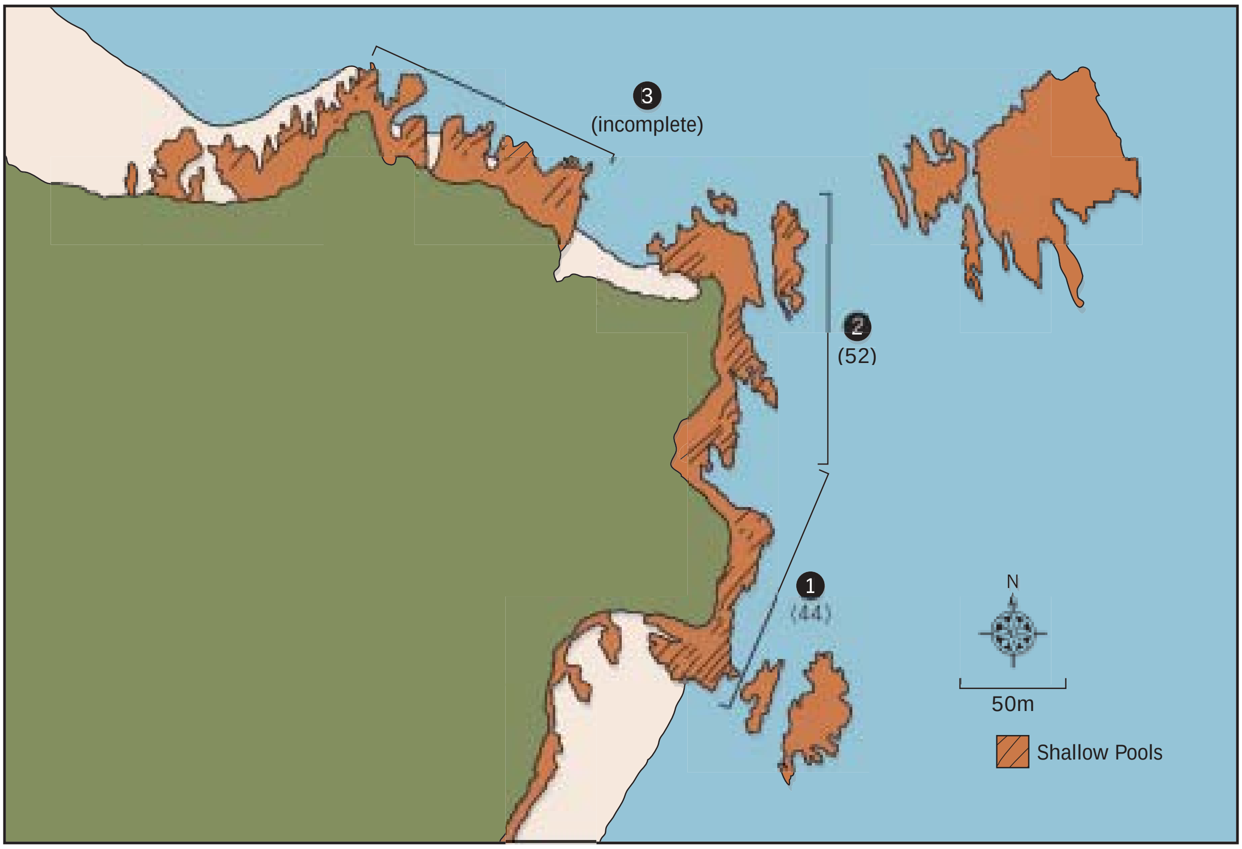
Comparison with previous studies

Because the Moat at Lennox Head Reef has been the focus of a number of previous studies it is possible to provide a comparison of the results of this study with earlier works. The most striking differences were evident for the population structure of the sea-urchins and also the general species richness of the Moat. In this study, urchins were most abundant in the northern section of the Moat and were rare or absent from the southern region. In 1990 Bent indicated that the invertebrate assemblage in the Moat was dominated by urchins and that 8 species were present. In a study conducted one year later (Smith 1991) 4 species were found during a single, brief investigation and one of these (*Heliocidaris erythrogramma*) was found to be abundant. In a study that targeted urchins, Lothian (1993) recorded 7 species of urchin and reported densities of the most common species (*Centrostephanus rodgersii*) of 11.3 per square metre. *Heliocidaris erythrogramma* also occurred in moderate densities with a mean of 3.95 per square metre. Finally, Warren (1996) repeated the surveys conducted by Bent (1990) and found no specimen of *C. rodgersii*, high abundances of *H. erythrogramma*, and a total of 4 urchin species within the Moat. To recap the results of the present study, 4 species of urchin were found in the Moat of which *H. erythrogramma* and *Tripneustes gratilla* were moderately common in the northern region, and *Salmacis* sp. and *Pseudoboletia indiana* were represented by 2 and 1 specimen, respectively, in the southern area of the Moat. No *C. rodgersii* were recorded although dead tests of urchins that were approximately the right size for this species were sighted along the western margin of the Moat. It is difficult to know how to interpret these data other than to say that there is considerable dynamism in urchin assemblages within the Moat. However, the comparatively low abundance of urchins encountered during this study almost certainly reflects the lack of suitable habitat. Thus, most rocky surfaces were covered in a layer of sand and urchin populations were mostly confined to the relatively sand-free substrata in the northern part of the Moat. Of concern is the apparent decline in urchin abundance over time. Thus, the earlier studies suggested that urchins were dominant components of benthic assemblages; both species richness and abundance of the dominant species appear to have declined since 1993. Although it is impossible to determine a cause for this decline, changes in the physico-chemical conditions in the Moat resulting from the realignment of the shoreline and the establishment of storm-water drains can not be ruled out as a potential contributor.

