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Assessment of rocky reef fish assemblages close to seaweed farming

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[*Correction added on 6 October 2015, after first online publication: the name of the author 'Maurício Rocha da Mata Júnior' has been corrected to 'Mauricio Roque da Mata Júnior'.].

Abstract

The seaweed *Kappaphycus alvarezii* (Doty) Doty ex P. C. Silva, a red algal species, is the main global source of *Kappa carrageenan*. The introduction of such exotic species in regions outside their original locale can change the community structure of the areas into which they are introduced. The possible influence of seaweed farming on the rocky reef fish assemblage was assessed in Paraty, Brazil. The reef fish assemblage in the seaweed farming area was compared before and after the commencement of farming with two undisturbed control areas. Among the ten species ranked as the most frequently occurring in each area, eight were the same. The fish community structure close to the seaweed farming area did not change from that of the control areas, over the months of the study. Neither the fish diversity and richness indices, nor the total average abundance among areas was significantly altered. The average abundance of the different trophic groups varied over time in both the farm and control areas, revealing similar patterns. These results suggest that *K. alvarezii* can be cultivated up to at least 50 m from a rocky coast without altering the fish community structure of the surrounding waters.

Keywords: algal farming, *Kappaphycus alvarezii* (Doty) Doty ex P. C. Silva, macroalgae, mariculture, rocky reef fish, visual census

Introduction

The decline in fishing has encouraged fishermen in the developing countries to seek alternative revenue sources (Salayo, Garces, Pido, Viswanathan, Pomeroy, Ahmed & Masae 2008). Besides their fishing activities, seaweed farms have contributed to a new occupation for village populations that live inshore (Hill, Rowcliffe, Koldewey & Milner-Gulland 2012). As most seaweed farms are built in shallow calm waters such as bays and often in reef zones close to shore (Conklin & Smith 2005; Chandrasekaran, Nagendran, Pandiaraja, Krishnankutty & Kamalakannan 2008), the possible influence of seaweed cultivation on the coastal ecosystems raises an obvious question. However, there is very limited information regarding the impact of seaweed farms on fish communities. Bergman, Svensson and Ohman (2001) and Eklöf, de la Torre-Castro, Nilsson and Rönnbäck (2006) reported that seaweed farms with fixtures in the sea bottom modify the fish community in the shallow coastal lagoons in Zanzibar, Tanzania.

The environmental effects due to the presence of seaweed farms, although poorly reported, suggest both positive and negative aspects (Paula & Pereira 1998). Among the positive impacts, the recovery of polluted water due to gas exchange by seaweed has been described, as well as the attraction and protection of fish (Paula & Pereira 1998; Tewari, Eswaran, Rao & Jha 2006). However, seaweed farming, and other types of mariculture can affect the components of the ecosystem due to the changes they cause in water circulation, decomposition and formation of anaerobic spots on the substrate (Bryceson 2002; Paula & Oliveira 2004; Morberg 2006). Such changes can modify the composition and structure of the local marine communities, causing visual pollution and exerting a generally negative impact on the fisheries and tourism, among other departments (Bryceson 2002; Paula & Oliveira 2004; Eklöf, de la Torre-Castro, Adelskold, Jiddawi & Kautsky 2005; Eklöf *et al.* 2006; Morberg 2006).

The seaweed *Kappaphycus alvarezii* (Doty) Doty ex P. C. Silva (Basson & Moe) is a species of red alga and the main source of *kappa carrageenan* in the world. Seaweed farms are concentrated mainly in the Philippines, Indonesia and Tanzania (Ask & Azanza 2002). The *K. alvarezii* and the seaweed *Eucheuma denticulatum* (N. L. Burman) (F. S. Collins & Hervey) provide approximately 88% of the raw material for the production of *carrageenan* marketed globally (McHugh 2003). In Brazil, *K. alvarezii* was introduced experimentally in 1995 for feasibility tests for cultivation (Paula, Pereira & Ohno 2002). Currently, this exotic seaweed is being grown in various Brazilian coastal regions.

Studies on the environmental impact on the influence of seaweed farming in Brazil has shown that this activity neither causes harmful environmental changes nor increases the potential invasion risks along the southeast coast (e.g. de Paula, Pereira & Ohno 1999; Reis, Bastos & Góes 2007; Castelar, Reis, Moura & Kirk 2009). However, seaweed farms studied on the southeast coast, which were found constructed close to the rocky reef, invited concern regarding their impact on the reef fish communities living in these regions. Although the previous studies asserted that the farming structure attracted fish and considered it a positive influence (Paula & Pereira 1998; Tewari *et al.* 2006), the fish community can change with respect to abundance and diversity (Bergman *et al.* 2001; Eklöf *et al.* 2006; Hehre & Meeuwig 2015).

This study is the first to assess the reef fish structure close to a seaweed farm which employs a cultivation method quite different from any other assessment done by earlier researches (Bergman *et al.* 2001; Eklöf *et al.* 2006; Hehre & Meeuwig 2015). Besides, the prior studies compared the fish communities in the farming regions established previously for several years, whereas the present study had the opportunity to evaluate the fish community before and after the implementation of the. Here, the objective was to evaluate whether the advent of a potential new food source for the fish or the single presence of a floating structure was able to promote a change on a small-scale time in the relationship between the dominance of the local species or trophic groups, by comparing the reef fish community before and after the implementation of the seaweed farm. If the seaweed farm modifies the reef fish community in the area, then farming close to the rocky reef is not feasible or else the distance between the structures and the reef needs to be increased.

