Cah. Biol. Mar. (2007) 48 : 287-295

Crustacean macrofoulers in the Veracruz coral reef system, SW Gulf of Mexico: checklist, spatial distribution and diversity

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Abstract: Composition, spatial distribution, dominance, ecological diversity and evenness of crustacean macrofoulers were analyzed in the Veracruz coral reef system, southwestern Gulf of Mexico. Three test sites were established during May-June 2006 based on their distance from the shoreline and the influence of sewage discharged into the coral reef system. Artificial panels were submerged in Hornos, Pajaros and Blanca reefs for a month. The specimens collected represented 33 species, 27 families and 6 orders of crustaceans. One new record and nine geographic range extensions of amphipod species were documented. Barnacles, amphipods and isopods were the dominant foulers according to abundance and settlement strategies, with differences in species, genera and families among test sites. There were dominance, species richness and ecological diversity gradients of crustacean macrofoulers from Hornos to Blanca based on distance from the shoreline, sewage discharges and the influence of hotels and the Port of Veracruz with respect to the Veracruz coral reef system. The influx of sewage to the reef system has apparently caused a reduction in species richness and ecological diversity, an increase in the dominance of a few macrofoulers and morphological changes in gammarid amphipods.

Résumé: *Crustacés du fouling de l'écosystème corallien de Veracruz, partie sud-ouest du golfe du Mexique : inventaire spécifique, distribution spatiale et diversité.* La composition, la dominance, la diversité écologique, l'équitabilité et la distribution spatiale des macrocrustacés colonisateurs (fouling) associés au système de récifs de Veracruz ont été analysées dans le sud-ouest du golfe du Mexique. Trois localités test ont été choisies en mai-juin 2006, tenant compte de la distance entre ceux-ci et la côte et des rejets d'eaux résiduelles dans le système. Des supports artificiels ont été submergés pour une durée d'un mois sur les récifs Hornos, Pájaros et Blanca. Les organismes récoltés représentent 33 espèces, 27 familles et 6 ordres de crustacés. Un nouveau signalement et neuf nouvelles distributions géographiques ont été enrégistrés chez les amphipodes. Les balanes, les amphipodes et les isopodes sont les organismes dominants en termr d'abondance et de stratégie de colonisation, malgré des différences entre les espèces, les genres et les familles suivant les sites de récolte. Des gradients de dominance, de richesse spécifique et de diversité écologique ont été observés en fonction de la distance à la côte, de la décharge d'eaux résiduelles et de l'influence des hotels et du port de Veracruz. Les effluents (d'eaux résiduelles) ont apparemment causé une réduction de la richesse en espèces et de la diversité écologique, une augmentation de la dominance de quelques macro-colonisateurs et ont modifié la morphologie de certains amphipodes.

Keywords: Biofoulers ● Panels ● Taxocenosis ● Diversity ● Coral reef

Reçu le 30 janvier 2007 ; accepté après révision le 8 août 2007.
Received 30 January 2007; accepted in revised form 8 August 2007.

Introduction

Any submerged surface in the marine environment experiences a sequence of physical, chemical and biological events (Brown, 2005). These processes begin with biofilm production (Allison, 2003) and the subsequent colonization of organisms, termed biofouling (Marechal et al., 2004). The unwanted settlement and growth of biofoulers have been documented in coastal waters (Perkol-Finkel et al., 2005) because they are a source of man-made structures and large-scale economic losses to offshore oil and gas exploitation, shipping, and the mariculture industries (Bernstsson & Jonsson, 2003).

The marine fouling assemblages (MFA) include in successive order: bacteria and diatoms, macroalgae, spores and protozoa, and macrofouler larvae and adults, e.g., sponges, cnidarians, bryozoans, annelids polychaeta, mollusks, echinoderms and crustaceans (Richmond & Seed, 1991; Abarzua & Jakubowski, 1995). Knowledge of the biodiversity and of the community characteristics of the MFA (e.g. dominant foulers, spatial distribution, seasonality and diversity) in each coastal region is a fundamental requirement for the construction and preservation of biofouling on submerged structures (Yan & Yan, 2003).

