Macroalgal distribution in a Mexican Caribbean Reef

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Abstract. Macroalgae are important components of coral reef and seagrass ecosystems; however, the habitat structure macroalgae provide to the system has been little explored. We use architectural and morphological traits of macroalgae to describe and compare the reef and lagoon habitat complexity at Puerto Morelos reef in the Mexican Caribbean. Using a random-stratified method, macroalgae were sampled, then each organism was identified and morphometric features were recorded. A total of 101 species were found. The ordination analysis showed differences in species composition between the reef and lagoon. Small size, erect highly branched and dense clonal growth were more frequent in the reef compared to the lagoon where larger, erect, less branched and less dense algae with $CaCO_3$ were found. Higher species richness and diversity of forms in the reef suggest a higher habitat complexity provided by macroalgae in the reef compared with the seagrass beds. The increase of fleshy macroalgae has been shown to decrease the habitat complexity provided by coral structure, we highlight that the increase of only some macroalgae species will result in a loss of complexity provided by other macroalgae species.

Key words: Plant architecture, clonal growth, Coral reef, Mexican Caribbean, Plasticity, Shift-phase

Introduction

Macroalgae are important components of coral reef and seagrass ecosystems, they help cement the reef framework and give refuge for numerous invertebrate and fish species (Gil et al. 2006); however macroalgae are increasing in abundance as a synergistic response to decrease of herbivores, increase of nutrients inputs, coral bleaching and coastal development, in both coral reefs and seagrass environments (Hughes et al 2005, Orth et al. 2006, Collado-Vides et al. 2007). Therefore a better understanding of the different roles macroalgae play on reef and seagrass systems is needed in order to protect and manage these resources.

Spatial complexity has been recognized as an important characteristic of habitats and is a major determinant of local abundance and diversity (Dahl 1973, Gratwicke and Speight 2005); moreover, architecture and density of macroalgae can influence the relationship between abundance and recruitment of other species in the community (Carr and Hixon 1995), therefore adding complexity to the reef system. For example, Hacker and Steneck (1990) demonstrated that architectural elements of algae (space between fronds) can be an important factor in determining demographic patterns of amphipods. Interpretation of macroalgal communities in marine habitats has been facilitated by the classification of species into functional-form groups proposed by Littler and Littler (1980), and Steneck and Dethier (1994). This approach characterizes species according to features such as body plan, behavior and/or life history strategy. Based on fundamentals from these authors we suggest that different habitats will be inhabited by different functional form groups, moreover, we suggest that these groups will in turn express different levels of habitat complexity.

The Puerto Morelos Reef system, in the Mexican Caribbean, is in a relatively good condition, and has a rich macroalgal flora both in corals as well as seagrass beds (Collado-Vides et al. 1998). We selected this site to explore a combination of community aspects such as: macroalgae community structure, functional form group distribution, and several architectural parameters as proxies to the evaluation of habitat complexity. In this study we describe and compare the reef and lagoon, adding a spatial structure perspective to the macroalgal community.

Material and Methods

This study was carried out at the Puerto Morelos reef, a section of the Mesoamerican reef system in 1998. The reef profile in Puerto Morelos has been divided into four main zones —lagoon, back-reef, crest, and fore-reef zone— based on its topographic

characteristics, coral species composition, and wave action (Jordan 1979). Substrate, water movement, and light are the most contrasting physical factors differentiating the lagoon and the reef area. The coral reef formation consists of corals of the genera *Porites*, *Acropora* and *Agaricia*, and some areas intermix with soft coral. The reef lagoon is characterized by seagrass meadows of the species *Thalassia testudinium* Banks ex Koenig mixed with bare sand patches and S*yringodium filiforme* Kuetzing in Hohenacker. Nutrient sources come mainly from the mangrove watershed through underground systems opening in springs in the reef lagoon.