Materials and methods

Study area

This research was conducted in the town of Paraty, in the southernmost part of the State of Rio de Janeiro (Brazil), on a rocky shore at Ponta da Cajaíba (Fig. 1). The presence of this exotic seaweed in large amounts was being questioned by the local people and authorities regarding the possible changes that it could cause in the environmental setting, which could produce undesired effects for the rocky reef fish assemblage. This region is very favourable for seaweed farming because it presents a highly indented coastline with many natural inlets and large sheltered areas of clear water. The rocky reef reaches 8 m in depth and extends to 25-m seaward. The substrate is highly heterogeneous as it is covered by foliose algae, coralline algae, corals and zoanthids. Comparisons were made between the two control areas and one experimental area, where the *K. alvarezii* farming was established. In the control areas, the seaweed farming structures had not been installed, because the goal was not to test the effect of the farming structure without the algae, but rather to test the seaweed farm as a whole. The first control area, hereafter referred to as ‘Co1’, is found closest to the open sea, at the edge of Ponta da Cajaíba (23°13′35.0″S; 44°33′42.6″W). The second control area, hereafter alluded to as ‘Co2’, is closer to the coast (23°13′55.3″S; 44°35′20.2″W), and about 3 km away from Co1. The *K. alvarezii* farm area, termed ‘farm’, is established between the two control areas, about 1.5 km from Co1 and Co2 (23°13′59.0″S; 44°34′31.2″W). Both the experimental area as well as the control areas were very similar with respect to the topography and complexity of the substrate (Carvalho 2011).

The seaweeds were fixed into the structures floating on the water surface, 8 m above the sea bottom during neap tides and 50 m away from the nearby rocky shore (norm no. 185/2008 per

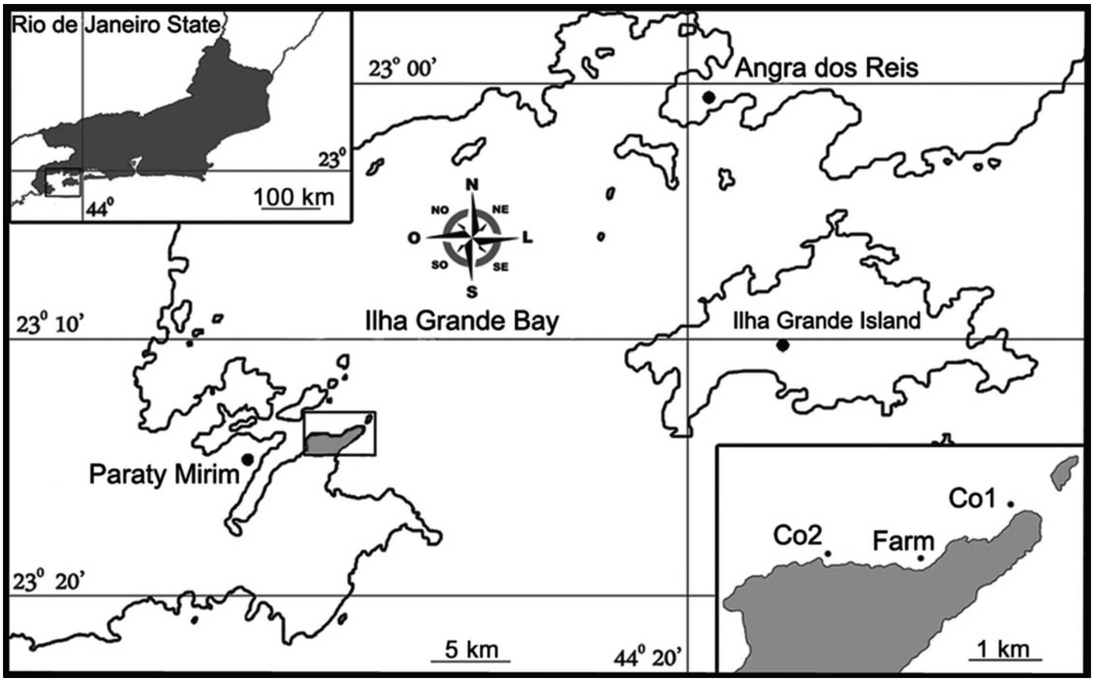


Figure 1 Map showing the location of the areas under study. Control areas – Co1 and Co2; farm area – Farm.

the requirements of the Brazilian Environmental Agency – Brasil, 2008). The farming method used here was very different from the one assessed by Bergman *et al.* (2001), Eklöf *et al.* (2006) and Hehre and Meeuwig (2015), in which the farmers used the 'off-bottom' method, where the algae were tied to lines stretched between wooden staves driven into the bottom of the reef. Furthermore, the farms assessed in the previous study were cultivated in shallow water of less than 1 m depth during the neap tides.

The *K. alvarezii* farms in this study were built on rafts with the seedlings inserted into the tubular nets floating on the water surface. The structure consisted of PVC (polyvinylchloride) pipes sealed at the ends, arranged in parallel and 5 m apart. The tubular nets with the seedlings were arranged in rows, perpendicular to the PVC pipes. The edges of the floating rafts were then tied with cables attached to the concrete blocks on the sea bottom. Each set of rafts was 12 m wide and set perpendicular to the coast along hundreds of meters parallel to the shoreline, occupying an area of approximately 4000 m^2, and constantly holding about 3000 kg of attached seaweed. According to Da Mata (2012) after every 2 months of vegetative growth, approximately 24 000 kg of seaweed are harvested.

