Research Article

Structure and temporal dynamic of tropical turf-forming macroalgal assemblages of the western coast of Mexico

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ABSTRACT. The study of the structure and dynamics of assemblages of benthic organisms has gained interest in recent decades because it can account for the influence of anthropogenic activities in the coastal zone and be incorporated into management and conservation plans. The region of Zihuatanejo, Mexico, has had an accelerated and unplanned urban development, negatively affecting coastal communities. However, studies on the structure and dynamics of algal assemblages, as well as some of the predominant physical factors in this region are scarce. The objective of this research was to carry out a preliminary study on the structure of macroalgal assemblages and their spatio-temporal variation in a depositional environment. The work was realized from June 2006 to December 2008 collecting randomly macroalgal samples and placing sediment traps on the bottom to characterize the deposition environment. The subtidal algal assemblages of the studied localities were predominantly turfs. The Detendred Correspondence Analysis showed that each locality had a particular species composition. The highest biomass was 37.82 ± 12.90 g dw m^{-2} and the lowest of 0-7.86 g dw m^{-2}. The highest total sedimentation rate was 1818.10 ± 82.11 g dw m^{-2} day^{-1} and the lowest was 58.82 ± 8.75 g dw m^{-2} day^{-1}. Significant differences were found in calcareous and articulated biomass, as well as in fine, coarse and total sedimentation rates among localities. The results obtained provide a basis for further research on the effects of sedimentation on the subtidal macroalgae assemblages of the study region.

Keywords: algal assemblages, functional groups, sedimentation, depositional environment, marine benthos.

INTRODUCTION

Coastal aquatic systems are seriously affected because of anthropogenic pressures such as wastewater discharges that have caused eutrophication problems (Panayotidis *et al*., 1999; Arévalo *et al*., 2007; Neto *et al*., 2012) which result in the deterioration of water quality affecting communities of organisms that inhabit the rocky shores, *e.g.*, macroalgae. In response to these problems of contamination of water bodies, was implemented by the European Union in 2000, the Water Framework Directive (WFD). The WFD promotes initiatives aimed at reducing impacts of pollution in aquatic ecosystems for restoring water quality levels (Arévalo *et al*., 2007). Since then different methodologies have been proposed for assessing the ecological status of water bodies. The assessment of the quality of

water has been defined by the response of organisms rather than by physical and chemical variables changes. Macroalgae have proved useful indicators of environ-mental quality (Orfanidis *et al*., 2003; Panayotidis *et al*., 2004; Ballesteros *et al*., 2007; Pinedo *et al.*, 2007; Hering *et al*., 2010; Cecchi *et al.*, 2014) because these organisms can integrate environmental pressures, respond to toxic substances, changes in nutrient concentrations and hydromorphology (Neto *et al*., 2012). Therefore it can be related to the sources of pollution and changes in community structure (Panayotidis *et al*., 2004; Arévalo *et al*., 2007; Cecchi *et al*., 2014). Undisturbed systems with low nutrient inputs are dominated by macrophytes slow growth, *e.g.*, *Zostera* sp. and *Fucus* sp., while systems under disturbance, with high concentrations of nutrients cause the growth of opportunistic macroalgae, *e.g.*, *Ulva* sp. and *Porphyra* sp. (Neto *et al*., 2012).

In intertidal and subtidal temperate and tropical rocky shores, the physical and biological factors are known to maintain the benthic marine organism assemblages' structure. Among the most important physical factors are sedimentation (Airoldi & Virgilio, 1998; Balata *et al.*, 2011), wave patterns (Díez *et al.*, 2003; Wernberg & Connell, 2008; Smale *et al.*, 2011), tides (Metaxas & Scheibling, 1993), and water movement (Cheroske *et al.*, 2000).

Anthropogenic activity in coastal areas has increased dramatically worldwide. One consequence has been the rapid rise of sediment into the sea due to deforestation, drain downloads, and changes in land use affecting the structure and dynamics of benthic communities (Ferretti *et al.*, 1989; Gorgula & Connell, 2004; Venturini *et al.*, 2004; Florez-Leiva *et al.*, 2009; Nava & Ramírez-Herrera, 2011).

The occurrence of turf-dominated macroalgal assemblages is widely reported both in temperate and tropical habitats (Kendrick, 1991; Airoldi *et al.*, 1995; Cheroske *et al.*, 2000; Coleman, 2002; Anderson *et al.*, 2005; Florez-Leiva *et al.*, 2009; Bahartan *et al.*, 2010). Turf is an algal growth-form extremely variable in terms of composition and structure (Wallenstein *et al.*, 2009; Mejia *et al.*, 2012), taxonomically is constituted by Rhodophyta, Chlorophyta, Ochrophyta (Phaeophyceae) and Cyanophyta, forming intermixed, multi-species communities (Anderson *et al.*, 2005) including morpho-functional groups (Littler & Littler, 1984; Steneck & Dethier, 1994) and/or algal categories (Díaz-Pulido *et al.*, 2007). The turf species have morphological, anatomical and reproductive attributes that allow them to tolerate the accumulation of sediments (Airoldi, 2003). Algal turfs can be dominant in habitats highly disturbed and stressed (Airoldi, 1998; Mejia *et al.*, 2012) as coastal areas with high sedimentation rates caused by an accelerated and unplanned urban development (McClanahan & Obura, 1997; Mora, 2008; Florez-Leiva *et al.*, 2009; Shepherd *et al.*, 2009; Martins *et al.*, 2012).

