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Temporal and spatial patterns on the settlement of reef fish larvae in a South Atlantic reef, Bahia, Brazil

MARIA ISABEL G. PAIVA[1*], LIANA F. MENDES[2], JORGE EDUARDO LINS-OLIVEIRA[3], CARLOS EDUARDO R. D. ALENCAR[2,3] & FELIPE O. TORQUATO[4]

[1] Universidade Federal do Rio Grande do Norte (UFRN), Departamento de Oceanografia e Limnologia, Via Costeira, Praia de Mãe Luiza s/n, Natal-RN, Brasil.

[2] Universidade Federal do Rio Grande do Norte (UFRN), Departamento de Ecologia . Lagoa Nova BR101 s/n, Natal-RN, Brasil.

[3] Universidade Federal do Rio Grande do Norte (UFRN) Programa de Pós-Graduação em Ecologia, Via Costeira, Praia de Mãe Luiza s/n, Natal-RN, Brasil.

[4] Universidade Federal do Rio Grande (FURG), Programa de Pós-Graduação em Oceanografia Biológica, Instituto de Oceanografia, Avenida Itália s/n, Carreiros, Rio Grande-RS, Brasil.

Corresponding author: E-mail: migpfish@gmail.com

Abstract The larval settlement of reef fish - the moment in which the larvae establish on the reefs - is a critical phase and a determinant process in the structure of the adult assemblage. Artificial Reef Moorings (ARMs) were used to verify temporal and spatial variation on the settlement of competent fish larvae in the Itacolomis Reefs, located on the north portion of the Abrolhos Bank, Brazil. A total of 459 individuals settled on the ARMs, representing 8 families and 11 species. Cluster analysis showed spatial patterns, in relation to depth and protected versus non-protected area, and temporal patterns (season). The Carangidae was the most representative family, followed by Lutjanidae and Monacanthidae. The highest number of taxonomic groups was recorded during summer. Some groups, such as Pomacentridae (*Abudefduf saxatilis*), Labridae, Serranidae (*Serranus* sp. and *Mycteroperca bonaci*), Blenniidae and Chaenopsidae were registered only during summer. Non-protected areas had the highest richness and abundance, whereas protected areas were important for some species, registered exclusively there. The information presented here may support the development of detailed studies for the management and conservation of reef fish communities in this region.

Key words: Artificial reef moorings, Itacolomis, Marine Protected Area, Abrolhos, Ichthyoplankton

Resumo Variação espacial e temporal no assentamento de larvas de peixes recifais em recifes do Atlântico Sul, Bahia, Brasil. O assentamento de larvas de peixe recifal – momento no qual a larva se estabelece no recife – é uma fase crítica e um processo determinante na assembléia de peixes adultos. Recifes Artificiais Ancorados (Artificial Reef Moorings - ARMs) foram usados para verificar a variação espacial e temporal no assentamento de larvas de peixes competentes nos recifes de Itacolomis, localizados na porção norte do Banco de Abrolhos, Brasil. Um total de 459 indivíduos, pertencentes a 11 espécies e 8 famílias, assentaram nos ARMs. Análise de agrupamento mostrou padrão espacial, em relação à profundidade e área protegida e não protegida, e padrão temporal em relação às estação do ano. A Família Carangidae foi a mais representativa, seguida por Lutjanidae e Monocanthidae. O maior número de grupos taxonômicos foi registrado no verão. Alguns grupos, como Pomacentridae (*Abudefduf saxatilis*), Labridae, Epinephelidae (*Serranus* sp. e *Mycteroperca bonaci*), Blenniidae e

Chaenopsidae foram registrados apenas durante o verão. Áreas não protegidas tiveram a maior riqueza e abundância enquanto que a área protegida foi importante para algumas espécies, como único lugar de registro. As informações aqui presentes podem auxiliar como baseline para o desenvolvimento de estudos mais detalhados acerca do manejo e planos de conservação para comunidades de peixes recifais dessa região.

Palavras-chave: Recife artificial ancorado, Itacolomis, Área Marinha Protegida, Abrolhos, Ictioplâncton.