Sampling

Fish abundance was assessed monthly in both the control areas and the farm area, using the visual census method, as described by Brock (1954) and Bortone, Kimmel and Bundrick (1989). Each method of quantifying fish abundance has its own advantages and disadvantages. The visual census method selected in this study has been suggested by a few authors to be disadvantageous because of the attraction or repulsion of some fish species due the presence of the scuba divers (Cole 1994; Cole, Syms, Davey, Gust, Notman, Stewart, Radford, Carbines, Carr & Jevs 2007; Watson & Harvey 2007). However, the problems involved in the effect of attraction or repulsion of the fish species are nullified when the study is comparative and the method is standardized between the sampling areas. Thus, as the objective of this study was to compare the fish community before and after a hypothetically impactful event in relation to the non-impacted areas, such effects as the diver's presence were disregarded. Regarding the benefits, the diver-based visual methods generally tend to obtain greater species richness than the methods based on video due to the advantages of the human eyes (Le Grand 1968). The video technique methods, like the Remotely Operated Vehicle (ROV), are advantageous only in the deeper regions which divers cannot reach; however, they too include some drawbacks. Andaloro, Ferraro, Mostarda, Romeo and Consoli (2013) showed that fish quantification using the ROV underestimates the number of species and the abundance compared to the diver-based visual method. Others suggestions, as an alternative to the traditional diver-based visual methods such as the video-based stationary methods, however, are indicated when the visibility condition is above 7 m (Bohnsack & Bannerot 1986; Burge, Atack, Andrews, Binder, Hart, Wood, Bohrer & Jagannathan, 2012). The average visibility in the areas sampled in the present study was 4 m and therefore the visual census method performed by the diver was chosen as the best option. Moreover, due to the topographic characteristics of the areas sampled here, the quantification of some species could be affected, because the stationary method does not effectively sample those fish hidden in crevices, holes and caves (Bohnsack & Bannerot 1986).

The census was taken 1 month prior to the implementation of the farm (from January 2010) and, thereafter, once a month (from February to August, 2010). In area Co2, the fish abundance was not assessed in June, due to the very poor visibility conditions. Likewise, the sampling in March 2010 was not performed in both the control areas as well as the farm area. Every month, the same scuba diver measured the fish abundance with twelve replicates in each of the three areas and the time spent in assessing the three areas on the same day was around 4 h. For each replicate, a 20 m-long transect parallel to the shore was established randomly at a depth from 2 to 6 m to assess the fish abundance. The fish observed along each transect were counted within 1 m of either side by the scuba method, covering 40 m^2 of the rocky reef habitat (Ferreira, Goncalves & Coutinho 2001). All the fish were identified to the lowest possible taxa and were distinguished into five trophic groups (herbivores, carnivores, invertivores, omnivores and piscivores) based on Ferreira *et al.* (2001). The planktivorous group was not considered for analysis because only two species were recorded, viz., *Chromis multilineata* (Guichenot) and *Pempheris schomburgkii* (Müller & Troschel). In addition, both species were excluded because they were considered rare, as less than 10% had been sighted from January to August, 2010 (*C. multilineata* – 2.83%; *P. schomburgkii* – 1.06%).

The aim of the sampling prior to the commencement of the farm was to obtain an estimate of the fish community structure as an initial reference point to compare with the samplings after the installation of the farm. Moreover, the prior census was used to select the regions without seaweed farms as the control areas, but having a community structure similar to that of the farm area. Thus, the possible changes observed in the fish community structure could be attributed to the presence of the farming or to the temporal variations; however, the possibility of the pre-existing spatial variation between the cultivated and uncultivated areas would be excluded. Regarding the sampling time, drastic alterations in the environmental settings could result in changes in the fish community in a short time span (Williams 1986; Letourneur, Harmelin-Vivien & Galzin 1993; Lindahl, Öhman & Schelten 2001). The 8-month assessment conducted in the present study aimed at detecting possible changes in large proportions in the fish community over a brief time scale. The results obtained within this period enable the estimation of the level of impact of the risk of seaweed farming on the fish community. It could prove to be a highly risky venture in the event of changes occurring in the fish community structure or a lower risk factor if changes were not observed, although careful monitoring programmes are required to estimate the potential long-term impacts.

Data analysis

Exploratory analysis was done using non-metric multidimensional scaling. All the data was transformed prior to the square root and arranged in a Bray–Curtis similarity matrix (Clarke 1993). The analysis was run with 500 restarts and a minimum stress of 0.02. The similarity percentage analysis (SIMPER) was used to evaluate the contribution of each species to the dissimilarity between the areas (Warwick, Clarke & Suharsono 1990). The analysis of similarity (ANOSIM), with 9999 permutations (Clarke 1993), compared the structures of the fish communities between the control areas and the farm area.

The statistical power ranged from 0.71 to 0.85, when the time and locale were the main factors respectively. The two-factorial analysis of variance (ANOVA) compared the average abundance of the trophic groups between location and time. The first factor showed three levels (Co1, farm and Co2), whereas the second one had six (January–August). The data were tested for normality and homoscedasticity (Shapiro–Wilk test and Cochran test respectively). All analyses were performed only with the species which were recorded above 10% frequency, to exclude the rare species.

The fish community diversity and richness were measured using the diversity index (Shannon–Wiener) in $\log_2$ and the richness index (Margalef) respectively. A two-factorial ANOVA was used to analyse the variations between the areas and over time, as described above. When the differences between the areas or over time were significant, the Tukey test was used to identify the factor responsible for the differences.