Broken Head

Broken Head is the northernmost headland of a complex of small headlands that stretch for a number of kilometres to the south. The headland is composed of metamorphic rock (greywacke) with a steep profile and little platform development. There is very little rocky intertidal habitat at the northern end of the headland with the best developed area in the mid and southern sections (Fig. 7).

The narrow platform combined with the relatively high wave energy restricts the ability of the site to support diverse intertidal communities. Habitat diversity is low. Shallow pools are scattered across the headland but many of these are inundated with sand and thus provide relatively poor habitat for marine biota. A total of 2 replicate 30 minute surveys were conducted in the shallow pool habitat. A third was started but there was insufficient habitat to complete this replicate.



[FIGURE 7]

Map of Broken Head showing the distribution of habitats and approximate location of each of the replicate surveys. Numerals in brackets are the number of species recorded at each survey location (replicate).

Results of this study

A total of 60 species were recorded from Broken Head comprising 21 algal, and 39 faunal, species. Species richness was relatively low in all replicate surveys at Broken Head (Fig. 7). The highest species count was for the mid-section of the headland from which 52 species were recorded over the 30 minute search time. Pools to the south were generally more exposed to wave action and those to the north were affected by sand inundation from the adjacent beach. The higher species count for the mid-headland region partly resulted from the additional habitat offered by a small outcrop of rock which is separated from the headland at high tide. Shallow pools at the low tide level at this location supported a number of species that were not found elsewhere on the headland (the red alga *Rhodymenia* sp., the tube worm *Sabellastarte* sp., and a number of mollusc and ascidian species – see the Appendix). In general, most shallow pools contained sand and only vertical surfaces supported appreciable growths of sessile biota, primarily dominated by algae. Anemones were abundant in most pools, especially the sand-tolerant species *Oulactis muscosa* and the large green species *Cnidopus verater* (Plate 15). The suite of molluscs that were abundant at all other headlands also dominated the mollusc fauna at Broken Head (*Austrocochlea porcata*, *Bembicium nanum*, *Cellana tramoserica*, *Morula marginalba* and *Montfortula rugosa*). Of interest was the presence of sometimes dense aggregations of two species of small anemones which lined the cracks in some of the pools. One species was unidentifiable but the second, and most abundant species appeared to be *Actinia tenebrosa* (although small specimens). These aggregations were not found at either Flat Rock or Lennox Head Reef but were also common at Cape Byron (Plate 16). The low tide region in the mid and southern section of the headland was dominated by algae with the ascidian *Pyura stolonifera* also forming dense cover in some areas. Motile fauna at the same tidal level included the swift-footed shore crab, *Leptograpsus variegatus*, and the shiny bait crab, *Plagusia glabra*.

[PLATE 15]

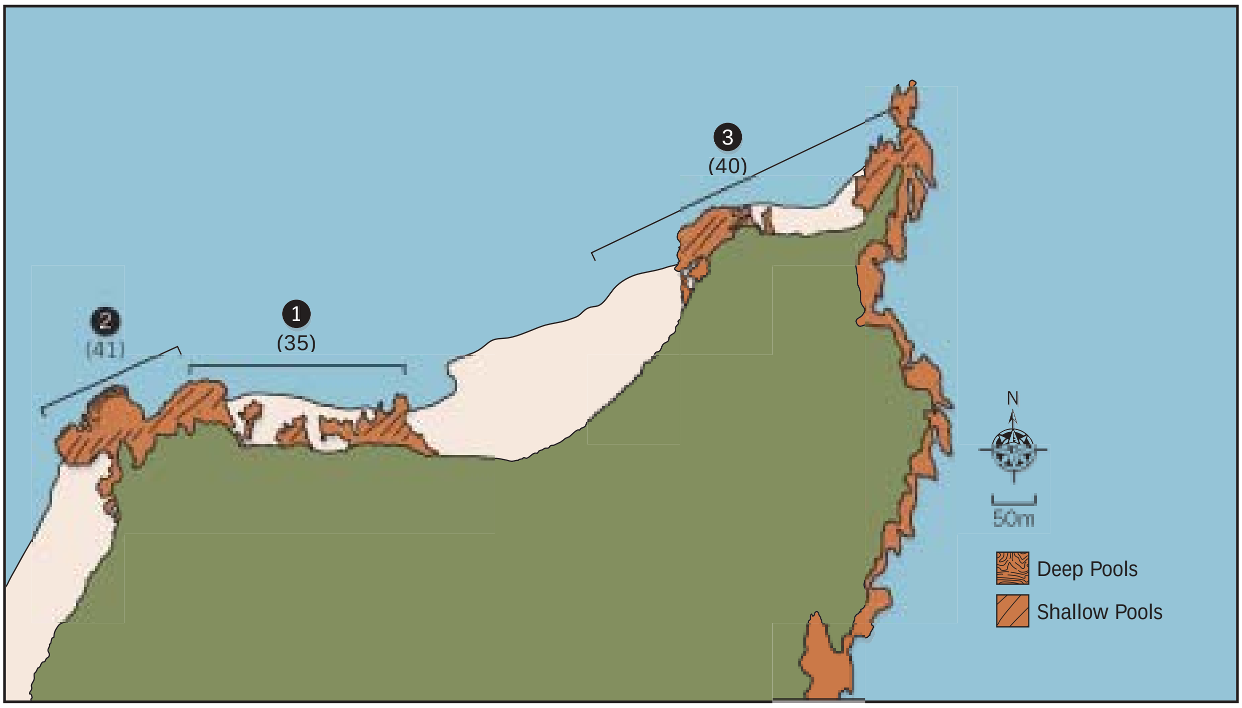
The anemone Oulactis muscosa *in sand-dominated pools at Broken Head.*

