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Vertical Distribution and Seasonality of Intertidal Macroalgae on the Coast of Hawon-Pando, Southwestern Korea

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An overview of the spatial and seasonal patterns of phytobenthic communities is described from the intertidal zone at Hawon-Pando on the southwestern coast of Korea based on quantitative and qualitative estimates of macroalgae. There were considerable variations of macroalgal diversity and cover value with the intertidal levels. In general, the number of species decreased with increasing intertidal height. The upper region was dominated by *Sargassum thunbergii*. *S. thunbergii* and crustose red algae were dominant in the mid intertidal habitat. In the lower intertidal *Corallina pilulifera* and crustose red algae were the conspicuous dominants. Macroalgal community structure at Hawon-Pando is discussed in the context of functional-form groups. The Hawon-Pando intertidal is characterized as consisting of a relatively high cover of species assigned to the thick leathery, crustose and jointed calcareous groups, and is distinguished by a paucity of the filamentous group.

INTRODUCTION

In general, seasonal patterns of distribution and abundance of macroalgae are associated with the seasonal changes in water temperature and daylength. Major perturbations to normal seasonal patterns have been associated with the effects of disturbances such as sewage pollution, sand scouring and sediment burial, substratum instability and extreme aerial exposure (Sousa, 1980; Seapy and Littler, 1982; McQuaid and Branch, 1984; Murray and Littler, 1984; Josselyn and West, 1985; Lüning, 1993; Airoldi *et al.*, 1995; Kim *et al.*, 1996, 1998).

Despite a detailed knowledge of the macroalgal flora of southwestern Korea (Choi *et al.*, 1994), there is a little information regarding the ecology of intertidal communities. The limited ecological studies refer to the shores of Chungsando (Lee *et al.*, 1991), Uido (Choi *et al.*, 1994) and Neobdo (Kim and Lee, 1995) and deal with phytobenthic community structure. The relatively low species diversity and biomass in this region were attributed to the limited extent of rocky shores, the instability of boulder substrata, and the effects of environmental disturbances. The latter included the effects of turbidity, with seasonal changes of macroalgal biomass mostly dependent upon the presence or absence of larger brown algae.

Functional-form groups have been widely used to classify algal species into ecologically significant categories independent of taxonomic affinity. Aspects of this functional-form model have been successfully employed to interpret population dynamics of macroalgae in rocky intertidal community (Littler and Littler, 1981; Littler *et al.*, 1983; Murray and Littler, 1984) and to establish relationships between algal primary productivity and thallus morphology (Littler, 1980; Littler and Arnold, 1982).

The major objective of this study is to provide an overview of the spatial and seasonal patterns of phytobenthic communities in the Hawon-Pando intertidal. The intertidal ecosystem in this region has not been described previously. In addition, I present an analysis of the composition of macroalgal communities based on ecologically related functional-form groups.

MATERIALS AND METHODS

Study area

Hawon-Pando, on the southwestern coast of Korea, is a well-protected coastal shore, but it experiences strong tidal currents which run along the Shia-Hae Strait (Fig. 1). Maximum tidal currents are over 1 m s^{-1}, and this occurs at both high and low tide. This causes extensive resuspension of sediments. The seawater is very turbid, and as much as 53-75 mg L^{-1} of suspended solids occur at Hawon-Pando (CNU, 1992).