Results

A total of 238 visual censuses were performed in this study and 56 species belonging to 31 families were recorded (See Appendix). Among the taxa observed, 14 species were carnivores, 12 herbivores, 16 invertivores, 10 omnivores, 2 piscivores and 2 planktivores. A total of 45 species were recorded in Co1, 49 in the farm area and 39 in Co2, 37 species being common to all the three areas. The most abundant species in all the areas was the omnivore *Abudefduf saxatilis* (Linnaeus). The average abundance of fish throughout the sampling period was found to be similar among the farm area and the control areas (ANOVA, $P > 0.05$).

Among the ten species ranked the most frequent in each area, eight were the same: *A. saxatilis*, *Anisotremus virginicus* (Linnaeus), *Chaetodon striatus* (Linnaeus), *Diplodus argenteus* (Valenciennes), *Haemulon aurolineatum* (Cuvier), *Holocentrus adscensionis* (Osbeck), *Mycteroperca acutirostris* (Valenciennes) and *Stegastes fuscus* (Cuvier) (Table 1). However, the densities and average frequencies varied between the species and areas, especially for *S. fuscus* and *H. aurolineatum*, when compared between the areas, which presented a lower

Table 1 List of the ten fish species most frequent in areas controls (Co1 and Co2) and farming area (farm). The bold values are highlighting the top ten most frequently sighted fish at each area

Family/species	Trophic group	Co1			Farm			Co2		
		d ± SD	*n*	Fr (%)	d ± SD	*n*	Fr (%)	d ± SD	*n*	Fr (%)
Chaetodontidae										
Chaetodon striatus	Invertivores	1.69 ± 0.14	157	**65.59**	1.14 ± 0.11	107	**55.32**	0.94 ± 0.16	63	**43.28**
Gobiidae	–	1.23 ± 0.23	114	**43.01**	0.54 ± 0.20	51	19.15	0.81 ± 0.19	54	32.84
Haemulidae										
Anisotremus virginicus	Invertivores	3.24 ± 0.22	301	**76.34**	0.61 ± 0.15	57	**34.04**	0.88 ± 0.17	59	**41.79**
Anisotremus surinamensis	Invertivores	0.17 ± 0.10	16	16.13	0.30 ± 0.12	28	22.34	0.51 ± 0.15	34	**35.82**
Haemulon aurolineatum	Invertivores	7.20 ± 0.47	670	**65.59**	6.94 ± 0.31	652	**75.53**	3.33 ± 0.36	223	**52.24**
Haemulon steindachneri	Invertivores	0.13 ± 0.17	12	6.45	7.18 ± 0.43	675	**53.19**	1.78 ± 0.27	119	**43.28**
Holocentridae										
Holocentrus adscensionis	Carnivores	0.65 ± 0.16	60	**38.71**	0.43 ± 0.10	40	**36.17**	0.55 ± 0.15	37	**34.33**
Pomacentride										
Abudefduf saxatilis	Omnivores	13.87 ± 0.73	1290	**80.65**	11.11 ± 0.28	1044	**93.62**	12.84 ± 0.40	860	**92.54**
Chromis multilineata	Planktivores	1.53 ± 0.26	142	**43.01**	0.14 ± 0.13	13	8.51	0.09 ± 0.12	6	8.96
Stegastes fuscus	Herbivores	1.77 ± 0.18	165	**52.69**	4.39 ± 0.20	413	**74.47**	3.87 ± 0.17	259	**86.57**
Serranidae										
Mycteroperca acutirostris	Carnivores	1.18 ± 0.15	110	**51.61**	1.35 ± 0.16	127	**56.38**	1.90 ± 0.22	127	**59.70**
Epinephelus marginatus	Carnivores	0.71 ± 0.19	66	32.26	0.74 ± 0.15	70	**39.36**	1.21 ± 0.48	81	34.33
Sparidae										
Diplodus argenteus	Omnivores	2.66 ± 0.21	247	**60.22**	3.04 ± 0.29	286	**55.32**	2.04 ± 0.27	137	**46.27**

D, density of fish per transect (40 m^2); SD, standard deviation; *n*, total number of fish; Fr, average frequency.

density in Co1 and Co2 respectively. On the other hand, *A. virginicus* displayed a higher density in Co1 and *Haemulon steindachneri* (Jordan & Gilbert), in the farm area.

The global fish community structure recorded over the study period was found to be similar in all the three areas (Fig. 2a). In the analysis of similarities, no significant difference was observed between the seaweed farm area and the two control areas, or even between the two control areas. The species that contributed the most to the similarity within each area were *A. saxatilis* and *H. aurolineatum*, although the Haemulidae family was the one with the most contributions to accentuate the differences between the fish communities of the areas studied (Co1 vs. farm = 16.15%; Co2 vs. farm = 15.17%; Co1 vs. Co2 = 11.70%). The analysis of similarity did not show any difference among the three areas over time (Fig. 2c–g; R < 0.5, $P < 0.05$), except in January where the values of only Co2 differed from the two other areas (Fig. 2b; R > 0.5, $P < 0.05$).

The diversity and richness of the fish community varied slightly over the months in each area (Fig. 3). The ANOVA tests showed significant differences between the months due to the slightly decreased diversity in July and August when compared with May. However, globally, no differences were observed among Co1, Co2 and the farm areas for all the months of study and the pattern of variation over time was also similar among the three areas (Table 2). The average total abundance of fish assemblages varied over the study period with a significant decrease in August in all the areas (Fig. 3). However, for any month, no significant difference in average total abundance was recorded among the farm area or those of Co1 and Co2 (Table 2). Furthermore, the posteriori tests showed that the fish diversity and richness before the implementation of the seaweed farm were similar to the subsequent months. Significant differences over time were found (Table 2) due to variations during some specific months after the initiation of the farm. Only in the month of May, did the diversity and richness show a higher average than in July and August respectively. With respect to the average values of the fish abundance in the three areas, only in the month of August were the values lower than all the other months.

