

Expansion of the macroalga *Caulerpa racemosa* and changes in softbottom macrofaunal assemblages in Moni Bay, Cyprus

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Abstract – The recent expansion of the Red Sea macroalga *Caulerpa racemosa* and its impact on the diversity and abundance of macrobenthos were examined and compared in the summers of 1992 and 1997, in Moni Bay, Cyprus. The phyto-benthic community of the bay in 1992 was dominated by the seagrass *Posidonia oceanica* while, in 1997, the Lessepsian migrant *C. racemosa* became the most dominant, forming extensive mats. Changes in the vegetation system in Moni Bay have caused significant compositional changes in macrofaunal assemblages. A total of 178 individuals of 62 species are recorded. The composition of the macrofauna in 1992 was dominated by gastropods (44 %), crustaceans (22 %), bivalves (17 %), polychaetes (11 %) and echinoderms (6 %). In 1997, the gastropods and crustaceans had decreased to 13 % and 16 % respectively, while, polychaetes had increased to 38 % becoming the most dominant taxon. Bivalves and echinoderms also increased to 22 % and 11 %, respectively, in 1997. The proliferative growth of *C. racemosa* imposed successional changes on the macrofaunal assemblages in Moni Bay, Cyprus, between 1992 and 1997. It remains to be tested whether the expansion of *C. racemosa* is related to the increase of water temperature associated with global warming or nutrient inputs or with the differences in the life history characteristics of this migrant vs. native algal species. © 1999 Ifremer / CNRS / IRD / Éditions scientifiques et médicales Elsevier SAS

Lessepsian migrant / *Caulerpa racemosa* / benthos / community composition / Moni Bay, Cyprus

Résumé – Expansion de la macroalgue *Caulerpa racemosa* et variations de la macrofaune des fonds meubles dans la baie de Moni, Chypre. L'expansion récente de la macroalgue de mer Rouge *Caulerpa racemosa* et son impact sur la diversité et l'abondance du macrobenthos ont été comparés dans la baie de Moni, à Chypre, entre les étés 1992 et 1997. La communauté phytobenthique de la baie était dominée en 1992 par l'algue *Posidonia oceanica*, alors qu'en 1997, l'immigrant lessepsien *C. racemosa* dominait, formant de vastes prairies. Les changements de végétation dans la baie de Moni ont entraîné des modifications significatives dans la composition de la macrofaune. Au total, 178 individus de 62 espèces ont été examinés. La composition de la macrofaune était dominée en 1992 par les gastéropodes (44 %), les crustacés (22 %), les bivalves (17 %), les polychètes (11 %) et les échinodermes (6 %). En 1997, les gastéropodes et les crustacés étaient réduits à 13 et 16 % respectivement, tandis que le polychètes devenaient le taxon dominant (38 %) ; les bivalves et les échinodermes progressaient également jusqu'à 22 et 11 % respectivement. La croissance proliférante de *C. racemosa* a provoqué une série de changements dans la macrofaune de la baie de Moni entre 1992 et 1997. Il reste à établir si l'expansion de *C. racemosa* est due à l'élévation de la température de l'eau associée au réchauffement global, à l'apport des nutriments, ou aux différences entre les caractéristiques de l'évolution de cet immigrant et celles des espèces algales indigènes. © 1999 Ifremer / CNRS / IRD / Éditions scientifiques et médicales Elsevier SAS

immigrant lessepsien / *Caulerpa racemosa* / benthos / communauté / baie de Moni, Chypre

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1. INTRODUCTION

The construction of the Suez Canal in 1869, linking the southeastern corner of the Mediterranean with the northern tip of the Gulf of Suez, Red Sea, provided unrivalled opportunities for marine organisms to extend their geographical ranges [19, 21, 23, 27]. The Suez Canal, once established as a pathway of Lessepsian migration (i.e. migration of organisms through the Suez Canal into the Mediterranean), has brought a considerable number of marine species into the Mediterranean during the last few decades. Only relatively few organisms migrated in the opposite direction [27, 28], probably because of prevailing current flows, but the reasons for this are not yet clear. As a whole, the influx of Red Sea species into the Mediterranean has been 'successful', as a considerable number of Red Sea species have become well adapted to the new environment. It has been estimated that Lessepsian migrants constitute nearly 5 % of the total marine fauna of the Mediterranean in comparison to 12 % found in the southeastern Mediterranean [11]. In fact, about 20 % of the decapod species off the Israeli Mediterranean coast are represented by the Indo-Pacific Erythraean fauna [12].

The migration of benthic marine plants (seagrasses and macroalgae) from the Red Sea into the Mediterranean has also been successful [20]. Several Red Sea plant species have been reported from the Mediterranean, among those the seagrass *Halophila stipulacea* which grows intermingled with the immigrant *Caulerpa racemosa* [20]. The seagrass *H. stipulacea* was the first Red Sea immigrant via the Suez Canal to be reported from the Mediterranean [21]. At present, this species is common in the waters around Rhodes, in the Aegean Sea, in the waters of Cyprus, on the coast of Egypt and all along the Suez Canal [1, 16, 14]. On the other hand, the green alga *C. racemosa*, which is very common in the Red Sea, was found at various stations in the eastern Mediterranean in both underdeveloped and developed forms [20].

Over recent years, *C. racemosa* has been undergoing prolific growth in the coastal waters of Cyprus. This species was first reported in 1991 in Moni Bay [13] at a depth of 30 m. At present, it can be found all around the island forming extensive dense beds. Other Red Sea migrants, such as the filamentous green alga *Cladophora patentiramea* (Boudouresque and Verlaque, pers. comm.) and the brown alga *Styopodium schimperi*, have caused considerable ecological problems on our coastline in recent years [14].