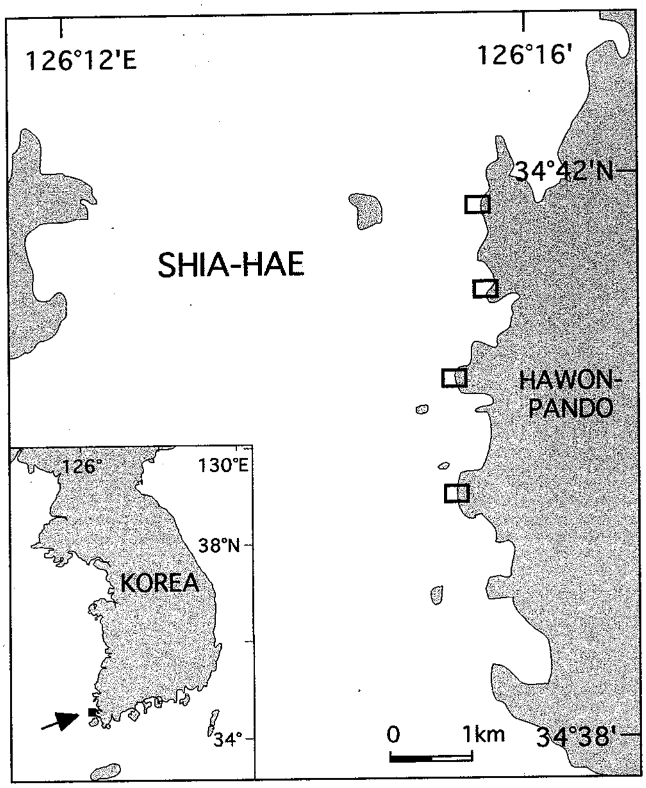

Fig. 1. Map of Korea (insert) showing the general location of the study area (arrow) and four intertidal shores sampled in the present study (rectangles).

Thirty year records (1966-1995) for surface-water temperature and salinity were obtained for the hydrographic station 311–04 (approximately 30 km west of study area) (NFRDI, 1997a,b). The temperature ranges from 5.5 (February) to 23.6°C (August). There is little variation in salinity with extremes of 33.2 (June) and 32.3‰ (August). Tides are semi-diurnal with amplitudes between ca. 0.5–2.5 m during neap tides and ca. 1.9–4.4 m during spring tides (CNU, 1992).

Intertidal habitats of Hawon-Pando consist of a short and gentle slope with massive granitic rocks. There are many boulders and broken rocks of varying sizes. The transect is mainly dominated by algal species but in upper intertidal region, there is a rocky outcrop encrusted with barnacles.

Sampling and analysis

Three intertidal levels have been distinguished based on personal observations at study sites. Sampling was done at three arbitrarily selected intertidal zones, these are designated as upper, mid and lower regions (tide heights of 10–20 cm, 70–90 cm and 130–150 cm below mean sea level, respectively). Two to three belt transects, 10 to 15 m apart as dictated by the steepness of the shoreline and topography, were laid perpendicular to the waterline. The transects extended from immediately above the highest level of intertidal organisms to just below the waterline at low tide. The site was visited at virtually bimonthly intervals from November 1992 through September 1993. Percent cover was used to quantify abundance of phytobenthic algae. A 0.25 m^2 quadrat was subdivided into 25, 10×10 cm subquadrats using nylon thread. Macroalgae in each subquadrat were identified, and the percentage cover for each taxon visually determined by dividing the number of subquadrats occupied by the total number of subquadrats. Species which were observed within a subquadrat but did not (cover) half the space were arbitrarily assigned a cover value of 0.1. Measurements were done in two stages: the canopy-forming algae were assessed first, followed by the understory species. Cover of individual species was obtained from about 500 subquadrats at each tidal level. Cyanobacteria and crustose red algae were each treated as single taxonomic category.

The Shannon-Wiener index (Shannon and Weaver, 1949) was used to quantify diversity. Evenness (a measure of similarity in cover estimates among species in a given sample) was calculated according to Pielou (1975).

Data on macroalgal cover were also analyzed in terms of functional-form groupings using the six categories described by Littler and Arnold (1982). Thus macroalgae were classified as being members of one of the following: the sheet group, the filamentous group, the coarsely branched group, the thick leathery group, the jointed calcareous group and the crustose group.

RESULTS

A total of 55 taxa was identified during the study, of which there were 29 red algae, 15 brown algae, and 10 green algae, as well as Cyanobacteria (Table 1). Species number varied during the study period and ranged from 20 (July) to 43 (January). One green alga (*Ulva pertusa*), four brown algae (*Ishige okamurae, Myelophycus simplex, Hizikia fusiformis, Sargassum thunbergii*) and nine red algae (*Gelidium amansii, G. divaricatum, Corallina officinalis, C. pilulifera, Gloiopeltis furcata, Gracilaria verrucata, Gymnogongrus flabelliformis, Chondrus ocellatus,*

Table 1. Cover (%) of macroalgae in the intertidal zone of Hawon-Pando. Cover values below 0.1% are designated with a + (abbreviations for F-F, functional-forms: C, Crustose; JC, Jointed Calcareous; CB, Coarsely Branched; F, Filamentous; S, Sheet; TL, Thick Leathery)