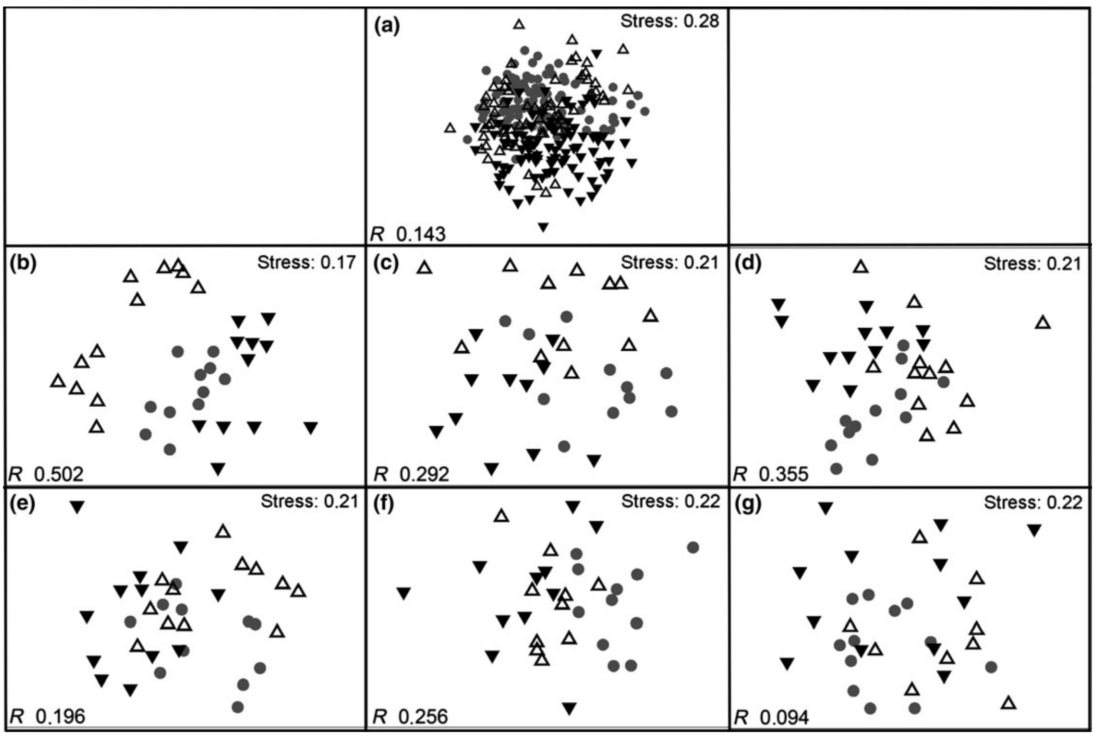


Figure 2 Analysis of the non-metric multidimensional scaling of the fish community in the farm area and control areas over the study period (a) and for each month (b–g). Site markers are: Co1 (▼), Farm (●), Co2 (Δ).

