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THE EFFECT OF ARTIFICIAL REEF STRUCTURAL COMPLEXITY AND BENTHIC COLONIZATION ON GILL NET FISH ASSEMBLAGES

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RESUMO

Uma das principais questões em estudos recifes artificiais refere-se aos agentes modeladores da comunidade íctica associada. Módulos de concreto experimentais foram distribuídos na costa norte do estado do Rio de Janeiro (21^{o}29'S, 41^{o}00W) de acordo com a combinação da complexidade estrutural através da presença/ausência de cavidades e de superfície favorável/desfavorável à colonização bêntica. O programa de amostragem (março de 2002 a março de 2003) consistiu de capturas mensais com redes de espera de fundo por 24 horas. Os valores de densidade por espécie, densidade por grupo funcional de acordo com a posição na coluna d´água, tipo preferencial de substrato, hábito alimentar, sexo e estágio ontogenético e os descritores de comunidade não revelaram diferenças significativas (ANOVA, $p > 0,05$) entre as unidades recifais e entre os tipos de módulos. O dispositivo de pesca é seletivo para peixes pelágicos e demersais, sugerindo baixa associação com os módulos recifais. O maior número de presas nos módulos com bentos sugere uma predação íctica sobre a comunidade bêntica mais diversificada. Os peixes fêmea mostraram uma associação com os módulos sem complexidade estrutural. Uma maior similaridade entre os módulos com complexidade foi observada para diversidade, densidade e composição do conteúdo estomacal. A complexidade estrutural desempenhou um papel mais importante como agente modelador da comunidade íctica nos módulos recifais do que a presença de comunidade bêntica, embora esta última implique em recursos alimentares mais diversificados para a ictiofauna associada.

ABSTRACT

One of the main ecological issues of artificial reefs are the fish community modeling agents. Experimental concrete modules were distributed along the northern coast of Rio de Janeiro (21°29'S, 41°00W) according to a combination of structural complexity with the presence/absence of cavities and favorable/unfavorable surface for benthic colonization. The sampling program (March 2002 to March 2003) consisted of 24 hour-monthly captures with bottom gill nets. Fish density, density by functional groups according to position in the water column, preferential type of substrata, feeding habit, sex and ontogenetical stage, and community descriptors did not show significant (ANOVA, $p > 0.05$) differences among reef units and among module types. This fishing method is selective for pelagic and demersal fish, suggesting their low association to the modules. A larger number of prey in fish stomachs at modules with benthos suggest that these fish were preying on a more diverse benthic community. Female fish showed a clear association to modules without a structural complexity. A higher similarity was observed among the modules with structural complexity for diversity, density and stomach content composition. Structural complexity played an important major role as a modeling agent of fish community compared to the presence of benthic community, although the latter implies in more diverse food resources to the fish community.

Keywords: Artificial reef, fish assemblages, structural complexity, gill nets, Rio de Janeiro.

INTRODUCTION

On the last three decades ~~of~~ artificial reef~~s~~ studies have evolved from a superficial and pragmatic view to a more scientific and experimental one, leading to a better understanding of related processes and consequences. Brock & Norris (1989) registered higher fish abundance and richness in planned reefs built with specific materials compared to the scrap ones. Carr & Hixon (1997) sustained that artificial reef similar to natural substrate in structural complexity result in higher species diversity and biomass. The influence of benthic communities on reef fish colonization has been studied by Carlisle et al. (1964), Sale & Dybdahl (1975) and Ogden & Ebersole (1981). The ecological implications of the artificial reefs must be evaluated as a tool to their deployment and management; nevertheless the considerable efforts allocated to artificial reefs construction surpass the efforts to comprehend their ecology (Bohnsack and Sutherland, 1985).

Physical space increases the available habitat, providing food and shelter in minimum levels, which guarantees the capacity of recruitment and survival rates through the perpetuation of their populations. Sherman et al. (2002) found a positive correlation between habitat complexity, fish abundance and diversity. Ferreira et al. (2001) characterized benthic organisms as a reef fish community-modeling factor on natural rocky shores.

Although artisanal fisheries plays an important role in the local economy of north Rio de Janeiro state, the area presents a flat and homogeneous coastline with few rocky outcrops or bays which could support good fishing grounds and safe moorings, making the region disfavorable for the development of a commercial fishing fleet. The implantation of artificial reefs might enhance the local fisheries, which justifies previous research on the effects of these man-made structures in the marine environment. The present study aims to complement (see Brotto, Krohling & Zalmon, 2006 for visual census technique) studies of the structural complexity and benthic community effects on artificial reef fish assemblages with a common local fishing device. It is expected that an artificial reef with different availability of these variables would result in a distinct ichthyofauna related to composition, species abundance, richness and diversity.