[PLATE 16 – TOP & BOTTOM]

Two species of small anemones found in aggregations in sand-dominated pools at Broken Head and Cape Byron.

Cape Byron

The study site at Cape Byron was very similar, both in topography and community structure, to the northern section of Broken Head. Thus, although the substratum comprises hard-wearing greywacke which has the potential to support diverse intertidal communities, community development is constrained by the lack of suitable platform and also the influence of sand inundation from the adjacent beaches. Surveys of the Cape Byron region spanned the area from The Pass to the north-eastern tip of the Cape (all termed the "Cape sites" below – Fig. 8). Despite the relatively large area this represents, the paucity of habitats and biotic diversity is reflected in the fact that the whole area was examined in just 3 replicate 30 minute surveys.



[FIGURE 8]

Map of Cape Byron showing the the distribution of habitats and approximate location of each of the replicate surveys. Numerals in brackets are the number of species recorded at each survey location (replicate).

Results of this study

Shallow pools were scattered throughout the rocky shore across the Cape sites; deep pools were also present at The Pass but were represented by few examples (Fig. 8). For this reason, data for these pools were combined with those for shallow pools. A total of 47 taxa were recorded from the Cape sites, comprising 20 algal, and 27 faunal, species. With the exception of the intertidal area adjacent to The Pass, most pools were filled with sand leaving little available substratum for the establishment of sessile communities (Plate 17). As at Broken Head, algal communities dominated in these pools and the fauna were mainly confined to the suite of common gastropod molluscs and anemones.

At The Pass, the shore had a steep profile but still supported a number of pools that were relatively free from sand. These pools generally supported a greater diversity of biota including sponges, ascidians and some species of algae that were uncommon or absent at other sites (e.g. *Galaxaura spatulata – Plate 18*). Crabs were also common in the mid to low tide areas around The Pass and at some other sites (the eastern point of the Cape) with *Ozius truncatus* found sheltering in crevices amongst areas of the tube-worm *Galeolaria caespitosa* and the swift-footed shore crab (*Leptograpsus variegatus*) and the shiny bait crab (*Plagusia glabra*) found foraging on the lower shore. In general, the diversity in pools was low compared to Flat Rock.

[PLATE 17]

Sand-inundated rocky intertidal habitat at Wategos Beach, Cape Byron.

[PLATE 18 – PAGE 39]

Deep pools are present on shores adjacent to The Pass. Biota in these pools includes algae that were uncommon, or absent, at other sites (e.g. Galaxaura spatulata *– pictured).*