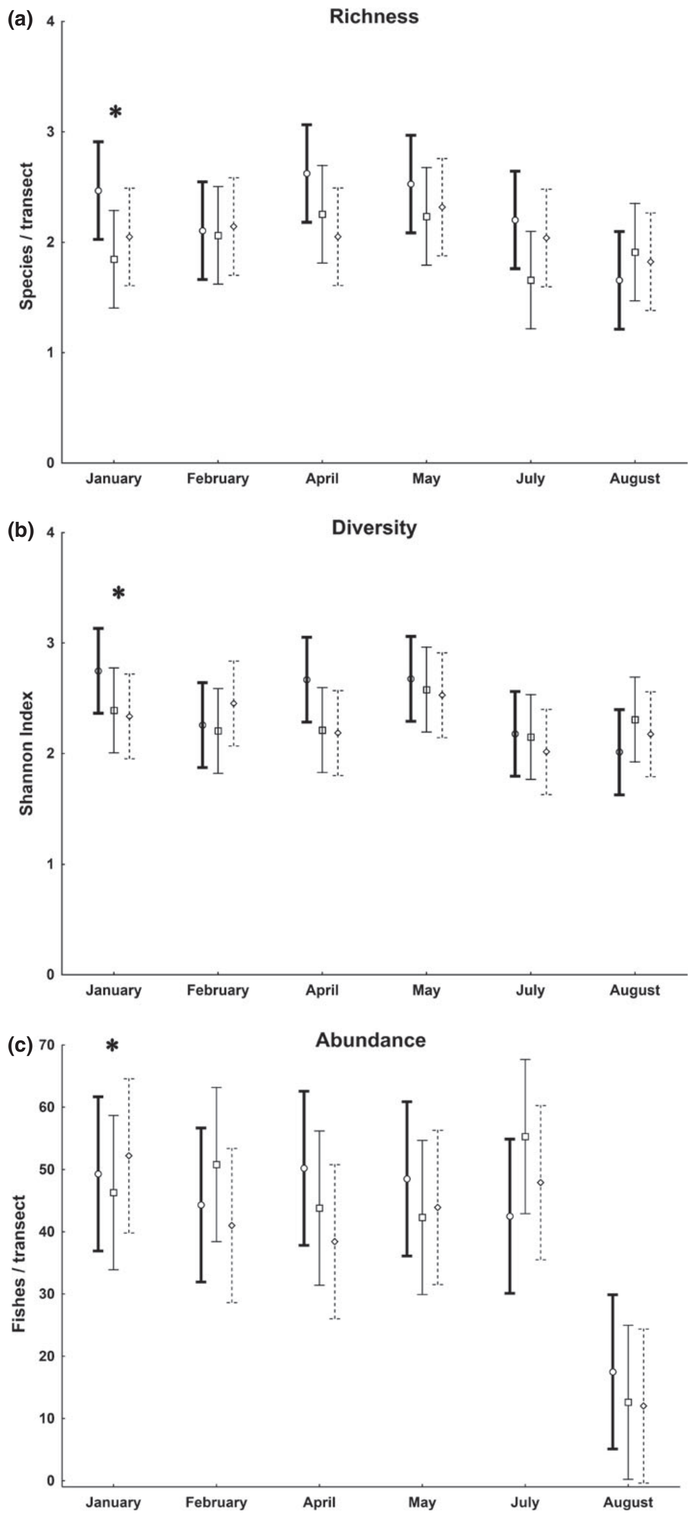


Figure 3 Mean and standard error of the richness of the fish community (a), diversity index of the fish community (b) and total abundance of the fish community (c). Control area Co1 (heavy line), farm area (hairline) and control area Co_2 (dotted line). Asterisks indicate the month prior to farming.

Besides the global assessment of the fish community, the average abundance for the main trophic groups was also assessed. Omnivores were the most abundant group in both the control areas and in the farm area (Fig. 4a). At the species level, *A. saxatilis* was the most abundant and responsible

Table 2 ANOVA comparing abundance, fish diversity and richness index between area (factor 1) and time (factor 2)

	d.f.	SS	MS	*F*	
Diversity					
Area	2	0.6845	0.3422	0.904	n.s.
Time	5	5.1086	1.0217	2.700	***
Area*Time	10	2.8307	0.2831	0.748	n.s.
Error	162	61.3129	0.3785		
Richness					
Area	2	2.3177	1.1588	2.317	n.s.
Time	5	6.6340	1.3268	2.653	***
Area*Time	10	3.7697	0.3770	0.754	n.s.
Error	162	81.0276	0.5002		
Abundance					
Area	2	1.700	0.850	0.421	n.s.
Time	5	224.257	44.851	22.218	***
Area*Time	10	11.003	1.100	0.545	n.s.
Error	162	327.025	2.019		

d.f., degrees freedom; SS, sum of square; MS, mean Square; n.s., not significant. ***$P < 0.05$.

for about 16% of the similarity in the communities found in any of the three areas. Similarly, a high abundance of invertivores was also observed (Fig. 4b). The highest average abundance of the invertivores was found in the Co1 area, especially during April and May. The most abundant species was *H. aurolineatum*, although large variations in the number of species were recorded over the months. Furthermore, *H. aurolineatum* was responsible for more than 10% of the similarity in the communities among both the control areas and the farm area.

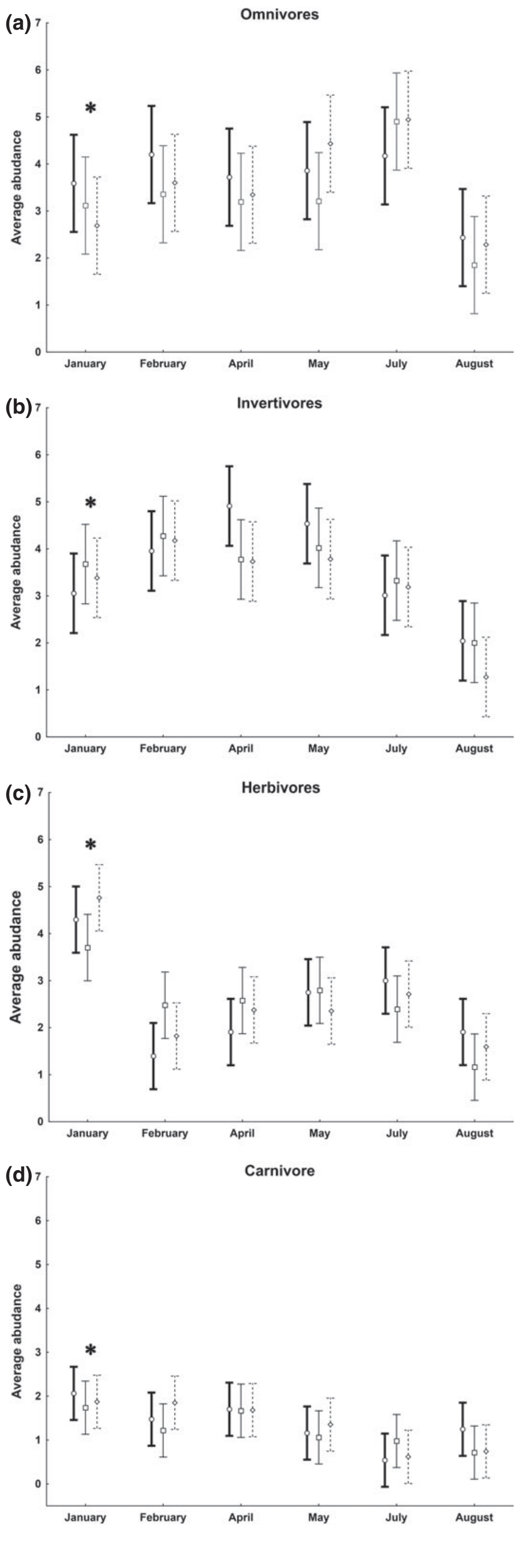
During the entire study period the herbivores and carnivores registered low abundances (Fig. 4c and d respectively) with the exception of January, during which the herbivore group showed the highest average abundance of all the trophic levels. At the species level, *S. fuscus* and *M. acutirostris* were the most abundant species for the herbivore and carnivore groups respectively. The analysis of similarity (SIMPER) indicated that the contribution of *S. fuscus* for the variation observed was 6 to 10%, whereas the contribution of *M. acutirostris* was around 5% for all the three areas.