The need to understand what is triggering the rapid expansion of *C. racemosa* off the coast of Cyprus is crucial, since the colonization of this migrant is in a 'dynamic on-going process' which may cause serious ecological problems, such as habitat alterations and vital changes in macrobenthic assemblages. Changes in the vegetation type of an ecosystem may cause dramatic changes in macrofaunal assemblages [17] and, subsequently, may alter the dynamics of the whole ecosystem. It is generally shown that macrofaunal communities can be used as indicators, since they respond predictably to environmental perturbations [3].

The aim of this study was to summarize the present expansion of the Lessepsian migrant *C. racemosa* in the coastal waters of Cyprus and to examine the possible effects of the proliferation of this species on the soft-bottom macrofaunal assemblages. Macrobenthic data (phytobenthos and zoobenthos) were collected in Moni Bay, Cyprus, before (1992) and after (1997) the occurrence of *C. racemosa*. The diversity and abundance data of zoobenthos, before and after the spread of *C. racemosa*, were used to characterize the community structure, and to compare possible alterations in macroinvertebrate composition associated with the recent colonization of *C. racemosa*.

2. MATERIALS AND METHODS

2.1. Site Description

The study area (figure 1) is located in Moni Bay, adjacent to the city of Limassol which is the largest coastal city in Cyprus. Close to the study area, about 450 m from the sampling stations, a sewage outfall discharges approximately $6000 \text{ m}^3 \text{ d}^{-1}$ tertiary effluents, at a depth of 5 m. In addition, an open sea cage-culture farm, with a production of about 100 t yr^{-1} is located near the sampling area, at a distance of about 500 m.

The phytobenthic communities found in the area consist mainly of the meadows of the seagrass *Posidonia oceanica* which are the most important habitats in the Mediterranean. *Posidonia* forms extensive meadows in the area starting from shallow waters (5 m depth) and extending down to over 30 m depth [13]. In 1991, the Red Sea migrant *Caulerpa racemosa* was found for the first time, in Moni Bay, at a depth of 30 m. Since then, densely-formed beds of *C. racemosa* have been rapidly expanding around the island, with its greatest abundance in the

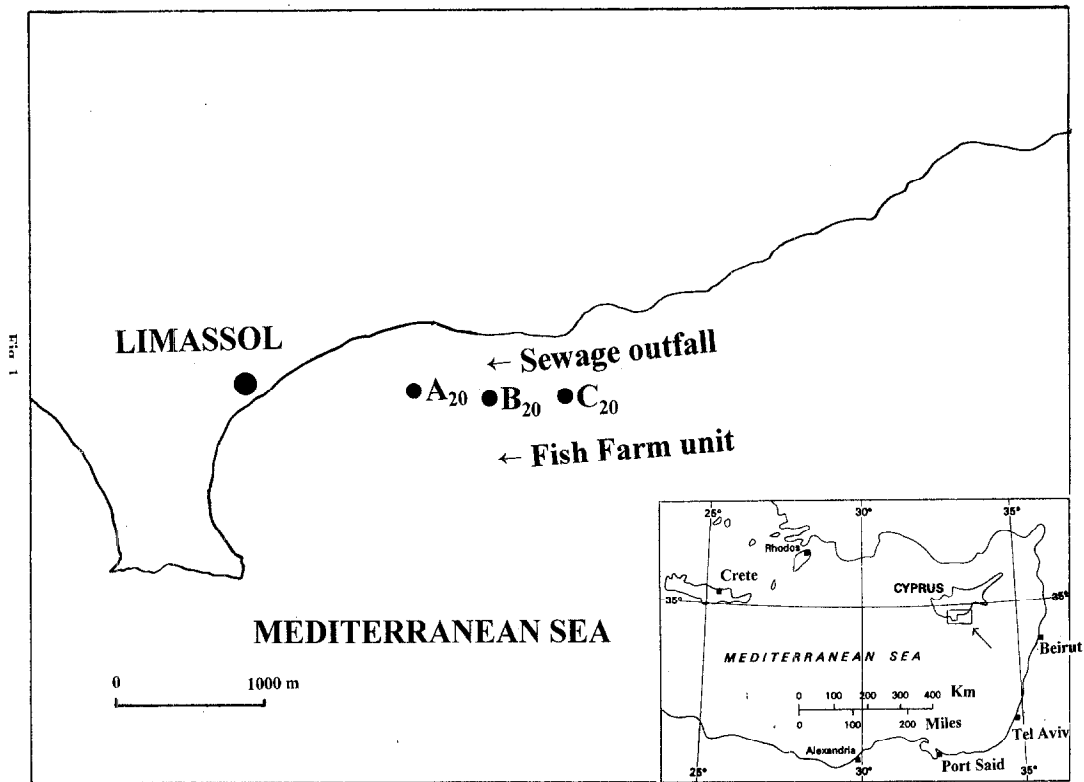


Figure 1. Map of Moni Bay, showing the three stations sampled during summers 1992 and 1997, before and after the proliferation of *Caulerpa racemosa*.

southern regions (Limassol–Moni Bay). *C. racemosa* has been found to occupy a wide range of habitats, from sandy to muddy substrates, from the intertidal zone down to 60 m depth [15].