The coast hydrodynamics, determined by the geomorphological characteristics and patterns of winds and waves, influences the transport and distribution of sediments (Ferretti *et al.*, 1989; Larcombe *et al.*, 2001; Ogston *et al.*, 2004; Presto *et al.*, 2006). Sediment deposition and movement determines the depositional environment (Airoldi *et al.*, 1995). Worldwide studies have shown that sedimentation plays a crucial role in the structure and dynamics of the algal assemblages (Piazzi & Cinelli, 2001; Miller *et al.*, 2002; Eriksson & Johansson, 2005; Balata *et al.*, 2007; Florez-Leiva *et al.*, 2009; Shepherd *et al.*, 2009). However in the Mexican tropical Pacific, the scarce studies carried out on sedimentation has been addressed to assess its effect on sponges communities (Carballo, 2006), on stony corals (Granja-Fernández & López-Pérez, 2008) and as an indicator of coral reef degradation (Nava & Ramírez-Herrera, 2011, 2012), nevertheless its relationship with macroalgal communities is unknown.

Therefore, the aim of this paper is to carry out a preliminary survey on macroalgal assemblage' structure, and its variation in time and space in a depositional environment, in three locations in the Bay of Zihuatanejo. This information could be incorporated into monitoring strategies and plans eventually for a sustainable management of Zihuatanejo coastal zone.

MATERIALS AND METHODS

Study area

Zihuatanejo Bay is in Guerrero State, Mexico at 17°37'N, 105°15'W (Fig. 1). The climate is Aw or (w) i (García, 1973) with an average annual temperature of 25°C, and the annual rainfall is 800-1600 mm. In Guerrero coasts, predominate NE trade winds during the cold and drought months, but close to the coast the wind direction is NW and tends to be parallel to the coastline. In the rainy season, the winds are from the SE. The SE and NE winds are separated by a zone of weak winds because of high temperatures and humidity of the sea surface, leading to the formation of cyclones and hurricanes (Pacheco-Sandoval, 1991).

The study sites were Puerto Mio and Las Gatas. Puerto Mio is a site divided into two parts by a breakwater. Puerto Mio Internal is the inner side of the breakwater, which is subject to a high degree of disturbance because the breakwater stops the flow of water currents, and siltation, occurs. Also, this site is in constant contact with Las Salinas Lagoon, which has serious problems of pollution, due to wastewater discharges, fuel and oils, waste of small boats and trash. On the seafloor of this site, some boulders and fine sediments predominate. Puerto Mio External is on the outer side of the breakwater. This site is exposed to the prevailing currents of the Zihuatanejo Bay with constant pounding waves that increase during hurricane season, the bottom is composed of large rocks and sand around them. Las Gatas is a site protected from the currents and waves because of its location into the bay, the bottom is composed of small scleractinian corals, rocks, and sand.

Sampling

Five algal samplings at four meters depth were carried out using scuba diving in June and December 2006 and March, July and November 2007 in areas of 20×10 m in each locality. Eight 10×10 cm quadrats (Airoldi, 2000;
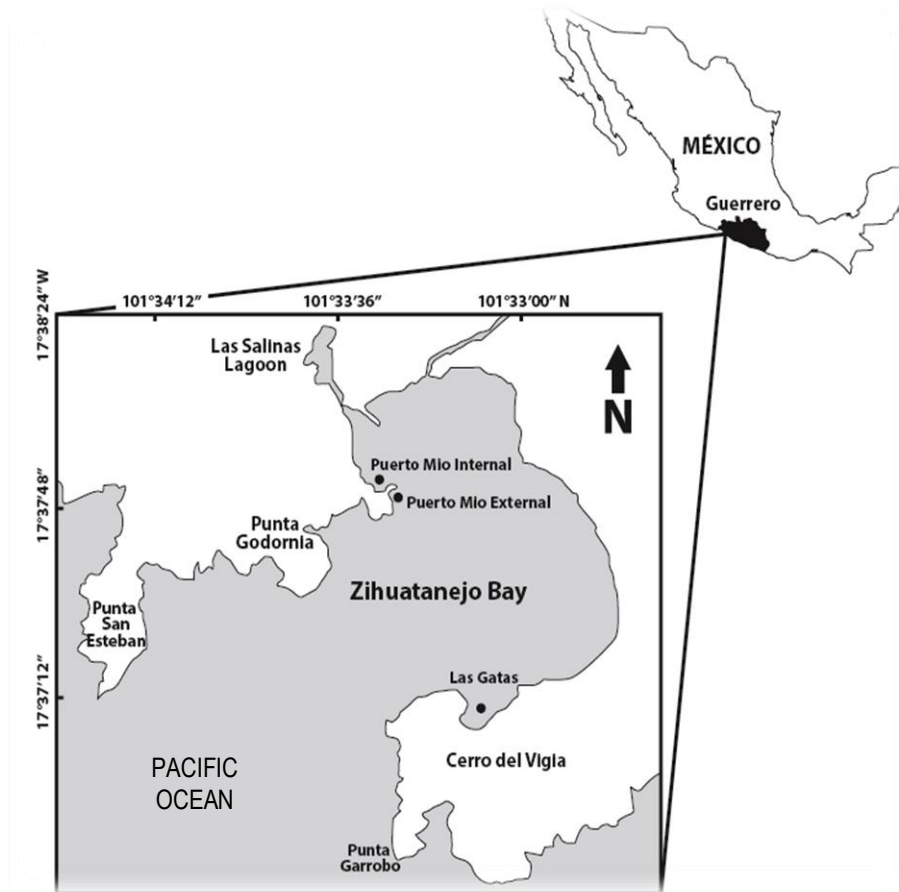
Figure 1. Studied sites at Zihuatanejo Bay, Mexico.

