Floristic composition and zonation of seaweeds on Zabargad Reef (Red Sea, Egypt)

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El-Manawy I. M. 2001. Floristic composition and zonation of seaweeds on Zabargad Reef (Red Sea, Egypt). ***Taeckholmia*** **21(1):** 115-134.

Composition, dominance, distribution and zonation of seaweeds were investigated, using line-transect technique, in three sites of varied water activity on Zabargad reef during November 1994. Fifty-four taxa included 16 green, 13 brown and 25 red macroalgae were identified, adding four new records for the Red Sea. The flora appears rich and diverse, composed of filamentous, turf-forming, fleshy sac, foliose, erect shoot, and coralline forms. It showed a geographic distribution pattern similar to that of the Indo-Pacific.

The seaweed vegetation appears heterogeneous, having a dissimilar construction at each side of the reef. It showed a conspicuous zonation, revealing six zones related in general to reef topography, water movement and in a lesser extent to grazing and nutrient enrichment. The intertidal zone had a marked reduced flora due to exposure to air during low tide, and mobility of coral sand. Reef flat was the richest in species composition and dominance, as it lies in a shallow, well-illuminated, and less fluctuated subtidal region. Peculiar was the presence of high species dominance in strong surf on the windward reef crest. The reason for this is that the crest is extensively eroded, rich in crevices and fissures within which the algae hideaway from wave action. Moreover, strong rhizoids, dwarfing of thalli, crustose morphologies, growing in adherent to substrata were some modifications allowing algae to persist in strong surf.

Key words: Seaweeds, biogeography, marine zonation, algal reef, Zabargad, Red Sea

Introduction

Seaweeds constitute an important component of the reef dwellers and play significant roles in reef building and productivity (Dawes, 1998). In Red Sea, the seaweeds have been the subject of taxonomic works since the 18th century (e.g., Forsskål, 1775). In 1968, Papenfuss reviewed forty-five scientific papers while cataloguing the benthic algae of the Red Sea. Contributions to the knowledge of the Red Sea macroalgal flora and their ecology have increasingly come through the efforts of Aleem (1978, 1981), Farghaly (1980), and Hegazy (1992). More recently, El-Manawy and Gab-Alla (2000) studied the composition, distribution and biodiversity of the seaweeds on the fringing reefs at Shalateen-Halaib. El-Manawy and Shafik (2000) studied the morphology and ecology of the genus *Caulerpa* along the Egyptian coasts of Red Sea and the Suez Canal.

Zabargad is among the beauty coral reef islands of the Red Sea. Despite some of the mentioned publications dealt with the algae at some islands of the Red Sea, the seaweeds on the coral reefs at Zabargad have not yet been investigated. The geology of this island has been investigated in detail (Bonatti *et al.*, 1983), while Hassan (1997) briefly described its coral reefs, when she studied the bioerosion of and bioaccretion on coral reefs in the Red Sea.

The aim of the present investigations was to study the floristic composition and zonation of seaweeds on Zabargad Island. It is attempted to highlight factors governing algal distribution.

Received 7 March 2001. Revision accepted 4 April 2001.

Area of investigation

Zabargad Island (Figure 1) is situated at 23º 36'N, 36º 12'E, on the border of northern central part in the remote south of Egypt, 70 km off the coast. The island is almost 300 m above the sea level and roughly triangular in shape. Each side of the triangle is approximately 1 km in length. Old reef limestone, perhaps of Pleistocene age, outcrops at the island. Younger, un-cemented reef and lagoon deposits form terraces at various altitudes and are proposed to be of latest Pleistocene age (Bonatti *et al.*, 1983). Hassan (1997) has described the fringing coral reefs around the island. The reefs resemble those described by Mergner and Schuhmacher (1985) and Head (1987) for the Central Red Sea. Large areas of reef are entirely dominated by a few coral species but providing a high living coverage.

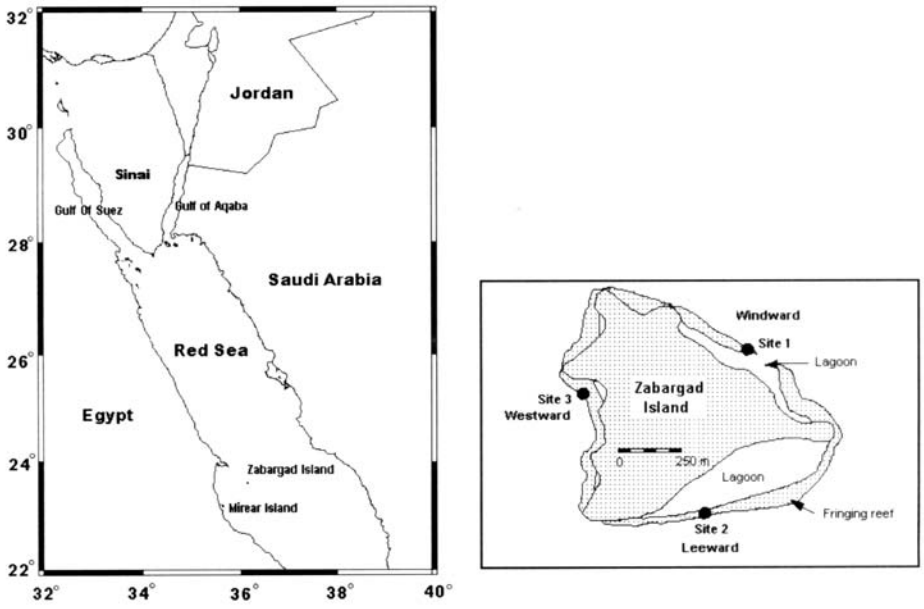

Fig. 1: Map of the Red Sea, and the investigated sites at Zabargad Island.

Three sites were investigated at Zabargad Island. The first (Site 1) was chosen on the northern windward side of the island, the second (Site 2) on the southern leeward side and the third (Site 3) on the western side (Figure 1).

Materials and Methods

The data were obtained during November 1994. At each site, snorkeling and random collections were done, covering the different sheltered and exposed habitats on reef flat, front, slope, reef crevices and gullies, as well as the reef lagoons. Algal samples were preserved as herbaria or in 4% formalin-seawater solution for further identification. Records of site, depth, habitat types, and the general ecological conditions are included

with all voucher specimens. Identification of species and their geographic distribution were checked using standard references (e.g., Aleem, 1993; Børgesen, 1920, 1925–36, 1944-57; Jaasund, 1976, 1977; Coppejans and Beeckman, 1989, 1990). The R/P and R+C/P indices (Sørensen, 1948) were used to examine the geographic affinities. The abbreviations R, C and P are the number of species of Rhodophyta, Chlorophyta and Phaeophyta, respectively.