2.2. Sampling Regime

Three stations (A₂₀, B₂₀, C₂₀), located in Moni Bay at 20 m depth were sampled during the summers of 1992 (before the appearance of *C. racemosa* at this depth) and 1997 (figure 1). Each station was positioned using an echosounder and an Interphase Star Pilot 6 GPS (Global Positioning System) unit. Stations were at a distance of about 500 m from each other and about 650 m from the coast. During the summers of 1992 and 1997, sediment and macrobenthic samples were collected by the RV *Alkyon* from all three stations.

2.3. Sediment Characteristics

Granulometric analyses on surficial sediments were conducted using a series of sieves (2.36 mm, 1.18 mm,

0.6 mm, 0.3 mm, 0.15 mm, 0.075 mm) to separate out the gravel fraction, very coarse sand, coarse sand, medium sand, fine sand, and very fine sand [18].

Percent organic matter was measured by weight loss upon combustion at 500 °C for 16 h.

2.4. Macrobenthos

At each station, ten macrobenthic samples were obtained with an “orange peel” grab sampler (0.14 m²) and pooled together, covering a total surface area of 1.45 m². Sediment samples were then filtered through a 500 µm sieve to collect macrofauna, algae and seagrasses. After collection, specimens were preserved in 70 % alcohol and identified to the lowest possible taxa using the following sources [4–10, 22, 24, 25, 29, 31].

2.5. Statistical Analysis

An F_{\max} was used prior to Anova to check for homogeneity of variances. One-way Anova was used to test for significant effects between species diversity, abundance

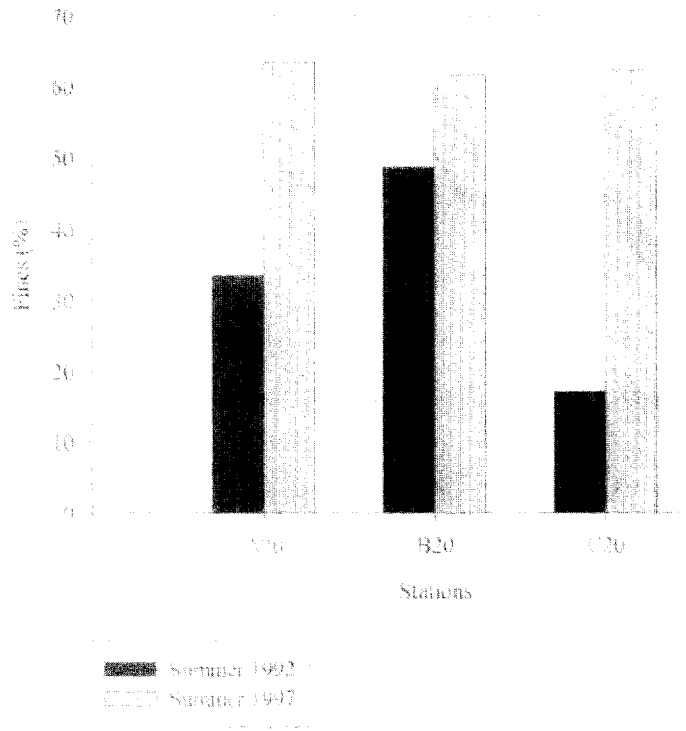


Figure 2. Percent fines (%) in sediments of Moni Bay for all three stations, from summers 1992 and 1997.

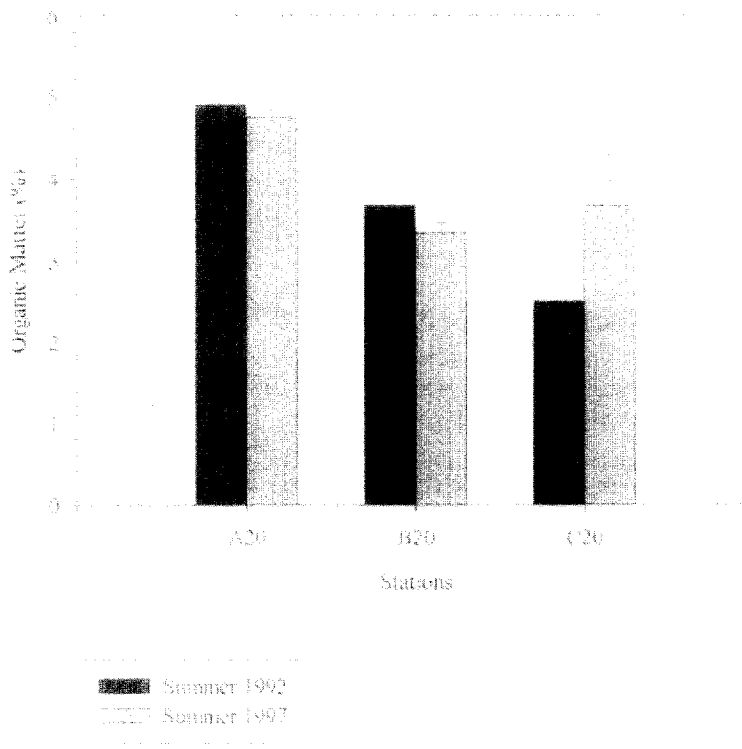


Figure 3. Percent organic matter (%) in sediments of Moni Bay for all three stations, from summers 1992 and 1997.

Table I. Macrobenthic diversity and abundance data for all 3 stations sampled off the Moni Bay, Cyprus, during Summers 1992 and 1997. ** = 40 %–60 % coverage; *** = 70 %–90 % coverage; p = present; numbers = number of individuals of each species per 1.45 m² surface area.