Wallenstein *et al*., 2009) were randomly placed around of each trap system and the algae were collected by hand using hammer and chisel. The distance among samples units was 2-4 m. One hundred and twenty samples were obtained. The samples were put into plastic bags with ice and taken to the laboratory for processing and taxonomic identification.

July and November 2007, June, October, and December 2008 were characterized by the depositional environment in each locality. Two trap systems were placed 8 m apart among them. Each system had four vinyl polychloride pipes fixed on a plastic base with plastic belts, which was placed on the bottom and retrieved after a period of 48-96 h. Each pipe had a diameter of 7 cm and a height of 21 cm maintaining an aspect ratio (height/diameter) of 3:1 (Håkanson *et al*., 1989). The traps with the sediment were cover with a tap and were taken to the laboratory for the gravimetric analysis.

Quantification of biomass and sediments

Macroalgae of all samples were taxonomically identified to species or genera level. From each sample, each species was allocated to the corresponding functional-form group (Littler & Littler, 1984). Particularly, *Ulva flexuosa* was assigned as part of the filamentous group utilizing morpho-functional criteria established by the same authors.

To quantify the algal biomass of each sample, each functional group was separated and placed in trays of preweighed and dried paper, into a Lab Tech at 60°C oven for 24 h. Subsequently, each functional group was weighed on an analytical balance (precision 0.015 g). This procedure was repeated until the weight maintained constant. The amount of total biomass of each functional group was expressed as g dw (dry weight) m^{-2}. Single algal species recorded in this study does not reach the minimal level of balance precision.

To quantify the sediment content per trap and separate it into the coarse (> 200 µm) and fine (< 22 µm) fractions, the material was passed through a 200 µm mesh preweighed. From material that passed through the mesh, 10 mL aliquots were taken which were filtered with Millipore 0.22 µm GSWP filters previously weighed for the fine fraction.

Both sediment fractions were placed in Petri dishes and dried following the same procedure as the biomass samples. The total amount of sediment was obtained from the sum of the fine and coarse fractions per trap. Fine, coarse and total sedimentation rates were expressed as g dw m^{-2} day^{-1}.

Statistical analyses

Multivariate methods were used to determine the algal assemblage structure and their spatial distribution patterns. Using Detrended Correspondence Analysis (DCA) with the PCord 5 (DECORANA) package, we ordered the species based on their abundance expressed as biomass, at the sites using a matrix of presence/absence of each species.

Differences among sites in sedimentation rates and algal biomass were analyzed using a nonparametric Kruskal-Wallis test ($P < 0.05$). The relationship between algal biomass and sedimentation rate was examined using Spearman R correlation.

RESULTS

A total of 67 species were recorded in Zihuatanejo Bay, 47 (70.1%) were Rhodophyta, 13 (19.4%) Chlorophyta, and 6 (8.9%) Ochrophyta (Phaeophyceae). Puerto Mio Internal was the locality with the lowest richness, 19 species were recorded, 13 Rhodophyta, 6 Chlorophyta and no Ochrophyta. All of those species were observed only in December 2006 and July and November 2007, mainly in the dry season. Puerto Mio External had a total of 37 species, 27 Rhodophyta, 7 Chlorophyta and 3 Ochrophyta. All of Rhodophya species were present in June, December 2006 and March 2007. Chlorophyta species were recorded in December 2006 and March and November 2007; two of three Ochrophyta species were found once during the study. Las Gatas was the locality with the highest richness, with 58 species; 44 Rhodophyta, 9 Chlorophyta and 5 Ochrophyta; only 7 species were observed in November 2007. A notorious fact was that Puerto Mio External and Las Gatas showed the most richness during the dry season (June and December 2006 and March 2007). Algal assemblages in Zihuatanejo Bay were composed primarily by filamentous (41.8%) and branched (32.8%) species. The remaining algae were calcareous jointed, sheets and crustoses (25.4%). The filamentous and branched species predominated at the three sites.

There was a wide difference in the richness per site; in Puerto Mio Internal was 19 species, at Puerto Mio External 37 species, and Las Gatas 58 species. There were no macroalgae in Puerto Mio Internal in June 2006 and March 2007 (Table 1). Twelve of the 67 species recorded in this study were found at all three sites, *Amphiroa beauvoisii*, *A. misakiensis*, *A. rigida* (jointed calcareous), *Chondria* sp., *Hypnea pannosa, H. spinella*, *Grateloupia* sp. (branched), *Ceramium* sp., *Caulerpa sertularioides*, *Bryopsis pennata*, *Cladophora* sp. (filamentous) and *Lithophyllum* sp. (crustose) (Table 1).

DCA revealed groups of species characteristic of each site (Fig. 2). DCA explains 60% of species variation in the study sites and the first two axes resulting contributed 32% Axis 1 (eigenvalue = 0.322) and 16% Axis 2 (eigenvalue = 0.156) (Fig. 2). DCA analysis results in 9 groups of species (called groupings herein after to distinguish them of functional-form groups) and each site was characterized by a particular grouping (particular grouping for each species is indicated in Table 1). Las Gatas is characterized by the Grouping 5, Puerto Mio External by the Grouping 7 and Puerto Mio Internal by the Grouping 9 (Fig. 2).

