PANAMJAS
Pan-American Journal of Aquatic Sciences

Effects of recreational activities on the fish assemblage structure in a northeastern Brazilian reef

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Abstract. Uncontrolled recreational activities are known to cause severe damage to reef dwelling organisms and to the reef overall structure. In order to investigate the effects of human recreational activities on the reef fish assemblage, surveys were undertaken in two shallow coastal reefs (Picãozinho and Quebra Quilhas) with similar physiographic features. However, recreational activities only take place at the former, and the latter was investigated as a control reef. The most speciose and abundant families on both reefs were Pomacentridae, Scaridae, Haemulidae, Acanthuridae and Labridae, but species evenness was fairly different between the reefs due in particular to the extremely high abundance of the sergeant major *Abudefduf saxatilis* at Picãozinho. This species represented almost ⅔ of all individuals recorded at Picãozinho and was the underlying feature responsible for the assemblage structure pattern observed on this reef. The present study showed that one single species was of major influence on species evenness and trophic structure, and that unregulated recreational activities have the potential to severely alter reef fish assemblage structure.

Key words: Tourism, assemblage, reef fishes, Brazil, *Abudefduf saxatilis*.

Resumo. Efeitos de atividades recreativas sobre a estrutura da assembléia de peixes em um recife Brasileiro Atividades recreativas não controladas são conhecidas por causarem danos a organismos associados a recifes, bem como em sua estrutura geral. Para investigar os efeitos das atividades recreativas na assembléia de peixes recifais, amostragens foram realizadas em dois recifes costeiros (Picãozinho e Quebra Quilhas) com características fisiográficas semelhantes. No entanto, as atividades recreativas ocorrem somente no primeiro e este último foi investigado como um recife controle. Em ambos os recifes, as famílias com o maior número de espécies e abundância foram Pomacentridae, Scaridae, Haemulidae, Acanthuridae e Labridae, mas a uniformidade foi bastante diferente entre os recifes, principalmente devido à abundância extrema do sargentinho *Abudefduf saxatilis* em Picãozinho. Esta espécie representou aproximadamente ⅔ de todos os indivíduos registrados em Picãozinho, e foi a principal responsável pelo padrão observado na estrutura da assembléia neste recife. O presente estudo mostrou que uma única espécie exerceu uma forte influência na uniformidade e na estrutura trófica, e que atividades recreativas não controladas têm o potencial de alterar severamente a assembléia de peixes recifais.

Palavras-chave: Turismo, assembléia, peixes recifais, Brasil, *Abudefduf saxatilis*.

Introduction

Fishing and tourism, when mismanaged, are potentially threatening activities to reefs (Milazzo *et al.* 2002). Fishing is clearly one of the most harmful sources of human impact on coral reefs (Bell 1983, Garcia-Rubies & Zabala 1990, Polunin & Roberts 1993, Garcia-Rubies 1999, Jackson *et al.* 2001, Myers & Worm 2003). One of the harshest effects of fishing is that, when certain species are caught, reef fish structure may be altered due to a cascade of interactions (McClanahan & Kaunda Arara 1996, Sala *et al.* 1998, Pinnegar *et al.* 2000). As a consequence, while the abundance of some species drastically collapses, particularly those targeted by fisheries, other species are benefited and rapidly increase their population size. As a result of this discrepancy, the whole community structure is modified (Sala *et al.* 1998, Pinnegar *et al.* 2000).

When compared to fisheries, recreational activities seem like a minor component with the potential to alter reef fish assemblage structure (see Milazzo *et al.* 2002). However, uncontrolled recreational activities are also potentially threatening. Many investigations have demonstrated the effects of trampling (Beauchamp & Gowing 1982, Liddle & Kay 1987, Liddle 1991, Brosnan & Crumrine 1994, Chandrasekara & Frid 1996, Brown & Taylor 1999, Eckrich & Holmquist 2000), boat anchoring (Walker *et al.* 1989, Hastings *et al.* 1995, Creed & Amado Filho 1999, Backhurst & Cole 2000), SCUBA-diving and snorkeling (Hunnam 1987, Hawkins & Roberts 1992, Davis & Tisdell 1996, Sala *et al.* 1996, Harriot *et al.* 1997, Medio *et al.* 1997, Rouphael & Inglis 1997) and artificial feeding (Perrine 1989, Cole 1994, Sweatman 1996, Hawkins *et al.* 1999, Milazzo *et al.* 2005, M. I. Ilarri *et al.* in prep.) on marine environments. Therefore, just as fisheries, recreational activities have the potential to strongly affect the overall community structure of marine environments, whether directly (e.g. boat anchoring) or indirectly (e.g. artificial feeding) (Brosnam & Crumrine 1994, Eckrich & Holmquist 2000, Milazzo *et al.* 2002).