Taxa	F-F group	November '92	January '93	March	May	July	September	Mean
Cyanobacteria	C	0.6	1.0	2.1	2.1	4.1	4.3	2.4
Capsosiphon fulvescens	S	+						+
Monostroma grevillei	S	+	0.1	+				+
Cladophora albida	F				+	+	+	+
Cladophora sakaii	F	+						+
Enteromorpha compressa	S		+	+				+
Enteromorpha linza	S	0.1	+	+	+	5.6		+
Ulva pertusa	S	6.3	12.2	15.5	1.0		5.6	6.8
Bryopsis plumosa	F	+	+		+	+		+
Codium adhaerens	C			0.1	+	+	+	0.1
Codium fragile	CB	0.1	+		0.1	0.1	+	+
Ishige okamurae	CB	0.3	0.3	0.1	+	+	0.1	0.1
Colpemenia sinuosa	CB	0.1	0.0				+	+
Petalonia fascia	S				0.1	1		+
Scytosiphon lomentaria	S	+	+	+			+	+
Myelophycus simplex	TL	+	+	+	+	+	0.3	0.1
Sphacelaria furcigera	F	+	+	+				+
Desmarestia viridis	S						+	+
Undaria pinnatifida	TL	0.0	0.4	0.7	+	+		0.2
Dictyota divaricata	S	2.6	0.3				0.1	0.5
Myagropsis myagroides	TL	+						+
Pelvetia siliquosa	TL						+	+
Hizikia fusiformis	TL	0.1	0.7	4.2	2.6	2.6	1.6	1.8
Sargassum confusum	TL	+	+					+
Sargassum horneri	TL	+	+	+				+
Sargassum thunbergii	TL	17.9	25.3	17.3	5.3	5.3	8.7	13.3
Porphyra yezoensis	S	+	0.3					0.1
Delisea fimbriata	CB	+	+				0.0	+
Gelidium amansii	CB	1.4	2.2	+	+	0.3	3.9	1.3
Gelidium divaricatum	CB	2.0	0.7	0.3	0.4	0.7	+	0.7
Dumontia simplex	CB	0.0						+
Crustose red algae	C	4.9	4.3	3.0	8.0	28.7	15.5	10.7
Corallina officinalis	JC	0.7	2.7	0.1	0.5	3.8	0.8	1.4
Corallina pilulifera	JC	8.7	4.9	6.7	12.7	9.3	6.0	8.0
Carpopeltis affinis	CB	+	+				0.1	+
Carpopeltis cornea	CB						+	+
Grateloupia turuturu	CB						+	+
Halymenia acuminata	CB	+	+					+
Pachymeniopsis elliptica	CB						+	+
Gloiosiphonia capillaris	CB	+	+					+
Gloiopeltis furcata	CB	+	+	0.9	1.2	0.2	0.2	0.4
Plocamiumt elfairiae	CB		+	+				+
Hypnea saidana	CB	+	+				0.0	+
Gracilaria verrucata	CB	0.5	0.1	0.2	+	0.5	1.6	0.5
Gymnogongrus flabelliformis	CB	+	2.0	3.6	+	+	2.3	1.3
Chondrus ocellatus	CB	0.3	2.0	2.8	1.3	0.3	+	1.1
Gigartina intermedia	CB		+	0.1				+
Gigartina tenella	CB	+	+	+	0.1			+
Lomentaria hakodatensis	CB	+	+	0.1				+
Ceramiopsis japonica	F		+	+	+	0.1	0.1	+
Acrosorium uncinatum	S		+					+
Chondria crassicaulis	CB	+	+	+	1.3	7.3	4.9	2.3
Laurencia pinnata	CB		+	–			+	+
Polysiphonia morrowii	F	+	+	0.1	+		+	+
Symphyocladia latiuscula	CB	+	0.7	0.5	1.6	0.7	+	0.6
Tatal cover		47.2	61.0	58.7	38.8	63.5	56.4	54.3

Chondria crassicaulis) as well as Cyanobacteria and crustose red algae were found throughout the entire sampling period.

There was large variation in algal species number in relation to tidal levels. The lower zone showed higher species number than the mid and upper zones.

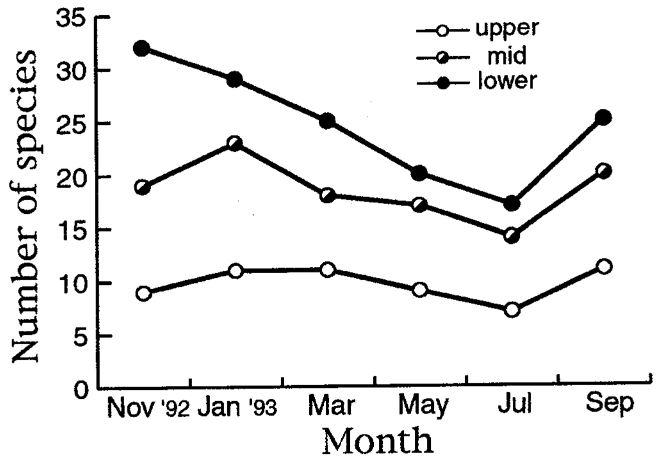

Fig. 2. Seasonal changes in the number of species associated with different tidal levels.