At Las Gatas, branched species such as *Gelidiella* spp., *Gelidium* spp., *Gracilaria* spp., and filamentous species as *Herposiphonia secunda*, *Neosiphonia simplex* and *Cladophoropsis membranacea* formed the Grouping 5. Puerto Mio External was defined by the Grouping 7, the filamentous species as *H. plumula* and *Cladophora sericea* and sheets as *Ulva californica* and *Lobophora variegata* predominated. The Grouping 9, formed by three filamentous species, *Ceramium affine, Boodleopsis* sp. and *U. flexuosa* characterized to Puerto Mio Internal (Fig. 2).

DCA also showed that the Groupings 1, 2, 4, 6 and 8 and some species non-grouped as *Cladophora* sp., *Ceramium* sp., *Hypnea spinella* and *Lithophyllum* sp. find in the center of the figure, this means they are groupings and species common to the three sites. However from all species, non was persistently found in all of sites, for example *Grateloupia* sp. was at Puerto Mio Internal only in November (2007), at Puerto Mio External in December (2006) and March (2007) and at Las Gatas in January (2006) and March (2007) (Table 1). Although some species groupings and some species have a wide distribution because they are common to all three sites, their presence is seasonal.

The lowest biomass was recorded in Puerto Mio Internal, 0-7.86 ± 4.55 g dw m^{-2}, the highest in Puerto Mio External, 5.42 ± 2.24-37.82 ± 12.90 g dw m^{-2} and intermediate in Las Gatas, 8.01 ± 1.94-26.86 ± 8.10 g dw m^{-2} (Table 2). It found significant differences in biomass of jointed calcareous algae between sites in 2006 (KW-H$_{(2.25)}$ = 10.716, P = 0.0047) (Fig. 3a) and 2007 (KW-H$_{(2.44)}$ = 14.2599, P = 0.0008) (Fig. 3b) as well as the sheet group in 2006 (KW-H$_{(1.9)}$ = 4.2, P = 0.0404) (Fig. 3c).

Table 1. Composition spatio-temporal variation at Zihuatanejo Bay. J: June 2006, D: December 2006, M: March 2007, Jl: July 2007, N: November 2007, G: DCA grouping, FG: functional-form group, Jc: jointed calcareous-group, Fil: filamentous-group, B: coarsely branched-group, Cr: crustose-group, S: sheet-group. *No grouped.

| | | | Puerto Mio Internal | | | | | Puerto Mio External | | | | | Las Gatas | | | | |
| | | | 2006 | | 2007 | | | 2006 | | 2007 | | | 2006 | | 2007 | | |
	G	FG	J	D	M	Jl	N	J	D	M	Jl	N	J	D	M	Jl	N
Rhodophyta																	
1. *Amphiroa beauvoisii*	1	Jc		+				+	+	+			+	+	+		
2. *Amphiroa misakiensis*	1	Jc		+				+	+	+			+	+	+		
3. *Amphiroa rigida*	2	Jc				+			+				+		+		
4. *Antithamnionella* sp.	3	Fil	+														+
5. *Ceramium affine*	9	Fil	+														
6. *Ceramium clarionense*	4	Fil							+				+				
7. *Ceramium paniculatum*	*	Fil								+				+	+		
8. *Ceramium* sp.	8	Fil				+			+								+
9. *Ceramium vagans*	*	Fil	+							+							
10. *Ceratodictyon variabile*	*	B							+				+	+	+		
11. *Champia parvula*	4	B							+						+		
12. *Chondria repens*	5	B															+
13. *Chondria* sp.	2	B	+							+			+		+		
14. *Dasya* sp.	4	Fil							+							+	
15. *Gayliella flaccida*	4	Fil							+						+		
16. *Gelidiella hancockii*	5	B													+		
17. *Gelidiella ligulata*	5	B														+	
18. *Gelidiella* sp.	5	B											+				
19. *Parviphycus antipae*	5	B											+				
20. *Gelidium mcnabbianum*	4	B							+						+		
21. *Gelidium pusillum*	8	B								+					+		+
22. *Gelidium sclerophyllum*	5	B														+	
23. *Gelidium* sp.	5	B														+	
24. *Gracilaria pachydermatica*	5	B											+				
25. *Gracilaria* sp.	5	B													+	+	
26. *Gracilaria veleroae*	5	B													+	+	
27. *Grateloupia* sp.	2	B					+		+	+			+		+		
28. *Gymnogongrus crustiformis*	5	B											+			+	
29. *Halymenia* sp.	*	B						+		+				+			
30. *Herposiphonia littoralis*	4	Fil							+	+				+		+	
31. *Herposiphonia plumula*	7	Fil							+	+							
32. *Herposiphonia secunda*	5	Fil														+	
33. *Herposiphonia secunda* f. *tenella*	4	Fil							+				+				
34. *Hypnea johnstonii*	5	B														+	
35. *Hypnea pannosa*	1	B					+	+	+	+			+	+	+		
36. *Hypnea spinella*	*	B				+			+	+					+		
37. *Jania adhaerens*	4	Jc								+							+
38. *Jania* sp.	4	Jc							+				+				
39. *Jania subpinnata*	8	Jc							+					+		+	
40. *Jania tenella*	4	Jc								+			+				
41. *Lithophyllum* sp.	*	Cr	+					+	+	+			+				
42. *Lophosiphonia* sp.	5	Fil											+				
43. *Murrayellopsis* sp.	5	Fil															+
44. *Neosiphonia simplex*	5	Fil														+	
45. *Peyssonnelia rubra*	7	Cr								+							
46. *Porphyra* sp.	5	S															+
47. *Pterocladiella caloglossoides*	3	B				+							+				
48. *Tayloriella dictyurus*	5	Fil															+