The Gulf of Mexico (GM) constitutes a large marine ecosystem (Sherman, 1999) with a highly developed oil and gas industry established since the 1940s (Darnell & Defenbaugh, 1990), mainly in the northwest and northeast sectors (Cato & Adams, 1999). MFA research in the GM has been mainly focused on the USA coastal ocean, due to public and private interests in the construction, maintenance and control of oil platforms resistant to biofouling (Pequegnat & Pequegnat, 1973; Gallaway & Lewbel, 1982; Beaver, 2002). Notwithstanding, knowledge on the macrofouler crustacean species in the GM has been documented in only three publications, Culpepper (1969), Pequegnat & Pequegnat (1968) and Lewbel et al. (1987).

Despite the economic importance of biofouling in oil, tourist and ship industries in the southwest GM, very few publications exist on this issue. This study constitutes the first part of an ongoing investigation that analyses the biofouling fauna assemblages and their space-time variations in SW-GM coral reef systems. The purpose of this research was to identify the crustacean assemblage that develops on artificial panels in the Veracruz coral reef system. To account for the spatial distribution, three test sites were selected and compared in relation to distance from the shoreline and sewage discharge. Finally, dominance, diversity and evenness variations were analysed.

Material and methods

Study area and location of artificial panels-test sites

The National Park "Veracruz Coral Reef System" (VCRS) is located on the continental shelf of the state of Veracruz, in the northwestern region of the Bay of Campeche in the polygon delimited by 19°00.0' and 19°16.0' N, and 95°45.0' and 96°12.0' W (Fig. 1). The VCRS covers a surface area of 520 km^2 and constitutes a complex reef structure formed by more than 20 coralline shallows with different degrees of development and accretion (Vargas-Hernández et al., 1993). This National Park has suffered severe impacts derived from human activities and the influx of the Papaloapan, Jamapa-Atoyac and La Antigua rivers (Horta-Puga, 2007). There are two major sewage discharges into the VCRS located at Playa Norte, between Gallega and Punta Gorda reefs, and off Veracruz Aquarium, in front of the Port of Veracruz; in addition, a number of hotels have been built on the beaches, near to Hornos reef.

The VCRS includes two large areas separated by a soft bottom transition area formed by the inlet of the Jamapa River. The northern area, which lies off the Port of Veracruz, represents almost a third of the National Park and includes 10 shallow reefs. The southern area, off Punta Anton Lizardo, is characterized by 12 shallows and a greater area than its northern counterpart. During May and June the average values of water surface temperature and water surface salinity have been reported as 26.6°C and 35.98, respectively (Carrillo et al., 2007).

Fouling panels and recording

Three test sites were established in May 2006 in the VCRS (Table 1) considering sewage discharges and the distance from the coast: Hornos and Pajaros reefs in the northern area, and Blanca reef in the southern area (Fig. 1). A structure was built and placed at each test site according to the design of Mayer-Pinto & Junqueira (2003). Two 15 x 15 cm artificial clay panels were fixed vertically on each structure at 13 m depth and 1.5 m from the bottom. Before submerging the panels, they were washed and pre-soaked in water to remove displaced air and to extract water-soluble components that could affect fouling abundance and diversity. The test panels were recovered manually, using SCUBA, four weeks after immersion, and placed in hermetically sealed plastic bags, underwater. After reaching the shoreline, formalin was added to each sample for transportation back to the laboratory at the Centro de Ecología y Pesquerías. Crustaceans were recovered from the panels manually and stored with 70% ethanol.