The number of recreational activities has strongly increased worldwide in the past decades (Milazzo *et al.* 2002) and a corresponding increase in the number of studies investigating the effects of these activities on marine ecosystems can also be recognized (see Milazzo *et al.* 2002 for a review). However, only a few studies that investigated these effects on assemblage structure have been accomplished in Brazil (e.g. Creed & Amado Filho 1999, Vuelta, 2000, Costa *et al.* 2007), despite its almost 8000 km of coastline and the fact that the Brazilian coast has unique features (Maida & Ferreira 1997, Leão & Dominguez 2000) and holds a rich endemic fauna (Floeter & Gasparini 2000, Rocha 2003).

The present study was carried out in the northeastern coast of Brazil, an area which has received very little scientific attention in synecology and overall conservation ecology. Although attempts have been made in order to describe the effects of tourism on the studied reef, no quantitative data on these effects has been published up to date, and these few available attempts (Vuelta, 2000, Costa *et al.* 2007) are somewhat descriptive, thus providing limited information. The aim of this study was to verify the long-term effects of recreational activities on fish assemblage in a tropical shallow reef of the northeastern coast of Brazil, by comparing its fish assemblage structure to a nearby similar control reef, where tourism does not occur.

Material and Methods

Study area

Reef fish assemblage structure was evaluated at Picãozinho (W 34º 48’45”, S 7º 06’ 45”), a coastal tropical reef with a maximum depth of 6 m, located 1.5 km off the coast of João Pessoa, Paraíba, Brazil. The control reef, Quebra Quilhas (W 34º 48’ 45”, S 7º 06’ 9”) is also a shallow reef with a maximum depth of 5 m located 0.3 km to the north of Picãozinho (Figure 1).

Both reefs have similar physiographic characteristics being formed by large patches separated by internal pools and small water channels. The benthic community is dominated by algae and corals, with the most common algae being *Caulerpa racemosa* (Forsskal) J. Agardh, *Halimeda opuntia* (Linnaeus) and *Dictyopteris delicatula* J.V. Lamouroux, and the most common corals being *Palythoa caribaeorum* (Duchassaing & Michelotti), *Zoanthus sociatus* (Ellis), *Siderastrea stellata* Verril and *Mussismilia hartii* Verril. Other components of the benthic communities, such as the sea urchin *Echinometra lucunter* (Linnaeus), the hydrocoral *Millepora alcicornis* Linnaeus, and other invertebrates including mussels, barnacles, sponges and ascidians, are also present, albeit much less abundant than the algae and corals. Large boulders, sand and limestone predominate in the adjacent areas of the patches.

Despite their similarities and the fact that neither Picãozinho nor Quebra Quilhas are under any kind of legal protection, tourist visitation is a common activity throughout the year at Picãozinho, being an important source of income to the local tourism industry since the mid 80’s. Nowadays, during low tides, between 90 and 200 tourists, in up to nine boats, visit the reef without any type of legal supervision. However, Quebra Quilhas is not visited by tourists mainly because of its small surface area, low water visibility and lack of anchoring places for boats close to the reef. Further, Picãozinho is traditionally regarded as one of the main tourist attractions of the city.

Sampling design

Fish assemblages were evaluated using a stationary visual census technique adapted from Bohnsack & Bannerot (1986). A diver remained in the centre of an imaginary cylinder with a 2.5 m radius and listed all species observed from the surface to the bottom during the first five minutes.