Along this system, three contrasting areas were chosen as representatives of the range of habitat types: A) the fore reef and crest; B) deep lagoon and C) shallow lagoon. An imaginary line was laid out parallel to the shore trough these habitat types and these ones were considered as replicate transects. Each transect was then divided in five points: 1) La Bocana; 2) Astilleros; 3) ICMyL; 4) La Ceiba and 5) El Pueblo (Fig. 1). At each point, macroalgae were collected from four, non-overlapping, randomly-placed quadrants (0.25 m^2), for a total sample area of 5m^2 for each habitat. Based on the findings of Collado-Vides et al (1998), this sample area accounts for the maximum species found at each habitat type. All complete algal thalli present in the quadrants were collected by hand by SCUBA divers. Material was identified at species level and classified accordingly to morphological groups suggested by Steneck and Dethier (1994). In addition the following morphometric parameters were recorded in each plant: size (length in cm), type of growth (clonal or solitary); branching or frond density (non-medium-high); gregarious habit (solitary-regular-compact), attachment system (holdfast, rhizoids, stolon), anatomy (i.e. filament, blade, medullar) and presence-absence of $CaCO_3$.

Distributional patterns of species, in the range of habitat types, were analyzed by means of multivariate techniques that were applied to the presence-absence data matrix. A Bray-Curtis similarity matrix was obtained. No previous transformations were required. An ordination analysis by means of a non-metric multidimensional scaling program (MDS) was carried out. The Kruskal stress coefficient was applied in order to test the ordination obtained by the MDS using PRIMER VI package (Clarke 1993). A two way ANOSIM was used in order to test for significant differences between environments and seasons.

A contingency table was created with the distribution of species based on form-functional group classification. An X^2 was applied to the contingency table in order to find if the distribution of form-function groups were randomly distributed or differ as

their interaction with environment. An ANOVA test was applied to the morphometric data comparing reef, lagoon and species present in both places. All statistic tests were conducted using the statistical package SPSS V. 13.
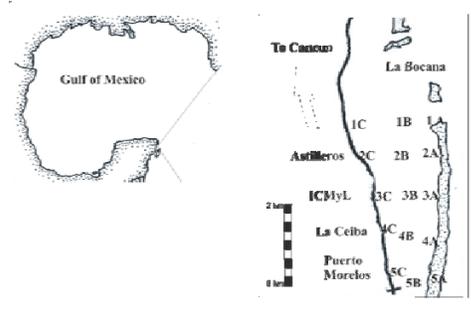

Figure 1: Study site and sampling stations. A= Reef sites, B= deep lagoon sites, C= shallow lagoon sties.

Results

A total of 101 species were found with a clear floristic difference between the reef and lagoon. A higher number of species, diversity and forms in the reef compared with the lagoon were found. Rhodophyta, which generally need hard substratum for attachment, were dominant in the reef, while Chlorophyta with sand-dwelling holdfasts were dominant in the lagoon. The most frequent large species found in the shallow and deep lagoon were the drifting brown species *Lobophora variegata* and *Dictyota bartayresiana* and sand-welling green species *Halimeda* spp., *Udotea* spp. and *Penicillus* spp; and no differences were found among seasons (Fig 2).
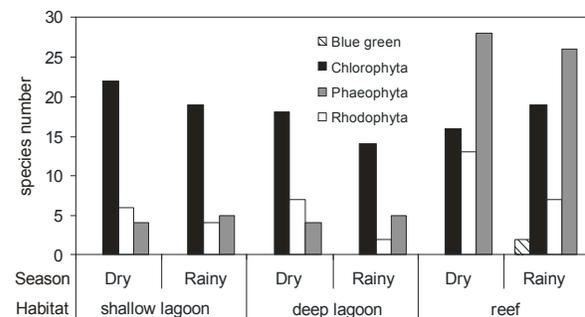

Figure 2. Total number of species at the reef, shallow and deep lagoon during both seasons sampled.