Classification	1992			1997		
	A ₂₀	B ₂₀	C ₂₀	A ₂₀	B ₂₀	C ₂₀
ALGAE						
CHLOROPHYCEAE						
Caulerpaccae						
<i>Caulerpa prolifera</i>		**				
<i>Caulerpa racemosa</i>				***	***	***
Dasycladaceae						
<i>Dasycladus clavaeformis</i>					p	p
Codiaceae						
<i>Udotea petiolata</i>				p		
PHAEOPHYCEAE						
Dictyotaceae						
<i>Dilophus mediterraneus</i>				p		
ANGIOSPERMAE						
Potamogetomaceae						
<i>Posidonia oceanica</i>	***	***	***	**		**
ANNELIDA						
POLYCHAETA						
Eunicidae						
<i>Eunice floridana</i>		1				
<i>Marphysa sanguinea</i>						
<i>Marphysa bellii</i>			1	1		
Capitellidae						
<i>Capitella</i> sp.			1			
<i>Pseudocapitella incerta</i>				3	8	2
Onuphiidae						
<i>Onuphis eremita</i>						1
Glyceridae						
<i>Glycera convoluta</i>		2		3		1
Nephtyidae						
<i>Nephtys hombergii</i>		1				
Nereidae						
<i>Neanthes pelagica</i>			1			
Aphroditidae						
<i>Aphrodita aculeata</i>					3	
Hermonia hystrix						
Syllidae						
<i>Exogone gemmifera</i>				1	3	1
Goniadidae						
<i>Goniada norvegica</i>				1		3
Pectinariidae						
<i>Amphictene auricoma</i>				1	2	3
Orbiniidae						
<i>Naineris laevigata</i>					1	
Sigalionidae						
<i>Sthenelais boa</i>				1		
SIPUNCULIDA						
Sipunculidae						
<i>Phascolosoma</i> sp.					1	

Table I. (continued).

Classification	1992			1997		
	A ₂₀	B ₂₀	C ₂₀	A ₂₀	B ₂₀	C ₂₀
MOLLUSCA						
PLACOPHORA						
Chitonidae						
<i>Chiton olivaceus</i>						1
GASTROPODA						
Columbellidae						
<i>Columbella rustica</i>						1
Turbinidae						
<i>Bolma rugosa</i>	1	1		1		
Cerithiidae						
<i>Cerithium vulgatum</i>	2					
Conidae						
<i>Conus mediterraneus</i>						1
Trochidae						
<i>Jujubinus exasperatus</i>	1					
Pyramidellidae						
<i>Euparthenia bulinea</i>	1					
Neritidae						
<i>Smaragdia viridis</i>	2	2	8			
Tricoliidae						
<i>Tricolia speciosa</i>	1		1			
Turrillidae						
<i>Turritella turbona</i>	3	2	3	3	1	2
Philinidae						
<i>Philine catena</i>						4
LAMELLIBRANCHIATA						
Turridae						
<i>Bela nebula</i>						1
Tellinidae						
<i>Tellina balaustina</i>		1				1
Semelidae						
<i>Abra alba</i>						2
Carditidae						
<i>Glans aculeata</i>					2	1
Cardiidae						
<i>Parvicardium exiguum</i>	2				1	1
<i>Plagiocardium papillosum</i>						
Pectinidae s						
<i>Lissopecten hyalinus</i>		1	1			
Lucinidae						
<i>Loripes lacteus</i>						1
Myrtea spinifera						
Veneridae						
<i>Gouldia minima</i>		3		3	1	6
<i>Venus verrucosa</i>						
Glycymeridae						
<i>Glycymeris glycymeris</i>		1				
Mytilidae						
<i>Modiolula phaseolina</i>						1

Table I. (continued).

Classification	1992			1997		
	A ₂₀	B ₂₀	C ₂₀	A ₂₀	B ₂₀	C ₂₀
ARTHROPODA						
CRUSTACEA						
Decapoda						
Alpheidae						
<i>Athanas nitescens</i>	1					
Processidae						
<i>Processa edulis</i>						1
Paguridae						
<i>Cestopagurus timidus</i>	2		2	3	2	
Diogenidae						
<i>Clibanarius erythropus</i>	1			2	1	1
<i>Paguristes eremita</i>						
Eriphiidae			1	1		
<i>Eriphia verrucosa</i>	1					
Dorippidae						
<i>Ethusa mascarone</i>		1			1	
Galatheidae						
<i>Galathea squamifera</i>		1		1		
Portunidae						
<i>Liocarcinus arcuatus</i>	2					
<i>Liocarcinus corrugatus</i>						
<i>Liocarcinus maculatus</i>			1			
Majidae				1		
<i>Inachus dorsettensis</i>					1	
Isopoda						
Sphaeromatidae						
<i>Sphaeroma serratum</i>	1					
Amphipoda						
Gammaridae						
<i>Gammaridae</i> sp.				2		1
ECHINODERMATA						
HOLOTHUROIDEA						
Holothuriidae						
<i>Holothuria mammata</i>			1			
ECHINOIDEA						
Loveniidae						
<i>Echinocardium cordatum</i>				3		
Fibulariidae						
<i>Echinocyamus pusillus</i>				5		
Schizasteridae						
Schizaster canaliferus		1				
OPHIUROIDEA						
Amphiuridae						
<i>Amphiura chiajei</i>		1		3		
Ophiuridae						
<i>Ophiura albida</i>				1	1	
Ophiodermatidae						
<i>Ophioderma longicaudum</i>	1					

and sediment characteristics [26]. When Anova differences were significant (i.e. $p < 0.05$), a Scheffé multiple range test was performed to detect for differences ($p < 0.05$) between stations and sampling dates. Pearson Product-Moment Correlation analysis was also performed to test for relationships between all variables.