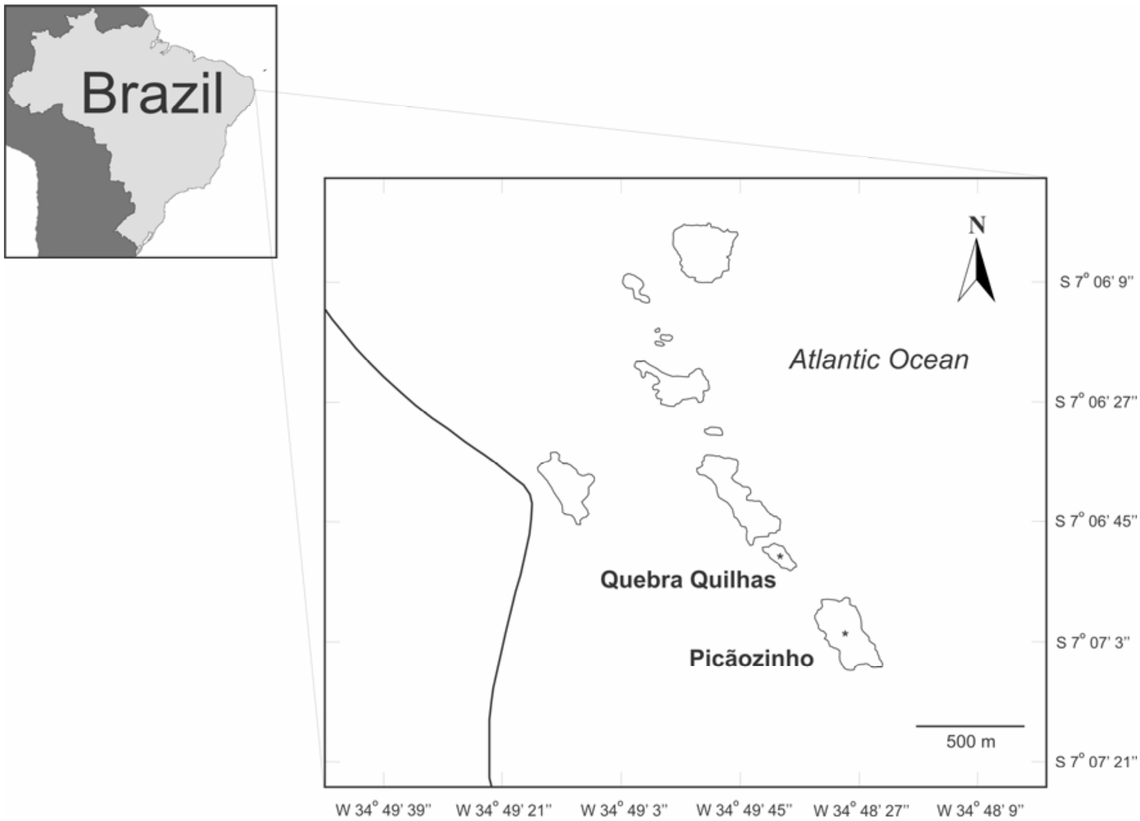

Figure 1. Location of the studied reefs in the northeastern coast of Brazil

In the subsequent five minutes, the number of individuals observed and their estimated size classes were listed. Size classes used were: 1-5 cm, 6-10 cm, 11-15 cm, 16-20 cm, 21-25 cm, 26-30 cm and 31-35 cm. Prior to the beginning of the study, the method described above was tested and researchers were familiarized with the areas by snorkelling along all extensions of the reefs.

A total of 60 censuses were done in haphazardly chosen areas within each reef between 8:00 and 14:00, from April through October of 2006, during low tides at depths between 0.4 and 2.5 m. All censuses totalled 1,200 minutes of underwater observation. Since the aim of the present study was to compare the long-term effects of tourism on fish assemblage, and not *in situ* influence of their visitation, censuses at Picãozinho were always done during the times with no tourist visitation to avoid bias caused by the human presence and their activities. Also, within-habitat, all sites sampled on both reefs presented similar physical characteristics being located near the reef border and composed of at least 75% consolidated substrata.

Species were grouped into one of nine trophic categories: carnivores, cleaners, mobile invertivores, omnivores, piscivores, planktivores, roving herbivores, sessile invertivores and territorial-herbivores (see Ferreira *et al*. 2004 for description of the categories). Trophic categories were presumed based on the available literature (Randall 1967, Hobson 1975) and from direct observations of the species behaving in their natural areas within each reef.

Data analysis

Species richness was the number of each species at each area and is always shown as an integer value. Frequency was the proportion of censuses that contained the species and was calculated by dividing the number of occurrences for a single species by the total number of occurrences for all species. Relative abundance was the number of individuals of a given species relative to overall abundance and was calculated by dividing the abundance of a species by the total abundance of all species combined.

Shannon Wiener's diversity (H') and equitability (E) indexes were estimated using Bio DAP (Biodiversity Data Analysis Package). Student's *t* tests were performed to compare the values obtained in each census between the reefs and was calculated with the program Statistica version 5.1 (Statsoft Corp., United States).

Results

A total of 4659 fishes belonging to 33 species and 19 families were recorded at Picãozinho (Table I). The most speciose families were Haemulidae (6 species), Acanthuridae (3), Pomacentridae (3) and Scaridae (3) and the five most frequent species, in decreasing order, were *Abudefduf saxatilis* (Linnaeus), *Sparisoma* sp., *Stegastes fuscus* (Cuvier), *Halichoeres brasiliensis* (Bloch) and *Haemulon parra* (Desmarest). Occasional and rare species (< 10% of occurrence) represented 49% of all fishes recorded. The pomacentrids *A. saxatilis* (n = 2869) and *S. fuscus* (n = 577) were the most abundant species accounting together for 73.98% of all individuals recorded, while the other 31 species represented 26.02%. Of the 19 families recorded, Pomacentridae (75.16%), Haemulidae (9.05%), Scaridae (7.27%), Labridae (2.6%) and Acanthuridae (2.47%) grouped 96.55% of all fishes observed in this reef.