Continuation

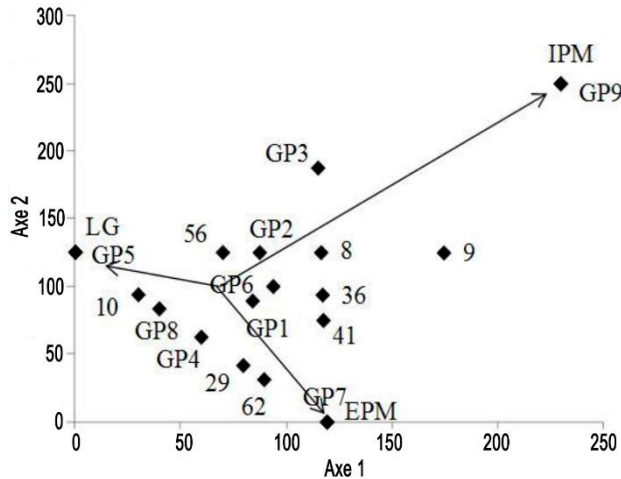|			Puerto MioInternal					Puerto MioExternal					Las Gatas				
			2006		2007			2006		2007			2006		2007		
	G	FG	J	D	M	Jl	N	J	D	M	Jl	N	J	D	M	Jl	N
Chlorophyta																	
49. *Boodleopsis* sp.	9	Fil					+										
50. *Bryopsis* sp.	4	Fil									+		+				
51. *Bryopsis pennata*	2	Fil			+						+				+	+		
52. *Caulerpa sertularioides*	6	Fil			+				+	+				+	+		
53. *Cladophoropsis membranacea*	5	Fil															+	
54. *Cladophora microcladioides*	3	Fil			+									+			
55. *Cladophora sericea*	7	Fil									+						
56. *Cladophora* sp.	*	Fil			+				+				+	+		+	
57. *Chlorodesmis* sp.	5	Fil															+	
58. *Derbesia* sp.	4	Fil							+					+			
59. *Ulva californica*	7	S								+							
60. *Ulva flexuosa*	9	Fil			+												
61. *Ulva* sp.	5	S															+	
Ochrophyta (Phaeophyceae)																	
62. *Dictyopteris delicatula*	*	S						+	+	+				+			
63. *Dictyota dichotoma*	4	S									+				+		
64. *Lobophora variegata*	7	Cr							+								
65. *Ralfsia pacifica*	5	Cr											+				
66. *Ralfsia* sp.	5	Cr											+		+		
67. *Sphacelaria rigidula*	5	Fil													+		

Figure 2. Detrended Correspondence Analysis (DCA). PMI: Puerto Mio Internal, PME: Puerto Mio External, LG: Las Gatas, GP: species grouping. The species in each grouping and its corresponding numbers are indicated in the Table 1.

The total sedimentation rate along the study showed a wide variation, 58.82 ± 8.75-1818.10 ± 82.11 g dw m^{-2} day^{-1}. Puerto Mio Internal had the total sedimentation rate highest (719.15 ± 91.18 g dw m^{-2} day^{-1}) and Las Gatas the lowest (234.61 ± 47.44 g dw m^{-2} day^{-1}) (Table 3). The fine sedimentation rate was higher than the coarse everywhere and on all dates (Table 3).

The total, fine and coarse sedimentation rates showed significant differences among sites in 2007 (total sedimentation rate KW-H$_{(2.20)}$ = 15.8143, P = 0.0004; fine sedimentation rate KW-H$_{(2.20)}$ = 15.8143, P = 0.0004 and coarse sedimentation rate KW-H$_{(2.20)}$ = 12.0964, P = 0.0024) (Fig. 4a) and in 2008 (total sedimentation rate KW-H$_{(2.20)}$ = 13.725, P = 0.001; fine sedimentation rate KW-H$_{(2.20)}$ = 13.9821, P = 0.0009; coarse sedimentation rate KW-H$_{(2.20)}$ = 10.6357, P = 0.0049) (Fig. 4b). Also found a significant negative correlation of biomass with fine (R: -0.41 Spearman R) and total (Spearman R: -0.40) sedimen-tation rates (Table 4).

DISCUSSION

Rhodophyta, Chlorophyta and Ochrophyta (Phaeo-phyceae) richness found in Zihuatanejo Bay corres-ponds with reports from tropical regions (Tribollet *et al*., 2010; Villaça *et al*., 2010). The variability of abiotic conditions in the tropical zone is limited from the influence of the rainy season which can reduce salinity and increase water velocity (Mejia *et al*., 2012), such conditions may to explain the low richness in this season in Zihuatanejo Bay. Other abiotic conditions as temperature, light and nutrients have a defining influence on algal distribution, diversity and dynamics

Table 2. Biomass spatio-temporal variation at Zihuatanejo Bay. J: June 2006, D: December 2006, M: March 2007, Jl: July 2007, N: November 2007.

Site	Mean ± SE algal biomass (g dw m^{-2})				
	J	D	M	Jl	N
	2006		2007		
Puerto Mio Internal	0	0.41 ± 0.17	0	0.63 ± 0.18	7.86 ± 4.55
Puerto Mio External	10.25 ± 2.45	5.42 ± 2.24	37.82 ± 12.90	13.28 ± 3.99	12.19 ± 3.89
Las Gatas	11.35 ± 3.39	26.86 ± 8.10	9.66 ± 1.89	8.11 ± 2.21	8.01 ± 1.94

of tropical macroalgae. Besides over a few decads macroalgae have become more abundant in different tropical marine ecosystems often as a response to human activities (Mejia *et al*., 2012).