Species richness showed significant differences by habitat (p<0.01), with the highest richness found in the reef compared with the shallow lagoon and deep lagoon (23.1 ± 3.5, reef, *vs* 13.4 ± 3.9 and 12.9 ± 2.6, shallow and deep lagoon respectively). The MDS ordination analysis (Fig. 3) showed different species composition for the reef compared with the lagoon,

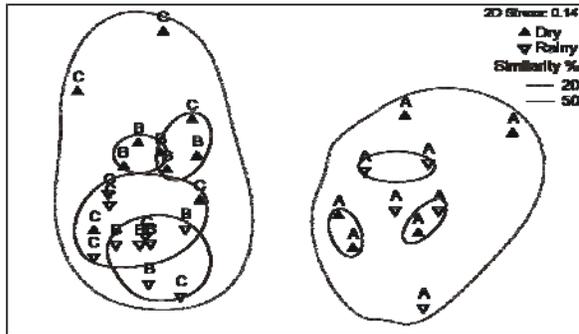however shallow and deep lagoon were very similar among themselves (ANOSIM p>0.05).

Figure 3: MDS configuration of species similarity matrix (stress= 0.14) for both seasons sampled and all sites. A= Reef, B= Deep lagoon, C= Shallow lagoon. Different line pattern shows different level of similarity between sites of different habitats.

The distribution of species classified on form-functional groups, demonstrated that different groups were present in the reef compared to the lagoon, $x^2 = 63.37$ (F=4, P= 0.0001) therefore form-functional groups were not randomly distributed. A higher diversity of forms was found in the reef with all 8 form-functional groups present, with the highest number of species belonging to the group of filamentous (turf forming) and corticated macrophytes. Five groups were present in the lagoon with the highest number of species belonging to the coenocytic group. Species present in both environments belonged to five form-functional groups without any group being dominant above the others (Table 1).

Table 1. Number of species belonging to each functional group and its frequency by habitat A= Reef, BC= Lagoon (shallow and deep), D= Reef and Lagoon. 1= Filamentous algae (uniseriate), 2 = Foliose algae (single layer), 2.5 = Corticated Foliose algae, 3 = Corticated macrophytes, 4 = Leathery macrophytes, 5 = Articulated calcareous, 6 = Coenocytic algae, 7 = Globular algae.

	Habitat			
FFG	**A**	**BC**	**D**	**Total**
1	20	0	3	23
2	2	0	0	2
2.5	5	1	7	13
3	17	1	4	22
4	6	0	0	6
5	9	3	5	17
6	6	18	5	29
7	6	1	0	7
Total	71	24	24	119

The morphological and architectural parameters had a distinct distribution of features among both environments. Small short organisms were found in the reef compared with those of the lagoon. Deep and shallow combined (ANOVA p<0.013), however no differences were found between reef and lagoon species that were present in both places (p<0.264), species present in both environments tended to have medium values, smaller than in the lagoon, but larger than the reef.

The orientation of the thallus: erect vs. prostrate reflects the way the thallus colonizes space, 85% of the reef and 87% of lagoon species had erect fronds with no clear stolon above ground, however all species that were found in both environments had prostrate arrangement of the thallus, mainly *Caulerpa* species. The attachment structures of the reef species were holdfasts or rhizoidal elongations which are strongly attached to hard substratum. Lagoon species had mainly rhizoidal systems either bulbous or just rhizoidal elongations that were embedded in the sand. Branching and gregarious habit which reflects how the thallus are packed in space, were significantly higher (p<0.04) in the reef compared to the lagoon showing a more compact and dense growth in the reef than in the lagoon. Species found in both environments tended to be more or less solitary with medium values of branching, among both extremes. More species with $CaCO_3$ were present in the lagoon than in the reef.

Discussion

The species composition found was similar to the species previous reported for the studied area and region (Collado-Vides et al 1998 for a review), at least in 1998 no strong shifts or macroalgal blooms were detected in the area, therefore this description can be used as a macroalgae base-line for present and future studies in Puerto Morelos, as no published historical records were found.

Species richness was higher in the reef than in the shallow and deep lagoon, this is consistent with the suggestion of McCoy and Bell (1991) that structural complexity of habitats is a major determinant of local abundance and diversity. The higher macroalgae species and architectural diversity found in the reef compared with the lagoon could be explained by the fact that corals offer a more complex environment due to the heterogeneity inherent to the form and shape of hard corals. This heterogeneity results in differences, at small scale in available space, water movement, and irradiation; therefore provide a greater spectrum of resources for macroalgae than seagrass beds (MacArthur and Levins 1967, Dahl 1973, McCoy & Bell 1991, Gratwicke and Speight 2005, Toohey et al. 2007).