Introduction

Nearly all reef fish species present two distinct phases in their life cycle. The first stage is larval, planktonic and potentially dispersive, occurring in the pelagic environment, while the juveniles and adults are territorial, occurring on the reef habitat (Leis 1991, Lecchini *et al.* 2007). During the planktonic period, the larvae may travel long distances, from a few meters to hundreds of kilometres (Sale 2002) and, depending on the species, they may remain from one to several weeks in the water column (Leis 1991). After this period, the larvae move onto the reefs - a suitable habitat to complete their lifecycle - where they settle. Survival at this stage is tenuous and mortality reaches up to 99% (Jones 1991), which is mediated by physical (wind, currents, habitat complexity) and ecological (predation, competition) processes (Milichi & Doherty 1994). The end of the larval period is characterized by the transition from the pelagic environment to settling on the reef substrate (Sale 1991). At this stage the larvae are considered competent (i.e. capable of swimming/settling).

Reef fish larvae influence and are influenced by the abundance and distribution of the adult population (Forrester 1999). The settlement process is highly variable in space and time (Doherty 1991) and has direct consequences on the size, structure and functioning of the adult population (Robertson 1992). Thus, recruitment success is considered a key factor on the size of the population in a particular reef (Doherty 1991, Jones 1991).

The understanding about reef fish communities is incomplete without information on the natural history of the species involved, including the early stages of their life cycle (Nakatani 1997). One way to obtain this kind of information is through the study of settlement and recruitment using Artificial Reef Moorings (ARMs) to capture competent fish larvae. These traps are the most economical and appropriate for this type of environment (Shroeder 1987, Leis *et al.* 2002).

The knowledge about processes such as spatial and temporal patterns of larval settlement and fish recruitment are extremely important to understand the ecology of reef fish (Cowen 2002). During the 80's and 90's, considerable attention was given to this issue (Sale 2002). Many studies have sought to comprehend the mechanisms behind the settlement process, focusing on factors that can influence the structure of the adult population on a given reef (Thorrold *et al.* 1994a,b,c, Wilson 2001, Leis *et al*. 2002). Some of these demonstrated that the process of larval replacement and settlement may be influenced by seasonal (Wilson 2001), spatial (protected versus non-protected) (Leis 1991a) and temporal (lunar cycle) (Thorrold *et al.* 1994b) processes. The information gathered here on the recruitment of reef fish in a reef environment in northeastern Brazil are preliminary, therefore, should be used as a baseline for the understanding of fish settlement dynamics, which is a relevant aspect for the management and conservation of reef ecosystems.

Materials and Methods

Study Area

This study was conducted in the Itacolomis reefs (16 º 54'S, 39º02'W), located on the North portion of the Abrolhos Bank, south Bahia, Brazil. This area is part of the Corumbau Marine Extractive Reserve (RESEX Marinha do Corumbau) (Fig. 1), created in September 2000 to promote the sustainable use and conservation of its natural resources. Additionally, a Marine Protected Area (MPA) was established inside the RESEX, extending from the central portion of the reefs to the eastern limit of the RESEX, with 1850 ha, which corresponds to 20% of the Itacolomis reefs total area (Fig.1). Fishing is not permitted inside the MPA. The Itacolomis reefs are formed by large, rounded reef structures cut through by irregular coastal channels with depths of up to 20 m. The reefs are elongated with lengths varying from 20 to 100 m and heights ranging between 4 and 7 m. During low tide, the tops of many of these formations are exposed (Castro & Segal 2001). They are characterized by vertical pinnacles expanded laterally at the top, called "chapeirões" ('hoods': reef or ridge of sand lying near the surface of the water; cf. Leão *et al.* 1985, 1988).

Figure 1. Distribution of sampling stations (A, B and C). The rectangle indicates the Marine Protected Area (MPA) in the Itacolomis reefs.

