THE SUBTIDAL SEAWEED COMMUNITIES OF THE SYDNEY REGION

P. A. FARRANT and R. J. KING

School of Botany
University of New South Wales
Kensington NSW 2033

INTRODUCTION

Three periods have been recognised in the history of Australian marine phycology (Ducker, 1981). The first was the period of early exploration when sailors and naturalists, especially the British and the French, returned to Europe with their collections. In the second period collections were made by resident Australians, and by W.H. Harvey, but described in Europe. The third period dates from the middle of the 19th century when Australian botanists described algae from their own collections. In the first two of these periods, 'Sydney Harbour' and 'Port Jackson' figured prominently as collecting localities and are the type localities for a number of species: for example, *Claudea bennettiana* Harvey, type locality Parramatta River, near the east end of Spectacle Island, Port Jackson; and *Kallymenia brachycystidea* J. Agardh, type locality Port Jackson. Despite this initial impetus the algae of the Sydney region are still comparatively unknown, though there are some reasons why this should be the case. The algal flora of New South Wales is not nearly as rich as that of southern Australia and does not show such a high degree of endemism. At the same time there is no particular feature of interest, such as the Great Barrier Reef in Queensland, to attract phycologists to the area.

Until the SPCC (1981) report on the benthic flora and fauna of rocky shores in Botany Bay the only study with more than a passing reference to the subtidal flora of the coast near Sydney was that of May *et al.* (1978), in which the algal epiphytes of seagrasses in Botany Bay were discussed. The present paper gives a preliminary description of the subtidal flora at four sites in the Sydney region (two in Sydney Harbour, one in Middle Harbour, one in the lower Parramatta River) and provides some quantitative data on community structure.

THE STUDY AREA

Sydney Harbour, Middle Harbour and the Parramatta River estuary, on the east coast of Australia (approximately 34°S, 151°E) are part of the same drowned river valley. The underlying rock is predominantly sandstone, and slow sedimentation since submergence has resulted in the deposition of an average of 30m of unconsolidated sediment leaving only a fringing rocky shoreline. The tidal range is 2m at the Heads, but as the harbour widens it becomes less. The Parramatta River is the only major river flowing into the system, and it drains only a minor part of the hinterland to Port Jackson, so that fresh water inflow is limited. As a consequence salinity generally approximates that of seawater. Average monthly water temperature ranges from about 12°C in July to 24°C in January, which makes the biota warm-temperate in character.

The four sites selected for detailed study are shown in Figure 1 and they can be regarded as a graded series from open coast to almost estuarine conditions. The Middle Harbour site was at Rocky Point, 'Balmoral', and presented conditions most like those on the adjacent open coast. A wide band of rock extends down to sand at about 4.5m depth. The 'Zoo' site was located near the Taronga Park ferry wharf on the northern shore of Sydney Harbour. At this site, there is little urban development along the foreshore. A 2m wide band of rock gives way to fine rocky rubble and then to mud at about 2.5m depth. The 'City' site was at Mrs Macquaries Point on the southern shore of Sydney Harbour. The foreshore is parkland, subjected to heavy public usage. There is a narrow rock fringe, and a wide band of coarse rubble (bottles, cans), with mud at about 4m depth. The fourth site, 'Drummoyne', at Wrights Point, was in the Parramatta River. The foreshore is heavily urbanized and boats are generally moored just offshore. The substrate at this site is mud, with a rock fringe about 1m wide at the low water mark.