Turf-forming algal assemblages were predominated in the three studied sites. The occurrence of turf-dominated macroalgal assemblages is widely reported both in temperate and tropical habitats (Kendrick, 1991; Airoldi *et al*., 1995; Cheroske *et al*., 2000; Coleman, 2002; Anderson *et al*., 2005; Florez-Leiva *et al*., 2009; Bahartan *et al*., 2010).

Algal turfs can be dominant in habitats highly disturbed and stressed (Airoldi, 1998). This occurs in coastal areas with high sedimentation rates caused by an accelerated and unplanned urban development (McClanahan & Obura, 1997; Mora, 2008; Florez-Leiva *et al*., 2009; Shepherd *et al*., 2009; Martins *et al*., 2012). Turfs are known for trapping and accumulating sediment (Airoldi *et al*., 1995). Zihuatanejo Bay is one of the most important destinations of international tourism, for this reason it has been having an accelerated coastal development. In 2004, the status of the Cerro del Vigía, south of the bay, as Ecological Reserve changed to residential tourist area by municipal authorities. Zihuatanejo Bay has been subjected to a large deforestation between 2005 and 2007 that may lead to an increase in terrigenous sediments. For instance, a site 0.8 km SE from Las Gatas recorded a sedimentation rate of 1.2 kg m^{-2} day^{-1} (Nava & Ramírez-Herrera, 2011). The total and fine sedimentation high rates recorded in Puerto Mio Internal may be due to the bay hydrodynamics generated by the tides. The currents low intensity, the small volume of water exchanged by tidal cycle and the limited influence of winds because the orography causes inefficient water renewal (IMTA, 2010). Therefore, the dominance of turf algal assemblages in our study sites seems related to an accelerated coastal urbanization process.

Turf is a term applied to a broad range of algal associations. Those associations can refer to a morphological or ecological or systematic definitions;

also it is recognized its extreme variability in composition and structure (Airoldi *et al*., 1995). The turf species may be taxonomically close and/or belong to the same functional-form groups and to have morphological, anatomical and reproductive attributes that allow them to tolerate the accumulation of sediments (Airoldi, 2003). Some branched species have apical meristems that keep cell division; also regenerate their erect portions from the remaining holdfast resistant to burial as *Pterocladiella capillacea* (as *Pterocladia capillacea* in Stewart, 1983), and *Gracilariopsis lemaneiformis* (Santelices *et al*., 1984). The presence of filamentous species in this study coincides with other temperate and tropical coasts influenced by high sediment input as Galapagos (Kendrick, 1991); Hawaii (Cheroske *et al*., 2000); Italy (Airoldi *et al*., 1996; Piazzi & Cinelli, 2001); the North Atlantic, North Pacific and Caribbean (Steneck & Dethier, 1994). Those species are *Bryopsis pennata*, *Cladophora microcladioides* and *Derbesia* sp. (Chlorophyta), *Ceramium affine*, *C. clarionense*, *Dasya* sp., *Gayliella flaccida*, *Herposiphonia littoralis* and *H. secunda* (Rhodophyta) and *Sphacelaria rigidula* (Ochrophyta). Its presence in Zihuatanejo Bay may be because this functional morphology is tolerant to the constant input of sediment. Besides these algae have reproductive attributes that allow them to persist despite the presence of sediments as *Womersleyella setacea,* that is a filamentous species which is dominant in the Mediterranean Sea and reproduces vegetatively (Airoldi *et al*., 1995; Airoldi, 1998).