Line-transect technique was used to study the spatial and vertical distribution of seaweeds. This technique is widely used for description and mapping of coral reefs and macroalgae by marine zoologists (e.g., Schuhmacher *et al.*, 1995), and marine botanists (e.g., Littler and Littler, 1985; Lobban *et al.*, 1988). A marked line was spread out from the highest to lowest zones and a metric tape was stretched along this line. Each five meters of the transect was considered as a station and, thus, 23 stations in site 1 and 20 stations were sampled in each of the two other sites. Water depth was measured using a line level. Species cover was measured as the length (cm) of the transect which the species covered.

Results

1) Floristic composition:

A total of 54 taxa (Table 1) were identified from Zabargad reef; consisting of 16 green, 13 brown and 25 red macroalgae. The R/P and R+C/P indices result in values of 1.9 and 3.1, respectively. Four species could be considered as new records for the Red Sea. These were *Hypnea hamulosa*, *Coelothrix irregularis*, *Dipterosiphonia* and *Gracilaria debilis*. The windward reef (Site 1) contained 23 species; the leeward reef (Site 2) contained 34 species, while the western reef (Site 3) contained 40 species.

The identified seaweeds belong to 43 genera; 10 green, 12 brown and 22 of red algae. The percentage of total number of genera to the total number of species is thus equal to 79.6 %, and this indicates a high diversity of species within the area. *Caulerpa*, *Halimeda* and *Valonia* were the largest genera among Chlorophyta, as they contributed to this group by 4, 3 and 2 species, respectively. Other genera of green algae were represented by single species. *Padina* (Phaeophyta), *Galaxaura*, *Gelidium* and *Hypnea* (Rhodophyta) were the genera that contained two species, while other genera in these groups contained single species.

The recorded seaweeds comprised diverse forms of algae. Many species were filamentous (*Giffordia, Griffithsia, Feldmannia, Sphacelaria, Rhizoclonium, Centroceras, Ceramium, Herposiphonia* and *Heterosiphonia*), turf forming (*Gelidiella* and *Gelidium*), or articulated coralline forms (*Jania* and *Amphiroa*). Other forms such as fleshy sac-like species (*Valonia*, *Colpomenia*, and *Dictyosphaeria*), foliose forms (*Avrainvillea, Halimeda, Caulerpa*, and *Pocockiella*) and large shoot-like brown algae (*Sargassum* and *Turbinaria*) were also found in the area.

Table 1: Floristic composition, coverage (in cm) and contribution of algal groups at studied sites. Previous records from other Red Sea Islands (Papenfuss, 1968; El-Manawy and Gab-Alla, 2000) are also included in the table.

Macroalgal taxa	Site 1	Site 2	Site 3	Other Red Sea Islands, previous records
CHLOROPHYTA				
Avrainvillea amadelpha (Montagne) Gepp	15	0	0	Farun, Mirear
Boodlea composita (Harvey) Brand	20	0	54	Siyal
Caulerpa fastigiata Montagne	0	30	51	Mirear, Siyal, Dibia
Caulerpa peltata Lamouroux	4	53	0	Mirear
Caulerpa racemosa (Forsskål) J. Agardh	61	90	305	Mandola
Caulerpa serrulata (Forsskål) J. Agardh	123	87	120	Mirear, Siyal, Dibia
Cladophoropsis zollingeri (Kützing) Børgesen	0	0	33	Mirear, Siyal
Codium tomentosum Stackhouse	0	0	37	-
Dictyosphaeria cavernosa (Forsskål) Børgesen	44	86	37	Mirear, Siyal, Hanish
Halimeda discoidea Decaisne	0	180	0	-
Halimeda opuntia (Linnaeus) Lamouroux	214	165	33	Mirear, Dibia, Mandola
Halimeda tuna (Ellis et Solander) Lamouroux	0	0	149	Mirear, Siyal, Dibia
Rhizoclonium kochianum Kützing	0	21	33	Siyal
Siphonocladus forsskalii (Küt.) Bornet ex Detoni	0	26	0	-
Valonia macrophysa Kützing	0	20	53	-
Valonia ventricosa J. Agardh	0	0	13	Siyal
PHAEOPHYTA				
Chnoospora implexa J. Agardh	20	0	0	-
Colpomenia sinuosa (Mer. ex Roth) Der. et Solier	0	59	8	-
Dictyopteris membranacea (Stackhouse) Batters	0	45	0	-
Dictyota sandvicensis Sonder ex Kützing	0	105	18	Mirear, Siyal, Dibia
Feldmannia irregularis (Kützing) Hamel	0	66	0	Dibia
Giffordia mitchellae (Harvey) Hamel	0	76	5	-
Hydroclathrus clathratus (C. Agardh) Howe	10	58	0	-
Padina pavonica (Linnaeus) Thivy	339	152	124	Mirear, Siyal, Dissei
Padina tetrastromatica Hauck	0	0	10	Mirear, Siyal, Dibia
Pocockiella variegata (Lamouroux) Papenfuss	66	234	107	Mirear, Siyal, Dibia
Sargassum subrepandum (Forsskål) C. Agardh	0	23	0	Mandola, Adjuz
Sphacelaria tribuloides Meneghini	117	0	14	-
Turbinaria elatensis Taylor	337	0	218	-
RHODOPHYTA				
Amphiroa fragillissima (Linnaeus) Lamouroux	157	82	168	Mirear, Siyal, Dibia
Asparagopsis taxiformis (Delile) Trevisan	0	0	8	-
Centroceras clavulatum (C. Agardh) Montagne	4	0	0	Dibia, Mirear
Ceramium gracillimum (Kütz.) Griffiths et Harvey	0	12	0	-
Chondria collinsiana Howe	0	0	20	Mirear, Siyal
*Coelothrix irregularis** (Harvey) Børgesen	0	0	55	-
Digenea simplex (Wulfen) C. Agardh	30	45	20	Siyal, Dibia, Mandola
*Dipterosiphonia dendritica** (C. Ag.) Falkenb.	0	0	21	-
Fosliella farinosa (Lamouroux) Howe	48	45	161	Dissei, Mandola
Galaxaura lapidescens (Ellis et Sol.) Lamouroux	20	0	67	Mirear, Siyal
Galaxaura schimperi Decaisne	0	0	10	-
Gelidiella acerosa (Forsskål) Feldmann et Hamel	12	23	3	Hanish, Mandola
Gelidium crinale (Turner) Lamouroux	0	44	23	-
Gelidium pusillum (Stackhouse) LeJolis	0	0	34	Mirear, Siyal
*Gracilaria debilis** Børgesen	0	10	0	-

Table 1: continued.