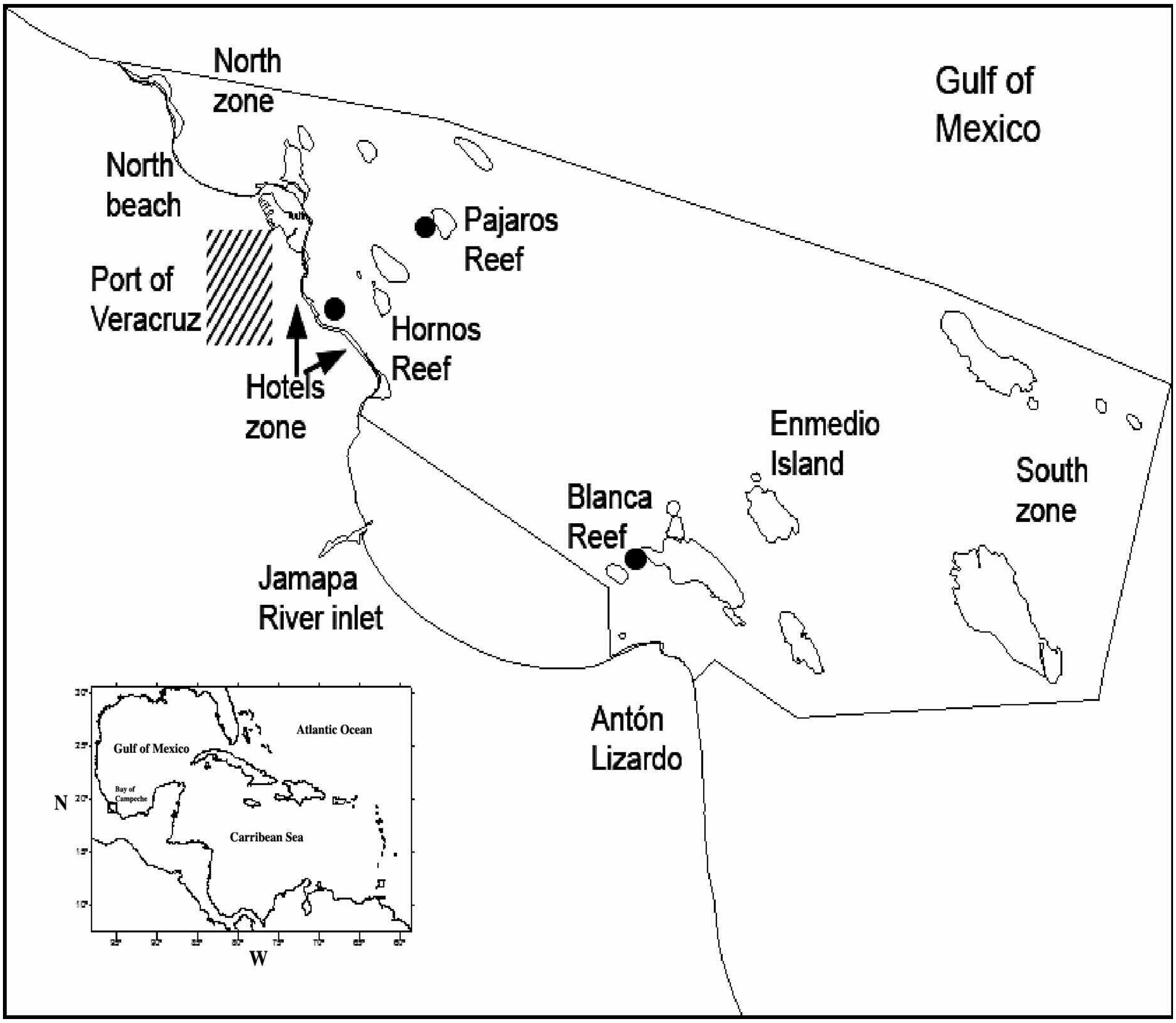

Figure 1. Location of the test sites in the Veracruz Coral Reef System, Southwestern Gulf of Mexico.
Figure 1. Localisation des stations test sur le système de récifs de Veracruz, sud-ouest du golfe du Mexique.

Table 1. Position of test sites in the Veracruz coral reef system, SW Gulf of Mexico.
Tableau 1. Position des stations test sur le système de récifs de Veracruz, sud-ouest du golfe du Mexique.