METHODS

In January 2002 an experimental reef complex was settled 3.0 miles from Guaxindiba beach (21º29'S, 41º00'W), north Rio de Janeiro state on a flat and homogeneous bottom, 9 m deep (Figure 1). The artificial complex was comprised of 36 prefabricated concrete reef balls of four types grouped into 12 sets according to the combination of structural complexity by the presence (WC) or absence (NC) of holes and favorable (WB) or unfavorable (NB) surface for benthic colonization with anti–fouling paint (Figure 2). The combination of these characteristics defined the reef type (WCWB: with complexity and with benthic coverage, WCNB: with complexity and no benthic coverage, NCWB: no complexity and with benthic coverage, NCNB: no complexity and no benthic coverage), and included three replicates of each – a reef unit (Figure 2). Each reef unit was randomly settled 100 m distant from each other, totaling a reef complex area of approximately 60.000 m^2.

Fish sampling was carried out monthly from March 2002 to March 2003, with bottom gill nets (25 x 2 m, 40 mm mesh) for 24 hours over each reef unit.

The fish was grouped according to the corresponding reef unit, identified, sexed, wet weighed (biomass) and measured. Total fish number, species richness, Shannon’s diversity (Zar, 1984) and individual number by functional group according to the species position in water column, preferential type of substrate, feeding habit, sex and ontogenetical stage were used to determine differences among fish assemblages according to each module type.

A cluster analysis (UPGMA, Euclidean distance) was performed to determine the similarity among the fish assemblages of the different modules. Species richness and fish number values were prior log-transformed to minimize heterocedasticity. The statistical analysis consisted of one-way ANOVA followed by *a posteriori* Tukey test (HSD) to determine the independence among reef units and the differences among the four modules types ($p < 0.05$). Qui-square tests were performed to evaluate the differences between male/female and juvenile/adult numbers and food items/food rates.

RESULTS

A total of 786 fish were caught during the sampling program at the reef complex (WCWB: 202, WCNB: 178, NCWB: 189 and NCNB: 219) distributed in 47 species (WCWB: 39, WCNB: 35, NCWB: 29 and NCNB: 36) (Table 1). Frequency of occurrence greater than 50% was verified for the species *C. jamaicensis*, *R. porosus*, *G. genidens*, C. *chrysurus* and *M. americanus* at NCWB modules; for *C. jamaicensis*, *R. porosus*, *G. genidens* and *C. virescens* at WCNB modules; for *C. jamaicensis*, *R. porosus* and *G. genidens* at NCNB, and just *C. jamaicensis* at WCWB. The species *C. nobilis* and *A. quadricornis* were exclusive to the complex modules and *H. aurolineatum*, *C. spinosus* and *D. formosum* occurred only at the non-complex ones (Table 1).

The species *C. virescens*, *R. porosus*, *C. jamaicensis*, *M. americanus* and *G. genidens* presented the highest total weight and standard length. The latter parameter showed a coefficient of variation lower than 20% for *C. chrysurus*, *R. porosus*, *G. genidens*, *M. americanus*, *C. latus*, *S. rastrifer* and *L. breviceps*, which allowed the analysis of variance among module types, although no significant (ANOVA, $p > 0.05$) differences were found (Table 2).

The community descriptors total fish number, total biomass and species richness did not show significant (ANOVA, $p > 0.05$) differences among reef units of each module type, suggesting independent samples units (Table 3).

Abundance, biomass, species richness and diversity values were similar for all module types (Figure 3), as well as the fish number values according to vertical position, preferential substrate and feeding guilds, with no significant (ANOVA, $p > 0.05$) differences except for substrate generalist fish, which preferred modules with complexity and with benthic coverage/WCWB (Figures 4, 5 and 6).

Cluster analysis showed a higher similarity for fish number, species richness and stomach content composition among modules with structural complexity, independent of benthic coverage (Figure 7).

Significant (Qui-square, $p < 0.05$) higher number of prey types of different taxonomic groups in fish stomachs occurred on modules with benthic coverage (Figure 8).

Females were significantly (Qui-square, $p < 0.05$) more abundant at non-complex modules and adults and juveniles showed a homogeneous distribution among the different modules with higher numbers for the first ones (Figure 9).

A significant temporal variability ($p < 0.05$) was registered with higher values in May and spring months for all the community descriptors as well as for pelagic, invertivorous and planctivorous fish at the different module types (Table 4).

DISCUSSION

Different researchers have elaborated different experimental designs disposed so as to obtain sampling independence. Sherman, Gillian & Spieler (2002) and Bortone et al. (1994) placed modules 30 meters apart, Bohnsack et al. (1994) at 100 meters and Chandler, Sanders and Landry (1985) with 200 meters distance; however evidence proving the independence of the respective reef units was not observed. In the present study the gill net sampling technique did not show significant differences for fish community descriptors among units of the same module type. The distance of 100 m between units and their random position seems to provide independent samples as the fishes were homogeneously distributed among the reef units of each module type.