3. RESULTS

Sediment Characteristics

Sediments generally consisted of 95 % sand (fine, medium, coarse) at all stations in both sampling periods. Fines expressed as a percentage of sediment particles smaller than 0.075 mm ranged between 17.10–48.65 % at all stations in summer 1992, while, in summer 1997, this had a range of 61.60–63.40 % (figure 2). There were significant differences in grain size distribution between the sampling periods ($P < 0.05$). In 1997, the percent of fines was significantly higher ($P < 0.05$) than that of 1992.

Percentage of organic matter ranged from 2.52 % to 4.90 % in all stations, for both sampling periods (figure 3). No significant differences ($P > 0.05$) in organic matter concentrations were observed between stations and between sampling dates. Despite the fact that the percentage of fines in sediments from all stations significantly increased in 1997 compared to 1992, there was no concomitant increase in the concentration of the sedimentary organic matter. The exact reason for this is not clear, but it is likely to be due to high degradation rates.

A total of 178 individuals belonging to 62 species were counted and identified in both sampling periods (table 1). The five most abundant macrofauna taxa in Moni Bay were polychaeta, gastropoda, bivalvia, crustacea and echinodermata.

The composition of the benthos in 1992 represents the original benthic community prior to environmental disturbances caused by the expansion of the Lessepsian migrant *C. racemosa* (table 1). The majority of the benthic community in the pre-disturbance period consisted of gastropods (44 %), followed by crustaceans (22 %), bivalves (17 %), polychaetes (11 %), and echinoderms (6 %) (figure 4). In 1997, the contribution of gastropods decreased to 13 %, and the contribution of polychaetes increased to 38 %, becoming the most dominant taxon (figure 4). Bivalves and echinoderms

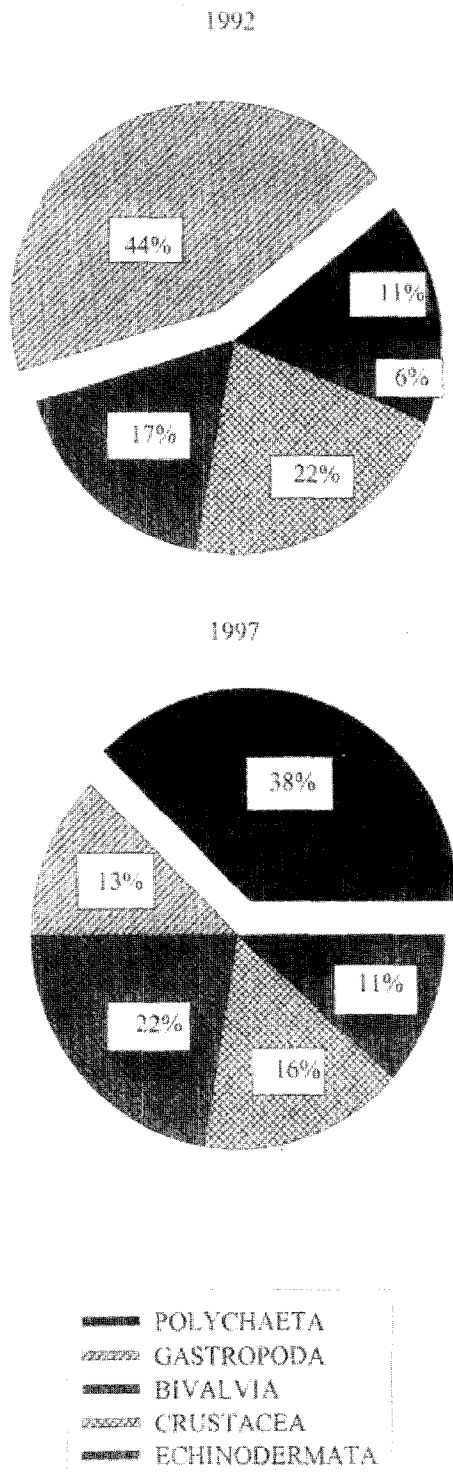


Figure 4. Percentage abundances of dominant macrofaunal groups from all stations of Limassol Bay, from summers 1992 and 1997.

increased to 22 % and 11 %, respectively, while crustaceans decreased to 16 % (figure 4).

The number of species per 1.45 m² surface area ranged from 12 to 15 in the summer of 1992, while in the summer of 1997 the range was 19 to 26 (figure 5). In 1997, the number of species significantly ($P < 0.05$) increased at all stations, compared to 1992. In fact, significant ($P < 0.05$) increases in the polychaete species were observed at all stations in 1997 (figure 6). Total species number was significantly correlated with fine sediments ($R = 0.80$) and OM concentrations ($R = 0.85$).

Macrofaunal abundance ranged from 19 to 23 in 1992 and from 32 to 44 in 1997 (figure 7). There were significant differences ($P < 0.05$) in macrofaunal abundance between sampling dates, with the highest abundance occurring in the summer of 1997. High abundance of polychaete species corresponded to the total increase of macrofaunal abundance in 1997 (figure 8). Polychaete abundance increased significantly ($P < 0.05$) in the summer of 1997 compared to the summer of 1992, suggesting that the proliferation of the Red Sea macroalga *C. racemosa* favoured their abundance. Total macrofauna abundance was positively correlated with fine-grained sediments ($R = 0.68$) and OM concentrations ($R = 0.63$) at all stations for both periods.