Field survey and Laboratory procedures

During summer (February) and winter (July/August) 2003 three stations (A, B and C) were sampled at the Itacolomis reefs, around and inside the MPA. Station B was inside the MPA, and the two other stations, A and C, in areas adjacent to the MPA. The stations were located between 1.5 and 2 km apart from each other and positioned parallel to the coast, approximately 6 km away from the coastline. The depth at the sampling stations ranged between 6 and 9 m (Fig. 1).

To sample the settlement of competent fish larvae, Artificial Reef Moorings (ARMs) were utilized. These ARMs consisted of two baskets attached by a clip to a line. The line was attached to the bottom with a block and to a subsurface float. The basket consisted of a piece of 3 m × 0.3 m plastic garden mesh rolled into a cylinder (30 cm long, 20 cm wide), placed in pairs at 2 m intervals above the bottom and between baskets (Fig. 2). Four ARMs were placed 10 meters away from each reef (station) in opposite directions (N, S, E, W) (Fig. 2).

The sampling was carried out in summer and winter 2003, during one lunar cycle (Declining moon, New moon, Increasing moon, Full moon) per season. At each change of lunar phase, the traps were recovered with the aid of scuba equipment to collect competent fish larvae. Firstly, mesh bags were placed around the basket, then they were disconnected from the cables, taken to the surface and onboard the boat, washed inside a container filled with sea water, and attached back to the subsurface to sample the next lunar phase. A total of 96 samples were collected in each season, summer and winter, totalling 192 samples during the entire study. The competent fish larvae collected were counted, identified, fixed in 10% borax buffered formaldehyde and subsequently preserved in 70% ethanol. The individuals were identified to the lowest possible taxonomic level following Menezes and Figueiredo (1980, 1985, 2000) and specialists.

Statistical analysis

Analysis of agglomerative hierarchical clustering were calculated using Jaccard index and Ward method as linkage function, which offered more efficiency and quality to show spatial and temporal patterns on larval fish settlement. The efficiency and quality of clusters was assessed using two coefficients: Criterion Agglomeration (CA) and Cophenetic Correlation Coefficient (CPCC). The CA indicates differences between the dissimilarities of each sample before and after each hierarchical clustering with values that range from 0 to 1 (Maechler *et al.* 2012). The CPCC is a correlation between the original matrix of dissimilarity and the matrix before the cophenetic transformation (Legendre & Legendre 2003); the values also vary from 0 to 1.

According to Singh *et. al.* (2011) high values in CPCC indicate that there was not much distortion between the matrix of dissimilarity and the matrix after clustering. Furthermore, the higher the values in CA and CPCC, the higher the quality, fit and efficiency of clustering. Therefore, the best algorithm of clustering