Trammel and gill nets are quite common practices used for fish community assessment in natural environments but a few researchers have applied these methods in artificial reefs (D`Anna et al., 2004; Fabi & Fiorentini, 1994; Santos & Monteiro, 1998; Relini et al., 2002). These methods are selective for pelagic and soft bottom demersal fish, suggesting a low association of the fish to reef modules. Visual census sampling at our artificial reef on the northern coast of Rio de Janeiro provided important information about fish community usage patterns (Brotto, Krohling & Zalmon, 2006). However, trammel and gill net sampling allows the assessment of reproductive and feeding habits data.

As stated by Smith & Tyler (1975) coral domes of considerable internal volume and structural complexity favor a diversified and dense fish community of different species and sizes. Other studies using gill nets in artificial reefs (D`Anna et al., 2004; Gomes et al., 2001; Godoy, Almeida & Zalmon, 2002) related increasing fish diversity and abundance to higher structural complexity of the substrate. In contrast, Fabi & Fiorentini (1994) and Santos & Monteiro (1998) suggest that trammel and gill nets could not identify differences among fish communities of artificial reefs and other substrates. The present study showed similar results due to fewer differences of community descriptors among module types. This could be related to the sampling method, which is more appropriate for demersal fish on unconsolidated substrate (Fabi & Fiorentini, op cit.), which was the category with higher abundance in the reef complex.

Bohnsack, Johnson & Anderson (1991) indicated two mechanisms acting in the colonization of an artificial reef, the creation of new habitats and the increase in benthic biomass that represents food resources. Relini et al. (2002) concluded that energy transfer in the form of food resources (e.g. decapods and amphipods) occurs from the reef complex to the associated fish. On the other hand, Randall (1963) observed several reef fish species feeding in the adjacent unconsolidated substrate and returning to the reef for shelter. Lindquist et al. (1994) verified demersal zooplankton and infauna macroinvertebrates of adjacent sandy bottom as an important food source, suggesting that reef fish community depends on biological productivity of non-reef environments. However, higher numbers of prey types in the fish stomachs at modules with benthic coverage indicate that they also explore the consolidated substrate as an additional food resource. Three of the most abundant predator fish species and an invertivorous (*R. porosus*, *C. virescens*, *C. jamaicensis* and *M. americanus*) were associated with unconsolidated substrate, suggesting that these species visited the reef complex seeking prey such as small fish and invertebrates that were attracted to the modules.

Shelter against predation provided by structural complexity could be understood as a resource. Therefore, as suggested by Crowe (1996), the differences in adults and juveniles' distribution among modules might reflect an intra-specific competitive exclusion due to the intensive use of a given resource by one of the ontogenetical stages.

Smith (1978) reported that reef fish have their life history strongly influenced by their relative size. Almany (2004) registered higher abundance of adults but not juveniles in structurally complex habitats due to the different effects of potential predators. Connell (2000) accepted the hypothesis of juvenile fish being more exposed to predation in larger reefs as he registered a higher abundance of small predatory fish in this environment. This could explain the non-selectivity of juvenile fish to our complex modules. Juveniles were expected to present higher mobility and be potentially more vulnerable to the nets of small mesh size due to their intense feeding activity. Gill net selectivity might be related to adult fish density being equally distributed. Dyehl (1992) observed that a trophic hierarchy based on the size of the species characterizes aquatic communities. However, most of the fish in the present reef complex correspond to adults of several species or juveniles of large predators; their higher vulnerability to the sampling method excludes small cryptic species. Thus, no significant differences for length and weight among module types were registered, reflecting no habitat selection due to fish size.

Sexually maturating female fish were expected to present a higher mobility due to the increase in feeding activity. The vulnerability to gill nets could explain their higher densities at the four module types. Also, the highest density of females in non-complex modules suggests habitat selection.

The higher similarity among modules with complexity for diversity, specific abundance and stomach content composition supports the hypothesis that structural complexity plays a major role as a fish community-modeling agent compared to the presence of a benthic community. The latter implies that the local fish community explores a more diversified food resource.

The present study revealed that the gill net sampling device did not show the influence of the substrate complexity and benthic community as fish assemblages modeling agents compared to the visual census technique (Brotto, Krohling & Zalmon, 2006). Through this selective sampling technique, a seasonal influence seems to be more important than the modeling agents. Visual census samplings would provide better knowledge concerning artificial reef usage patterns by the fish community aiming to improve reef design or to a sustainable exploration of artificial reefs.