The average abundance of the fish trophic groups in the seaweed farming area was compared over the months, as well as among the three areas over the months (Table 3). The average abundance of the omnivores in July was higher than in August for the farm area; however, this increase was similar between the control areas. Regarding the invertivores, this group showed a lower abundance in January than in April and May for the farm area (Table 3). However, during this period the average abundance of the invertivores in the farm area was also similar to that of the Co1 and Co2 areas. The herbivore abundance in January was higher than all the months after the implementation of the farm in that area as well as in both the control areas. Regarding the carnivore group, the fish average abundance was similar among all the areas over time.

Discussion

In this study, the possible changes in the relationship between the dominance of the species or trophic groups among the rocky reef fish after the establishment of an exotic seaweed farm were investigated. The results revealed that the fish communities in the farm area did not significantly change after the introduction of *K. alvarezii* farming and was similar to those of the two control areas. Thus, the farming did not appear to influence the local fish richness and diversity, as well as the total abundance. Significant differences in the average abundance of all the trophic groups were recorded after the introduction of the seaweed farm in the farm area for certain months. However, these changes were similar to the controls areas. This suggested that variations in the fish abundance were caused by natural seasonal fluctuations and not linked to the seaweed farm activity.

The fish communities observed in this study were similar not only among the areas sampled, but also resembled those of the other reefs along the Brazilian coast. Although the abundance was variable, the species most conspicuous were common among the various study sites recorded in the literature. Ferreira *et al.* (2001) recorded 91 species of rocky reef fish in Forno Island, Rio de Janeiro State, Brazil. Despite the greater number of species observed, 80% of the individuals were limited to the following species, *H. aurolineatum*, *S. fuscus*, *D. argenteus*, *A. saxatilis*, *Halichoeres poeyi* (Steindachner), *Pseudupeneus maculatus* (Bloch), *C. striatus*, *Acanthurus chirurgus* (Bloch), *H. steindachneri* and *Acanthurus bahianus* (Castelnau). The ten most abundant species found by Ferreira *et al.* (2001) were also observed in the experimental and control areas of this study. Besides, five species



were likewise recognized as the most abundant among the rocky reefs surveyed in Paraty. In the work conducted by Ferreira, Maida and Souza (1995), although the reef was composed of a calcareous base built by corals, the fish community was similar to those of the rocky reefs observed in this study. These results reveal that, although the Brazilian reefs show variations in habitat complexity, there appears to be a similarity between the dominant fish species groups. Feitosa and Araújo (2003) observed a high degree of similarity between the communities of the reef fish from the coastal State of Maranhão to Rio de Janeiro, in Brazil. Although it was not included in the review of Feitosa and Araújo (2003), some of the most abundant species observed in Paraty are also present in most of the reef fish communities in southern Brazil (Hostim-Silva, Andrade, Machado, Gerhardinger, Daros, Barreiros & Godoy 2005). The similarity between the fish assemblages recorded in the review of Feitosa and Araújo (2003) and the fish assemblages in the present study concurs with the results, which indicates that the seaweed farms do not induce changes in the fish community over a short term. Furthermore, the similarity observed between the assessment data on the fish abundance recorded in the literature and the data observed here demonstrate that the visual census method was successful.

Variations in abundance are considered a natural process which occur mainly in species that form schools (Thompson & Mapstone 2002; Willis, Badalamenti & Milazzo 2006; McClanahan, Graham, Maina, Chabanet, Bruggemann & Polunin 2007; Irigoyen, Galván, Venerus & Parma 2013). This is in accordance with the variations observed in this study in the omnivore and invertivore trophic groups, mainly represented by *A. saxatilis* and *H. aurolineatum* respectively. Both species usually form large schools (Lindeman 2001; Carter 2002) and the large reduction in abundance of this species across all areas in certain months,

Figure 4 Mean and standard error of the fish average abundance per month for each trophic group. Control area Co1 (heavy line), farm area (hairline) and control area Co2 (dotted line). Asterisks indicate the month prior to farming.

Table 3 ANOVA comparing abundance of the trophic groups between area (factor 1) and time (factor 2)

	d.f.	SS	MS	*F*	
Carnivores					
Area	2	0.6681	0.3341	0.3546	n.s.
Time	5	31.7393	6.3479	6.7392	***
Area*Time	10	5.2187	0.5219	0.5540	n.s.
Error	162	152.5936	0.9419		
Herbivores					
Area	2	0.229	0.114	0.0897	n.s.
Time	5	132.599	26.520	20.7855	***
Area*Time	10	19.532	1.953	1.5308	n.s.
Error	162	206.693	1.276		
Invertivores					
Area	2	3.608	1.804	0.984	n.s.
Time	5	128.254	25.651	13.992	***
Area*Time	10	15.022	1.502	0.819	n.s.
Error	162	296.976	1.833		
Omnivores					
Area	2	4.855	2.427	0.8871	n.s.
Time	5	101.806	20.361	7.4415	***
Area*Time	10	17.532	1.753	0.6408	n.s.
Error	162	443.257	2.736		
Total					
Area	2	1.700	0.850	0.421	n.s.
Time	5	224.257	44.851	22.218	***
Area*Time	10	11.003	1.100	0.545	n.s.
Error	162	327.025	2.019		

d.f., degrees freedom; SS, sum of square; MS, mean square; n.s., not significant. ***$P < 0.05$.