TABLE 1

Algal species list

	BALMORAL	ZOO	CITY	DRUMMOYNE
Chlorophyta:				
Bryopsis sp.			X	X
Caulerpa filiformis (Suhr) Hering	X	X	X	
Chaetomorpha aerea (Dillwyn) Kützing	X	X	X	X
Cladophora spp. (3 species)	X	X	2	2
Codium galeatum J. Agardh	X			
Codium harveyi Silva - *C. australicum* Silva complex	X			
Codium lucasii Setchell in Lucas	X			
Enteromorpha sp.		X		X
Enteromorpha intestinalis (Linnaeus) Link				X
Enteromorpha prolifera (Muller) J. Agardh	X	X	X	X
Microdictyon umbilicatum (Velley) Zanardini	X			
Ulva lactuca Linnaeus	X	X	X	X
Phaeophyta:				
Colpomenia peregrina (Savageau) Hamel	X	X	X	
Dictyopteris acrostichoides (J. Agardh) Börgesen	X		X	
Dictyota dichotoma (Hudson) Lamouroux	X	X	X	X
Dictyota furcellata (C. Agardh) J. Agardh		X		
Ecklonia radiata (C. Agardh) J. Agardh	X	X	X	X
Lobophora variegata (Lamouroux) Womersley	X			
Padina spp. (2 species)	X	2	2	
Sargassum spp. (16 separate recognisable forms)	8	6	9	2
Spathoglossum sp.		X	X	
Sphacelaria sp.	X			
Zonaria turneriana J. Agardh	X			
Rhodophyta:				
O. Bangiales:				
Erythrotrichia australis Rosevinge				X
O. Gelidiales:				
Gelidium sp.	X		X	
Gelidium pusillum (Stackhouse) Le Jolis			X	X
O. Cryptonemiales:				
Amphiroa anceps (Lamouroux) Decaisne	X			
Corallina sp.	X	X	X	X
Grateloupia filicina (Lamouroux) C. Agardh		X		
O. Gigartinales:				
Gracilaria edulis (Gmelin) Silva	X	X	X	X
Gracilaria furcellata Harvey	X			
Gracilaria verrucosa (Hudson) Papenfuss				X
Hypnea sp.	X	X	X	X
Schottera sp.		X	X	
O. Rhodymeniales:				
Champia sp.	X	X		X
Champia zostericola (Harvey) Reedman and Womersley	X	X		X
Lomentaria sp.		X	X	
Rhodymenia australis (Sonder) Harvey	X	X	X	X

Table 1 (continued)	BALMORAL	CITY	ZOO	DRUMMOYNE
O. Ceramiales:				
F. Ceramiaceae:				
Antithamnion sp.		X		X
Callithamnion spp. (4 species)	2	3	X	X
Centroceras clavulatum (J. Agardh) Montagne	X	X	X	
Ceramium spp. (3 species)	3	X		X
Griffithsia spp. (2 species)	X	X	2	2
Monosporus australis (Harvey) J. Agardh		X	X	
Ptilocladia sp.	X			
Spyridia filamentosa (Wulfen) Harvey		X		X
F. Delesseriaceae:				
Acrosorium uncinatum (J. Agardh) Kylin	X	X	X	
Caloglossa leprieurii (Montagne) J. Agardh		X		
Martensia sp.	X			
Myriogramme sp.	X	X	X	X
Nitophyllum sp.	X	X		X
Phycodrys sp.	X	X	X	
F. Dasyaceae:				
Dasya sp.	X	X	X	X
Heterosiphonia australis (J. Agardh) De Toni		X	X	
F. Rhodomelaceae:				
Laurencia spp. (2 species)	2			
Lophurella sp.	X	X	X	
Polysiphonia spp. (4 species)	2	3	2	3
Pterosiphonia sp.				X
Symphocladia marchantioides (Harvey) Falkenberg	X			