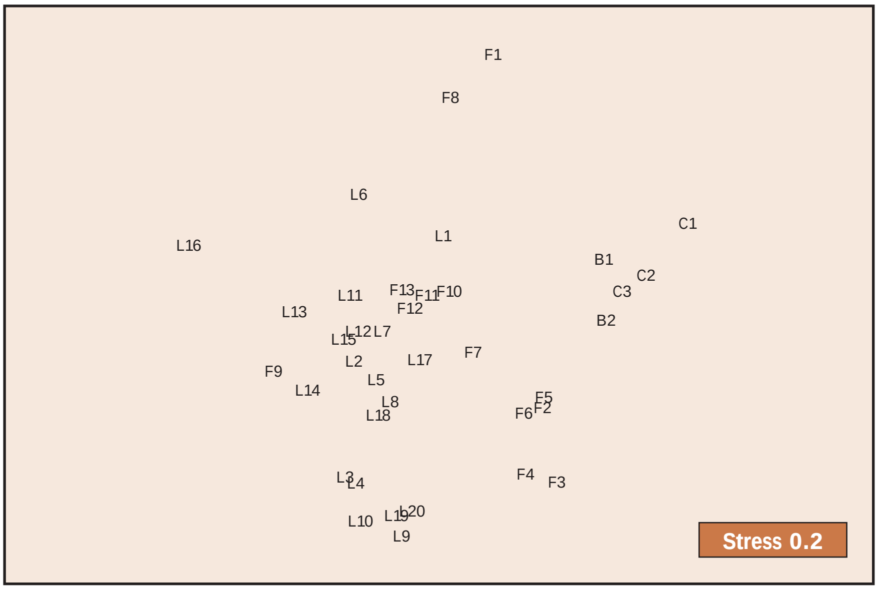
Comparisons across sites

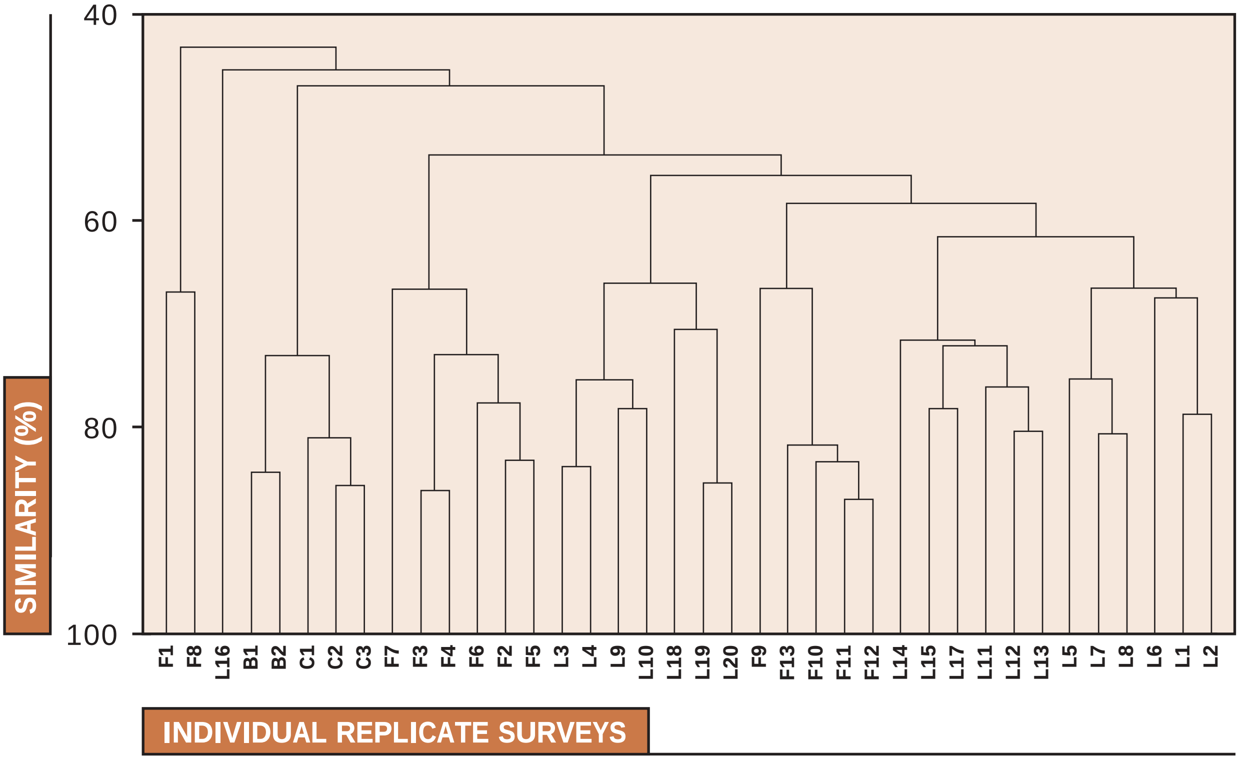
Community structure

Using the data from all 38 of the 30 minute replicate surveys conducted during the study, it was possible to determine the broad patterns of community structure occurring across the 4 sites included in the study. Data were analysed using nMDS and cluster analysis. Cluster analysis uses the same similarity matrix as nMDS but instead of displaying the results in a two-dimensional ordination, the output is a dendrogram in which similar samples form discrete clusters. Cluster analysis is often useful to confirm patterns evident in nMDS plots or to clarify patterns when these are ambiguous in the nMDS analysis. In this case, the nMDS (Fig. 9) identifies some strong patterns across the samples from the 4 sites. The samples from the Cape and Broken Head are similar to each other and form a group to the right of the plot. Below and slightly to the left of this group is a group of 5 samples, all from the marginal pools at Flat Rock. Below and to the left of this group is the group of low tide boulder field samples from Lennox Head Reef. The large group of samples in the centre of the plot comprises mid-tide samples from the boulder field at Lennox Head Reef but also includes the boulder field samples from Flat Rock. At the top of the plot are the central pools from Flat Rock; between these and the central group are the high tide boulder field samples from Lennox Head Reef. The single sample from the sand-based shallow pools at Lennox Head Reef is placed at the extreme left of the plot. The cluster analysis provides a little more information on similarities in community structure (Fig. 10). Focusing on the region between 70-80% similarity, it can bee seen that discrete groups of samples are evident. Starting at the left of the plot, the first cluster of 2 samples comprises the central pool samples from Flat Rock. The shallow pool sample from Lennox Head Reef is clearly distinct from all other samples and has a similarity of only 45% with all others. The rest of the dendrogram shows distinct clustering of samples with clusters comprising (from left to right); all samples from Broken Head and Cape Byron; the marginal pools from Flat Rock; the low tide boulder field samples from Lennox Head Reef; the boulder field samples from Flat Rock plus the sample from the adjacent shallow pools at the low tide level; the mid-tide samples from boulder fields at Lennox Head Reef; and the mid to high tide samples from boulder fields at Lennox Head Reef. These patterns match those in the nMDS (Fig. 9) but also clarify the distinction between boulder field samples from Flat Rock. To summarise, there are a total of 7 groups of samples representing distinct community types plus one additional sample (survey 16 at Lennox Head Reef) that does not readily fit into any of these major groups. Differences in species richness between the main groups are explored further, below.