Macroalgal taxa	Site 1	Site 2	Site 3	Other Red Sea Islands, previous records
Hypnea esperi Bory	39	60	35	Mirear, Dibia
*Hypnea hamulosa** (Turner) Montagne	0	18	0	-
Herposiphonia tenella (C. Agardh) Ambronn	0	0	16	Mirear, Siyal, Hanish
Heterosiphonia wurdemanni (Bail. et Har.) Falk.	0	10	12	Siyal
Jania rubens (Linnaeus) Lamouroux	31	54	15	Hanish, Mandola Mirear,
Laurencia papillosa (C. Agardh) Greville	61	125	24	Siyal, Kamaran
Leveillea jungermannioides (Her. et Mart.) Harvey	0	0	4	Mirear, Siyal
Martensia elegans Hering	0	14	0	Mandola, Siyal
Porolithon onkodes (Heydrich) Foslie	184	552	164	Brothers, Abulad
Total number of species	23	34	40	
Total coverage of green species	481	758	918	
Total coverage of brown species	889	818	504	
Total coverage of red species	586	1104	907	
Total coverage of all species	1956	2680	2329	
Percentage of total coverage per transect length	19 %	26 %	23 %	

2) Habitats and macroalgal zonation:

The coral reefs at Zabargad form several main habitats very different in their topography and ecological factors. Moreover, exposure of these habitats to the hydrodynamic factors resulted in many types of microhabitats in which attached algae are dominant. The following is the description of the surveyed transects alongside the reef of Zabargad at three different directions, the windward, the leeward and the westward. The description includes substrates, algal cover, profiles, zonation and the dominant species of the recorded taxa.

a) Zonation on the windward reef:

In the windward side of the island (Site 1, Figure 2), a shallow lagoon separates the reef flat from a relatively wide reef crest. The lagoon has a maximum width of 60 m, a maximum depth of 14 m, and a sandy bottom with dispersed coral fragments. The reef flat is 50 m wide, much poorer in coral cover and characterized by undulated flattened surface that gives way to sand to stand over. The reef crest is 5-10 m wide and extensively eroded and rich in crevices and reef pockets. The fore reef descends, as slant walls, into a terrace of 30-60 m width at a water depth of 40 m.

The windward reef contained 23 species covering 1956 cm, i.e. 19 % of the total length of the transect (Table 1). Phaeophyta was the dominant group in this site, as it covered 889 cm of the transect. *Padina pavonica* (339 cm) and *Turbinaria elatensis* (337 cm) were the major contributors within this group. Rhodophyta covered 586 cm of the transect, and *Amphiroa fragillissima* (157 cm) and *Porolithon onkodes* (184 cm) were the important participants of this coverage. Chlorophyta shared by 481-cm cover to the vegetation of this side, and *Halimeda opuntia* (214 cm) and *Caulerpa serrulata* (123 cm) were the dominant species.

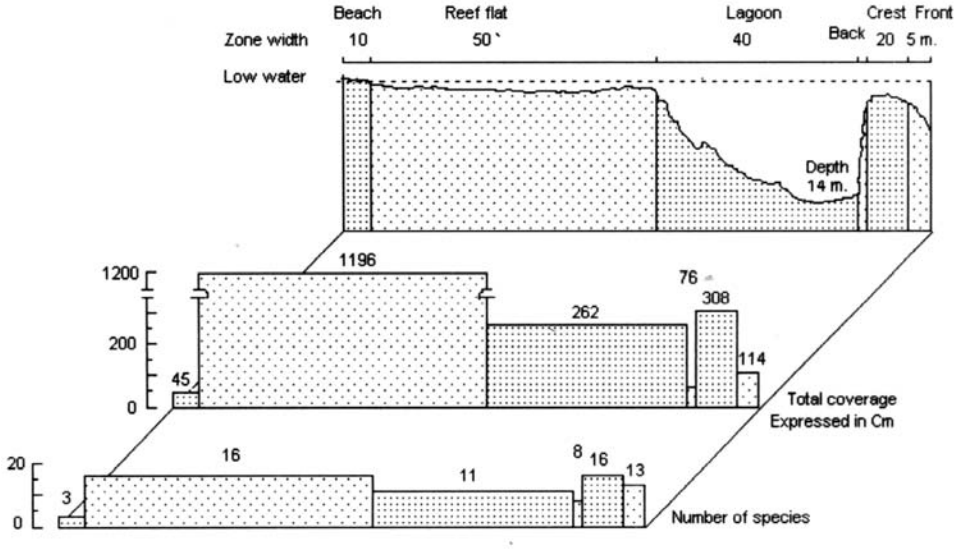

Fig. 2: The profile of windward transect showing the reef morphology (upper), the total coverage of species on each zone (middle), and the number of species in each zone (lower).

The profile of windward transect; total algal cover and the number of species are illustrated in Figure 2. The distribution and coverage of species are represented in Table 2. In relation to reef topography and substrates, six zones of benthic algae were distinguished on this transect, and are represented in the figure as a beach, reef flat or fringing reef, lagoon, crest back, reef crest, and reef front. The intertidal zone ranged from an upper region of coral rubbles and a beach-rock bordering the sandy shore of the island. The substrates on this beach were dark-green in color due to the dominance of blue-green algae. The first small growths of seaweeds were found in very shallow pools on coral rubbles, usually represented by several patches of *Padina pavonica* with *Porolithon* and *Sphacelaria*. They were greatly influenced by exposure.