At Quebra Quilhas, 1793 fishes belonging to 34 species and 19 families were recorded (Table I). The most speciose families were Haemulidae (5 species), Pomacentridae (3), Scaridae (3) and Serranidae (3) and the five most frequent species, in decreasing order, were *S. fuscus*, *A. saxatilis*, *Sparisoma* sp., *H. brasiliensis* and *Stegastes variabilis* (Castelnau). Occasional and rare species (< 10% of occurrence) represented 46% of all fishes recorded. The most abundant species were *S. fuscus* (n = 636) and *A. saxatilis* (n = 461), which accounted together for 61.16% of all individuals recorded, while the other 32 species represented 38.84%. Of the 19 families recorded, Pomacentridae (64%), Scaridae (8.53%), Haemulidae (8.03%), Acanthuridae (6.42%) and Labridae (5.3%) grouped 92.28% of all fishes observed in this reef.

Of the 41 species recorded, 26 were found on both reefs, seven were found exclusively at Picãozinho (*Acanthurus bahianus* Castelnau, *Entomacrodus vomerinus* (Valenciennes), *Eucinostomus argenteus* Baird & Girard, *Haemulon squamipinna* Rocha & Rosa, *Mugil curema* Velenciennes, *Ocyurus chrysurus* (Bloch) and *Sphoeroides testudineus* (Linnaeus)) and eight were found exclusively at Quebra Quilhas (*Ablennes hians* (Valenciennes), *Apogon americanus* Castelnau, *Cephalopholis fulva* (Linnaeus), *Elacatinus figaro* Sazima, Moura & Rosa, *Lutjanus analis* (Cuvier), *Pareques acuminatus* (Bloch & Schneider), *Rypticus saponaceus* (Bloch & Schneider) and *Scorpaena plumieri* Bloch) (Table I).

The overall diversity at Picãozinho (H' = 1.52) was considerably lower than at Quebra Quilhas (H' = 2.11). However, when considering fish diversity per area, values at both reefs were not significantly different (Table II). The overall equitability at Picãozinho (E = 0.43) was lower than at Quebra Quilhas (E = 0.6) and also, when considering equitability per area, Quebra Quilhas had significantly higher values. Number of species per area and total number of fishes per area were significantly higher at Picãozinho (Table II).

Of the species observed on both reefs, eight showed significant differences in abundance (Figure 2). Of these, six species were significantly more abundant at Picãozinho (*A. saxatilis*, *Acanthurus coeruleus* Bloch & Schneider, *Caranx latus* Agassiz, *Haemulon aurolineatum* Cuvier, *H. parra* and *Sparisoma* sp.) and two were more abundant at Quebra Quilhas (*Anisotremus moricandi* (Ranzani) and *Coryphopterus glaucofraenum* Gill).

At Picãozinho, the most speciose trophic category was mobile invertivores (n = 12 species), comprised mostly of haemulids and labrids, followed by roving herbivores (n = 8), mostly acanthurids and scarids, and carnivores (n = 4) (Table I). The other categories were omnivores (n = 3), planktivores (n = 2), territorial herbivores (n = 2), piscivores (n = 1) and sessile invertivores (n = 1). The most abundant trophic categories were omnivores (62.85%), territorial herbivores (13.57%), mobile invertivores (11.87%) and roving herbivores (9.83%), grouping 98.12% of all fishes recorded.

At Quebra Quilhas, the most speciose trophic category was also mobile invertivores (n = 11), comprising mostly haemulids and labrids, followed by carnivores (n = 7) mostly serranids, and roving herbivores (n = 5) mostly acanthurids and scarids. Other categories were planktivores (n = 3), omnivores (n = 2), territorial herbivores (n = 2), cleaners (n = 1), piscivores (n = 1) and sessile invertivores (n = 1). The most abundant trophic categories were territorial herbivores (38.32%), omnivores (26.1%), roving herbivores (14.95%) and mobile invertivores (13.78%), grouping 93.15% of all fishes recorded (Table I).

With regards to the abundance of trophic groups, a comparison between the reefs is shown in Figure 3. The trophic structure at Picãozinho was highly influenced by the high abundance of omnivores and that of Quebra Quilhas was much more homogeneous. Additionally, of the nine trophic categories recorded on both reefs, five were significantly different (i.e. mobile invertivores, omnivores, piscivores, planktivores and roving herbivores) (Table III).

Table I. Trophic categories, number of individuals, density per 20 m² (mean ± SE), frequency (%) and relative abundance (%) of reef fishes at Picãozinho and Quebra Quilhas.