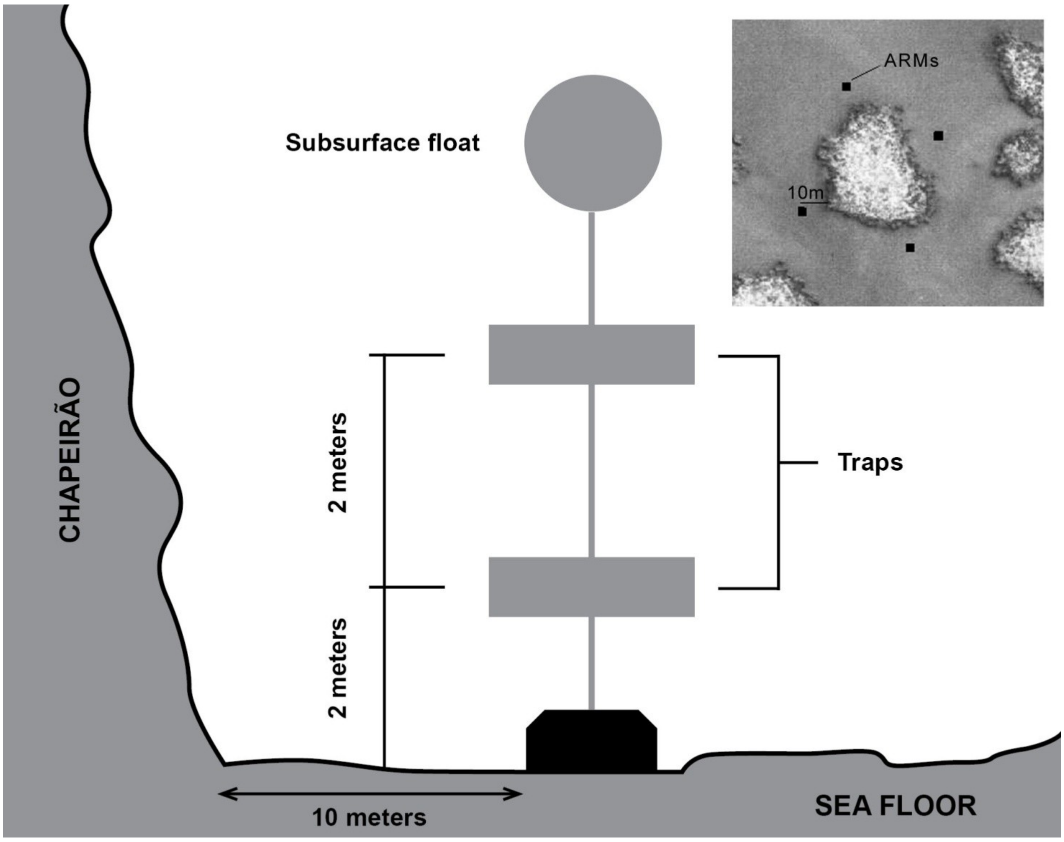

Figure 2. Illustration of the structure of the ARMs used and details of their placement around the stations.

was confirmed based on the interpretation of the indexes CA, CPCC and by visual inspection of dendograms. The hierarchical clusters used were bootstrap multiscale (for details see: Suzuki & Shimoidara 2006, Shimoidara 2008). For each test group 10,000 resampling type multiscale were used, considering the values of confidence (AU - Aproximately Unbiased) greater than 95%.

All analysis were performed in R (R Development Core Team 2012). The CA was calculated using the routine "agnes" contained in the package "cluster" (Maechler *et al.* 2012). The hierarchical clusters with bootstrap multiscale were performed using the package "pvclust" (Suzuki & Shimoidara 2009).

Results

Settlers of at least eleven species and 8 families were found on the ARMs, with a total of 459 individual competent fish larvae. The most abundant settlers were the Carangidae, with 391 individuals, followed by the Lutjanidae, with 47 individuals (*Lutjanus chrysurus* and *Lutjanus synagris*), and Monacanthidae, with 14 individuals (*Stephanolepis* sp.) (Fig. 3).

Temporal Pattern of Settlement

Seasonal Distribution (summer/winter)

During summer 131 individuals of 8 families were recorded. Carangidae was the most representative with 66 settled individuals, followed by *Lutjanus chrysurus*, with 45. During winter 328 individuals of 3 families were registered. The hierarchical cluster analysis distinguished 2 main groups regarding larvae that recruited in summer and winter (Fig. 4II). Some groups, such as Pomacentridae (*Abudefduf saxatilis*), Labridae, Serranidae (*Serranus* sp. and *Mycteroperca bonaci*), Labrisomidae and Blenniidae were registered only during summer. This season was also significant for *L. chrysurus* and the Monacanthidae (*Stephanolepis hispidus)* when they were mostly recorded. The species *Lutjanus synagris* was recorded only during winter (Table 1).

Lunar distribution

The larvae of Carangidae, Lutjanidae and Monocanthidae were observed during all phases of the moon. The full moon phase showed the greatest settlement, with 196 individuals, represented by the Carangidae, Lutjanidae and Monacanthidae families. Carangidae were the most representative in all phases of the moon. Other species, such as *Mycteroperca bonaci* and *abudefduf saxatilis,* settled during declining moon, and *Serranus sp*, settled during new moon (Table 2). The cluster analysis did not show patterns related to the lunar phases for the assemblages (Fig. 4II).