4. DISCUSSION

4.1. Macrobenthic community structure

In 1992, the seagrass *Posidonia oceanica* was uniformly distributed in all stations with a scattered appearance of the green alga *Caulerpa prolifera* at station B₂₀ (table 1). In 1997, the seagrass *Posidonia oceanica* occurred at stations A₂₀ and C₂₀, while the green alga *C. racemosa* dominated in densely extensive beds at all stations (table 1). The green algae *Dasycladus clavaeformis* and *Udotea petiolata*, as well as the brown alga *Dilophus mediterraneus* had a scattered distribution among stations (table 1).

Since 1991, when *C. racemosa* was observed in the Moni Bay, at a depth of 30 m [13], this species has been undergoing proliferative growth around most of the island. This species has successfully colonized a wide range of habitats (mainly sandy or muddy bottoms) and depths, and can be found from the intertidal zone down to 60 m depth [15]. The overwhelming expansion of this Red Sea

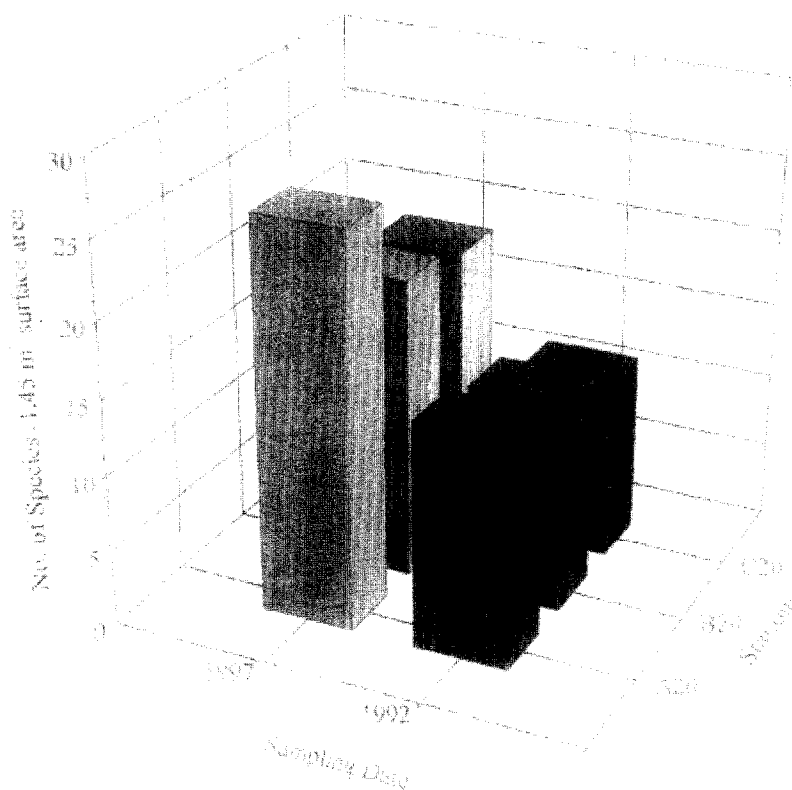


Figure 5. Number of macrofaunal Species per 1.45 m² surface area, from all three stations of Moni Bay, from summers 1992 and 1997.

migrant in the coastal waters of Cyprus may inter alia threaten the *Posidonia* meadows. The controlling mechanisms for the pronounced growth of *C. racemosa* off the coast of Cyprus are not yet known, but, the inherent differences in the life history traits of this migrant vs. native algal species, the local nutrient dynamics and differences in grazing intensity are likely to be related. Moreover, the high salinities and temperatures occurring in the eastern Mediterranean may be of benefit to its expansion, especially in mild winters. It has recently been suggested that climate change has affected the temperature of the Mediterranean with a notable warming of deep waters [30]. It is likely that the recent increase of water temperature in the Mediterranean will accelerate the proliferation of this Red Sea migrant.

The recent expansion of the macrophytic alga *C. racemosa* has raised the question as to how far this is related to nutrient inputs from sewage discharges and inputs from the fish farm. However, it is considered unlikely that nutrients from the sewage could have an impact on the

Caulerpa and other phytobenthos at this depth. A recent study on the effect of sewage on benthos has shown that the impact was prominent at shallow stations (up to 10 m depth) [2]. Though some nutrient increases would be predicted due to the fish farm, the proliferation of *C. racemosa* in other areas seems to indicate that the proliferation of *C. racemosa* may be unrelated to this source.

Changes in the phytobenthic community in Moni Bay, with the dominance of the macroalgal beds of *C. racemosa*, may also cause significant changes in macrofaunal assemblages.

Based on the available data from Moni Bay, there is evidence that the recent expansion of *C. racemosa* in the coastal waters of Cyprus imposed successional changes on the macrofaunal communities with significant increases in species diversity and abundance. These increases are, however, mainly associated with increases in polychaete diversity and abundance.