		Picãozinho				Quebra Quilhas			
Family/Species	Trophic category	n	Density	Frequency (%)	Abundance (%)	n	Density	Frequency (%)	Abundance (%)
Acanthuridae									
Acanthurus bahianus Castelnau, 1855	Rov. Herbiv.	4	0.07 ± 0.04	5	0.09	—	—	—	—
Acanthurus chirurgus (Bloch, 1787)	Rov. Herbiv.	28	0.47 ± 0.11	30	0.6	79	1.32 ± 0.62	35	4.41
Acanthurus coeruleus Bloch & Schneider, 1801	Rov. Herbiv.	83	1.38 ± 0.16	71.66	1.78	36	0.6 ± 0.26	30	2.01
Apogonidae									
Apogon americanus Castelnau, 1855	Planktivore	—	—	—	—	2	0.03 ± 0.03	1.66	0.11
Belonidae									
Ablennes hians (Valenciennes, 1846)	Piscivore	—	—	—	—	1	0.02 ± 0.02	1.66	0.06
Blenniidae									
Entomacrodus vomerinus (Valenciennes, 1836)	Rov. Herbiv.	4	0.07 ± 0.03	6.66	0.09	—	—	—	—
Ophioblennius trinitatis Miranda Ribeiro, 1919	Omnivore	44	0.73 ± 0.11	51.66	0.94	7	0.12 ± 0.05	10	0.39
Carangidae									
Caranx latus Agassiz, 1831	Piscivore	17	0.28 ± 0.07	25	0.36	5	0.08 ± 0.04	8.33	0.28
Chaetodontidae									
Chaetodon striatus Linnaeus, 1758	Sessile Invertiv.	5	0.08 ± 0.04	8.33	0.11	1	0.02 ± 0.02	1.66	0.06
Gerreidae									
Eucinostomus argenteus Baird & Girard, 1855	Omnivore	15	0.25 ± 0.06	23.33	0.32	—	—	—	—
Gobiidae									
Coryphopterus glaucofraenum Gill, 1863	Planktivore	31	0.52 ± 0.12	31.66	0.67	67	1.12 ± 0.21	36.66	3.74
Elacatinus figaro Sazima, Moura & Rosa, 1997	Cleaner	—	—	—	—	1	0.02 ± 0.02	1.66	0.06

continue

Table I. continuation

		Picãozinho				Quebra Quilhas			
Family/Species	Trophic category	n	Density	Frequency (%)	Abundance (%)	n	Density	Frequency (%)	Abundance (%)
Haemulidae									
Anisotremus moricandi (Ranzani, 1842)	Mob. Invertiv.	3	0.05 ± 0.03	5	0.06	24	0.4 ± 0.13	18.33	1.34
Anisotremus virginicus (Linnaeus, 1758)	Mob. Invertiv.	19	0.32 ± 0.11	20	0.41	31	0.52 ± 0.12	35	1.73
Haemulon aurolineatum Cuvier, 1830	Mob. Invertiv.	154	2.57 ± 0.54	58.33	3.31	6	0.1 ± 0.07	5	0.33
Haemulon parra (Desmarest, 1823)	Mob. Invertiv.	233	3.88 ± 0.95	80	5	50	0.83 ± 0.26	45	2.79
Haemulon plumieri (Lacepède, 1801)	Mob. Invertiv.	3	0.05 ± 0.04	3.33	0.06	33	0.55 ± 0.26	11.66	1.84
Haemulon squamipinna Rocha & Rosa, 1999	Mob. Invertiv.	10	0.17 ± 0.08	8.33	0.21	—	—	—	—
Holocentridae									
Holocentrus adscensionis (Osbeck, 1765)	Mob. Invertiv.	3	0.05 ± 0.03	5	0.06	3	0.05 ± 0.03	5	0.17
Myripristis jacobus Cuvier, 1829	Planktivore	1	0.02 ± 0.02	1.66	0.02	1	0.02 ± 0.02	1.66	0.06
Labridae									
Halichoeres brasiliensis (Bloch, 1791)	Mob. Invertiv.	102	1.7 ± 0.17	85	2.19	82	1.37 ± 0.18	71.66	4.57
Halichoeres poeyi (Steindachner, 1867)	Mob. Invertiv.	19	0.32 ± 0.07	28.33	0.41	13	0.22 ± 0.07	16.66	0.73
Labrisomidae									
Labrisomus nuchipinnis (Quoy & Gaimard, 1824)	Carnivore	21	0.35 ± 0.08	30	0.45	28	0.47 ± 0.12	33.33	1.56
Lutjanidae									
Lutjanus analis (Cuvier, 1828)	Carnivore	—	—	—	—	2	0.03 ± 0.02	3.33	0.11
Ocyurus chrysurus (Bloch, 1791)	Carnivore	4	0.07 ± 0.03	6.66	0.09	—	—	—	—
Mugilidae									
Mugil curema (Valenciennes, 1836)	Rov. Herbiv.	4	0.07 ± 0.07	1.66	0.09	—	—	—	—
Mullidae									
Pseudupeneus maculatus (Bloch, 1793)	Mob. Invertiv.	1	0.02 ± 0.02	1.66	0.02	2	0.03 ± 0.02	3.33	0.11