Plates	Latitude N	Longitude W	Depth m
Pajaros	19º11.63'	96º05.80'	13
Hornos	19º 11.23'	96º07.15'	13
Blanca	19º05.17'	96º00.17'	13

Fouling crustacean assemblages

The amphipod species names were validated according to Barnard & Karaman (1991), LeCroy (2000 & 2001), and Ortiz et al. (2002). The isopods were identified with the Kensley & Schotte (1989) key, and the Suárez-Morales et al. (2004) key was used for the tanaids. Decapods, stomatopods, and barnacles were identified with the criteria of Abele & Kim (1986), Hernández-Aguilera et al. (1996), and Newman & Ross (1976), respectively.

Fouling crustacean diversity

Abundance was calculated as the mean number of the crustacean species between the two artificial panels for each test site. Data were divided into taxonomic groups where all species were pooled into their family group. The Shannon Index for diversity, which combines information on the group members' richness and how individuals are distributed among the groups, was calculated for each data set. The equation for diversity used was $H' = - \Sigma p_i \log p_i$, where p_i is the proportion of individuals for each taxonomic group; a log base of two was used for all calculations. The evenness index J = H'/H_{max}, where H_{max} = log(S) (Pielou, 1975), was used in order to measure the amount of taxonomic group dominance. A value of one or close to it is indicative of a non-dominant taxonomic group in the community, while a value close to zero indicates the presence of a highly dominant taxonomic group. Because of the number of individuals used, a dominant taxonomic group is considered in terms of its abundance in this study.

In order to compare the diversity values between each pair of test sites, the *t* test proposed by Hutchenson (1970) was used. The null hypothesis H_0: $H'_1 = H'_2$ (the diversity of site one is statistically equal to that of site two) was considered. This hypothesis was tested at the taxonomic group level. The *t* value is calculated as:

$$t = \frac{H'_1 - H'_2}{S_{H'_1 - H'_2}} \quad (1)$$

where

$$S_{H'_1 - H'_2} = \sqrt{S^2_{H'_1}} + \sqrt{S^2_{H'_2}} \quad (2)$$

The variance is calculated by:

$$S^2_{H'} = \frac{\sum_{i=1}^{k} f_i \log^2 f_i - (\sum_{i=1}^{k} f_i \log f)^2 / n}{n^2} \quad (3)$$

where f_i is the relative abundance for taxonomic group *i*, *n* is the total number of individuals, and *k* is the number of taxonomic groups.

The degrees of freedom for the test were calculated by using:

$$v = \frac{(S^2_{H'_1} + S^2_{H'_2})^2}{\frac{(S^2_{H'_1})^2}{n_1} + \frac{(S^2_{H'_2})^2}{n_2}} \quad (4)$$

Table 2. Geographic range extension of the crustacean taxa to SW Gulf of Mexico. The previous reported (+) and the reference is indicated.

Tableau 2. Extension de la distribution géographique des espèces de crustacés du système de récifs de Veracruz, sud-ouest du golfe du Mexique. La distribution déjà connue (+) et la référence sont indiquées.

Species	NW	NE	Caribbean Sea	Reference
Metaprotella hummelincki	-	-	+	McCain, 1968
Ampelisca burkei	-	+	-	LeCroy, 2001
Plesiolembos rectangulatus	-	+	+	LeCroy, 2001
Batea carinata	+	+	+	LeCroy, 2004
Americorophium ellisi	-	+	-	LeCroy, 2004
Apocorophium acutum	-	+	-	LeCroy, 2004
Photis macromana	+	+	-	LeCroy, 2001
Podocerus kleidus	-	+	-	Ortiz et al., 2005

Results

Geographical extension and new records

This study contributes with 33 records of macrofouler crustacean taxa that are grouped into 27 families and 6 orders on the artificial panels at the VCRS. The distribution of nine amphipod species originally recorded for the northern GM and the Caribbean Sea is geographically extended to Southwestern of the Gulf of México (the VCRS). The occurrence of *Metaprotella hummelincki* in the VCRS, previously reported only for the Caribbean Sea (McCain, 1968), constitutes a new record for the GM. Other seven amphipod species, earlier documented from the NE-NW Gulf of Mexico, have their geographic distribution extended southwards (Table 2).