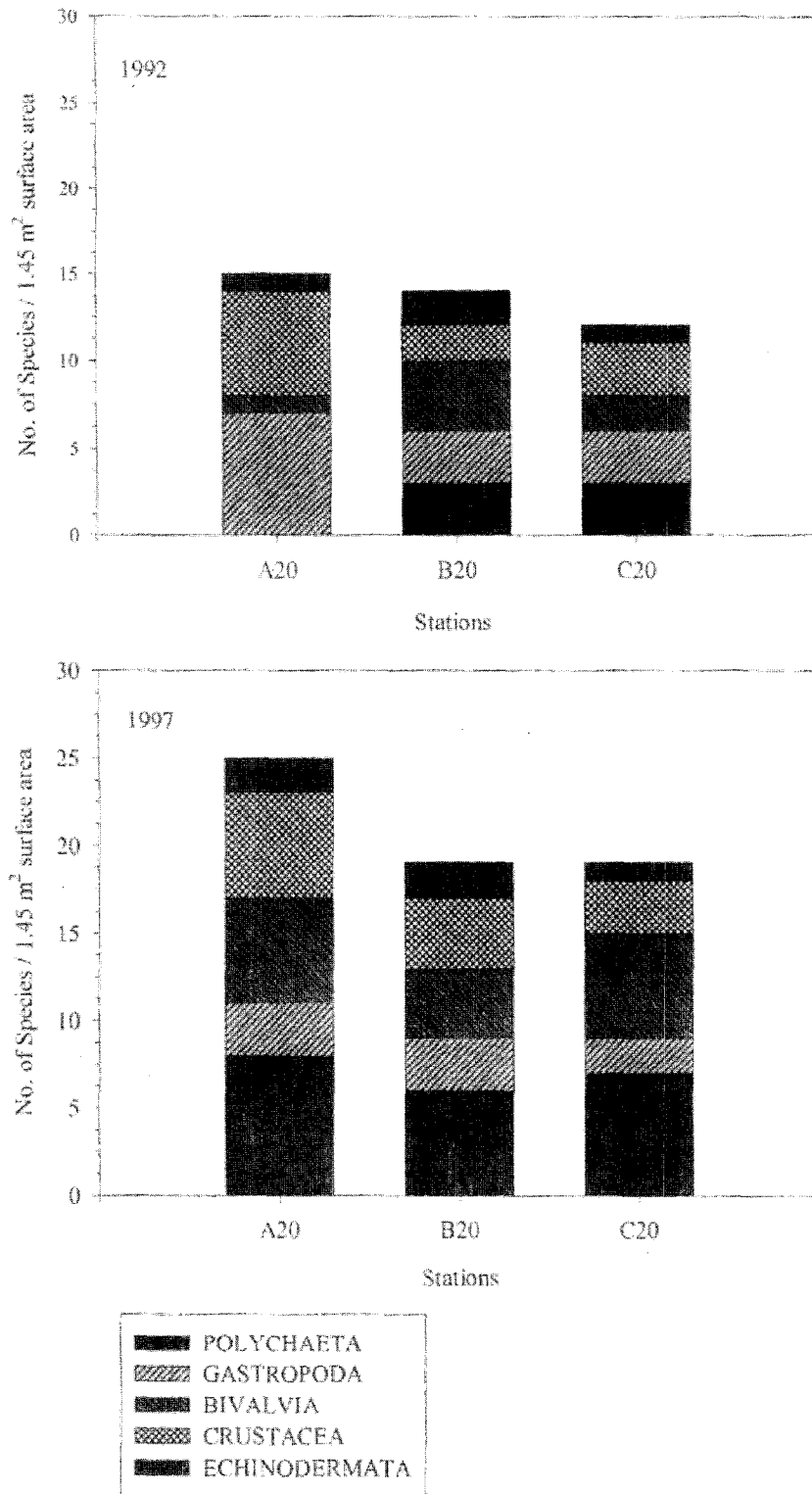


Figure 6. Number of species of the dominant macrofaunal groups per 1.45 m² surface area, from all three stations of Moni Bay, from summers 1992 and 1997.

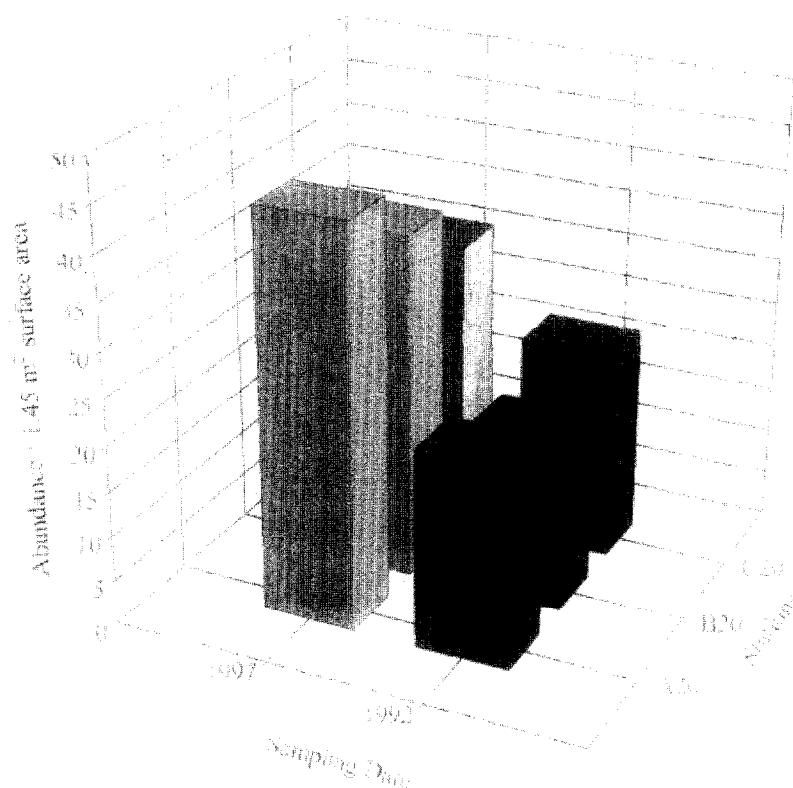


Figure 7. Macrofaunal abundance per 1.45 m² surface area, from all three stations of Moni Bay, from summers 1992 and 1997.