continue

Table I. continuation

		Picãozinho				Quebra Quilhas			
Family/Species	Trophic category	n	Density	Frequency (%)	Abundance (%)	n	Density	Frequency (%)	Abundance (%)
Ophichthidae									
Myrichthys ocellatus (Lesueur, 1825)	Mob. Invertiv.	1	0.02 ± 0.02	1.66	0.02	2	0.03 ± 0.02	3.33	0.11
Pomacentridae									
Abudefduf saxatilis (Linnaeus, 1758)	Omnivore	2869	47.82 ± 6.92	98.33	61.6	461	7.68 ± 1.02	88.33	25.71
Stegastes fuscus (Cuvier, 1830)	Ter. Herbiv.	577	9.62 ± 0.78	96.66	12.38	636	10.6 ± 0.91	96.66	35.45
Stegastes variabilis (Castelnau, 1855)	Ter. Herbiv.	55	0.92 ± 0.15	51.66	1.18	51	0.85 ± 0.15	50	2.84
Scaridae									
Scarus trispinosus Valenciennes, 1840	Rov. Herbiv.	2	0.03 ± 0.03	1.66	0.04	10	0.17 ± 0.05	15	0.56
Scarus zelindae Moura, Figueiredo & Sazima, 2001	Rov. Herbiv.	3	0.05 ± 0.04	3.33	0.06	6	0.1 ± 0.04	10	0.33
Sparisoma sp. Swainson, 1839	Rov. Herbiv.	334	5.57 ± 0.42	98.33	7.17	137	2.28 ± 0.39	80	7.64
Scianidae									
Odontoscion dentex (Cuvier, 1830)	Carnivore	1	0.02 ± 0.02	1.66	0.02	2	0.03 ± 0.03	1.66	0.11
Pareques acuminatus (Bloch & Schneider, 1801)	Mob. Invertiv.	—	—	—	—	1	0.02 ± 0.02	1.66	0.06
Scorpaenidae									
Scorpaena plumieri Bloch, 1789	Carnivore	—	—	—	—	1	0.02 ± 0.02	1.66	0.06
Serranidae									
Cephalopholis fulva (Linnaeus, 1758)	Carnivore	—	—	—	—	1	0.02 ± 0.02	1.66	0.06
Epinephelus adscensionis (Osbeck, 1765)	Carnivore	8	0.13 ± 0.04	13.33	0.17	9	0.15 ± 0.05	15	0.5
Rypticus saponaceus (Bloch & Schneider, 1801)	Carnivore	—	—	—	—	2	0.03 ± 0.02	3.33	0.11
Tetraodontidae									
Sphoeroides testudineus (Linnaeus, 1758)	Mob. Invertiv.	1	0.02 ± 0.02	1.66	0.02	—	—	—	—