The reef flat at site 1 contained 16 species of macroalgae with a total coverage of 1196 cm. At its beginning, the reef flat was occupied by a few species. The richest algal growths were found at the end on the uppermost part of this zone (12 species). The algae dominating the reef flat were *Caulerpa serrulata, Halimeda opuntia, Padina pavonica* and *Turbinaria elatensis*. These frondose macroalgae were usually found under coral heads, in channels and crevices, and were also common in the lagoon. The lagoon at this site contained 11 species that covering 262 cm of the transect. Most of these species occupied the shallow areas of the lagoon, becoming rare near the bottom. *Caulerpa racemosa* and *C. serrulata* were the commonest species in the unconsolidated sediment of the lagoon between seagrasses. The seagrass bed supported an abundant epiphytic flora such as *Fosliella farinosa* and *Amphiroa fragillissima*.

Table 2: Distribution and algal coverage (in cm) of species at windward side. Species found in only two stations are omitted from the table.

Zones in Site 1	Beach		Fringing reef									Lagoon							Back		Crest		Front
Transect stations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Avrainvillea amadelpha																				5	5		5
Boodlea composita																					8	7	5
Pocockiella variegata											20									4	16	6	20
Laurencia papillosa											20										34		7
Digenea simplex											10										10		10
Jania rubens											15									6	10		
Turbinaria elatensis								81	94	49	73										28	6	6
Hypnea esperi							16	5	5											13			
Dictyosphaeria cavernosa						5		10	14	5		10											
Halimeda opuntia					10	19	32	30	28	45	30	20											
Caulerpa racemosa							7		8					26	20								
Caulerpa serrulata							8	8	11		10				23	33	30						
Fosliella farinosa					5	4	4	4	3	3	5	4		4	4						3	3	2
Amphiroa fragillissima								10	13		61	21		20						8	24		
Padina pavonica	5	15		98	80	76	50												5	10			
Sphacelaria tribuloides		10	8	10		11				10	38	5										13	12
Porolithon onkodes	5	10		10						10	5	15								12	23	70	24

The crest back was dominated by 8 species crossing 76 cm of the transect. Although this side of the reef is more sheltered from the wave action, the species found on it formed a small coverage due to less light intensity. The reef crest was occupied by 16 species crossing 308 cm of the transect. The algae dominating the crest were *Amphiroa fragillissima, Laurencia papillosa, Pocockiella variegata, Turbinaria elatensis* and the predominant crustose coralline alga, the *Porolithon onkodes*. The poorer algal growth was found on the reef front as a group of 13 species forming a total cover of only 114 cm. *Laurencia papillosa* and *Porolithon onkodes* were the dominant species on the reef front.

The distribution of the species as a horizontal profile is shown in Table 2. Four groups of plants can be distinguished. The first one includes those species (from *Fosliella farinosa* to *Porolithon onkodes*) present throughout the reef complex of windward. *Padina pavonica* was the predominant species on the fringing reef as it crossed 50-98 cm of the transect. The second group was found on both the fringing reef and the lagoon, and consists of *Caulerpa racemosa, C. serrulata, Dictyosphaeria cavernosa* and *Halimeda opuntia*. The latter species covered 10-45 cm of the transect on fringing reef. The third group consists of five species, from *Pocockiella* to *Turbinaria*, which were found on fringing reef, crest back, crest and reef front but were not found in the lagoon. The fourth group included *Avrainvillea amadelpha* and *Boodlea composita*, which faced the current on the crest and front.

b) Zonation on the leeward reef:

The leeward southern reef (Site 2, Figure 3) differs greatly from the windward one. It is characterized by a large lagoon of approximately 600m at its widest stretch and a maximum depth reaches to 14m. The bottom of the lagoon is composed of unconsolidated sand with dispersed fragments of coral heads. The reef begins with an intertidal sandy beach of 10-30m wide. Limestone boulders and coral rubbles dominated this area. The beach gradually drops into the lagoon. The reef flat forms a relatively horizontal platform of 50m width. It is very rich in cracks and crevices. Sandy channels or sandy plains frequently interrupt this reef flat. The reef margin, on which coral pinnacles are found, descends into a terrace 10-30 m wide at 20 m water depth.

The leeward reef contained 34 species covering 2680 cm, i.e. 26 % of the total length of the transect (Table 1). Rhodophyta was the dominant group in this site, as it covered 1104 cm of the transect, and *Laurencia papillosa* (125 cm) and *Porolithon onkodes* (552 cm) were the important participants of this coverage. Phaeophyta covered 818 cm of the transect, and *Dictyota sandvicensis* (105 cm), *Padina pavonica* (152 cm) and *Pocockiella variegata* (234 cm) were the major contributors within this group. Chlorophyta shared by 758-cm cover to the vegetation of this side, and *Halimeda discoidea* (180 cm) and *Halimeda opuntia* (165 cm) were the dominant species.

The profile of leeward transect, total algal cover and the number of species are illustrated in Figure 3. The distribution and coverage of species are represented in Table 3. Six zones of benthic algae were distinguished on the leeward side of the island, and are represented in the figure as a beach in an intertidal zone, a large lagoon, reef back, reef flat or fringing reef, reef front, and reef pinnacle. The intertidal zone was narrow; ranged from an upper region of a beach-rock bordering the unconsolidated sediment in the periphery of the lagoon. Coral rubbles and stones covered the lower limit of the beach. Blue-green algae dominated the upper region of the beach, while small growths of

Feldmannia irregularis, Rhizoclonium kochianum and *Porolithon onkodes* covered the rubbles and stones in the lower limits of the intertidal. Here, the effect of exposure and wave action idly influenced these algae.

The lagoon in this site contained 31 species covering only 182 cm of the transect. Most of these species were rare and occupied the shallow areas of the lagoon, whereas very dense seagrass beds dominated the bottom. The upper region of the lagoon was dominated by filamentous species such as *Feldmannia irregularis, Rhizoclonium kochianum* and *Siphonocladus forsskalii*. The unconsolidated sediment of the lagoon included dwarfed forms of *Caulerpa racemosa* and *C. serrulata* in-between the seagrasses. The seagrass leaves and stolons supported an abundant epiphytic flora such as *Amphiroa fragillissima, Porolithon onkodes* with small growths *of Dictyota sandvicensis* and *Padina pavonica*.

Ten species of seaweeds were found on the back of the fringing reef, forming small coverage of the transect (81cm). These species were also found on the fringing reef but with a little coverage. Patches of *Halimeda, Dictyota* and *Padina* usually represented them.