[FIGURE 9]

Non-metric multidimensional scaling (nMDS) plot for the complete data set from rocky intertidal surveys in the Cape Byron Marine Park. Sample labels refer to the individual replicate surveys conducted at each site as shown in Figs. 2, 5, 7 and 8. F = Flat Rock; L = Lennox Head Reef; B = Broken Head; and C = Cape Byron.



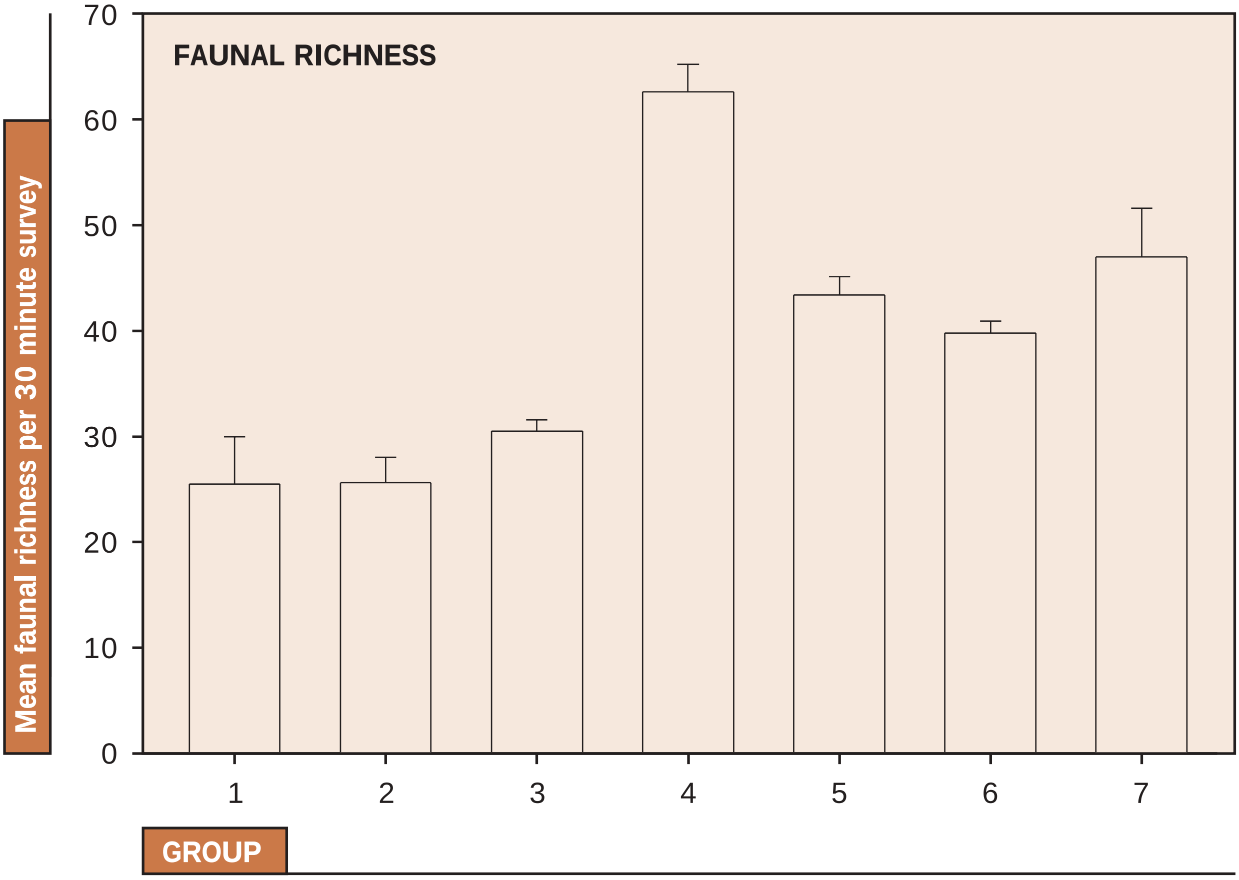


[FIGURE 10]

Cluster analysis for the complete data set from intertidal surveys conducted for this study. Sample labels refer to the individual replicate surveys conducted at each site as shown in Figs. 2, 5, 7 and 8. F = Flat Rock; L = Lennox Head Reef; B = Broken Head; and C = Cape Byron.