Species composition and macrofoulers abundance-distribution

Table 3 summarizes the 33 species of macrofouler crustacean found on the artificial panels during this study. The Orders Sessilia and Stomatopoda included a single species each. The Order Amphipoda was presented by 19 species, the Isopoda by four species, the Tanaidacea by one and the Decapoda by seven species. The crustacean macrofouler assemblages included 10 tube-dwelling (TD) and 14 free-living (FL) species; three peracarids were using vacant tubes (VTD) from tube-dwelling species, and two amphipods were semi-sessile on substrate (SS). The other three species [*Leucothoe spinicarpa* (Abildgaard, 1789), *Podocerus brasiliensis* (Dana, 1853) and *Podocerus kleidus* (Thomas & Barnard, 1992) have been reported on hard substrates (HS), and only *Balanus eburneus* (Gould, 1814) was sessile (S) (Table 2). Twenty species occurred in all three test sites, eight species were found in Pajaros and Blanca only, and five species appeared in Blanca only (Table 3).

Crustaceans total abundance in Hornos was clearly dominated by barnacles (81%), followed by isopods (9.5%), and amphipods (8.5%) (Table 4). Blanca and Pajaros showed a similar trend for the dominant crustaceans, but amphipods were in first place with 70.4% and 50.2%, respectively, and barnacles in second place with 19.2% and 37.2%, respectively (Table 4). The third place in abundance was different for each one of these two test sites, with tanaids (3.8%) for Blanca and isopods (2.5%) for Pajaros (Table 4).

A difference in the total number of taxa and abundance was observed among all three test sites. Blanca presented the

Table 3. Abundance of crustacean species at test sites of Veracruz coral reef system. VTD, vacant tube-dwelling; TD, tube-dwelling; FL, free-living; SS, semi-sessile; S, sessile; HS, hard substrate.

Tableau 3. Abondance des espèces de crustacés sur les supports artificiels disposés sur le système de récifs de Veracruz. VTD, espèces colonisant des tubes vides; TD, espèces tubicoles; FL, espèces vagiles; SS, espèces semi-sessiles; S, espèces sessiles; HS, espèces associées à des substrats durs.

Species	Hornos	Pajaros	Blanca	Category species
Order Sessilia				
Balanus eburneus Gould, 1841	500	180	102	S
Order Stomatopoda				
Neogonodactylus bredini Manning, 1969	—	1	2	FL
Order Amphipoda				
Phtisica marina Slabber, 1769	—	1	3	SS
Metaprotella hummelincki McCain, 1968	—	1	1	SS
Ampelisca burkei Barnard & Thomas, 1989	1	20	39	TD
Ampelisca lobata Holmes, 1908	1	30	40	TD
Hourstonius tortugae (Shoemaker, 1933)	—	—	8	FL
Ampithoe ramondi Audouin, 1826	1	15	28	TD
Plesiolembos rectangulatus (Myers, 1977)	3	25	35	TD
Carinobatea carinata (Shoemaker, 1926)	—	—	2	FL
Americorophium ellisi (Shoemaker, 1943)	—	27	41	TD
Apocorophium acutum (Chevreux, 1908)	—	25	40	TD
Pontogeneia sp.	—	—	1	FL
Photis macromana McKinney, Kalke & Holland, 1978	8	26	33	TD
Ericthonius brasiliensis (Dana, 1953)	10	28	39	TD
Leucothoe spinicarpa (Abildgaard, 1789)	4	3	3	HS
Elasmopus levis (Smith, 1873)	4	4	6	VTD
Podocerus brasiliensis (Dana, 1853)	10	8	10	HS
Podocerus kleidus Thomas & Barnard, 1992	6	7	8	HS
Shoemakerella cubensis (Stebbing, 1897)	—	—	2	FL
Stenothoe gallensis Walker, 1904	4	23	34	TD
Order Isopoda				
Carpias algicola (Miller, 1941)	10	12	3	FL
Cirolana parva Hansen, 1890	10	9	2	FL
Exosphaeroma sp.	20	15	6	VTD
Paracerceis caudata (Say, 1818)	18	5	7	VTD
Order Tanaidacea				
Leptochelia forresti (Stebbing, 1905)	—	12	20	TD
Order Decapoda				
Synalpheus minus (Say, 1818)	—	1	3	FL
Palaemon sp.	—	—	1	FL
Petrolisthes armatus (Gibbes, 1850)	2	1	2	FL
Acanthonyx petiverii H. Milne Edwards, 1834	1	1	5	FL
Macrocoeloma sp.	—	1	1	FL
Microphrys bicornutus (Latreille, 1825)	2	2	2	FL
Pilumnus sp.	1	1	1	FL