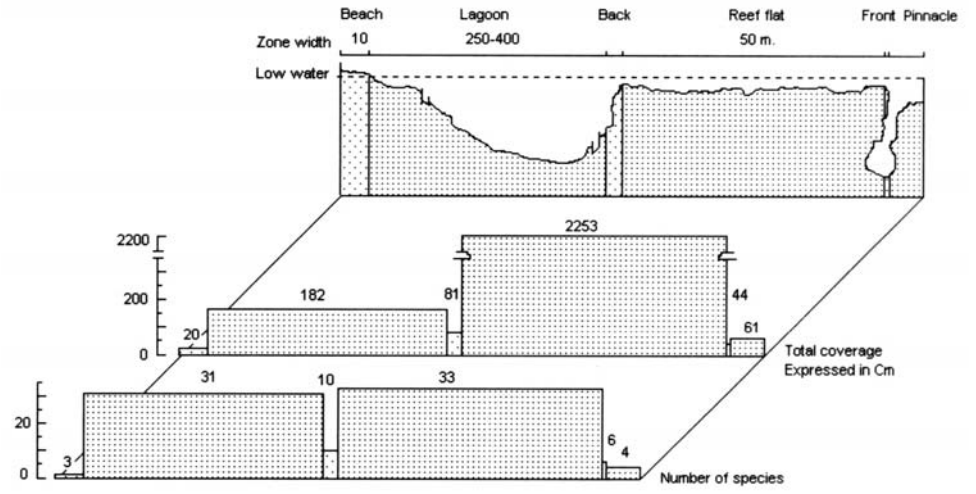

Fig. 3: The profile of leeward transect showing the reef morphology (upper), the total coverage of species on each zone (middle), and the number of species in each zone (lower).

The richest algal growth was found on the reef flat as it contained 33 species with a total coverage of 2253cm. Blue-green algae dominated the upper region and were graded into a multispecies turf of *Rhizoclonium kochianum, Feldmannia irregularis, Siphonocladus forsskalii*, with many other algae of Rhodophyta. Phaeophycean algae such as *Dictyota, Padina, Giffordia*, and many others of Chlorophycean and Rhodophycean species dominated the middle part of the reef flat. The breaker zone (stations 14-17, in Table 3) ranged from 80-130 cm depth and was dominated by a large number of seaweeds. The most dominant species were *Dictyota sandvicensis, Giffordia mitchellae, Halimeda discoidea, Laurencia papillosa* and *Porolithon onkodes*. *Caulerpa serrulata*,

Table 3: Distribution and algal coverage (in cm) of species at leeward side. Species found in only two stations are omitted from the table.

Zones in Site 2	Beach	Lagoon					Back	Fringing reef										Front	Pinnacle	
Transect stations	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Rhizoclonium kochianum	5	10						6												
Feldmannia irregularis	4	10							15	12	15		10							
Siphonocladus forsskalii		5						9			2		10							
Amphiroa fragillissima				13	10		10	5			5		4	15	20					
Dictyota sandvicensis					12		13		22	10			10	6	32					
Caulerpa racemosa					30									11	21	28				
Colpomenia sinuosa						5	6				16		13	10	5	4				
Caulerpa serrulata				20	10				10	10				13	10	14				
Padina pavonica		7		6	10		10	16	10				33	40		20				
Jania rubens									4				9	16	15	10				
Giffordia mitchellae															39	24	13			
Valonia macrophysa											4	3	9				4			
Caulerpa peltata										12					19	12	10			
Dictyosphaeria cavernosa										8	12			21	10	25	10			
Gelidium crinale									20						10		14			
Digenea simplex								10				20		7			8			
Laurencia papillosa								11							72	24	18			
Hypnea esperi								17		21			10		6		8			
Fosliella farinosa							3	3	6	5		4	4	6	9		5			
Gelidiella acerosa							2	8							9		4			
Halimeda opuntia							13			18	23	27	13	23	10	28	10			
Halimeda discoidea							9					48		13	20	42	23	10	5	10
Dictyopteris membranacea									4			5		10			13	6	4	3
Pocockiella variegata							7	18	32		19	41	12	10		31	24	15	15	10
Porolithon onkodes	11	13		3	4		8	30	44	62	15	75	50	43	20	41	72		38	23

Halimeda opuntia, H. discoidea and *Padina pavonica* were common in cracks, crevices and sandy channels.

The poorer algal growth was found on both the reef front and pinnacles as 4-6 species forming small coverage were found (Figure 3). *Dictyopteris membranacea, Halimeda discoidea, Pocockiella variegata,* and *Porolithon onkodes* were the dominant species here.

The distribution of the species as a horizontal profile is shown in Table 3. Three groups of plants can be distinguished. The first one includes three species, present throughout the reef complex except the beach and the lagoon (*Dictyopteris membranacea, Halimeda discoidea* and *Pocockiella variegata*). *Porolithon onkodes* was present allover the reef complex. The second group was found on the fringing reef and its back, including the species from *Jania rubens* to *Halimeda discoidea*. *Laurencia papillosa* was the dominant species in this group as it covered 11-72 cm of the transect. The third group consists of nine species, from *Rhizoclonium* to *Padina*, which were found on the beach, lagoon and fringing reef.

c) Zonation on the western reef:

The western side of Zabargad (Site 3, Figure 4) is much more sheltered from the wave action. It has a topographic feature more or less similar to that of the leeward reef. The lagoon in this side is much shallower and narrow, 4m depth and 25m wide. The reef flat is deeper at the middle and slightly slants toward the lagoon.

The western reef contained 40 species covering 2329 cm, i.e. 23 % of the total length of the transect (Table 1). Chlorophyta shared by 918-cm cover, and *Caulerpa racemosa* (305 cm), *Caulerpa serrulata* (120 cm) and *Halimeda tuna* (149 cm) were the dominant species. Rhodophyta covered 907 cm of the transect, and *Amphiroa fragillissima* (168 cm), *Fosliella farinosa* (161 cm) and *Porolithon onkodes* (164 cm) were the important participants of this coverage. Phaeophyta covered 504 cm of the transect, and *Turbinaria elatensis* (218 cm), *Padina pavonica* (124 cm) and *Pocockiella variegata* (107 cm) were the major contributors within this group.