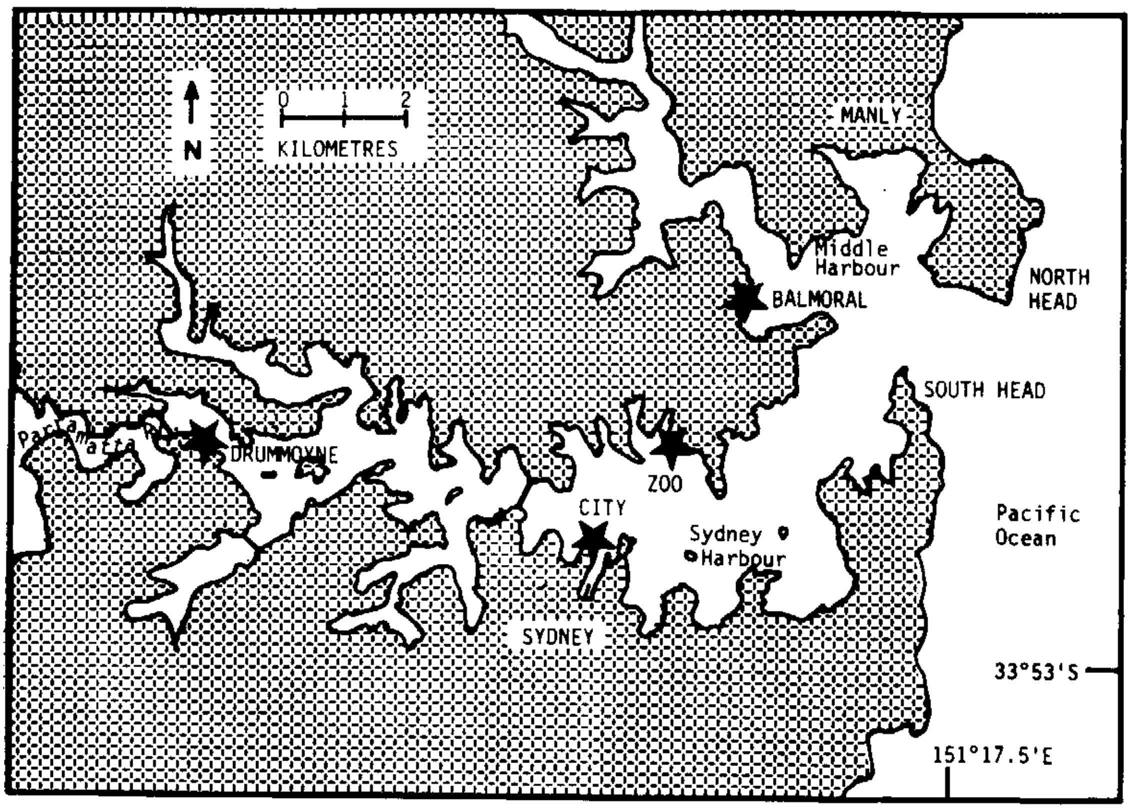


Figure 1. The Sydney Region ★ Sampling sites.

METHODS

Sampling: At each site a transect, perpendicular to the shore, was sampled. These transects were run out as far as the bulk of the algae extended: 20m (to 5m depth at the Zoo and City sites, and 3m depth at Drummoyne) and 44m (5m depth, at Balmoral). The transects were sampled at either 1m intervals (Zoo, City, Drummoyne), or 2m intervals (Balmoral), using 0.5m x 0.5m quadrats. Each site was visited on only three occasions between April and August 1979, with about two months between visits. The full length of each transect was sampled on each occasion and quadrats were spaced so that none was sampled more than once. The transects were selected for ease of access, but appeared to be representative of the area. Collections made in the vicinity of the transect lines increased the total species recorded for any one site by less than 10%.

For each quadrat the following were measured: species numbers, biomass, and percent cover. Number of species per quadrat (S) is the simplest and most objective measure of species richness, and one of the two components of species diversity. The biomass (B) of each species was measured (dry weight at 105°C) for each quadrat. Encrusting coralline algae were not collected. Percent cover was estimated *in situ* by using a quadrat divided into 100 5cm x 5cm grid squares and recording the single dominant species for each square. Percent cover of the *Ecklonia radiata* canopy was also estimated. Substrate, distance along the transect, and depth were also recorded.

Data treatment: The Shannon-Weaver diversity index (H") was calculated for each quadrat. The growth form of some algae makes it impossible to recognize individual plants and hence biomass or percent cover was used in place of abundance. A high correlation was found between biomass and percent cover for quadrats (significant at the 1% level), so calculations presented here are based on biomass only. The use of biomass in calculations was originally proposed by Wilhm (1968) and has since been used by a number of workers (John *et al.*, 1977).

RESULTS

A total of approximately 50 genera was recorded from the four sites in this study: 8 genera of green algae, 10 genera of brown algae, and 32 genera of red algae. An algal species list is give in Table 1 but this is by no means complete for each area. In the genus *Sargassum* 16 different forms were recognized and in the subsequent analyses these have been treated as species, though their taxonomic status is unclear. Only two seagrasses were recorded: *Zostera capricorni* Ascherson and *Halophila ovalis* (R. Brown) Hooker f., although *Posidonia australis* Hooker f. does occur within the Heads, e.g., in Vaucluse Bay.

There was a reduction in absolute species number with increasing distance from the Heads (Table 2). This reduction is in the number of red and brown seaweeds so that the relative proportion of green algae and seagrasses increased with distance from the Heads. The relative proportion of red algal species remained about the same at all sites.

TABLE 2

Numbers of green, brown, and red algal, and seagrass species (and genera) at four sampling sites in the Sydney region

	Balmoral	Zoo	City	Drummoyne
Green algae	8 (7)	6 (5)	7 (6)	9 (6)
Brown algae	16 (9)	13 (6)	16 (7)	4 (3)
Red algae	29 (22)	29 (24)	21 (18)	22 (17)
Seagrasses	1 (1)	2 (2)	2 (2)	2 (2)
Total	54 (39)	50 (37)	46 (33)	37 (28)

On the basis of observation, especially by S.A. Shepherd, Southern Australian subtidal algal communities have generally been shown to consist of three zones or associations. These three zones are distinguished on the basis of habit of the dominant life forms. On rocky coasts they are: 1. an upper zone of turf forming red algae such as *Corallina* and *Pterocladia*, 2. a broad zone of larger brown algae (including kelps), and 3. a lower zone of larger red algae (Womersley, 1972). The algal communities at all sites except Drummoyne can be accommodated within these categories and the following descriptions of the four sites are thus fitted within this framework. Profile diagrams for all sites are given in Figure 2.