highest number of crustacean species, genera, and families (33, 31, and 27, respectively) while Hornos had the fewest (20, 18, and 16, respectively). In contrast, Hornos presented the highest number of individuals of all the test sites with 616 in total, whereas Pajaros had the lowest values with 484 (Table 5).

Fouling crustacean diversity and tests among sites

According to the taxonomic groups set and species set, Blanca was the test site with the highest diversity value (1.57 and 4.04 bits ind^{-1}) while Hornos was the one with the lowest value (0.93 and 1.93 bits ind^{-1}). The evenness values presented the same trend as the diversity, with Blanca having the highest value (0.61 and 0.80), and Hornos with the lowest value (0.47 and 0.32) (Tables 6 and 7).

The diversity t test among the three test sites for the taxonomic groups presented a highly significant difference between Pajaros and Hornos ($p < 0.05$), and Blanca and

Table 4. Abundance of dominant crustaceans by taxonomic group established at the Veracruz Coral Reef System test sites. The percentage (%) is included in parenthesis.

Tableau 4. Abondance des crustacés dominants par groupe taxonomique aux stations test du système de récifs de Veracruz (en % pour chaque site).

Crustaceans	Hornos	Pajaros	Blanca
Barnacles	500 (81.0)	180 (37.2)	102 (19.2)
Stomatopods	—	1 (0.2)	2 (0.4)
Amphipods	52 (8.5)	243 (50.2)	373 (70.4)
Isopods	58 (9.5)	41 (8.5)	18 ((3.4)
Tanaids	—	12 (2.5)	20 (3.8)
Decapods	6 (1.0)	7 (1.4)	15 (2.8)

Table 5. Occurrence of crustaceans by taxonomic level in the Veracruz Coral Reef System test sites.

Tableau 5. Présence des crustacés, classés par niveau taxonomique, aux stations test du système de récifs de Veracruz.

Crustaceans	Hornos	Pajaros	Blanca
Family	16	22	27
Genera	18	26	31
Species	20	28	33
Abundance	616	484	530

Table 6. Shannon Diversity Index (H'), number of taxonomic groups (S), maximum diversity (H'_{max}) and evenness (J) for the set of taxonomic groups.

Tableau 6. Indice de diversité de Shannon (H'), nombre de groupes taxonomiques (S), diversité maximum (H'_{max}) et équitabilité (J) au niveau des groupes taxonomiques pour chaque station.

Index	Hornos	Pajaros	Blanca
H' (bits ind^{-1})	0.93	1.33	1.57
S	4.00	6.00	6.00
H'_{max}	2.00	2.58	2.58
J	0.47	0.52	0.61

Hornos sites ($p < 0.05$), and a statistically significant difference between Pajaros and Blanca ($p < 0.05$) (Table 8).

Discussion

The design of monitoring programs for marine hard-bottoms involves a variety of problems related to the sampling protocol, the collection of organisms and the use of destructive sampling techniques. In response to these difficulties, monitoring programs based on submerged artificial substrates have been significantly developed throughout the coastal ocean, particularly for coral reefs. Their importance has been documented in studies on biodiversity, biofoulers, bioindicators, and bioessays (Thomas, 2000; Qui et al., 2003), in addition to geographical range extensions, new locality records, community parameters and spatial distribution, as in this study.

Table 7. Shannon Diversity Index (H'), number of species (S), maximum diversity (H'_{max}) and evenness (J) for the species set.

Tableau 7. Indice de diversité de Shannon (H'), nombre d'espèces (S), diversité maximum (H'_{max}) et équitabilité (J) pour l'ensemble des espèces de chaque station.