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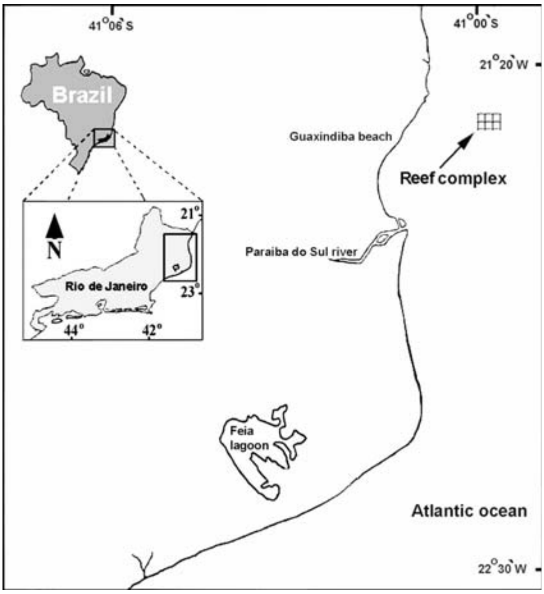

Figure 1 – Study site of the reef complex implantation on north coast of Rio de Janeiro, Brazil.

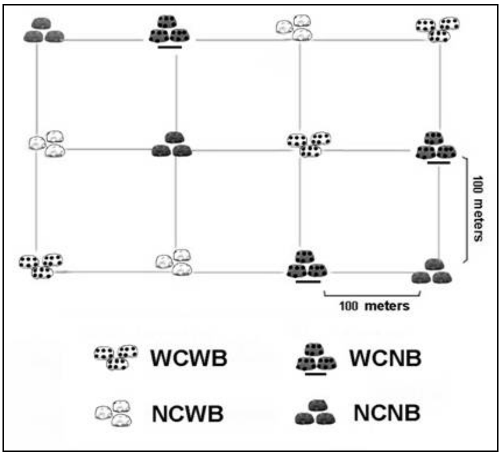

Figure 2 – Schematic draw of reef modules (WCWB: with complexity/with benthos, WCNB: with complexity/no benthos, NCWB: no complexity/with benthos and NCNB: no complexity/no benthos).

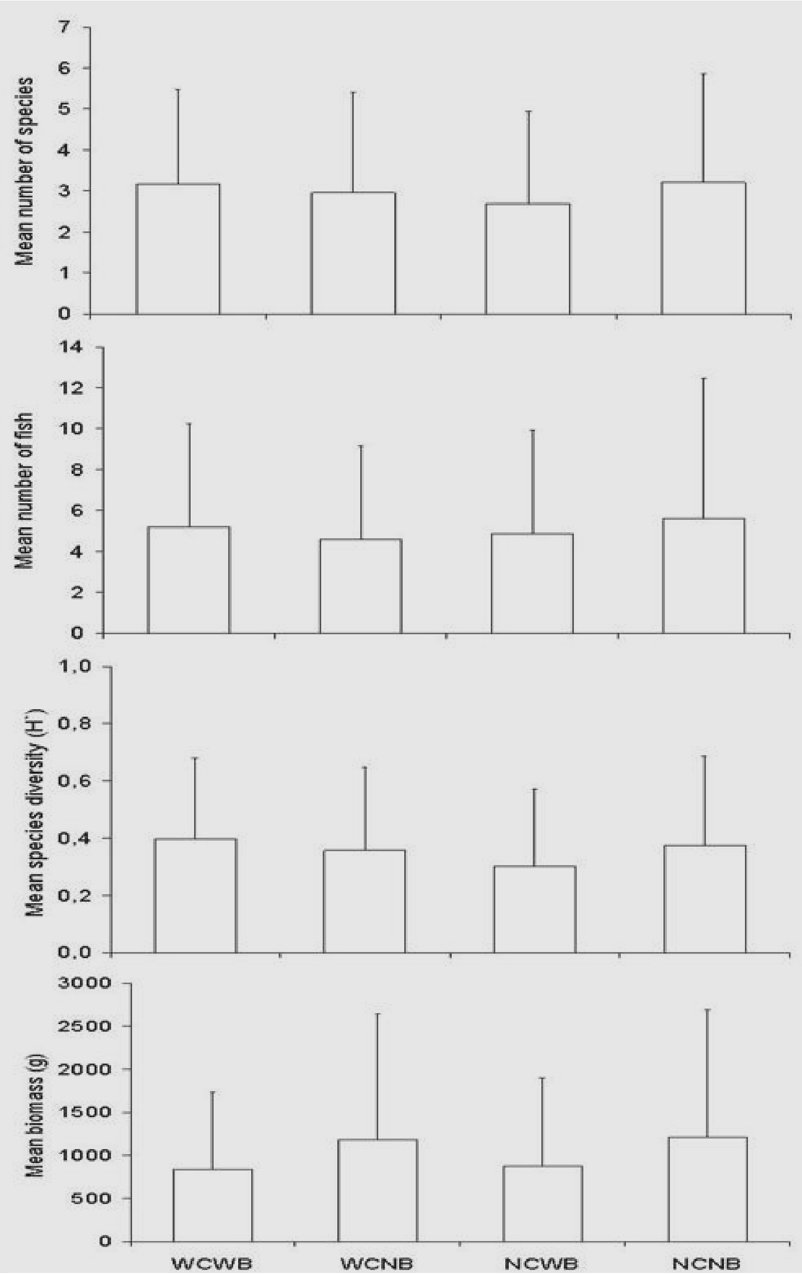

Figure 3 – Community descriptors mean values (vertical bars) + standard deviation (vertical lines) on each module type (WCWB: with complexity/with benthos, WCNB: with complexity/no benthos, NCWB: no complexity/with benthos and NCNB: no complexity/no benthos).