Turf filamentous species from Zihuatanejo Bay could be grouped in different morphological types (Balata *et al*., 2011) as filamentous Rhodophyta-uniseriate and pluriseriate with erect thallus (*e.g*., *Ceramium* spp.), siphonous Chlorophyta with thin compact filaments (*e.g*., *Bryopsis* sp. and *Derbesia* sp.) or filamentous Chlorophyta uniseriate (*e.g*., *Cladophora* spp.). Also, larger-sized corticated Rhodophyta group was found (*e.g*., *Gelidium* spp., *Gracilaria* spp. and *Grateloupia* sp.). These groups were observed in localities of which sedimentation rates were low (Puerto Mio Externo and Las Gatas), and occasionally
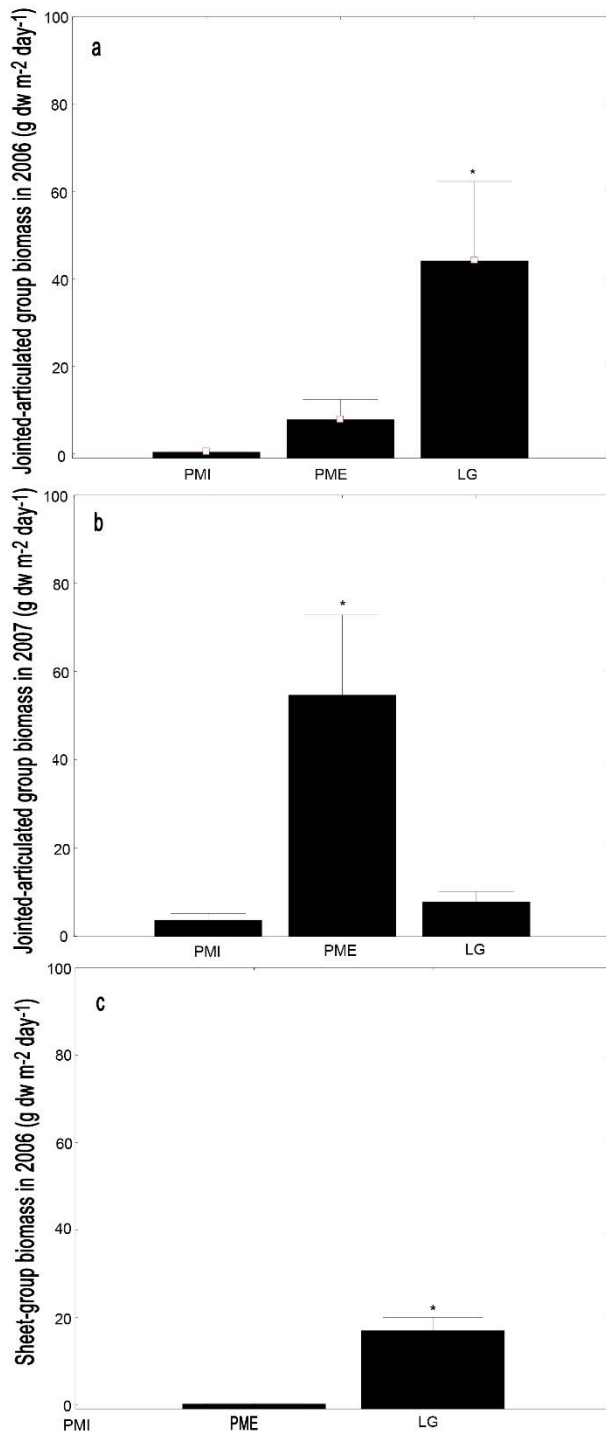
Figure 3. Main functional groups algal biomass. a) jointed calcareous in 2006, b) jointed calcareous in 2007, c) sheets in 2006. *Significant differences. PMI: Puerto Mio Internal, PME: Puerto Mio External, LG: Las Gatas.

in Puerto Mio Interno with the highest sedimentation rates. Our results could indicate that the filamentous and fleshy species from this region respond differentially to sedimentary stress conditions as reported Balata *et al.* (2011) at Mediterranean Sea.

The DCA showed to each site having a particular turfs species composition despite their relative proximity, suggesting that each site has particular environmental conditions. In fact, the characteristics of the depositional environment at the three sites were significantly different. In Puerto Mio Internal rates of fine, coarse and total sedimentation were highest, in Puerto Mio External intermediate, and in Las Gatas lowest. These differences can be explained because the hydrodynamics of each site is also particular, depending upon the patterns of local currents.

Rainfall also influences sedimentation, as reported in Huatulco, Oaxaca at Mexican tropical Pacific coasts, with a broad variation among the six locations studied. In Zihuatanejo Bay the higher rates of total and fine sedimentation occurred in rainy season of 2007, affected by Cosme Hurricane (winds of 120 km h^{-1} and gusts of 150 km h^{-1}) (CONAGUA, 2007) and Dalila tropical storm (winds of 90 km h^{-1} and gusts of 110 km h^{-1}) (CONAGUA, 2007), these weather conditions could cause the sediment loads in the bay with different orders of magnitude, and sometimes higher than normal (Airoldi, 2003).

The lowest average biomass occurred in Puerto Mio Internal (8.9 g dw m^{-2}), in Las Gatas was intermediate (63.99 g dw m^{-2}) and the highest in Puerto Mio External (78.96 g dw m^{-2}). Spearman correlation revealed that when sedimentation rates were higher, biomass decreased. The sediment increment limits the availability of substrate for the establishment of spores and other propagules (Balata *et al.*, 2005). Even the sediment may have a lethal effect (Rogers, 1983), as occurred in June 2006 and March 2007 when no algae recorded in Puerto Mio Internal, suggesting that high inputs of sediment in Zihuatanejo Bay can be harmful to macroalgal development.

Numerous species of macroalgae have characteristic morphological, physiological and life histories that allow them to tolerate higher levels of sediment, *e.g.*, *Gracilaria gracilis* develops thickly branched thalli of terete construction and *Caulerpa* spp. produce an extensive rhizome (Williams *et al.*, 1985). *Pterocladiella capillacea*, *Dictyota* sp. and *Sphacelaria rigidula* show several sediment tolerant characteristics (Stewart, 1983). They have apical meristems maintaining active cellular division; likewise the regeneration of erect portions from the remaining burial resistant holdfasts, and reproduction peaks synchronized with fluctuations of sand and vegetative reproduction are shown (Airoldi, 2003). Some species found in all the sites, *e.g.*, *Amphiroa* spp., *Lithophyllum* sp., *Hypnea pannosa*, *H. spinella* and *Caulerpa sertularioides* are exposed to different deposition environments, it means that they are psamophytic species.

Table 3. Temporal variation of total, fine and coarse sedimentation rates at the study sites. PMI: Puerto Mio Internal, PME: Puerto Mio External, LG: Las Gatas, Jl: July, N: November, J: June, O: October, D: December.