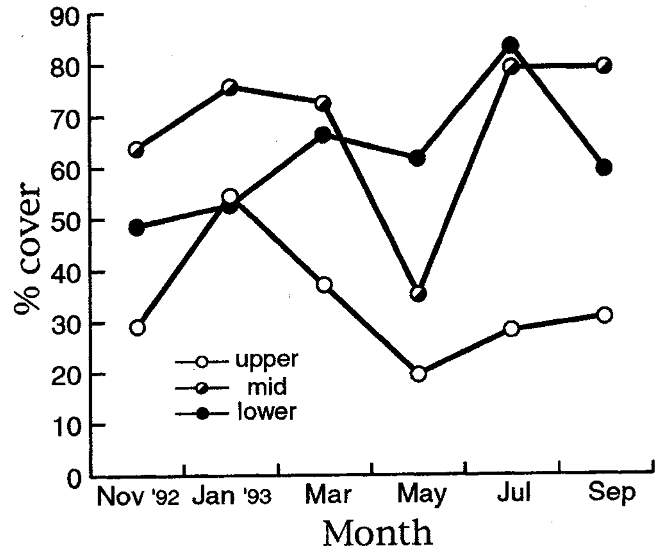

Fig. 3. Seasonal changes in cover associated with different tidal levels.

Accordingly, over the entire sampling period means of 11, 19 and 25 taxa were present in the upper, mid and lower intertidal zones. Cyanobacteria, *U. pertusa, I. okamurae, M. simplex, H. fusiformis, S. thunbergii, C. officinalis, C. pilulifera* and crustose red algae were distributed over the entire intertidal (data not shown).

Seasonal changes in species numbers occurred in each of the three intertidal zones (Fig. 2). Maximal species number in lower zone was recorded in November. The number of species continuously decreased until in July and then increased again in September, the last sampling time. The upper and mid zones, however, were more stable with fewer species over the study period.

Macroalgal cover averaged 54% over the intertidal habitats that were sampled and ranged from 39% in May to 64% in July (Table 1 and Fig. 3). Greatest algal cover was contributed by a brown alga, *Sargassum thunbergii* (13.3%). Only three other algal taxa contributed mean cover values over the study period greater than 5.0%. These were crustose red algae (10.7%), the turf-forming articulated coralline alga, *Corallina pilulifera* (8.0%) and the sheet-like forming alga, *Ulva pertusa* (6.8%). Macroalgae were unevenly distributed over the vertical range of sampled area. Annual mean cover of macroalgae was 33% in the upper, 68% in the mid, and 62% in the lower (Fig. 3).

Species diversity (H') was relatively similar and low throughout the year (Fig. 4). Diversity (H') for all intertidal samples averaged 1.78 and ranged from 1.65 in July to 1.97 in September. Evenness (J') was relatively similar in the samples throughout the year.

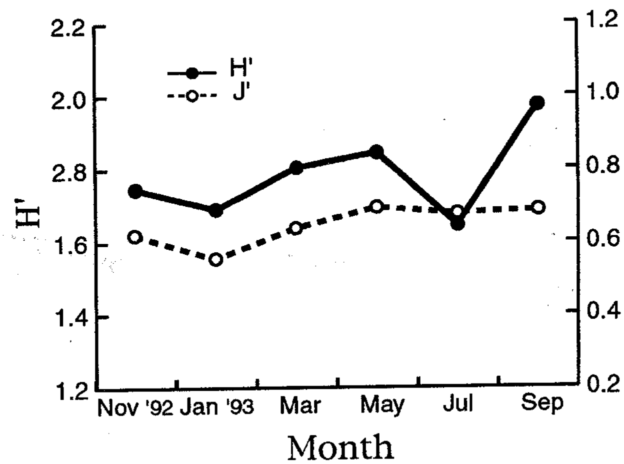

Fig. 4. Seasonal changes in diversity (H′) and evenness (J′).

J' averaged 0.65 during the study and ranged from 0.56 (January) to 0.70 (May).