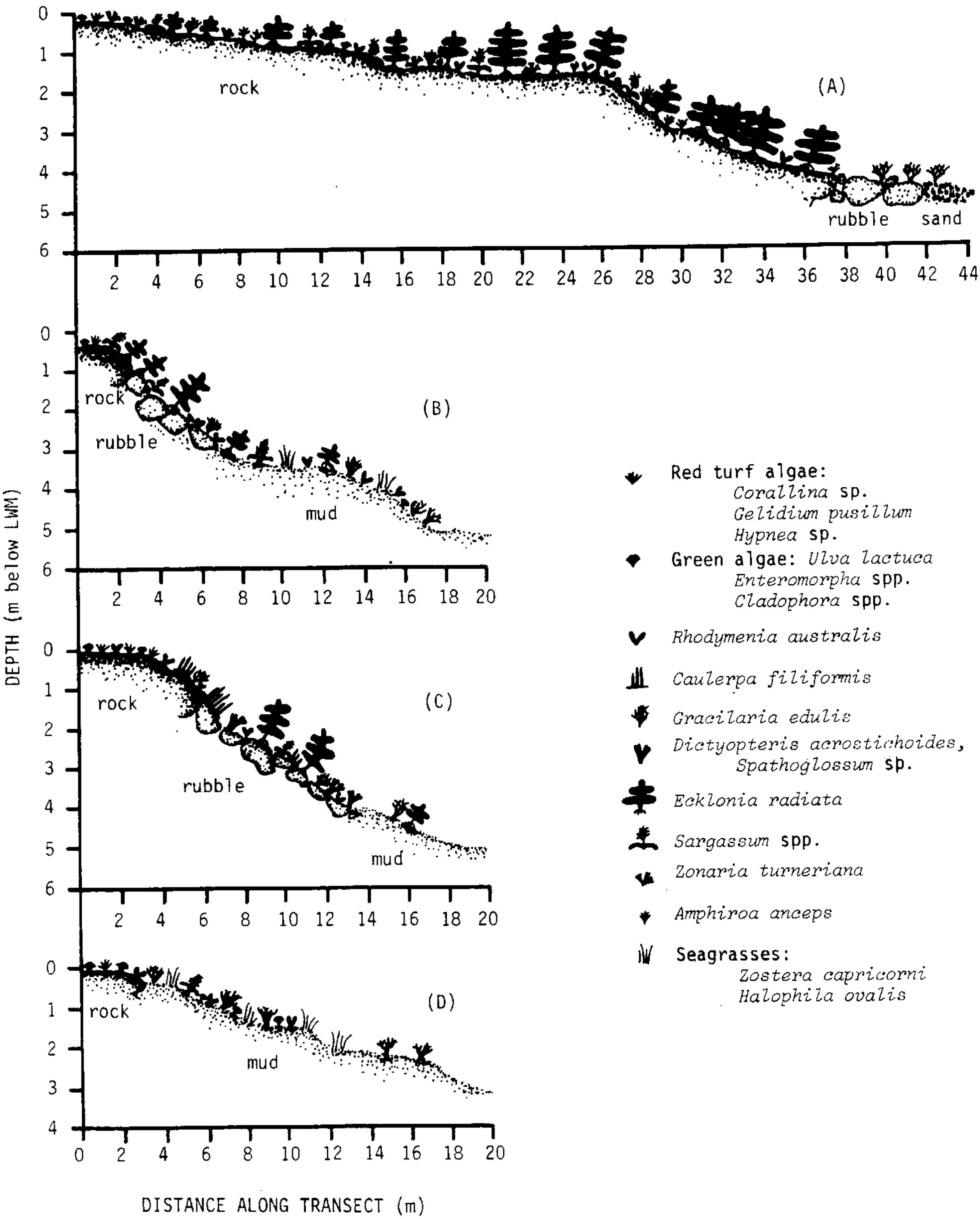


Figure 2. Algal profiles along transects at (A) Balmoral, (B) Zoo, (C) City, and (D) Drummoyne.

Balmoral: Figure 2a

(a) Turf association: on rock just below low tide with *Zonaria, Corallina, Sargassum* and *Colpomenia*, with *Dictyota, Amphiroa, Ulva,* and a large number of epiphytes (e.g., *Polysiphonia, Acrosorium*).

(b) Kelp association: on rock and rubble substrate from just below low water mark down to 4.5m. This association was dominated by *Ecklonia* and several species of *Sargassum*. In some areas, fronds of these brown algae completely covered the underlying substrate, and only coralline algae (*Amphiroa, Corallina,* and encrusting corallines) grew beneath the canopy. Other smaller species (e.g., *Rhodymenia, Dictyota, Ulva, Dictyopteris, Padina, Laurencia, Codium*) grew only where the canopy cover was not so great. The association supported several red epiphytes (e.g., *Polysiphonia, Griffithsia, Symphocladia*). The high biomass is attributable to the large size of individual *Ecklonia* plants.