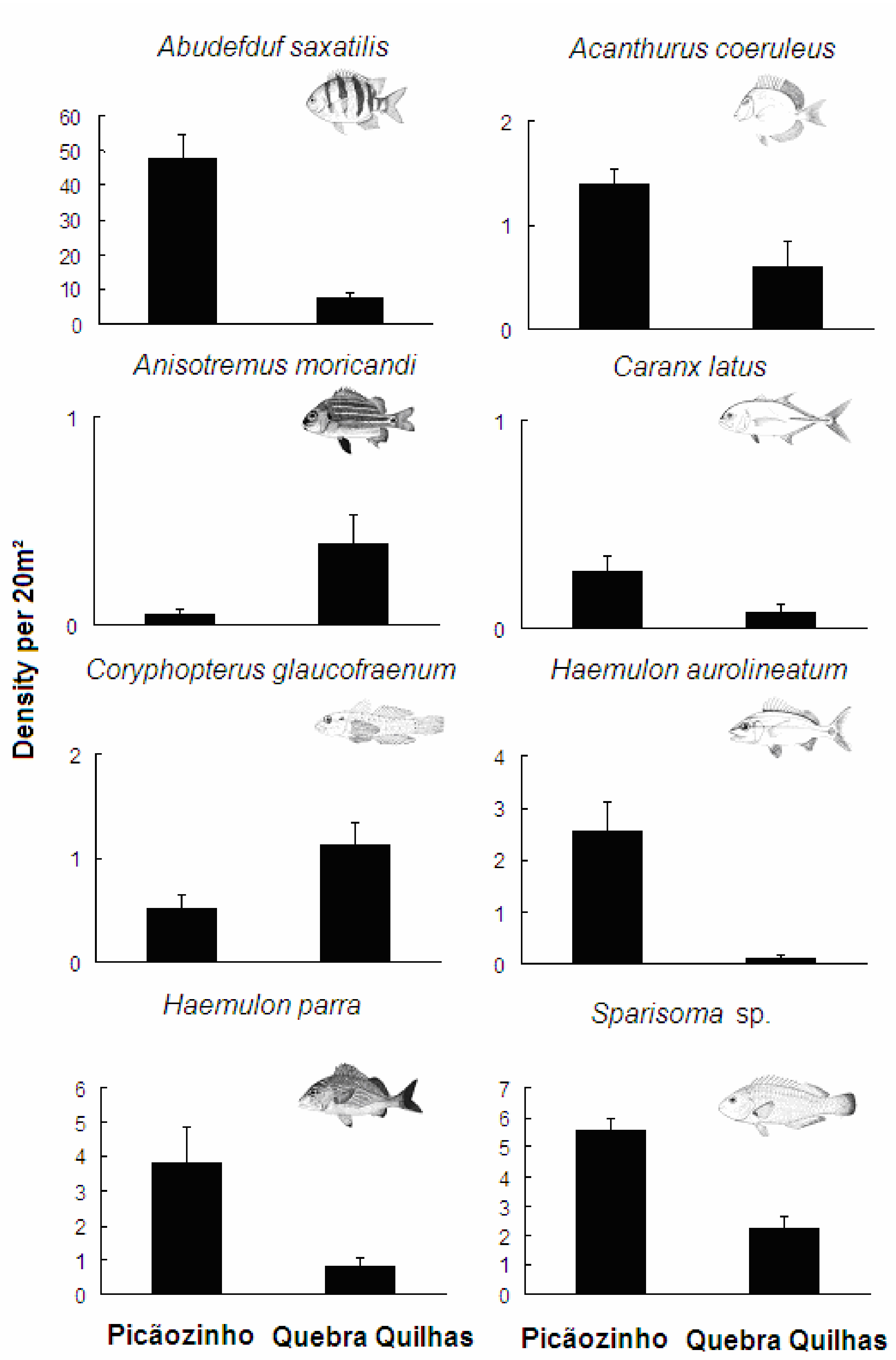

Figure 2. Density of fishes (per 20 m²) (mean ± SE) at Picãozinho and Quebra Quilhas. Student's *t* test showed significant differences in fish abundance between reefs ($P < 0.05$). Note that different scales were used.

Table II. Summary of reef fish variables (mean ± SD) plus the Student's *t* test results of comparisons between study sites. * Indicates significant difference.

	Picãozinho	Quebra Quilhas	Student's *t* test results
Fish diversity (H') per 20m²	1.45 ± 0.51	1.51 ± 0.37	*t* = -0.74; *P* = 0.46
Fish equitability (E) per 20m²	0.65 ± 0.2	0.75 ± 0.11	*t* = -3.67; *P* < 0.001*
Number of species per 20m²	9.57 ± 2.17	7.62 ± 2.10	*t* = 5.01; *P* <0.001*
Number of fishes per 20m²	77.65 ± 55.40	29.88 ±14.63	*t* = 6.46; *P* < 0.001*

Table III. Reef fish trophic categories (density per 20m²) (mean ± SD) plus the Student's *t* test results of comparisons between study sites. * Indicates significant difference.

Trophic Categories	Picãozinho	Quebra Quilhas	Student's *t* test results
Carnivores	0.14 ± 0.39	0.11 ± 0.43	*t* = 1.08 ; *P* = 0.28
Cleaners	-	0.02 ± 0.13	*t* = -1.00 ; *P* = 0.32
Mobile invertivores	0.71 ± 2.67	0.37 ± 1.44	*t* = 3.90; *P* < 0.001*
Omnivores	16.36 ± 38.13	3.9 ± 6.74	*t* = 5.87; *P* < 0.001*
Piscivores	0.28 ± 0.52	0.05 ± 0.22	*t* = 2.35; *P* < 0.05*
Planktivores	0.27 ± 0.73	0.39 ± 1.09	*t* = -2.45; *P* < 0.05*
Roving herbivores	1.09 ± 2.34	0.89 ± 2.8	*t* = 3.02; *P* < 0.01*
Sessile invertivores	0.08 ± 0.28	0.02 ± 0.13	*t* = 1.68; *P* = 0.1
Territorial herbivores	5.27 ± 6.15	5.73 ± 7.02	*t* = -0.75; *P* = 0.46