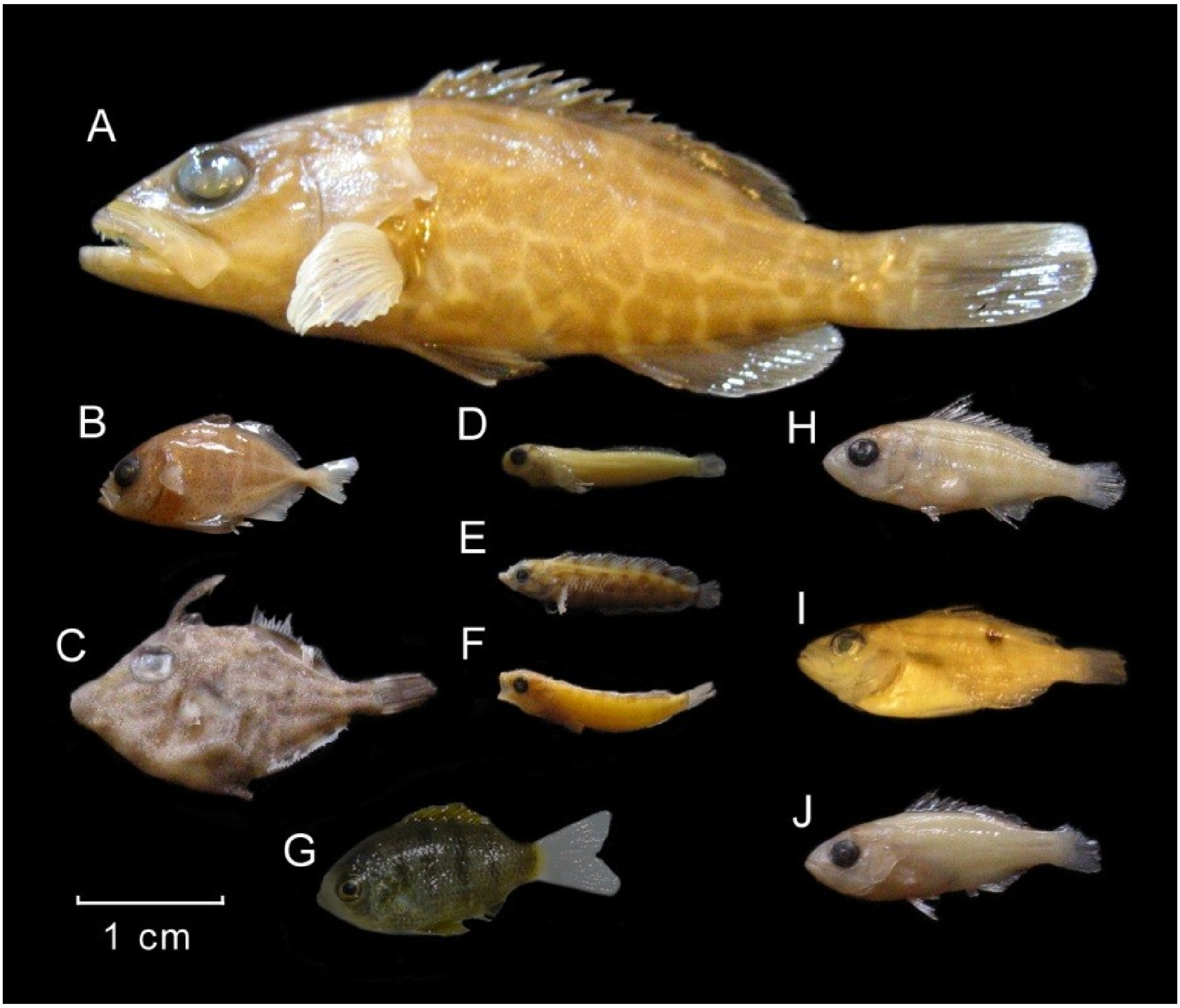

Figure 3. Reef-fish taxa that settled on the moorings: A- *Mycteroperca bonaci*, B- Carangiadae, C- *Stephanolepis hispidus*, D- Blenniidae, E- Labrisomidae, F – Labrisomidae, G -*Abudefduf saxatilis*, H- Ocyurus chrysurus, I - *Lutjanus synagris*, J-*Serranus sp*.