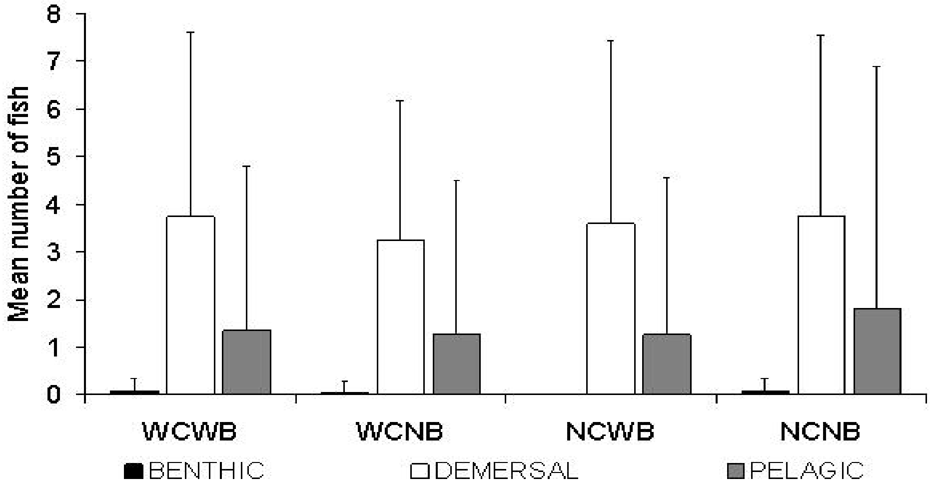

Figure 4 – Fish number mean values (vertical bars) + standard deviation (vertical lines) according to vertical position on each module type (WCWB: with complexity/with benthos, WCNB: with complexity/no benthos, NCWB: no complexity/with benthos and NCNB: no complexity/no benthos).

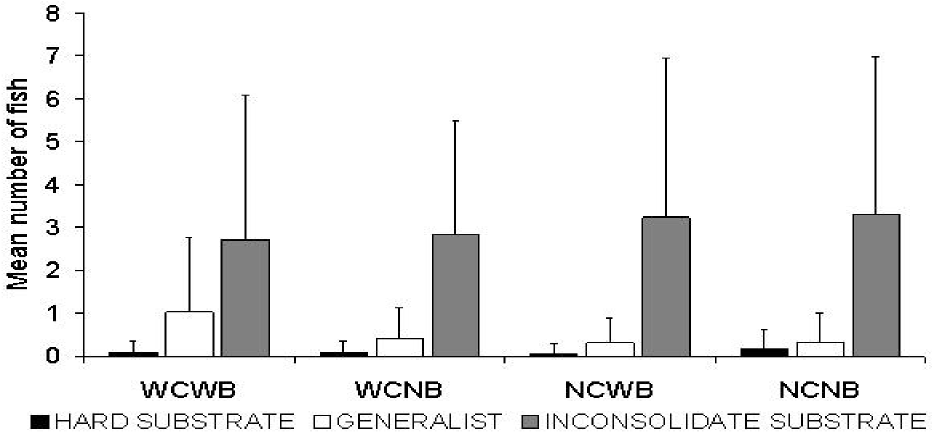

Figure 5 – Fish number mean values (vertical bars) + standard deviation (vertical lines) according to preferential substrata on each module type (WCWB: with complexity/with benthos, WCNB: with complexity/no benthos, NCWB: no complexity/with benthos and NCNB: no complexity/no benthos).

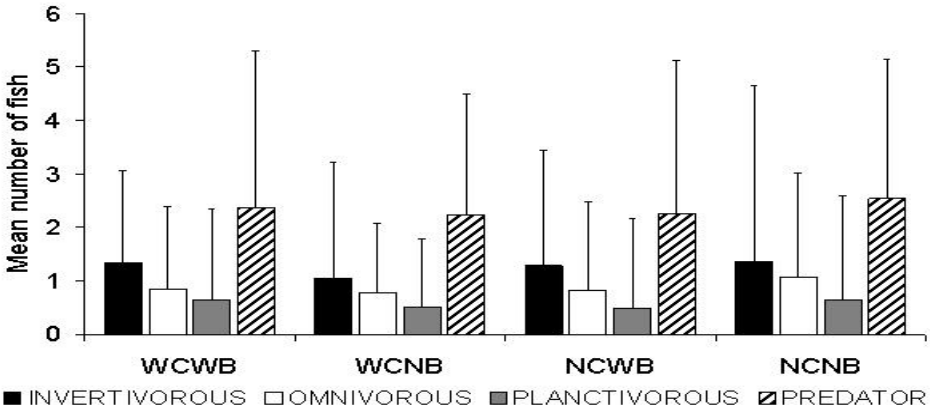

Figure 6 – Fish number mean values (vertical bars) + standard deviation (vertical lines) according to feeding habit on each module type (WCWB: with complexity/with benthos, WCNB: with complexity/no benthos, NCWB: no complexity/with benthos and NCNB: no complexity/no benthos).