Seasonal variations in the abundance of functional-form groups were apparent, indicating that the algal community structure of the site was variable (Fig. 5). The thick leathery-form was the most abundant functional group from November 1992 to March 1993. The jointed calcareous and crustose groups became more conspicuous after March. From July to September, the latter group ranked highest in cover. The sheet-form group was abundant in winter (until March), and then declined to virtual disappearance in July. This group became more conspicuous in the last sampling time. There was a notable lack of the filamentous-form during the study periods.

Relative cover of the various functional-form groups over the study period are given in Fig. 6. The

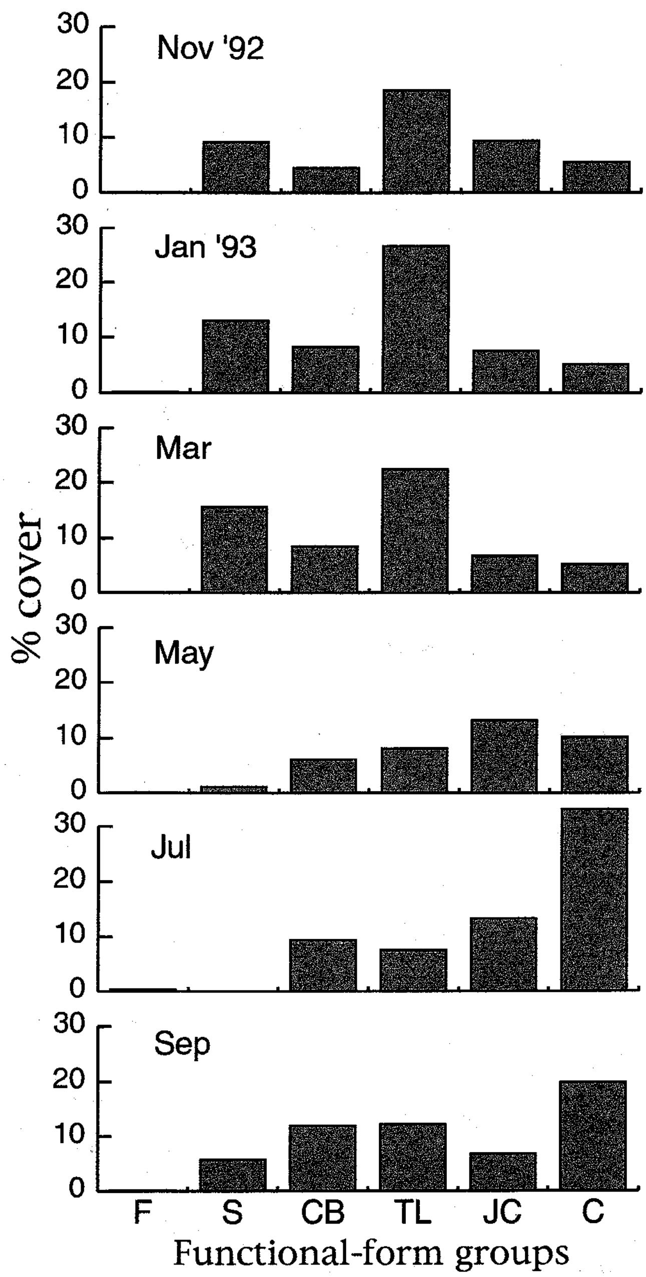

Fig. 5. Seasonal change in cover of functional-form groups (for abbreviations refer to Table 1).

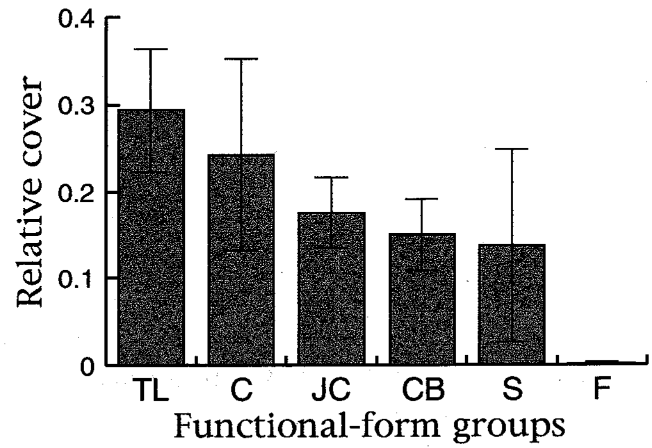

Fig. 6. Cover of macroalgae in Hawon-Pando based on functional-form groups. Data represent the proportion of cover provided by each functional-form group based on cover values of all samples. Vertical bars represent ±95% confidence intervals (abbreviations refer Table 1).

thick leathery (29.4%) and crustose (24.2%) groups dominated the cover, while moderate cover was furnished by members of the jointed calcareous (17.5%), coarsely branched (15.0%), and sheet (13.7%) groups. The filamentous functional group typically had less than 1.0%.