Index	Hornos	Pajaros	Blanca
H' (bits ind^{-1})	1.39	3.54	4.04
S	20.00	29.00	34.00
H'_{max}	4.32	4.86	5.09
J	0.32	0.73	0.80

Table 8. The *t* test values for the Shannon Diversity Index among test sites according to the set of taxonomic groups (v = degrees of freedom, *$p < 0.05$, ** $p < 0.01$).

Tableau 8. Valeurs du *t* de Student pour l'indice de diversité de Shannon entre les localités test au niveau des groupes taxonomiques (v = degrés de liberté, * p < 0,05, ** p < 0,01).

Test sites	v	t
Pajaros - Hornos	1095.4010	-8.5692 **
Blanca - Hornos	1087.3715	-4.8286 **
Pajaros - Blanca	987.0785	2.8963 *

Species composition

The crustacean assemblage was an important macrofouler group on artificial substrates in the VCRS during early recruitment of fouling assemblages. Due to their morphological and physiological adaptations, this subphylum constitutes an important component within the community composition of coastal oceans, and occurs in many coral reef microhabitats.

In this study, the composition of the crustacean macrofoulers included five groups of species with particular mobility-settlement on hard substrates. Sessile barnacle dominance in fouling assemblages has been documented in many places (Rasmussen et al., 2002) due to their wide distribution, availability of larvae and their dispersion (Brown & Swearingen, 1998), their high tolerance-intervals and settlement adaptations (Celis-Villalba, 2004). In the northern GM, *Balanus reticulatus*, *B. improvisus* (Gallaway & Lewbel, 1982; Lewbel et al., 1987) and *B. eburneus* have been recorded as dominant macrofoulers (Powers, 1998). *Balanus eburneus* was reported at the three test sites in the VCRS and was characterized as a dominant component according to its abundance in this study.

The amphipods collected from the test sites in the VCRS represented the second group of macrofoulers, based on numerical dominance, and the first with respect to species richness. The importance of these crustaceans in coral reef systems has been documented within regard to biodiversity, abundance, reproductive success and their role within food webs (Thomas, 1993). Their morphological characteristics have enabled them to adapt to all habitats within these ecosystems: as cryptofaunal on coral rubble and algae, as commensals of sessile or gelatinous invertebrates, as interstitial macrofauna, as hyperbenthos entering the water column periodically for feeding, reproduction, and colonization (LeCroy, 2000; Cházaro-Olvera et al., 2002) and, principally, as tube-dwellers and burrowers. In this study, *Ampelisca burkei, A. lobata, Ampithoe ramondi, Plesiolembos rectangulatus, Americorophium ellisi, Apocorophium acutum, Photis macromana, Ericthonius brasiliensis* and *Stenothoe gallensis* represented the dominant fouling species based on numerical abundance and spatial distribution, in addition to being tube-dwelling and hyperbenthos components.

Species of the families Ampeliscidae, Amphitoidae, Aoridae, Corophiidae, Isaeidae, Ischyroceridae, Meliidae (Amphipoda), Sphaeromatidae (Isopoda) and Leptochelidae (Tanaidacea) have been documented as tube dwellers or inhabitants of the vacant tubes of tube-dwelling species, as well as conspicuous species in the colonization of hard-bottoms (Kensley & Schotte, 1989; Barnard & Karaman, 1991; Suárez-Morales et al., 2004); these facts agree with observations made regarding the families and species collected from the artificial substrates at the VCRS.

Spatial distribution of fouling macrocrustaceans

Horta-Puga & Ramírez-Palacios (1996), Morlán-Cahue & Opengo-Piña (2005), and Horta-Puga (2007) have reported a gradient of sewage loads and heavy metal concentrations from Hornos to Blanca into the VCRS, based on Veracruz City discharges, surface circulation, and the distance from the shoreline. The effect of these organic-inorganic compounds on the scleractinian coral, sea urchin and algae species was revealed by a decline in the number of individuals and the reproductive rate, as well as by an increase in mortality rate. Our results are consistent with those studies and show a considerable reduction in the number of individuals for *Ampelisca burkei*, *A. lobata*, *Americorophium ellisi* and *Apocorophium acutum* (Table 2) from Blanca to Hornos. EPA (1990) reported a decline in the abundance and an increase in the mortality rate of Gammaridae and Ampeliscidae (Amphipoda) related to sewage waters, which agrees with this study.