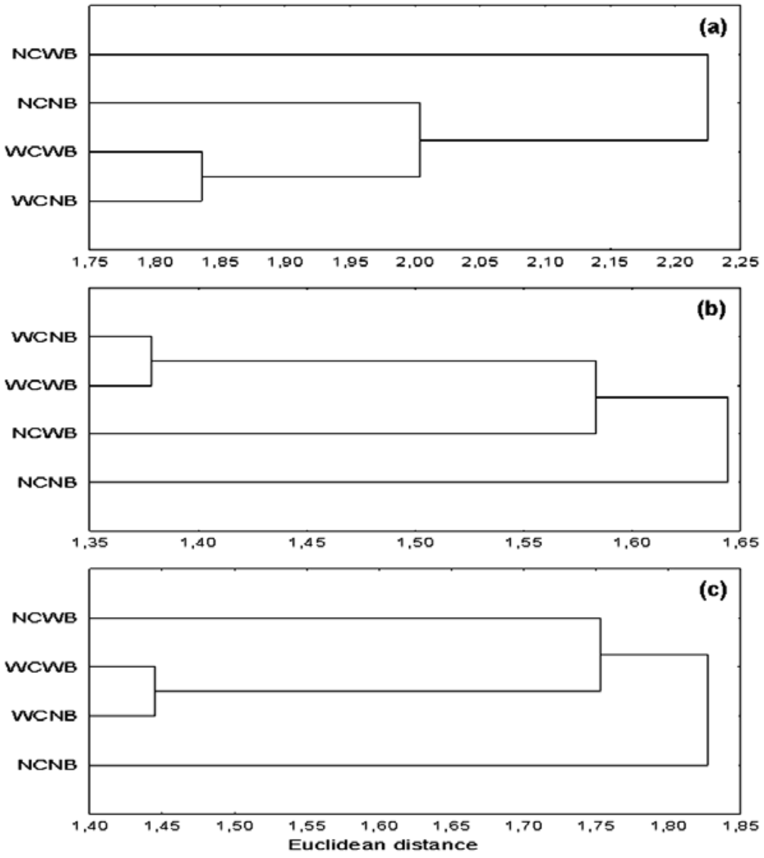

Figure 7 – Cluster analysis of different module types according to specific fish number (a), species richness (b) and stomach content

composition (c) (dissimilarity index Euclidean distance – UPGMA) (WCWB: with complexity/with benthos, WCNB: with complexity/no benthos, NCWB: no complexity/with benthos and NCNB: no complexity/no benthos).

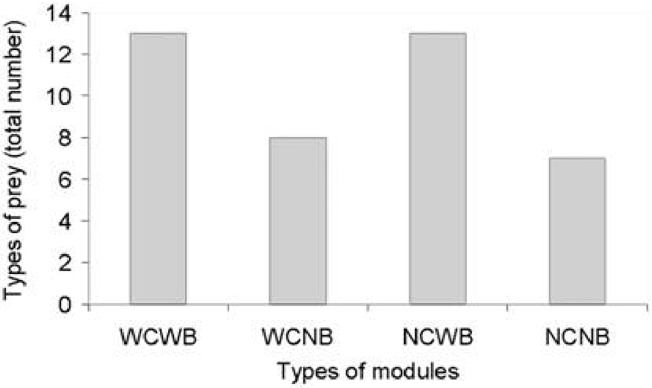

Figure 8 – Total number of prey types of different taxonomic groups on each module type (WCWB: with complexity/with benthos, WCNB: with complexity/no benthos, NCWB: no complexity/with benthos and NCNB: no complexity/no benthos).