The profile of westward transect, total algal cover and the number of species are illustrated in Figure 4. The distribution and coverage of species are represented in Table 4. The reef on this side extends to approximately 60 m, which is shallow compared with the previous sites. Analysis showed six zones dominated by corals and seaweeds. Figure 4 represents a beach, a shallow lagoon, a reef flat with a vertical back, a narrow reef crest, and a slightly slant reef front. The first zone occurred on intertidal rubbles and a beach-rock bordering the sandy shore of the island. It extended to about 45-cm depth and was greatly influenced by exposure. Ten species, representing 145 cm of the transect, were found here, but the visual and practical assessment indicated the dominance of blue-green algae with several patches of *Padina pavonica, Griffithsia tenuis* and *Fosliella farinosa* (Table 4).

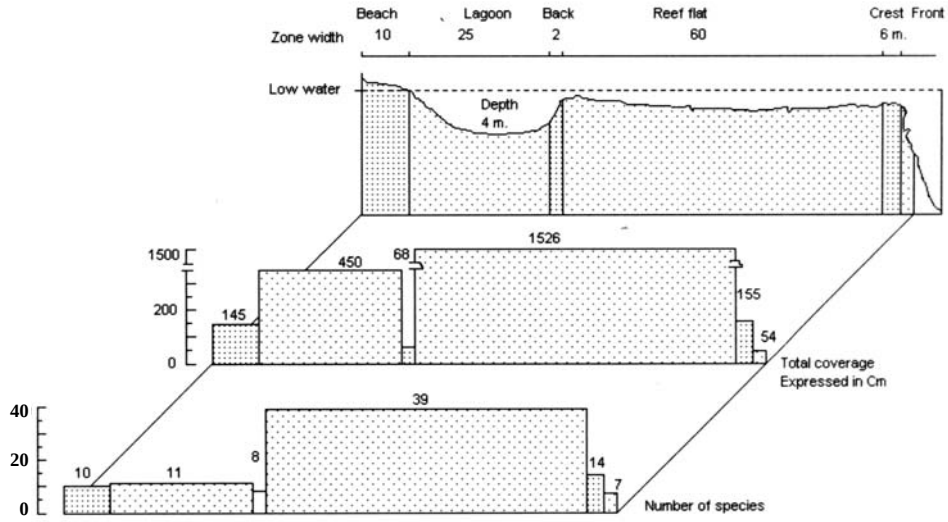

Fig. 4: The profile of windward transect showing the reef morphology (upper), the total coverage of species on each zone (middle), and the number of species in each zone (lower).

The shallow lagoon contained 11 species covering 450 cm of the transect. These species homogeneously occupied the bottom of the lagoon, on coral heads and boulders, and some were found in the unconsolidated sediment between seagrasses. *Caulerpa racemosa, C. serrulata* and *Turbinaria elatensis* were the commonest species here. *Amphiroa fragillissima, Dictyosphaeria cavernosa, Fosliella farinosa, Herposiphonia tenella, Valonia ventricosa* and *V. macrophysa* were found on dead coral fragments and/or as epiphytes on seagrasses. All of these algae were also common on the reef flat.

The vertical back of reef flat was dominated by 8 species crossing only 68 cm of the transect. Although this side of the reef is more sheltered from the wave action, the species found on it formed small coverage. In addition to *Halimeda opuntia, H. tuna, Hypnea esperi* and *Pocockiella variegata,* dwarf thalli of *Caulerpa serrulata* and *Padina pavonica* were found on the ridge of the back of reef flat.

The reef flat in this side contained the largest number of seaweeds in this study (16 species). The total coverage of macroalgae reached a length of 1526 cm. At its beginning, the reef flat was shallow, gradually deepened into a depth of 160 cm at the middle then raised again at its end. The algal dominance and growth was parallel to this graduation, i.e., richest at the middle and lowest at the two ends. The highest dominance on reef flat was recorded for *Caulerpa racemosa* as 41 cm, for *Halimeda tuna* and *Turbinaria elatensis* as 40 cm, and for *Amphiroa fragillissima* as 32 cm. Whereas coenocytic green algae (*Caulerpa, Halimeda*) dominated the channels, crevices and reef pockets. Tougher and frondose brown algae (*Turbinaria, Padina* and *Pocockiella*) grew on exposed dead coral surfaces.

Table 4: Distribution and algal coverage (in cm) of species at westward side. Species found in only two stations are omitted from the table.

Zones in Site 3	Beach	Lagoon					Back	Fringing reef										Crest	Front	
Transect stations	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Boodlea composita															15			16	23	
Dipterosiphonia dendritica															11	6			4	
Galaxaura lapidescens														20		27		20		
Coelothrix irregularis													14	20		13	8			
Caulerpa fastigiata										4	6	13		24					4	
Sphacelaria tribuloides									3	3									10	
Porolithon onkodes								31			4		10	15	23	23	18	21	19	
Halimeda opuntia							5	4							8				10	6
Halimeda tuna							5					13	40	21	30	15			15	10
Pocockiella variegata							6	13	4		9	5		11		21		10	13	15
Hypnea esperi							7	5							8				10	5
Valonia ventricosa				6	2								3				2			
Turbinaria elatensis				16	38	42						40	40		12	30				
Herposiphonia tenella				4	4							4			2				2	
Valonia macrophysa			10	13		14							5		5				6	
Caulerpa racemosa			33	30	20	23				8		15	41	10	26	35	33	19	12	
Amphiroa fragillissima			13	12				5	13	8		10	10	25	27	32	5	4	4	
Fosliella farinosa		5	10	10	21	14	11	27				5	10		4		21		23	
Caulerpa serrulata			10	30			13				18	8	7				20	14		
Dictyosphaeria cavernosa					10				5									22		
Padina pavonica		38	31				16	11	8	10	10									
Griffithsia tenuis		34														9	4			

Fourteen species dominated the reef crest, crossing 155 cm of the transect. Almost all of these species were found on the reef flat. *Porolithon onkodes* was less dominant here. The poorer algal growth was found on the reef front as a group of 7 species forming a total cover of only 54 cm.

The distribution of the species as a horizontal profile is shown in Table 4. Four groups of plants can be distinguished. The first one includes those species (from *Caulerpa serrulata* to *Griffithsia tenuis*) that were found throughout the lagoon, reef back and reef flat. *Padina pavonica* and *Griffithsia tenuis* were also found on the beach. The second group (from *Valonia ventricosa* to *Fosliella farinosa*) was found throughout the reef complex except the beach and reef front. The third group consisted of four species, from *Halimeda* to *Hypnea*, which were found throughout the reef complex except the beach and the lagoon. The fourth group including the species from *Boodlea* to *Porolithon,* occupied the fringing reef and the crest.