To understand fully the relationship between the invasive alga *C. racemosa* and the associated macrofaunal assemblages in the coastal waters of Cyprus, more data from other regions around the island are required.

5. CONCLUSIONS

On the basis of our field study in Moni Bay, we conclude that:

1. It is likely that the changes in composition and abundance of macrofaunal assemblages are attributable to the recent proliferation of the invasive macroalgal *C. racemosa* in the coastal waters of Moni Bay. While the most dominant taxon prior to the appearance of *C. racemosa* was gastropoda with 44 %, after the expansion of *C. racemosa*, the most dominant taxon was polychaeta with 38 %.

2. There were significant increases in macrofaunal diversity and abundance in 1997 compared to 1992 which are

attributed in part at least to the prolific growth of *C. racemosa*.

3. More data need to be gathered from other regions in Cyprus, where *C. racemosa* proliferates, in order to support the present data and conclusions.

4. The recent colonization of the Red Sea migrant *C. racemosa* is still in an evolutionary stage. Whether its expansion in this particular area relates to nutrient inputs and/or to grazing intensity or to inherent differences in the life history traits of this migrant vs. native algal species or to the warming of the waters due to climate change remains to be seen.

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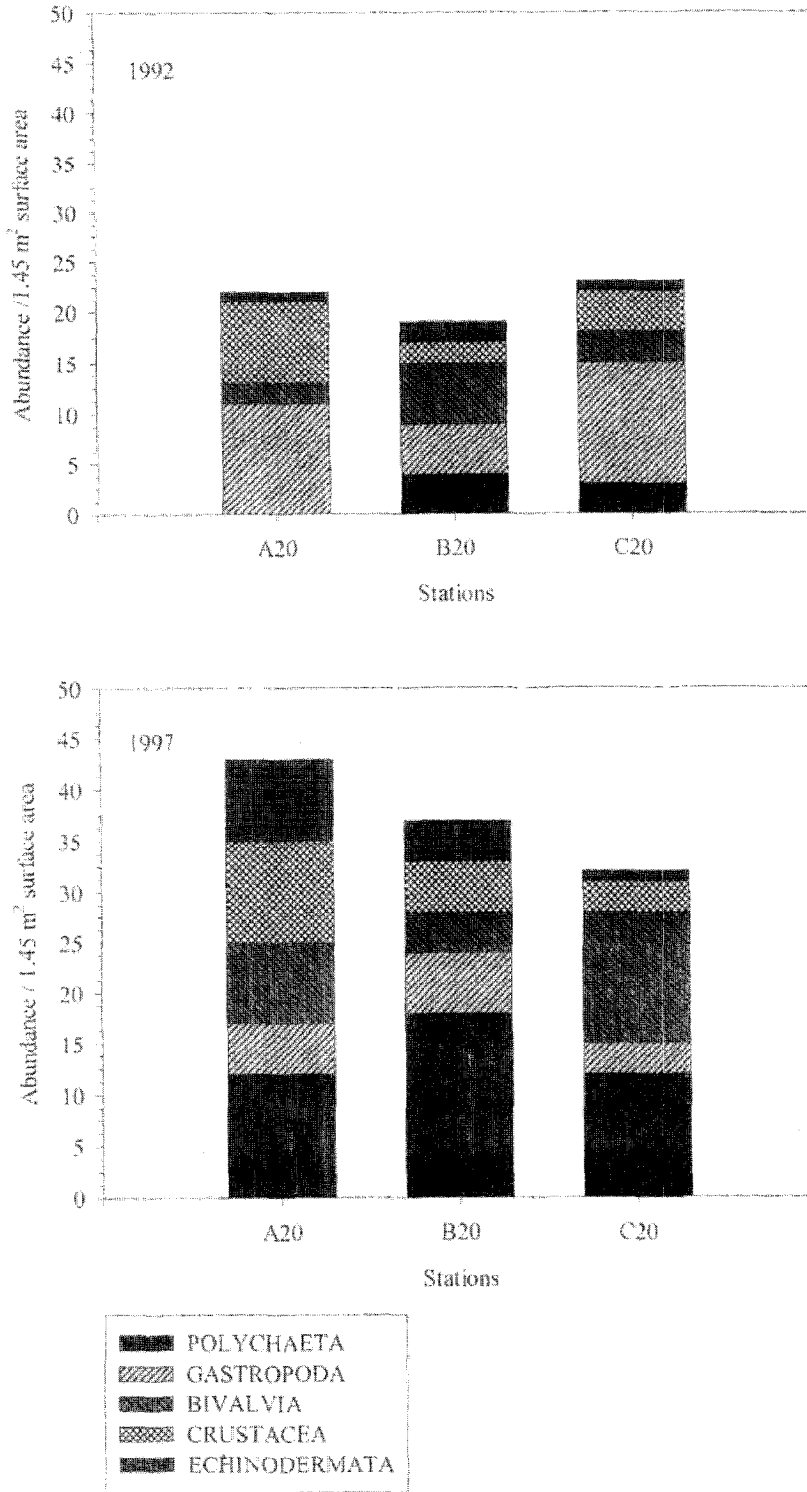


Figure 8. Abundances of the dominant macrofaunal groups per 1.45 m² surface area, from all three stations of Moni Bay, from summers 1992 and 1997.

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