Complexity in reefs is usually associated with different species of corals (Beukers and Jones 1997). Our study demonstrated that at least seven different

algal form-functional groups are present in the reef, adding layers of complexity to the already heterogeneous reef system. This is relevant as dominance of groups such as filamentous uniseriate algae, foliose algae (*Dictyota* type), and articulated calcareous green algae (*Halimeda* type), have been reported as main problems in reef systems going trough phase shifts due to environmental changes, (Gardner et al. 2003, Orth et al. 2006, Collado-Vides et al. 2007), therefore decreasing habitat complexity. Our findings agree with Lee (2006) in the fact that the increase of only one form-functional group (fleshy macroalgae) decrease the habitat complexity provided by coral, moreover we add that the increase of only a couple of species, within the fleshy macroalgae, will result in a loss of complexity provided by the diverse types of macroalgae present in a "healthy" reef system. The different scales at which each macroalgal group adds complexity will affect organisms functioning at such scale of complexity (Dahl, 1973). How the loss of complexity will impact the interaction with the following trophic level need to be addressed in long-term designed experiments (Toohey et al 2007), however we can assume that this loss can affect settlement (Lecchini et al 2007) and post-settlement (Eggleston 1995) of corals and survivorship of coral reef fishes (Beukers and Jones 1997).

The morphometric results showed that small size, erect highly branched and dense growth are more frequent in the reef compared to the lagoon where larger, erect, less branched and less dense algae are found. These morphological characters could be correlated to different environmental settings of water movement and substrate in the reef and lagoon at Puerto Morelos, since it is known that water movement differ through sections of Puerto Morelos coral reefs (Jordan 1979). In this regard, the small size, dense growths observed in reef species might be related to phenotypic plasticity to each site's hydrodynamic conditions, as turf-forming algae can tolerate and reduce water velocities (Hurd and Stevens 1997). This hypothesized hydrodynamic plasticity is especially evident for species found in both environments, for example Collado-Vides and Robledo (1999) described morphological and physiological plasticity in *Caulerpa cupressiodes* in Puerto Morelos reef system, where short and compact growth was found in the reef and larger less compact growth in the lagoon, a well recognized clonal strategy. Morphological characteristics, such as frond size, have been shown to affect dislodgment and survival in high-turbulence environments, such as intertidal zone (Carrington 1990).

Due to the karstic nature of the system, underground runoffs as well as isolated springs are the sources of nutrients from the watershed. We could expect a higher nutrient concentration on particular sites of the lagoon at localized springs, however our data showed that in general all sites in the lagoon had similar species composition, and the only strong difference was between reef *vs.* lagoon; therefore we are confident that the differences found, related with the goals of this study, are associated with the main significant difference between the reef and lagoon: substrate, water movement and light. An alternative explanation is that our sites were far away from springs and a direct effect of higher nutrient concentration was avoided. We do recognize that a more detailed study could detect differences in the macroalgal community as a function of nutrient sources as detected in other reef systems (Lapointe 1999). Particular algal morphologies have been related to nutrient uptake abilities (Littler and Littler 1980), and suggested to be used as potential indicators of nutrient sources in tropical systems (Fong et al 2001). Our results show a dominance of rhizophitic forms in the lagoon suggesting that macroalgae in the lagoon use nutrients from sediments, while *Laurencia* and other red attached species were found in the reef suggesting they have water column source (Fong et al 2001). Conducting a more detailed study including a survey of nutrient content of the different morphologies of macroalgae in order to detect sources of nutrients on the study site and its effects on the algal community is recommended.

This study show a high level of complexity in Puerto Morelos reef system, for the period studied, and in all categories used: number of species, number of functional-form groups and at the architectural level. In order to recover declining reefs and increase resilience in altered systems, we need to understand that macroalgae play different roles including being structural organisms.

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