Spatial Pattern of Settlement

Station C showed the highest number of families settled, represented by Carangidae, Lutjanidae, Labridae, Serranidae and Monacanthidae. The species *L. chrysurus* was the most representative, with 25 individuals (table 3). Station A showed the highest number of settlements, with 364 settled individuals, and Carangidae was the most successful, with 69 individuals (table 3). The species *L. chrysurus* was recorded in station C and protected area station B, with 24 and 7 individuals settled respectively. Carangidae obtained 345 individuals in station A and 15 in station C (table 3). Serranidae settled only in station C.

Deeper traps recorded the highest number of settlements, a total of 279 individuals, with 237 for Carangidae and 29 for Lutjanidae (*L. Chrysurus*). The *Stephanolepis* sp. (Monacanthidae) achieved 11 settlements in the deeper traps and 3 in shallower traps. The shallow traps showed a lower number of settlements, with 180 individuals, but a higher number of species, with nine species compared to five in the deeper traps (table 3).

The cluster analysis showed a different pattern of species for the shallow region in the MPA.

The *Lutjanus synagris,* observed only once in deeper traps, is an important species in the Abrolhos commercial fisheries. Station A showed differences in the analysis and was the only station that recorded Serranids (*Serranus* sp. and *Mycteroperca bonaci*) (Fig. 4I).