	Jl	N	J	O	D	Mean
		2007		2008		
			Total sedimentation rate (g dw m^{-2} day^{-1})			
PMI	1793.89 ± 107.73	551.09 ± 40.94	528.54 ± 49.19	271.86 ± 39.82	450.36 ± 34.91	719.15 ± 91.18
PME	1818.10 ± 82.11	406.08 ± 23.21	210.23 ± 50.33	297.55 ± 31.71	462.34 ± 31.48	522.43 ± 94.50
LG	774.66 ± 79.05	112.57 ± 14.74	100.62 ± 13.23	58.82 ± 8.75	104.42 ± 14.87	234.61 ± 47.44
			Fine sedimentation rate (g dw m^{-2} day^{-1})			
PMI	1638.65 ± 116.50	542.76 ± 41.20	503.48 ± 45.26	268.13 ± 39.25	434.66 ± 35.76	677.53 ± 82.88
PME	1722.97 ± 79.19	397.56 ± 23.12	200.90 ± 49.35	292.71 ± 31.22	383.61 ± 35.96	487.62 ± 89.80
LG	701.66 ± 85.46	110.83 ± 14.57	335.06 ± 94.44	57.89 ± 8.67	98.50 ± 15.87	265.99 ± 46.57
			Coarse sedimentation rate (g dw m^{-2} day^{-1})			
PMI	155.24 ± 14.25	8.32 ± 1.38	25.06 ± 5.88	3.73 ± 1.56	15.70 ± 3.13	41.60 ± 9.65
PME	95.13 ± 6.04	8.52 ± 0.59	9.33 ± 2.76	4.85 ± 1.69	78.73 ± 12.00	34.80 ± 7.35
LG	73.00 ± 14.53	1.73 ± 0.41	5.66 ± 1.53	0.93 ± 0.20	5.92 ± 1.25	17.87 ± 5.37
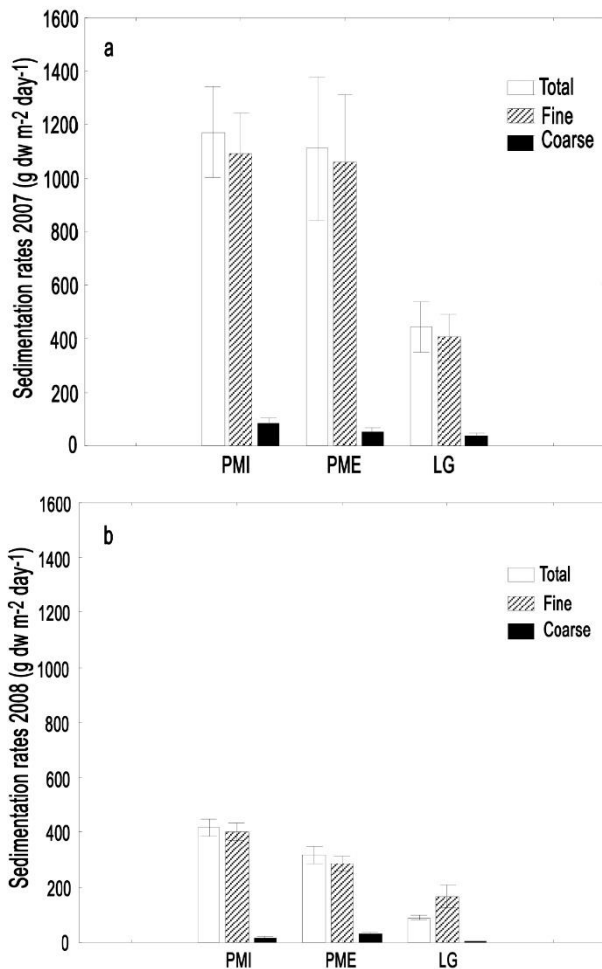
Figure 4. Spatio-temporal variation of total, fine and coarse sedimentation rates (mean ± EE) at Zihuatanejo Bay. PMI: Puerto Mio Internal, PME: Puerto Mio External, LG: Las Gatas.

Table 4. Spearman correlations (*correlations are significant at $p \leq 0.050$). FSR: fine sedimentation rate, CSR: coarse sedimentation rate, TSR: total sedimentation rate.

	Biomass	FSR	CSR	TSR
Biomass	1	0.41*	-0.30	-0.40*
FSR	-0.41	1	0.93	0.99
CSR	-0.30	0.93	1	0.93
Total	-0.40	0.99	0.93	1

Each of the sites studied in Zihuatanejo could be characterized by the composition and algal biomass amount, as well as by sedimentation rates and the hydrodynamics that determine the movement and transport of sediment into the bay.

More independent areas in each study site would be necessary to separate effects of sediments from natural patterns of spatial variability of the system. Thus, data obtained are to be considered as preliminary. However, they may represent a base for further appropriate studies to understand mechanisms affecting spatial and temporal dynamics of macroalgal assemblages of Zihuatanejo Bay. Moreover, information provided by the study could be incorporated into monitoring strategies and plans to a sustainable management of Zihuatanejo coastal zone.

Finally, this work provides the basis of the influence of sedimentation in subtidal algal assemblages in Zihuatanejo. The results agreed with overall patterns observed in other regions, sedimentation rates are determined by weather conditions on a large scale, and local hydrodynamics in a small scale. Likewise, a significant correlation between the amount of algal biomass and sedimentation regimes coincided with

some reports in other regions, suggesting that the turf algae are tolerant to the presence of sediments in moderate amounts. When the sediment input to a rocky coast exceeds the natural limits due to human activity, there may be severe consequences, such as assemblage reduction or disappearance generating blooms of other species, affecting the dynamics and functionality of the system. Knowledge of spatio-temporal variations in sedimentation regimes is essential to know its dynamics within the rocky shores. Therefore, being able to predict the impact that those variations can have on algal communities, is a crucial predictive element to consider in management and conservation of Zihuatanejo region.

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