(c) Red algal association: below 4.5m, several species of red algae (e.g., *Champia, Gracilaria* and *Rhodymenia*) grew on small pieces of solid substrate, such as shells, in the sand. The association was rich in species due to the large number of epiphytes (e.g., *Polysiphonia, Ceramium, Acrosorium*), but biomass was low because plants were small and scattered.

Zoo: Figure 2b

(a) Turf association: algae such as *Rhodymenia, Corallina, Dictyota* and *Ulva* grew in a narrow band on rock just below the low water mark.

(b) Kelp association: from close to the low water mark down to 2.5m, dominated by brown canopy-forming algae (*Ecklonia* and *Sargassum*), with species such as *Rhodymenia, Corallina, Gracilaria, Dictyota* and *Ulva* growing underneath.

(c) Seagrass-red algal association: the seagrass *Halophila ovalis* grew directly on the mud substrate, and several species of red algae (e.g., *Nitophyllum, Rhodymenia, Gracilaria, Spyridia*) and occasional *Ecklonia* or *Sargassum* plants grew upon small rocks and other solid substrate in the mud.

City: Figure 2c

(a) Turf association: on rock between low water mark and 1m depth, with species such as *Corallina, Ulva, Colpomenia* and *Rhodymenia,* and smaller amounts of, e.g., *Gracilaria, Dictyota* and *Chaetomorpha,* and many epiphytic species (e.g., *Centroceras, Polysiphonia, Griffithsia*). *Caulerpa filiformis* was abundant, covering rock which had a cover of unconsolidated sediment.

(b) Brown algal association: *Ecklonia,* codominant with other large browns (*Dictyopteris, Sargassum, Spathoglossum* and *Padina*), formed a canopy with only a few species of red algae (*Gracilaria, Rhodymenia*) growing beneath. There were isolated patches of *Caulerpa.*

(c) Red algal association: reds (e.g., *Rhodymenia, Gracilaria*) and browns (e.g., small *Ecklonia* plants, *Dictyota*), grew on small pieces of solid substrate in the mud. Biomass was low and cover patchy, and virtually no macroalgae were observed below 4.5m depth.

Drummoyne: Figure 2d

At this site only two algal associations were recognised.

(a) Green algal association: on rock just below low water mark, consisted of green algae (*Ulva, Cladophora, Chaetomorpha*) and one coralline red (*Corallina*). Number of species and percent cover were both low.

(b) Seagrass-red algal association: dominated by reds like *Gracilaria* and *Rhodymenia*, and the seagrasses *Halophila ovalis* and *Zostera capricorni*. Several other species were also present in small amounts (e.g., *Dictyota, Ulva, Chaetomorpha, Champia*), and there were epiphytes such as *Griffithsia* and *Polysiphonia*. The association was characterised by low biomass and patchy cover, and no growth was found below about 3m depth.

ANALYSIS OF QUADRAT DATA

Species richness, biomass, diversity and evenness of algal communities can be related to distance from the open ocean, depth and substrate type (Figures 3 and 4). All parameters, species richness, biomass, diversity and evenness, have been expressed per 0.5m x 0.5m quadrat.

Distance from the open ocean: (Figure 3). There was a reduction in species richness with increasing distance from the ocean. The average number of species per $0.25m^2$ dropped from 10.3 at Balmoral to 5.7 at Drummoyne. There was a marked decrease in biomass, from 151.7g at Balmoral to 5.7g per $0.25m^2$ at Drummoyne. Diversity showed no clear trend with distance from the ocean, but appeared to be related to changes in species evenness rather than to changes in species richness.