This trend is in agreement with the geographic position of the Port of Veracruz, where Blanca, as the farthest away, is least influenced by sewage discharges and Hornos, lying directly in front of the port, receives a great amount of hotel and city sewage discharges. This could indicate a pollution gradient decreasing from Hornos to Blanca. In addition, the reduction in the number of individuals and the species richness of amphipods in Hornos (Table 3), in comparison with the other two test sites, suggests an influence of organic pollution derived from hotel discharges on the settlement and colonization of the crustacean macrofoulers in this study. This is also reinforced when comparing diversity. There are highly significant differences between Hornos and the rest of the test sites as a result of the large number of individuals that may be resistant to these environmental conditions (e. g. *Balanus*).

On the other hand, the effect of sewage waters on the morphology of gammarid amphipods has been reported by Gross et al. (2001) as a change in the body or in the shape of their structures. These characteristics were found in the present study: Hornos, situated close to Veracruz Port and directly influenced by sewage waters, presented the lowest values of species richness and abundance of amphipods of the order Gammaridea. Furthermore, *Ericthonius brasiliensis* (Ischyroceridae), *Photis macromana* (Isaedidae), and *Leucothoe spinicarpa* (Leucothoidae) showed an abnormal reduction in the size and thickness of their gnathopods and antenna 2, which may be due to the sewage waters prevailing in the area.

Fouling diversity

The Shannon Diversity Index has been widely used as a parameter of stress on the community, mainly because the index is affected by dominant species resulting in a decrease in the index value. Considering the data set of the taxonomic groups, Hornos presented the lowest value while Blanca had the highest (Table 6). Spatially, Hornos coral reef is closest to the shore and to the Port of Veracruz, while Blanca the farthest, and this may have some influence on the diversity values encountered. These results are similar to those found when the species set was used for the calculations (Table 7). Furthermore, Hornos presented the lowest evenness value for the species data set, mainly due to the high abundance and dominance of barnacles in this area. In comparison, the other two test sites presented lower abundances of barnacles and a more even number of individuals for the various species.

The contrast in diversity values between the test sites led to different conclusions, depending on the data set used.

For the taxonomic groups set, all sites were different in their diversity value, even Pajaros and Blanca, which are relatively far from the shore and were expected to have similar diversity values. In the case of the species set, only the Hornos-Blanca contrast was significantly different, which agrees with their relative influence from the shore. The results found for evenness and diversity suggest that a comparison between diversity values of a high taxonomic hierarchy is enough to distinguish differences among sites with different degrees of anthropogenic impact and distance from the shoreline.

We suggest that Hornos reef is subjected to a strong anthropological influence (previously reported): it shows a low diversity accompanied by the presence of particular species and the dominance of species resistant to environments highly polluted by organic matter content. The use of the Shannon Diversity Index at the taxonomic group level may suffice to estimate significant differences among coastal localities with a strong influence from natural or anthropological sources.

Finally, we recommend that it is imperative to design strategies and sampling programs that allow reporting data on biodiversity, spatial and temporal variations, correlation with the environmental matrix, and community succession aimed at avoiding the potential impact of biofouling. These strategies would be instrumental in preventing and controlling the establishment of unwanted organisms that affect the durability and functionality of man-made structures in the southwestern GM.

Acknowledgments

We thank the Programs “Fondos Mixtos FOMIX-CONACyT-Veracruz” (37637), “Apoyos Complementarios a Proyectos de Investigación Científica-CONACyT (52164), and PAPIIT-UNAM (IN 224507) for the financial support. To Comisión Nacional de Acuacultura y Pesca (CONAPESCA) and El Parque Nacional Sistema Arrecifal Veracruzano for the collecting license. Thanks are due to Michel Hendrickx, Miguel Angel Lozano, Irene Marquina, Warren Haid and the Aquarium of Veracruz.

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