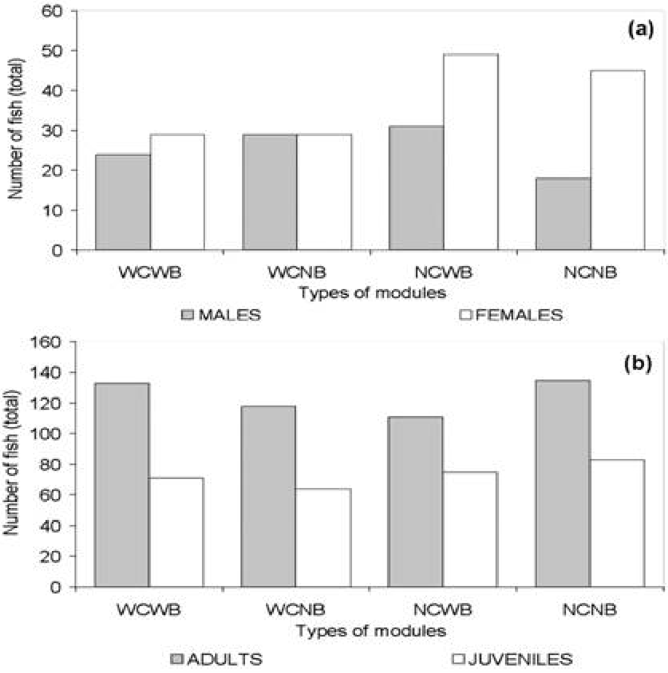

Figure 9 – Total fish number according to sex (a) and ontogenetical stage (b) on different module types (WCWB: with complexity/with benthos, WCNB: with complexity/no benthos, NCWB: no complexity/with benthos and NCNB: no complexity/no benthos).

Table 1 – Frequency of occurrence (FO), total number of fish (NO) and percentual fish number per each species in the different modules of the reef complex (WCWB – with complexity/with benthos, WCNB – with complexity/no benthos, NCWB – no complexity/with benthos and NCNB – no complexity/no benthos).

Species	**WCWB**			**WCNB**			**NCWB**			**NCNB**		
	FO	**NO**	**%**	**FO**	**NO**	**%**	**FO**	**NO**	**%**	**FO**	**NO**	**%**
Conodon nobilis	0	0	0,0	1	1	0,6	0	0	0,0	0	0	0,0
Cyclichthys spinosus	0	0	0,0	0	0	0,0	1	1	0,5	0	0	0,0
Diplectrum formosum	0	0	0,0	0	0	0,0	0	0	0,0	1	1	0,5
Echneis naucrates	0	0	0,0	0	0	0,0	0	0	0,0	1	1	0,5
Haemulon aurolineatum	0	0	0,0	0	0	0,0	1	1	0,5	1	1	0,5
Lagocephalus laevigatus	0	0	0,0	1	1	0,6	0	0	0,0	2	2	0,9
Mustelus higmani	0	0	0,0	2	5	2,9	1	1	0,5	1	1	0,5
Micteroperca microleps	0	0	0,0	1	1	0,6	0	0	0,0	1	1	0,5
Acantostracium quadricornis	1	1	0,5	0	0	0,0	0	0	0,0	0	0	0,0
Anisotremus surinamensis	1	1	0,5	0	0	0,0	0	0	0,0	0	0	0,0
Centropomus undecimalis	1	2	1,0	1	1	0,6	3	4	2,1	0	0	0,0
Lutjanus annalis	1	1	0,5	2	2	1,1	1	1	0,5	2	2	0,9
Lutjanus synagris	1	1	0,5	0	0	0,0	0	0	0,0	1	1	0,5
Micropogonias furnieri	1	1	0,5	4	4	2,3	2	2	1,1	2	2	0,9
Pellona harroweri	1	1	0,5	0	0	0,0	0	0	0,0	1	1	0,5
Porichthys porosissimus	1	1	0,5	1	1	0,6	0	0	0,0	2	2	0,9
Pomatomus saltatrix	1	1	0,5	0	0	0,0	1	1	0,5	0	0	0,0
Sciadeichthys luniscutis	1	1	0,5	1	2	1,1	2	2	1,1	2	10	4,6
Syascium papillosum	1	1	0,5	0	0	0,0	0	0	0,0	0	0	0,0
Scomberomorus brasiliensis	1	2	1,0	1	1	0,6	1	2	1,1	1	1	0,5
Caranx crysos	2	2	1,0	0	0	0,0	1	1	0,5	2	2	0,9
Cetengraulis edentulus	2	2	1,0	2	3	1,7	0	0	0,0	1	4	1,8
Chaetodipterus faber	2	3	1,5	0	0	0,0	1	1	0,5	1	1	0,5
Dactylopterus volitans	2	4	2,0	2	2	1,1	1	1	0,5	0	0	0,0

Table 1 – Frequency of occurrence (FO), total number of fish (NO) and percentual fish number per each species in the different modules of the reef complex (WCWB – with complexity/with benthos, WCNB – with complexity/no benthos, NCWB – no complexity/with benthos and NCNB – no complexity/no benthos). Continuation...