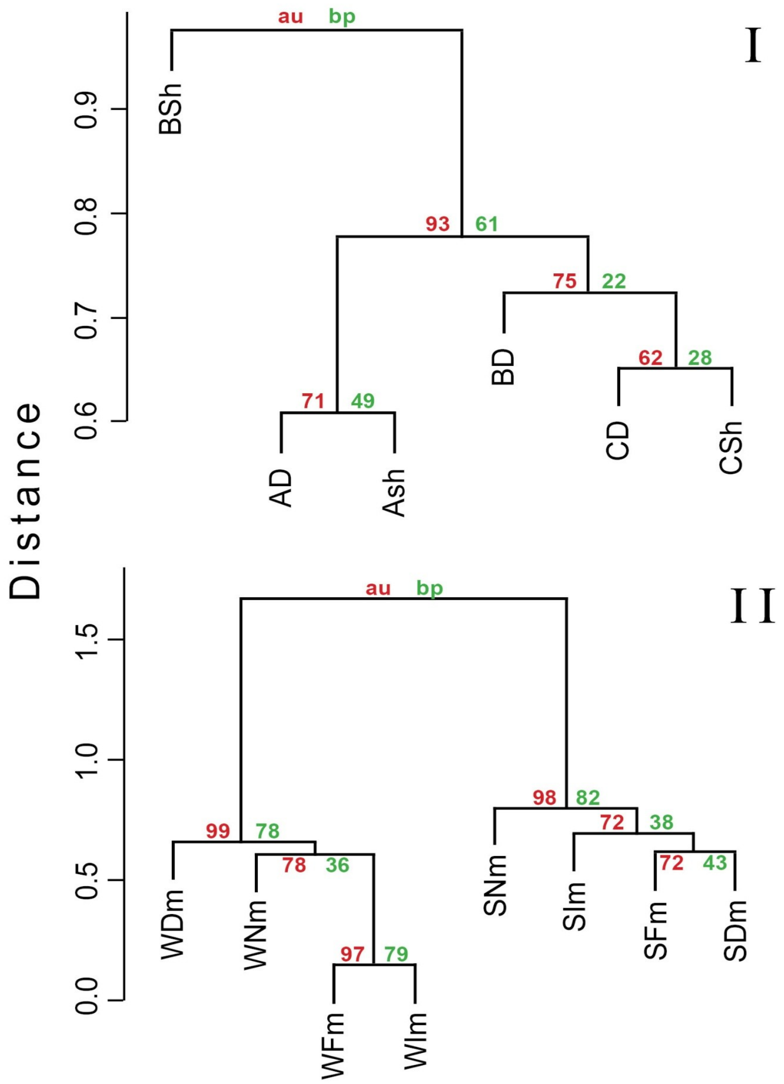

Figure 4. Analysis of agglomerative hierarchical clustering by Jaccard index using Ward as linkage method. (I) Spatial clustering, stations A, B and C; Deep sample (D), Shallow sample(Sh); (II) Seasonal/Temporal clustering Summer(S),Winter(W); Declining moon(Dm), New moon(Nm), Increasing moon(Im), Full moon(Fm). Approximately Unbiased (au). Bootstrap Probability (bp).

Table 1. Number of competent fish larvae settled on the artificial reef moorings during summer and winter.

Taxa	Summer	Winter
Carangidae	66	325
Lutjanus chrysurus	45	1
Lutjanus synagris	0	1
Stephanolepis hispidus	13	1
Mycteroperca bonaci	1	0
Serranus sp	1	0
Paraclinus arcanus	1	0
Labrisomidae	1	0
Labridae	1	0
Blenniidae	1	0
Abudefduf saxatilis	1	0

Table 2. Number of competent fish larvae settled on the artificial reef moorings during all moon phases.

Taxa	Full	Declining	New	Increasing
Carangidae	177	51	69	94
Lutjanus chrysurus	15	15	8	9
Lutjanus synagris	1	0	0	0
Stephanolepis hispidus	3	3	3	5
Mycteroperca bonaci	0	0	1	0
Serranus sp	0	0	0	1
Paraclinus arcanus	0	1	0	0
Labrisomidae	0	0	1	0
Labridae	0	1	0	0
Blenniidae	0	0	1	0
Abudefduf saxatilis	0	0	0	1

Table 3. Number of competent fish larvae settled on the artificial reef moorings in Stations A, B and C, and two different depths, shallow and deep.

	Horizontal			Vertical	
Taxa	**A**	**B**	**C**	**Shalow**	**Deep**
Carangidae	345	31	15	154	237
Lutjanus chrysurus	14	7	24	17	29
Lutjanus synagris	0	1	0	0	1
Stephanolepis hispidus	3	3	8	3	11
Mycteroperca bonaci	0	0	1	1	0
Serranus sp	0	0	1	1	0
Paraclinus arcanus	0	1	0	1	0
Labrisomidae	0	0	1	0	1
Labridae	1	0	0	1	0
Blenniidae	0	1	0	1	0
Abudefduf saxatilis	0	0	1	1	0

Discussion

The use of artificial reefs in marine ecology studies has a long and productive history. For studies including settlement and recruitment, ARMs have the advantage of allowing the observation of depth-related issues without confounding position or other effects (Leis *et al.* 2002). ARMs appear to be selective traps in studies of reef fish settlement (Leis *et al.* 2002, Shroeder 1987). In the present study, eleven species from eight families settled in the ARMs, but this is only a fraction of the local species, since more than 70 species of reef fish have been recorded at the Itacolomis reefs (Management Plan Phase 1, 2002). Leis *et al.* (2002) also suggested that ARMs were highly selective when studying the larval settlement of reef fish on Lizard Island, on the Great Barrier Reef, where larvae of 15 families were registered, three of which were also found in the present study. Shroeder (1987), at Midway Lagoon, Hawaii, registered 9 taxa, during two years of study. This selectivity permits the study of specific species of commercial interest, such as Lutjanidae, Serranidae and Carangidae. The results presented here provide important baseline information for the understanding of reef fish recruitment dynamics in Brazil.

Many studies registered periodical settlements, synchronized with particular seasons, tides and lunar phases (Robertson 1992, Sponaugle and Cowen 1994, Wilson, 2001), and clear seasonal patterns, monthly (lunar/tidal) and daily (Robertson 1992). Wilson (2001) observed that, in studies of larval recruitment, the process of replacement (settlement) of the larvae is highly seasonal on many locations. Doherty (1991) says that the event and duration of this replacement may vary among regions, with frequent seasonal episodes or others, often sporadic or even negligible. For example, at San Blas, Panama, the replacement of larvae occurs throughout the year for some species of the Pomacentridae Family (Robertson 1992); on the Great Barrier Reef, Australia, such replacement occurs only for a few months (Wilson 2001) and with a few particular species. In the present study, the differences found between summer and winter suggest specific settlement periods for certain species. In the Itacolomis reefs the Carangidae Family had the highest number of settlements during the winter, accounting for 71% of the total catch, which may be an indication of periodical settlements.