Comparisons of species richness

Because algal data are considered to be indicative only, comparisons of species richness were made using the data for the fauna. Samples were grouped according to the 7 distinct community types identified above and compared using one-way analysis-of-variance (ANOVA). The plot of mean faunal richness by group (Fig. 11) shows a clear distinction between some groups. The low tide boulder field samples at Lennox Head Reef supported the highest species richness with an average of 62.6 faunal species per 30 minute survey. Interestingly, the high tide boulder field samples from Lennox Head Reef supported the second highest species richness (47.0) despite the fact that diversity is generally considered to be lowest at the high tide mark, increasing down the shore. In this case, this is primarily due to the presence of sheltered pools within the boulder field at high tide sites. All groups of boulder field samples had higher mean species richness than groups of shallow pools samples. These descriptive patterns were confirmed by the results of the ANOVA which showed a highly significant difference in species richness across the sample groups ($F = 24.10$; df = 6, 30; $P < 0.001$). *Post hoc* comparisons of means between each group using Tukey's HSD test (Table 9) indicated that the low tide boulder field habitat at Lennox Head Reef supports a significantly higher species richness than all other groups. With the exception of the comparison between the central pools at Flat Rock and the western and mid-high tide pools at Lennox Head Reef, all sample groups from boulder fields supported a significantly greater species richness than sample groups from shallow pools. There was no significant difference between samples from shallow pools at Flat Rock (central), Flat Rock (marginal) and the Broken Head/Cape Byron complex.



[FIGURE 11]

Mean faunal richness (±SE) per 30 minute survey period for groups identified as supporting different community structure in multivariate analyses (Figs. 9 and 10). Group codes: 1 = Flat Rock central pools; 2 = Broken Head and Cape Byron; 3 = Flat Rock marginal pools; 4 = Lennox Head Reef low tide boulder fields; 5 = Flat Rock boulder fields and adjacent low tide shallow pool; Lennox Head Reef western boulder fields; 7 = Lennox Head Reef mid-high tide boulder fields.

	2	3	4	5	6	7
1	ns	ns	***	*	ns	**
2		ns	***	**	*	***
3			***	*	ns	**
4				***	***	**
5					ns	ns
6						ns

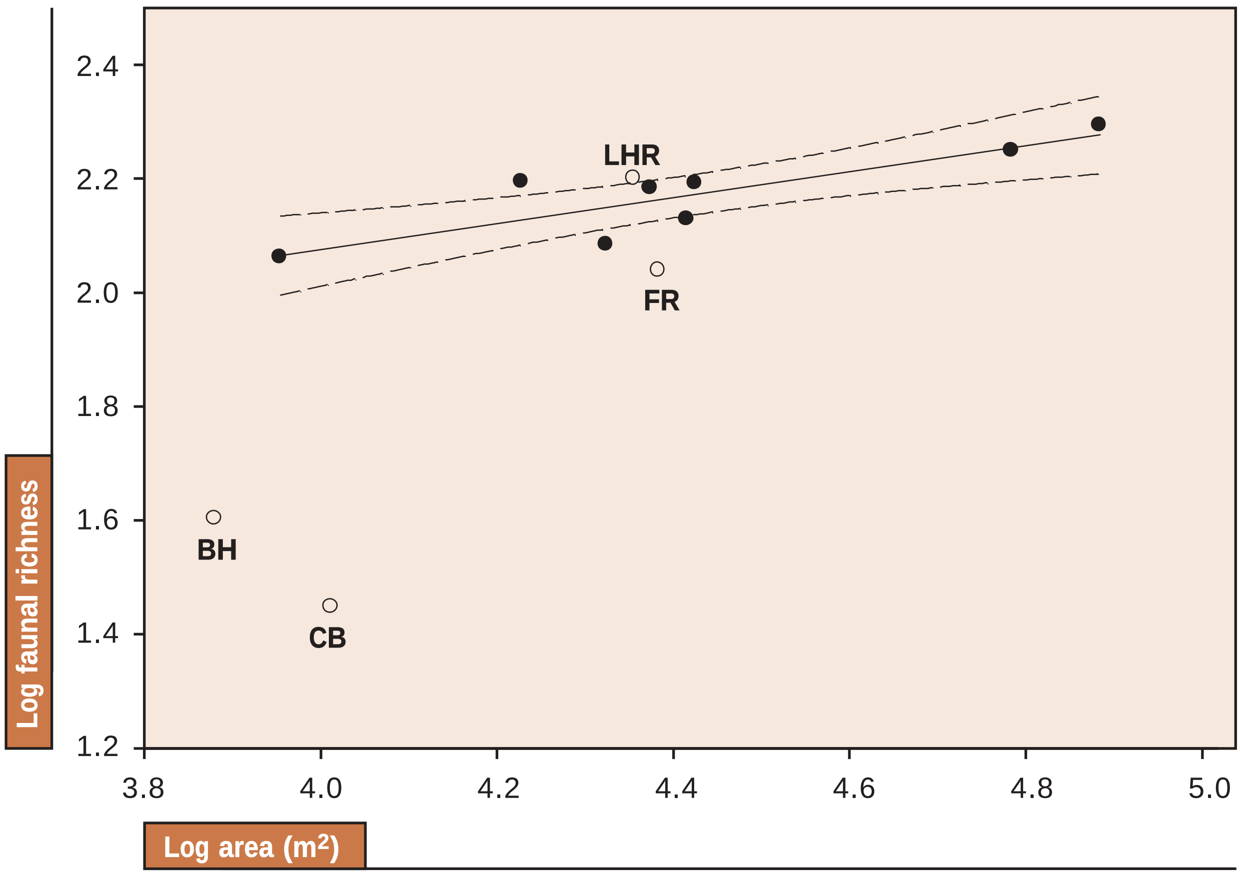
[TABLE 9]