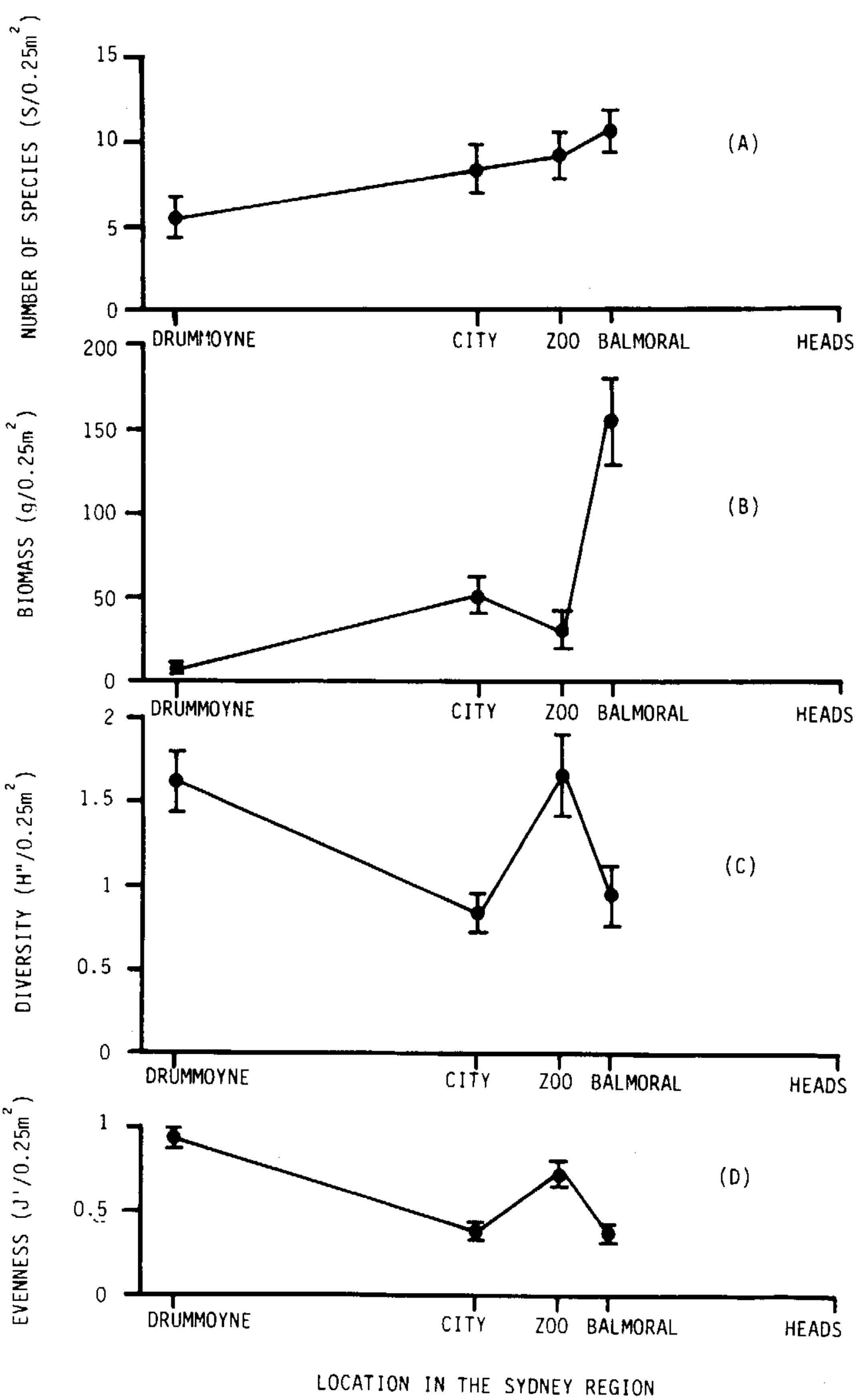
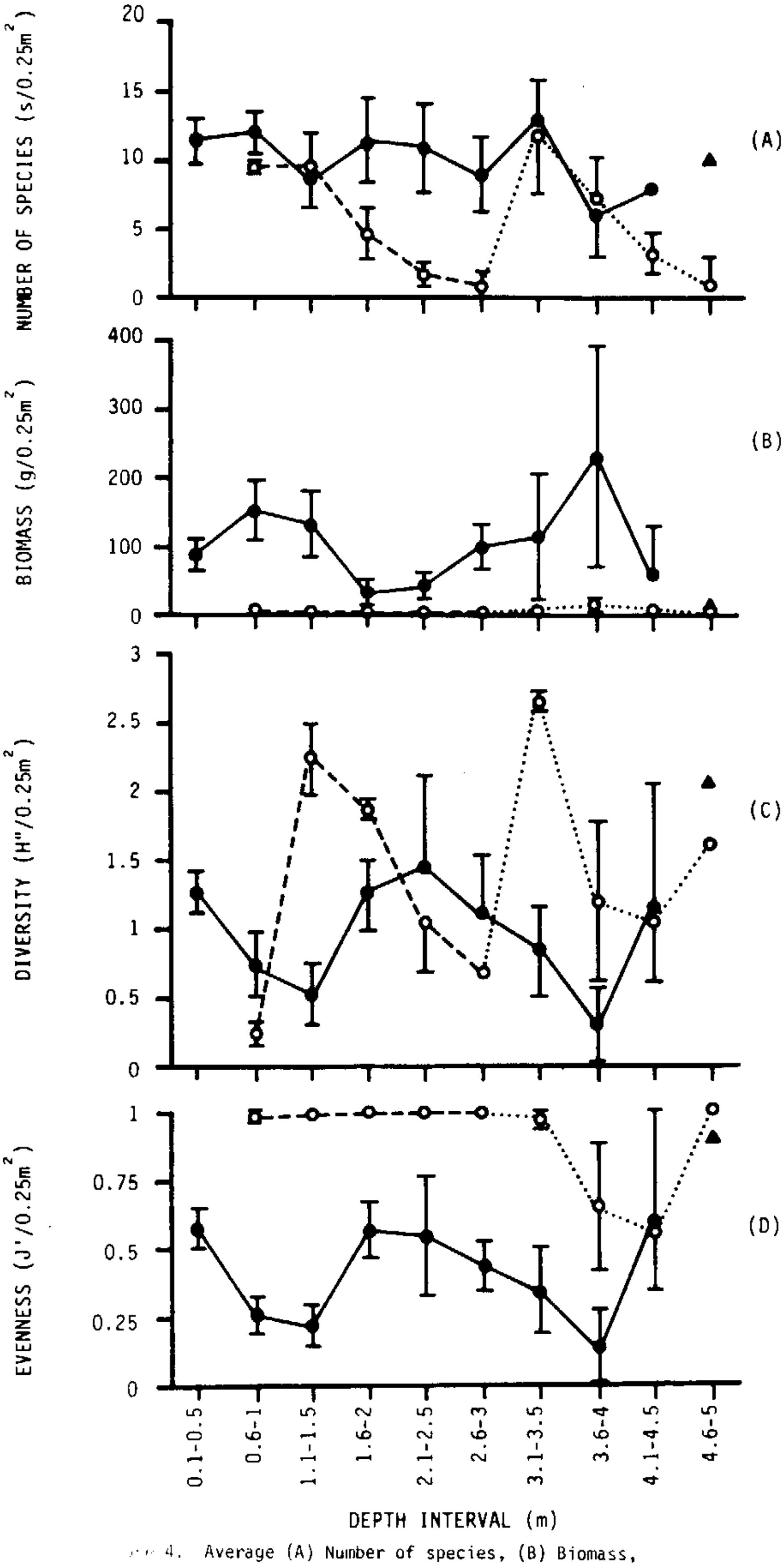