caused a decreased abundance observed for the omnivore and invertivore groups. Among the herbivores, *S. fuscus* was recurrent and primarily responsible for the changes in abundance within the group. Fish belonging to the genus Stegastes can hide from predators between the rocks of the rocky shore (Ferreira, Goncalves, Coutinho & Peret 1998). The areas in this study are represented by a rocky reef with many grooves, providing refuge for *S. fuscus*. Thus, sometimes, the populations of this species may be underestimated, resulting in such variations. The differences in the abundance observed for the herbivores in January (before the implementation of the farm) compared with the other months were due the high abundance of *A. bahianus*. The explanation for the great abundance of *A. bahianus* in January are not within the scope of this work, but similar results recorded in the control areas and farm area indicate that the seaweed farming plays no role in this phenomenon. The difference found over time in the herbivore group can be due to the species *A. bahianus* which live in shoals and the number of the individuals too varies greatly. Regarding the carnivore group, mainly represented by *M. acutirostris*, slight variations and low abundance were observed compared with the herbivores. This species is found mainly between the boundary of the rocky shore and the unconsolidated bottom (Gibran 2007) and so it can be easily sighted, because there are not many places to hide. Thus, the risk of underestimation in the census was probably minimal. Although variations in the abundance of the trophic groups have been observed, the large census sample allowed robust statistics which ensured the reliability of the results.

Fish community structure may undergo changes due to factors other than marine farming. Several studies show that the sewage input on the shore has been a major anthropogenic activity that may alter the fish community (e.g. Smith, Ajani & Roberts 1999; Guidetti, Fanelli, Fraschetti, Terlizzi & Boero 2002; Reopanichkul, Schlacher, Carter & Worachananant 2009). Sewage may also result in significant changes with respect to both total abundance and species level (Azzurro, Matiddi, Fanelli, Guidetti, La Mesa, Scarpato & Axiak 2010), caused by the attraction of large schools of planktivores (Guidetti, Terlizzi, Fraschetti & Boero 2003). In this work, the site of the study is away from any urban centre and, therefore, has no direct sewage discharge. Moreover, fishing may also influence the fish community. Both the total biomass and maximum size of the fish can be reduced in areas experiencing high fishing pressure (Albaret & Lae 2003; Ecoutin, Slimier, Albaret, Lae & de Morais 2010). However, both the control areas as well as the farm area in this study are not subjected to fishing pressure. Besides the anthropogenic factors, the abiotic factors may also affect the fish richness and abundance such as temperature and salinity (Selleslagh & Amara 2008), along with the substrate complexity (Bergman *et al.* 2001; De Raedemaecker, Miliou & Perkins 2010). In this study, the temperature and salinity did not show any significant differences between the control areas and the farm area (Carvalho 2011), thereby reducing the number of variables that could influence the fish community structure beyond cultivation.

The similarity of the richness index found between the farm area and the control areas suggests that the rocky bottom of all the three areas are similar in complexity, as several studies have correlated substrate complexity with richness (e.g. Jenkins & Sutherland 1997; Ohman & Rajasuriya 1998; Bergman, Öhman & Svensson 2000; Ferreira *et al.* 2001; Chabanet, Guillemot, Kulbicki, Vigliola & Sarramegna 2010). This result concurs with the data recorded in the work of Carvalho (2011), which noted close similarity in the benthic community structure between the same control areas and the farm area of the current study. Moreover, all the three areas also reveal a similar rocky reef profile with respect to slope and depth. This similarity among the areas suggests that the complexity was significantly greater than the farm infrastructure, thus minimizing the farm's desirability for the fish. The results found in this study are contrary to those of the earlier studies in which clear changes in the fish composition were observed close to the area of the seaweed farm (Bergman *et al.* 2001; Eklöf *et al.* 2006). Eklöf *et al.* (2006) showed that farms of *Eucheuma denticulatum*, compared with seagrass, affect the composition of the fishery catches. The author suggests that the explanation for the results may be due to the higher structural complexity of the seaweed compared with the seagrass. Bergman *et al.* (2001) suggest that the degree of complexity of the substrate can act as a buffer for the effects of the farming on fish abundance and richness. However, if the structural complexity of the farm is greater than that of the substrate, the composition of fish can be affected. The area studied in the present work is characterized by foliose algae, algal turfs, soft and hard coral, zoanthids and different-sized rocks forming a three-dimensional space complexity. Therefore, the rocky reefs appear to have positive characteristics which reduce the effects of seaweed farming on fish composition. However, other factors could have contributed towards maintaining the fish community structure, such as the distance from the farm to the substrate. Prior studies have been conducted on seaweed farming with an off-bottom system, where the algal beds are tied to lines attached between stakes driven into the bottom (Bergman *et al.* 2001; Eklöf *et al.* 2006). In this work, the census was performed on a seaweed farm with a floating system, where the algae are tied to lines attached between floating pipes on the water surface. In such a system, the seaweed farm is far removed from the sea bottom and its influence on the fish communities may be negligible. Moreover, a distance of 50 m from the shoreline, mandated by the environmental agency in Brazil, might be sufficiently far to detract the reef fish from being attracted to the floating structures. Future studies should be conducted in order to verify the influence of floating structures in the recruitment of fish and the implications for the local ecosystem which was not the scope of this work.

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