*Summary of post hoc comparisons (Tukey's HSD) of species richness across the 7 community types identified in the multivariate analysis of the total data (Figs. 9 and 10). ns – P > 0.05; * – P < 0.05; ** – P < 0.01; *** – P < 0.001. Columns and row labels refer to the sample groups listed in the caption for Fig. 11.*

Comparisons with surveys from the Solitary Islands Marine Park

Two main comparisons were possible between the regions: a comparison of mean number of species encountered per 30 minute replicate survey in the two main habitat types (shallow pools and boulder fields); and a comparison of species richness at the scale of the headland/platform taking the total survey area at each site into consideration. For the first analysis, replicate samples were pooled across sites within a region to provide replicate species richness measures at the scale of the habitat. Because algal assessments were indicative only, all analyses were for faunal species richness.

The shallow pool habitats differed considerably between the Byron Bay region (mean = 29.9, SE = 1.67) and the SIMP (mean = 53.0, SE = 1.52); sites surveyed for this study supported approximately 56% of the species richness recorded within the SIMP. Statistical analysis using ANOVA indicated that this difference was highly significant ($F = 71.10$, df = 1, 55, $P < 0.001$). For the boulder field habitat, samples from the SIMP (mean = 57.7, SE = 2.40) were also more species rich than samples from the same habitat in the Byron Bay region (mean = 50.2, SE = 2.41) but the differences were less marked although still significant ($F = 4.83$, df = 1, 45, $P = 0.033$).



[FIGURE 12]

Comparison of faunal species richness between sites in the Solitary Islands Marine Park (filled symbols) and those surveyed for this study (unfilled symbols - labelled by site) taking the area of each site into consideration. Both variables are $\log_{10}$ transformed. LHR = Lennox Head Reef; FR = Flat Rock; BH = Broken Head; CB = Cape Byron.

sites surveyed within the Byron Bay region supported equivalent faunal species richness to headland sites within the SIMP – Lennox Head Reef. Fig. 12 presents a comparison of faunal species richness by plotting the logarithm (log_{10}) of the number of species occurring at each headland against the logarithm of the area surveyed. Areas were determined by tracing actual survey sites using maps at the scale of 1:3000 (orthophoto series) (SIMP sites – Smith & James 1999), or extracting areas from the GIS database established for the Byron Bay region. The regression line fitted to the data points for sites from the SIMP shows the relationship between faunal species richness and area; this line explains 73.1% of the variation between the area and species richness (i.e. $r^2 = 0.731$). The dashed lines indicate the 95% confidence intervals. The unfilled symbols represent the samples from this study. While none of these points fall within the 95% confidence intervals, the data point for Lennox Head Reef lies above the regression line indicating a higher species richness than would be predicted based on area alone using the SIMP model. It should be noted that the Moat was excluded from this analysis, both in terms of the species encountered there and the area of the Moat, as it was not assessed using the rigorous searching methods applied to the more accessible intertidal habitats. The data point for Flat Rock lies below the SIMP regression indicating a lower species richness than would be predicted based on area alone according to the SIMP model. The data points for Cape Byron and Broken Head both lie considerably below the regression indicating much lower species richness than sites of equivalent area in the SIMP.

These comparisons indicate that the two dominant habitats at the sites surveyed in the Byron Bay region support a lower species richness than similar sites in the SIMP and that these differences are more marked for shallow pools. Lennox Head Reef supports a faunal species richness that is greater than equivalent sites in the SIMP but all other sites surveyed during this study support lower species richness than would be predicted by the SIMP model.

DISCUSSION AND RECOMMENDATIONS

This rapid assessment of rocky shore biodiversity at 4 sites in the Byron Bay region has identified some important patterns of community structure across sites and across habitats within and between sites. The most important observation with respect to the design of a systems of zones for the park is that 7 different community types can be readily identified. If the objective of the park is to provide the maximum level of protection to areas that support each distinct habitat type, representatives of each of these community types should be targeted. An important issue here is that Flat Rock is outside the current boundaries of the CBMP. However, it supports the largest area of shallow pools within the region and also 3 of the 7 distinct community types identified during the study. In addition, there were a number of species found at this site that were not found at any of the headlands/reefs that were surveyed. These included species of tropically affiliated taxa including cnidarians (a species of unidentified zoanthid) and echinoderms (the urchin *Diadema savignyi*).