3) Constant species:

The investigated seaweeds were regrouped in Table 5 to indicate their preference for the studied sites, i.e., windward, leeward, and westward site. A constant index was denoted for each species to indicate its constancy along the transect. Seven groups of species were distinguished. The first one includes those species restricted in their distribution to site 1 (*Avrainvillea amadelpha, Chnoospora implexa* and *Centroceras clavulatum*). Their constancy did not exceed 20% of the transect length in this site. The second and third groups consist of species that were restricted to sites 2 and 3, respectively. *Halimeda discoidea,* in the second group, had a relatively wide distribution along transect 2. The fourth, fifth and sixth groups composed of species, which can be found in two sites.

The seventh group includes the species present throughout the whole area of study. The constancy of species of this group varied markedly along different sites. In site 1, most species had a constancy of up to 40%, whereas *Porolithon onkodes* had a maximum constancy of 41-60% in this site. In site 2, *Halimeda opuntia, Padina pavonica, Pocockiella variegata,* and *Fosliella farinosa* had a constancy of 41-60%. *Porolithon onkodes* had also the maximum constancy (61-85%) in this site. *Caulerpa racemosa* and *Amphiroa fragillissima* were widespread (61-85%) in site 3, followed by *Pocockiella variegata* and *Fosliella farinosa* (41-60 %).

Table 5: The constancy classes for the species occurring at each of the studied sites. I, species present in up to 20 % of the stations; II, 21-40 %; III, 41-60 %; and IV, 61-85 %.

Site 1	Index	Site 2	Index	Site 3	Index
Avrainvillea amadelpha	I	*Caulerpa fastigiata*	I	*Asparagopsis taxiformis*	I
Boodlea composita	I	*Caulerpa racemosa*	I	*Boodlea composita*	I
Caulerpa peltata	I	*Ceramium gracillimum*	I	*Chondria collinsiana*	I
Caulerpa racemosa	I	*Gelidiella acerosa*	I	*Cladophoropsis zollingeri*	I
Centroceras clavulatum	I	*Gelidium crinale*	I	*Codium tomentosum*	I
Chnoospora implexa	I	*Giffordia mitchellae*	I	*Coelothrix irregularis*	I
Digenea simplex	I	*Gracilaria debilis*	I	*Colpomenia sinuosa*	I
Fosliella farinosa	I	*Griffithsia tenuis*	I	*Dictyosphaeria cavernosa*	I
Galaxaura lapidescens	I	*Heterosiphonia wurdemanni*	I	*Dictyota sandvicensis*	I
Gelidiella acerosa	I	*Hydroclathrus clathratus*	I	*Digenea simplex*	I
Hydroclathrus clathratus	I	*Hypnea hamulosa*	I	*Dipterosiphonia dendritica*	I
Hypnea esperi	I	*Laurencia papillosa*	I	*Galaxaura lapidescens*	I
Jania esperi	I	*Martensia elegans*	I	*Galaxaura schimperi*	I
Laurencia papillosa	I	*Rhizoclonium kochianum*	I	*Gelidiella acerosa*	I
Amphiroa fragillissima	II	*Sargassum subrepandum*	I	*Gelidium crinale*	I
Caulerpa serrulata	II	*Siphonocladus forsskalii*	I	*Gelidium pusillum*	I
Dictyosphaeria cavernosa	II	*Valonia macrophysa*	I	*Giffordia mitchellae*	I
Halimeda opuntia	II	*Amphiroa fragillissima*	II	*Griffithsia tenuis*	I
Padina pavonica	II	*Caulerpa peltata*	II	*Heterosiphonia wurdemanni*	I
Pocockiella variegata	II	*Caulerpa serrulata*	II	*Jania esperi*	I
Sphacelaria tribuloides	II	*Colpomenia sinuosa*	II	*Laurencia papillosa*	I
Turbinaria elatensis	II	*Dictyopteris membranacea*	II	*Leveillea jungermannioides*	I
Porolithon onkodes	III	*Dictyosphaeria cavernosa*	II	*Padina tetrastromatica*	I
		Dictyota sandvicensis	II	*Rhizoclonium kochianum*	I
		Digenea simplex	II	*Sphacelaria tribuloides*	I
		Feldmannia irregularis	II	*Caulerpa fastigiata*	II
		Hypnea esperi	II	*Caulerpa serrulata*	II
		Jania esperi	II	*Halimeda opuntia*	II
		Fosliella farinosa	III	*Halimeda tuna*	II
		Halimeda discoidea	III	*Herposiphonia tenella*	II
		Halimeda opuntia	III	*Hypnea esperi*	II
		Padina pavonica	III	*Padina pavonica*	II
		Pocockiella variegata	III	*Porolithon onkodes*	II
		Porolithon onkodes	IV	*Turbinaria elatensis*	II
				Valonia macrophysa	II
				Valonia ventricosa	II
				Fosliella farinosa	III
				Pocockiella variegata	III
				Amphiroa fragillissima	IV
				Caulerpa racemosa	IV

Discussion:

The fringing reefs at Zabargad encompassed 54 taxa of seaweeds; add four new records to the algal flora of the Red Sea. The number of taxa at this remote oceanic island compares that found at the neritic Mirear Island (57 species, El-Manawy and Gab-Alla, 2000). By contrast, the flora at Zabargad is much reduced in number when compared with that found

in Caribbean. It was estimated to be about 59 % of the actual flora present at Belize Island (Tsuda and Dawes, 1974), and about 33 % of flora present in neritic fringing reef at Belize (Norris and Bucher, 1982). The difference between the two floras of oceanic and neritic at Belize was attributed to the difference in nutrients levels, while the Red Sea water in both oceanic and neritic is known to be oligotrophic.

Michanek (1979) and Lüning (1990) identified seven biogeographical regions in world's oceans, with each having distinct seaweed floras. The flora at Zabargad contained species share in common between temperate and tropical regions, with a general tendency to the Indo-Pacific pattern. The contribution of different taxonomic groups (the R/P and R+C/P indices) to the floristic composition is also considered to be intermediate between temperate and tropical floras. Dubinsky (1990) and Veron (1995) referred the wide dispersion of Indo-Pacific biota to the spread from one island cluster to another wherever substrate is available. Comparison of floras from Zabargad and from other islands of the Red Sea (Table 1) indicated that the number of species shared among them is relatively high and is testimony for the wide distribution of the investigated species. Referring to the previous works (e.g., Jaasund, 1976, 1977; Børgesen, 1920, 1943) indicates the wide distribution of the new records in Australia, Brazil, Easter Island, Mauritius, Tanzania, and West Indies.