DISCUSSION

A total of 55 macroalgal taxa was found in the present study, although an average of only 33 taxa was obtained at each census. As the crustose red algae and Cyanobacteria were not identified to the species level, the actual resident flora is somewhat larger.

Tidal level was a primary factor in constraining the vertical distribution of the numbers and kinds of intertidal species. In the present study the shore was considered as three intertidal zones for purposes of interpretation. Thirty-eight and 48 macroalgae were recorded over the sampling period for mid and lower zones compared to 12 for the upper intertidal zone. The species number of lower habitats was fourfold that for the upper zone. The low number of species in my upper zone is typical of sites on southwestern coast of Korea (Choi *et al.*, 1989; Lee *et al.*, 1991). In the lower intertidal zone the primary seasonal change involved a reduction of sheet-forming species resulting from senescence of some annual species. This change can be attributed to the increased temperature during summer.

There was considerable spatial variation in macroalgal cover. *Sargassum thunbergii* was the sole conspicuous dominant in the upper zone. In the mid zone *S. thunbergii* was dominant with crustose red algae. In the lower intertidal *Corallina pilulifera* and crustose red algae were the conspicuous dominants. Filamentous algae had low cover values. A high contribution to macroalgal cover was made by the thick leathery and crustose forms. This pattern is relatively similar to previous descriptions of macroalgal communities of the southwestern coasts of Korea (Kang *et al.*, 1980; Lee and Boo, 1982; Lee *et al.*, 1983;

Boo and Choi, 1989; Choi *et al.*, 1989; Lee *et al.*, 1991; Kim and Lee, 1995). These authors also described high standing stocks of *Ulva pertusa, Myelophycus simplex* and *Hizikia fusiformis* that were present at Hawon-Pando intertidal only with low abundances.

Together with a knowledge of algal associations and seasonality, floristic diversity and composition are a prerequisite to understanding the distribution of attached seaweeds (Sears and Wilce, 1975). Depending upon habitat, the entire community must have a collective tolerance to the rigors of a particular site, *i.e.*, the sum of stresses from temperature, desiccation, salinity, etc. The communities at Hawon-Pando must be adapted to these general environmental constraints. In addition, there are environmental constraints that characterize this coast of Korea, in particular dealing with substrata and sediment load in the water. The substrata of the study sites consisted primarily of cobble, gravel and boulders of varying sizes. The presence of extensive mud and sand flats at adjacent to my quadrats constitutes another form of environmental instability or disturbance limiting macroalgal community development.

The Cyanobacteria may be metabolically very active, and comprise important components of intertidal communities (Murray and Littler, 1978); however including them requires special techniques and expertise beyond the scope of this work. Thus my observations were restricted to macrophytes that could be discerned with the unaided eyes. However, I did quantify microalgae (*e.g.* turfs of filamentous species) when they were abundant. These samples never exceeded 1.0 per cent of the cover in a given quadrat.

The intertidal macroalgae of Hawon-Pando have several common features. These include depauperate populations of filamentous opportunists (*e.g. Polysiphonia morrowi*), moderately abundant populations of sheet-like opportunists (*e.g. Ulva pertusa*), and dominant populations of thick-leathery perennials, with high tolerance for both exposure to sediment and desiccation (*e.g. Sargassum thunbergii*).

The most conspicuous feature of the intertidal phytobenthic communities of Hawon-Pando is that they are dominated by species of turf-forming articulated coralline and crustose red algae. These groups have been described as low-producers that are more resistant to grazing and have tougher thalli (Littler, 1980, 1981; Lubchenco and Gaines, 1981; Sousa *et al.*, 1981; Littler and Arnold, 1982). Additionally, most crustose red and articulated coralline algae are regarded as relatively long-lived or perennial seaweeds (Garbary, 1976). A final general feature of these shores is that the highly productive filamentous or sheet-forming species (Littler and Arnold, 1982), were never in high abundance. Consequently, the macroalgal community of Hawon-Pando intertidal largely consists of thick leathery opportunists, articulated coralline and crustose algae that are highly tolerant of both biological and physical disturbance, especially the substrate instability of this environment.

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