Differences between the settlement and recruitment of reef fish have been found to be associated with the lunar phases (Robertson 1992, Thorrold *et al.* 1994b). The periodicity of the lunar patterns on the settlement and recruitment process has been vastly documented in the West Indies (Milicichi 1994), West Atlantic (Shenker *et al*. 1993), Caribbean (Robertson 1992), Bahamas (Thorrold *et al*. 1994) and South Pacific (Duffour 1991). This may occur with peaks close to the new moon (Robertson 1992), lunar patterns with pulses at crescent moon (Sponaugle & Cowen 1997), semi-lunar patterns and even sporadic. In Brazil little is known about the lunar periodicity in the larval settlement of reef fish. The data analysis in the present study did not show a lunar pattern to the settlement, only a trend, since the full moon phase showed the highest number of individuals settled. Therefore, further temporal series would be necessary to confirm or refute the settlement pattern observed in the Itacolomis reefs.

Studies of larval distribution of reef fish describe spatial patterns for certain taxa (Leis 1991). The spatial differences in settlement may determine the structure of adult fish assemblages in a certain region and, thus, help in the determination of exact locations for Marine Protected Areas (Cowen 2002). Larvae can contribute to the resilience of reef populations and MPA networks (Jones *et al.* 2009). Studies about spatial and temporal variations on larval supply are therefore extremely important for the establishment of these areas. However, the relationship between reef fish recruitment in marine reserves and its effects to local and surrounding fish communities is still poorly understood, although these areas appear to be influential for some species (Sponaugle *et al.* 2012).

Although current marine reserves around the world do not have ecologically adequate sizes, some of them have been showing increases in adult fish populations (Wantiez *et al.* 1997) and are also important to export fishes to surrounding areas (Russ & Alcala 1996). Underwater monitoring conducted between 2001 and 2005 in the Itacolomis reefs indicate an increase in biomass for some of the main commercially targeted species within the fishery exclusion area and surrounding reefs (Francini-Filho 2005). This demonstrates that the exclusion area is beneficial to adjacent non-protected areas, probably through fish emigration ("spillover" effect; McClanahan & Mangi 2000). The data gathered in this study indicate the effectiveness of the MPA with relation to the abovementioned aspect, which might be confirmed through continuous temporal series.

The preference of competent reef fish larvae for settling at certain depths was verified in previous studies (Leis and Carson-Ewart 2001, Hendriks *et al.* 2001). Leis *et al.* (2002), on Lizard Island, tested ARMs (placed two meters apart) at 15 meter depth and found that two species of Bleniidae and one of Monocanthidae preferred the shallower traps, one species of the Pomacentridae family did not have any preference and the majority of taxa in the Tetraodonthidae, Gobiidae and Pomacentridae preferred greater depths. The present study found a preference of certain larvae for settling at depth, with 237 Carangidae and 30 *L. chrysurus* settled in deeper traps. Although important, currents, local circulation or other non-biotic aspects (water temperature, salinity) that could influence spatial and temporal patterns in larval settlement were not considered in this study.

Knowledge of larval ecology, such as the spatial and temporal distribution of settlement and recruitment is fundamental for the understanding of the dynamics of adult fish populations. The results obtained on the spatial and temporal variations in the settlement of reef fish larvae in the Itacolomis reefs improve previous knowledge about the functioning of fish assemblages in this area and provide an important baseline for the comprehension of these patterns. Nevertheless, long-term data, with continuous temporal series, are needed to confirm the patterns observed, given that this subject is of great relevance to support rational and consistent management and conservation strategies.

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