Based on habitats diversity, species richness, heterogeneity of community structure, and presence of the low energy, productive lagoon (the Moat) Lennox Head Reef has the highest conservation value of any of the sites surveyed for this study. Boulder fields have been found to support the greatest species richness on intertidal shores elsewhere (e.g. Smith et al. 1997; Smith & James 1999): the extensive boulder field at Lennox Head Reef is no exception. Sites along the eastern margin of the reef supported the highest species richness encountered at any site. Comparisons between sites within the Solitary Islands Marine Park based on the area of individual sites also suggest that Lennox Head Reef is important at an inter-regional scale. For these reasons, we suggest that Lennox Head Reef is given the maximum level of protection within the CBMP. We further recommend that management measures include efforts to ensue that adjacent land-management issues do not compromise the conservation value of the site (see below).

Despite the comparatively low species richness of rocky shore habitats associated with Broken Head and Cape Byron, shallow pools in these areas supported a community type that was not represented at the other sites. These communities appear to comprise taxa that are tolerant of periodic sand inundation as well as moderate wave action. Protection of one of these sites within a Sanctuary zone would ensure that this community type is adequately represented within the zoning scheme for the park. Given the higher species richness at Broken Head and the presence of the rocky reef and islets immediately offshore, this site may the best candidate for Sanctuary zoning.

The approach adopted in this study focuses on rapid assessment of rocky shore biodiversity and identifying distinct community types as well as habitats that support high species richness or unusual taxa. These results have been used to make the recommendations outlined above. The principle of the recommendations is that distinct habitats should be represented and, where there is a choice of sites that support the same community type, the one with the highest species richness should be afforded greater levels of protection. This represents the idea of selecting complementary areas rather than just those that support the most species. A more objective way of assessing the data to ensure that the system of zones provides protection for complementary habitats is by using complementarity analysis (e.g. Margules & Pressey 2000; McDonnell et al. 2002). These methods have recently been used to assist decision-making processes for the Representative Areas Program in the Great Barrier Reef Marine Park. We strongly recommend that additional data are gathered from throughout the CBMP to facilitate the application of these powerful reserve design tools for future reviews of the zoning scheme. Given the few sites that were assessed here, and the likely size of the management units to be used in the CBMP (i.e. the scale of the whole headland/platform for rocky intertidal shores), the application of complementarity analysis was, arguably, inappropriate for the data presented here.

Management issues identified during the study

The first issue has already been identified above – the fact that Flat Rock is currently outside the CBMP boundaries. Given the fact that this site supports the best examples of shallow pools within the region and 3 habitat types not fully represented elsewhere, careful consideration should be given to extending the marine park boundary southward to include this site.

The second issue has also been mentioned previously but, in our opinion, needs additional emphasis – storm-water run-off onto Lennox Head Reef. The data presented here indicate, unequivocally, that the area of intertidal habitat at Lennox Head Reef is the most diverse within the region and that it supports specific community types that do not occur elsewhere. The Moat area provides a sheltered habitat which would appear to have high primary productivity of both algae and seagrass. For these reasons, the area to the south of the boat channel can be considered to be of high conservation value and thus warrants careful management to ensure that these values are not compromised.

From observations made during the field work for this project, storm-water run-off has the potential to adversely affect benthic communities at this site through: sudden and considerable changes in salinity during periods of heavy rainfall which can potentially affect organisms through osmotic shock; the transportation of sediments from the adjacent beach which can bury and smother benthic organisms; the transportation of pollutants from the adjacent urban area (e.g. hydrocarbons, heavy metals, nutrients, organic material, litter). Storm-water run-off was observed in a number of areas on the western margin of Lennox Head Reef with the most obvious effects occurring adjacent to the large drain at the top of the beach to the west of the mid-section of the Moat (Plate 19). The effects of run-off from this drain were evident throughout the field work at the site and limited data gathering at times due to the high levels of turbidity encountered at adjacent sites. The fact that this is not an unusual occurrence is supported by the fact that erosion tracks are evident in aerial photographs taken in 1999 from which the maps for this report were produced.

It is possible that the establishment of storm-water drains has affected sediment dynamics in the Moat. One of the potential explanations for the apparent decline in urchin abundances since 1993 is that suitable habitat has been removed by increasing rates of sedimentation, possibly attributable to sediment transport from the adjacent beach. One method of examining this would be to review aerial photographs of the Moat area over the time scales of interest (e.g. 1970 to the present) to examine comparative cover of sand and reef habitats. However, regardless of the outcome of such an investigation, the visual evidence gathered during this study is sufficient for us to strongly recommend that alternatives to the current method of storm-water channelling are considered as part of the management strategy for this important part of CBMP.

[PLATE 19]

Erosion channel caused by the main storm-water drain adjacent to the Moat (Fig. 5), Lennox Head Reef.

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