Figure 3. Average (A) Number of species, (B) Biomass, (C) Diversity, and (D) Evenness per quadrat at four sampling sites located at different distances from the open ocean. Bars indicate standard error (n=19 to 23).



4. Average (A) Number of species, (B) Biomass, (C) Diversity, and (C) Evenness per quadrat vs depth for different substrates: ——●—— Rock/Rubble, ▲ Sand, ----O---- Mud (Drummoyne) ····O···· Mud (Zoo, City). Bars indicate standard error (based upon the following numbers of replicates: Rock/Rubble: n=2 to 16, Sand: n=1, and Mud: n=2 to 6).

Depth and substrate: (Figure 4). Large numbers of species grew upon solid substrate and upon small rocks and other solid substrates in the sand, while the number of species growing upon solids in mud substrate was lower and declined rapidly with depth. Biomass on solid substrate was much greater than that on either mud or sand substrates. Diversity on rock substrate was either high (turf associations) or low (kelp associations), but was generally lower than for mud or sand substrates. The highest diversity on mud substrate was reached at a shallower depth furthest from the open ocean. Mud and sand substrates supported associations with high evenness, whereas solid substrates supported associations with low and variable evenness.

DISCUSSION

A search of the earlier literature revealed that, in terms of current species concepts, a total of over 133 species of marine algae (in 82 genera) has been previously recorded for Sydney Harbour or the Parramatta River: Chlorophyta, 23 species in 11 genera; Phaeophyta, 39 species in 25 genera; Rhodophyta, 71 species in 46 genera. Eighty-seven species were recorded in this survey of only four subtidal sites and observations at other sites in the region and at other seasons indicate that this number of species will increase greatly as more sites are investigated. Unfortunately, many algae, especially filamentous reds, were collected only as small and infertile plants which makes identification beyond genus difficult (though not always impossible). Other genera require complete revision for the New South Wales coast, e.g., *Sargassum* is one of the more difficult genera since there appears to be over 40 valid species names applied to plants from New South Wales but in only a few of these is the specific concept clear.

For comparison 172 species of subtidal algae, exclusive of minute epiphytes, were recorded by Womersley (1966) for the Port Phillip Survey, 1957-1963, though in this case the collections were made by both dredging and diving, over a large number of collecting sites, and during a seven-year period. The southern coast of Australia is also known to be far richer in algal species (Womersley, 1981b). There are considerable difficulties in comparing the numbers of species recorded in earlier literature with those recorded in this survey. In the early records the exact collection locality is often unclear especially as 'Port Jackson' was often used to describe any coast localities in the general vicinity of the colony and also subtidal algae were seldom, if ever, collected *in situ*.