Species	**WCWB**	**WCNB**	**NCWB**	**NCNB**	**Species**	**WCWB**	**WCNB**	**NCWB**	**NCNB**	**Species**	**WCWB**	**WCNB**
	FO	**NO**	**%**	**FO**	**NO**	**%**	**FO**	**NO**	**%**	**FO**	**NO**	**%**
Notarius grandicassius	2	2	0,9	1	1	0,6	0	0	0,0	1	1	0,5
Oligoplites saliens	2	2	1,0	1	1	0,6	1	1	0,5	0	0	0,0
Peprilus paru	2	2	1,0	2	2	1,2	3	3	1,6	2	4	1,8
Polynemus virginicus	2	2	1,0	2	3	1,7	0	0	0,0	0	0	0,0
Trichiurus lepturus	2	2	1,0	2	4	2,3	1	1	0,5	4	5	2,3
Harengual clupeola	3	5	2,5	4	7	4,0	2	3	1,6	2	2	0,9
Opisthonema oglinum	3	13	6,4	2	7	4,0	3	12	6,4	3	14	6,4
Stelifer brasiliensis	3	6	3,0	2	2	1,1	3	9	4,8	3	3	1,4
Bagre bagre	4	5	2,5	4	5	2,8	3	3	1,6	4	6	2,7
Netuma barba	4	7	3,5	2	2	1,1	0	0	0,0	2	3	1,4
Orthopristis. ruber	4	4	2,0	3	3	1,7	0	0	0,0	1	1	0,5
Paralonchurus brasiliensis	4	4	2,0	3	3	1,7	3	3	1,6	5	5	2,3
Stelifer rastrifer	4	4	2,0	4	4	2,3	5	5	2,7	9	11	5,0
Cinoscion virescens	5	5	2,5	11	15	8,4	4	7	3,7	7	14	6,4
Haemulon steindachneri	5	7	3,5	1	1	0,6	4	4	2,1	4	4	1,8
Larimus breviceps	5	5	2,5	6	7	4,0	6	7	3,7	4	4	1,8
Menticirrhus americanus	6	6	3,0	4	4	2,3	11	14	7,4	5	5	2,3
Chloroscombrus chrysurus	8	23	11,3	5	24	13,4	9	26	13,7	8	38	17,3
Caranx latus	8	16	8,0	5	6	3,4	0	0	0,0	2	2	0,9
Genidens genidens	8	18	9,0	9	20	11,2	11	27	14,3	12	22	10,0
Rhyzoprionodon. porosus	8	21	10,4	12	21	12,0	9	28	14,8	10	22	10,1
Cinoscion jamaicensis	11	17	8,5	9	11	6,2	11	18	9,5	12	20	9,1

Table 2 – Total number of individuals (N), mean values of total individual weight ± standard deviation (TW ± sd), coefficient of variation of total individual weight (CV-TW), mean values of standard length ± standard deviation (SL ± sd), coefficient of variation of standard length (CV-SL) and analysis of variance results among module types (ANOVA, non significant p < 0.05) of the most abundant species.

Species	**N**	**TW ± sd (g)**	**CV-TW**	**SL ± sd (cm)**	**CV-SL**	**F**	***p***
C. virescens	41	428,4 ± 273,9	63,94	31,0 8,0	25,81	-	-
R. porosus	92	389,9 ± 496,1	127,24	31,3 5,4	17,25	1,23	0,302 NS
C. jamaicensis	66	211,8 ± 123,3	58,22	22,3 5,2	23,32	-	-
M. americanus	29	195,1 ± 91,5	46,90	21,2 3,5	16,51	0,88	0,461 NS
G. genidens	87	130,8 ± 54,3	41,51	19,6 2,2	11,22	0,40	0,752 NS
C. latus	24	98,6 ± 30,1	30,53	14,8 1,5	10,14	2,26	0,129 NS
L. breviceps	23	95,4 ± 21,0	22,01	14,7 1,2	8,16	0,18	0,905 NS
H. steindachneri	16	71,1 ± 64,9	91,28	12,4 4,5	36,29	-	-
S. rastrifer	24	61,7 ± 27,3	44,25	13,0 1,7	13,08	0,21	0,888 NS
C. chrysurus	111	43,8 ± 11,2	25,57	12,4 1,1	8,87	0,98	0,402 NS

NS: non significant,

Table 3 – Analysis of variance (ANOVA, non significant p < 0.05) of community descriptors among reef units of each module type (WCWB – with complexity/with benthos; WCNB – with complexity/no benthos; NCWB – without complexity/with benthos; NCNB – no complexity/no benthos).

Module types	**Total fish number**		**Total biomass (g)**		**Species Richness**		**Species Diversity**	
	F	***p***	**F**	***p***	**F**	***p***	**F**	***p***
WCWB	0.05	1,002	2,42	0,074	0,08	0,921	0,16	0,852
WCNB	0,09	0,916	1,67	0,936	0,39	0,685	0,17	0,844
NCWB	0.04	0,955	3,65	0,661	0,08	0,924	0,53	0,592
NCNB	0.27	0,761	0,97	0,954	0,28	0,763	0,04	0,964