Coral reefs have been described as a thin veneer of living organic material covering gigantic structures of limestone, producing the most complex and highly diverse marine ecosystem (Birkeland, 1997). The floristic composition at Zabargad was more diverse in terms of genera and species. The investigated taxa comprised many filamentous, turf-forming, fleshy sac-like, foliose, large shoot-like, and articulated and crustose coralline algae. By contrast, Benayahu and Loya (1977) found that turf forms in the Gulf of Eilat contained a few species with a filamentous brown alga, *Sphacelaria tribuloides*. Some macroalgae at Zabargad are known to be of the most important sources of reef and lagoon sediments (e.g., *Halimeda*, Hillis-Colinvaux, 1980; Littler, 1976). Coralline red algae (e.g., *Porolithon*) produce calcite and are the "cementers" of many coral reefs (Sorokin, 1993).

The seaweed vegetation of Zabargad appears as rather heterogeneous, having a dissimilar construction at each side of the coral reefs. The difference in species composition and their coverage at the different sides is good evidence for this. Only fourteen species shared in common between windward, leeward, and westward sides. Exposure of the island sides to different intensity of water movement could be the causative agent for the vegetation heterogeneity. Water motion is known as a critical factor affecting photosynthesis (Carpenter and Williams, 1996) and distribution of reef-building algae. Moderate waves and currents, with expectant excess nutrients, from the nutrient cycling of the seagrass bed, could be contributed for the increased coverage at the leeward side.

The macroalgal community of the fringing reefs at Zabargad showed a conspicuous zonation. Analysis of the studied transects revealed six zones related in general to the reef structure and its topography. The algal zonation in this study cannot be easily extrapolated to another part of the world. The reason is that reef structure depends on many factors, including historical, abiotic, and biotic conditions (Berner, 1990). At Solomon Islands in pacific, Womersley and Bailey (1969) described four zones included beach, moat, reef flat, and seaward rim. At Curacao Netherlands Antilles, van den Hoek *et al.* (1975) described seven zones included two on intertidal rubbles, three on shallow

water corals, and two on deep-water corals. In Caribbean, Norris and Bucher (1982) described five zones included upper intertidal beach rock, lower intertidal and subtidal breaker zone on reef flat and two on deep-water corals.

As might be expected for the intertidal plant communities in tropics, the beach zone at different sides of Zabargad has a marked reduction in floristic composition. High temperatures and exposure during low tide limit the development of most algae. Mobility of coral sand due to water movement could be another factor limiting the settlement and growth of seaweed spores. Crustose green, blue-green algae, *Feldmannia, Griffithsia* and *Rhizoclonium* found to be the most tolerant species in such conditions. The low species diversity of the intertidal habitats has been reported at many Islands in the Indo-Pacific (Womersley and Bailey, 1969).

The reef flat was the richest among the reef zones in both species composition and algal dominance, which is probably related to more favorable conditions at this zone. The reef flat lies in a shallow subtidal region and, thus, it is well illuminated and does not subjected to fluctuation of temperatures. Moreover, it contained a large variety of microhabitats in which attached algae became dominant.

The excessive water surge on reef flat of windward side resulted in the distribution of algal community in a more or less continuous pattern. By contrast, moderate water movement on the leeward resulted in subdivision of reef flat into three sub-zones, an upper region dominated by blue-green algae and turf seaweeds, a middle part contained a mixed community of brown, red and green algae, and a breaker zone dominated by larger forms of seaweeds. Norris and Bucher (1982) also reported the presence of large algae in the breaker zone from Belize Barrier Island. The characteristics of algal vegetation of the westward side intermediate between those found in the windward and leeward sides.

Comparison of seaweed vegetation in lagoons of the three sides of Zabargad suggests the effect of submarine illumination and water movement on the structure and primary productivity. Filamentous forms dominated the shallow areas of the lagoon, foliose algae grown deeper on the bottom sediment, while seagrasses supported a greater number epiphytic flora. Dahl (1973) also reported this observation in the reefs of Puerto Rico.

The vertical wall of the reef back was dominated by 8-10 species with poor algal growths. Grazing might be the reason for this low dominance. A large concentration of fishes, known to feed on algae, was observed close to this wall. There is similarly a conspicuous absence of algae along wave-sheltered parts of the nearby boulder breakwater system of Tema harbor, and this has been shown experimentally to be the result of fish grazing (John and Pople, 1973). Grazing pressure by fish and invertebrates might be one of the prime factors determining algal abundance and species composition in many benthic habitats in tropical and subtropical waters (Adey and Goeremiller, 1987; Hay, 1981; Mathieson et al., 1975; and Glynn, 1990).

The low wave energy in the leeward side of Zabargad resulted in a pettily developed reef crest. Although the reef crest on the windward side is highly exposed to wave action, it contained a higher number and coverage of species in comparison with the westward side. The reason for this peculiar dominance is that the windward reef crest is extensively eroded and rich in crevices and fissures within which the algae hideaway from wave action. Moreover, the morphology of algae found there showed minor modifications to persist in strong surf. The rhizoids of large forms, like *Laurencia* and *Turbinaria*,

became stronger than in sheltered habitats. The thalli were dwarf and grown in adherent to substrata. Santelices and Abbott (1988) interpreted the presence of strong rhizoids and haptera in many of species, or the crustose morphology of many others, as morphologies that allow adjustments to the very strong surf that continually beats the shores of the Easter Island. Payri (1987) reported the effect of wave exposure on the morphology of *Turbinaria ornata*.

Like the reef back, the reef front was poor in species composition and algal growths. The algae found here (e.g., *Halimeda, Pocockiella, Porolithon*) are known to be tolerant to wave action.

Examination of the horizontal distribution of species along the coral reefs at Zabargad revealed four groups of seaweeds on both windward and westward and three on the leeward side. Most of species were restricted in their distribution as they had low constancy (see Table 5) along the whole area of the coral reefs. The fact that most species had a low constancy suggests a continuous change of vegetation and the presence of algal zonation. The types of substrata and water movement could be the predominant factors leading to this zonation.

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