The reduction in species number with increasing distance from the Heads is perhaps not unexpected and similar results have been reported in other Australian studies. In the SPCC (1981) Study of Botany Bay, 16 species were 'common' in subtidal transects near the Heads, and only six species were recorded in transects at the airport — runway revetment.

In a comparable study, Lewis (unpublished) studied the subtidal algae in Hobsons Bay (north Port Phillip Bay, Victoria). He noted a decrease in species number moving towards the mouth of the Yarra River, from 60 species at the Gellibrand Light, to 51 (Breakwater Pier), 38 (Lagoon Pier) and 9 (No. 4 Channel Light). A similar decrease was found in this study (54 to 37 species). Decreases in species number approaching a river mouth are generally attributed to the lower and sometimes fluctuating salinity though it is sometimes possible to relate this to the relatively uniform environment of the river mouth with the consequent reduction in niche diversity. In this study, the proportion of green algae increased with distance from the open ocean; Lewis found a similar increase in Hobsons Bay. In both studies this increase was accompanied by a decrease in the number of brown algal species and red algal species. Studies reported by Wilkinson *et al.* (1976) on estuaries in both Britain and New Hampshire (USA) show the same pattern of algal distribution: in the upstream direction, decreases in red and then brown algae, with green algae remaining the same. Many green algae, especially those in the families Ulvaceae and Cladophoraceae (to which most of the species at Drummoyne belonged) are highly tolerant of estuarine conditions (Hamm and Humm, 1976).

Substrate appeared to have an important influence on the structure of algal communities in this study. Stable rock substrate supported either high biomass, species-poor kelp associations, or low biomass, species-rich turf associations. High biomass is due to large perennial species such as *Ecklonia radiata* and species of *Sargassum*, and the associated low species number probably results from the dense canopies of these species, which reduce light penetration. The red algal sand association at Balmoral was low in biomass, but high in species numbers. Algal species growing upon small solids in sand were found to act as substrates for a large number of epiphytes. On muddy bottoms algal growth was very sparse and again limited by lack of firm substrate.

Sediments are finer with increasing distance from the Heads, and this is reflected in increased turbidity of the water column. Secchi depth readings taken during the study indicated that turbidity at the Drummoyne site (secchi depth 1m) was much higher than turbidity at the Zoo and City sites (secchi depths both 2.5m) and the Balmoral site (secchi depth 3.5m). In this study the lower limit of vegetation at Drummoyne was only about 3m, whereas it was about 5m at Balmoral, and red algae have been observed at depths to 25m at Sydney Harbour Heads. These lower limits for algal growth may be compared with 9m at the Gellibrand Light in Port Phillip Bay (Lewis, unpublished), and 50m or more in the clear waters off the South Australian coast (Shepherd and Womersley, 1971).

The three basic sublittoral zones (with their distinguishing turf, kelp, and red algal associations) recognised by Womersley (1972) for southern rough water rocky coast could be recognised at the Balmoral, Zoo and City sites (e.g., in Middle Harbour and Sydney Harbour). These have been referred to by Womersley (1981a) as the upper, mid, and lower sublittoral, and as might be expected from an extrapolation of the situation at West Island, South Australia, the zones in the sheltered sites examined in the Sydney region were extremely compressed, and they also showed considerable gradation. At Drummoyne only two zones could be recognised: an upper green algal and lower red algal association. None of the transects published for Botany Bay (SPCC, 1981) clearly fit the pattern with three plant associations.

Algal communities in the Sydney region have many features in common with other estuarine algal communities. Zimmerman and Livingston (1976) reported reduced species numbers and reduced biomass for algal communities at sampling stations approaching the mouths of two rivers (one polluted, one unpolluted), in Florida, USA. Reduced dominance (i.e., high evenness) in the polluted areas, together with relatively stable species numbers, resulted in comparable values of species diversity (H") in polluted and unpolluted areas. In the Sydney region, species diversity (H") appeared to be related to species evenness (J'). Diversity indices are mathematical expressions which show the ratio between individuals and species in a biotic community (Wilhm, 1968) without depending upon the identity of species, but they need to be interpreted with care and the relative contributions of the two components, species richness (S) and species evenness (J'), identified. The influence of pollution on Sydney algal communities could only be surmised. Pollution could be assessed using a community approach, but this would require a detailed understanding of the natural variation that occurs and pre-pollution studies would be necessary.

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