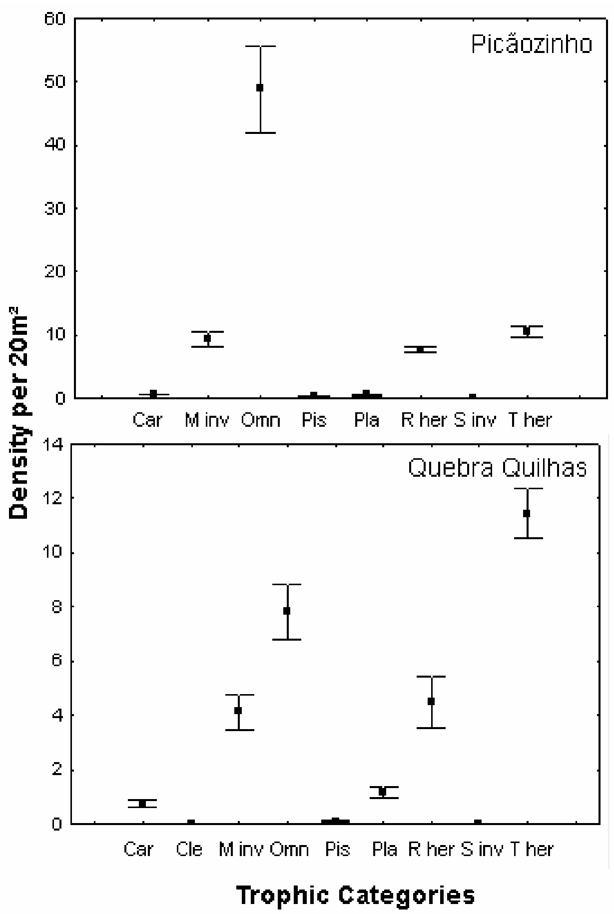

Figure 3. Density of fish trophic categories (mean ± SE) at Picãozinho and Quebra Quilhas. Note that different scales were used. Car: carnivores, Cle: cleaners, M inv: mobile invertivores, Omn: omnivores, Pis: piscivores, Pla: planktivores, R her: roving herbivores, S inv: sessile invertivores and T her: territorial herbivores.

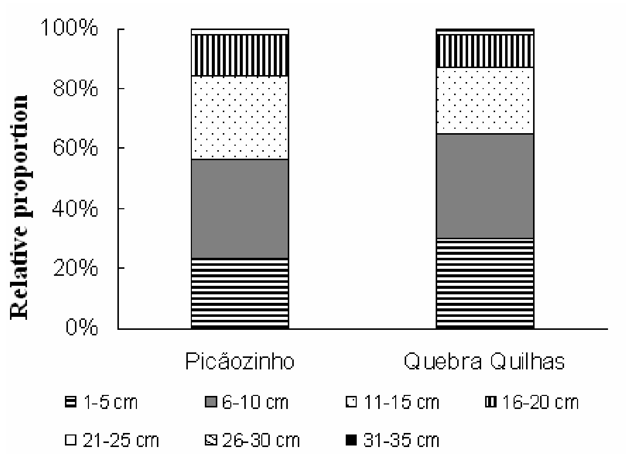

Figure 4. Relative abundance of the size classes of the fishes at Picãozinho and Quebra Quilhas.

At Picãozinho, 33% of the fishes measured between 6 and 10cm, 28% between 11 and 15cm and 23% measured between 1 and 5cm, whereas at Quebra Quilhas, 35% of the fishes measured between 6 and 10 cm, 30% between 1 and 5 cm and 22% measured between 11 and 15 cm (Figure 4). No significant differences related to size classes between the two reefs were detected (Student's *t* test, *P* > 0.05).

Discussion

The two studied reefs sustained similar fish assemblages with the most speciose and abundant families being Pomacentridae, Scaridae, Haemulidae, Acanthuridae and Labridae. These families group the typical reef dwelling fishes, which are very common in the northeastern coast of

Brazil (Ferreira *et al.* 1995, Rocha *et al.* 1998, Rocha & Rosa 2001, Dias *et al.* 2001, Feitosa *et al.* 2002).

Despite these similarities, remarkable differences were detected between the reefs. The most striking disparity concerns the extremely high abundance of the sergeant major *Abudefduf saxatilis* at Picãozinho, which accounted for almost ⅔ of all individuals recorded on this reef and was over six times more abundant than at Quebra Quilhas. During tourist presence at Picãozinho, this species is conspicuously the most affected fish, becoming effortlessly attracted by the external sources of food provided by tourists. In fact, a remarkable change in the behavior of this species can be observed ever since tourist arrival at the reef and changes in their overall abundance may also be observed when comparing between human-frequented and unfrequented periods (M.I. Ilarri *et al.* in prep.). Feeding by tourists has the potential to directly alter the behavior of many fish species, which are attracted by this external source of food (Cole 1994, Sweatman 1996) and eventually may display aggressive behaviors (Perrine 1989, Quinn & Kojis 1990). It is very likely that over the past decades, uncontrolled tourism may have strongly benefited the individuals of *A. saxatilis* and, as a consequence, the overall abundance of this species was dramatically increased. Human trampling is another activity that may supply the fishes with other sources of food in the studied reef (M.I. Ilarri *et al.* in prep.). When humans trample the substrate, especially in algal dominated areas, burrowing invertebrates become exposed and attract potential invertivores and carnivores which are nearby. Consequently, this activity also has the potential to alter fish behaviour considerably.

Furthermore, the higher abundances of juveniles of *Acanthurus coeruleus* and *Sparisoma* sp. at Picãozinho suggest that this reef is under a higher level of human interference, since high abundance of herbivores in marine ecosystems may indicate a sign of degradation due to the higher biomass of algae (e.g. Rogers & Beets, 2001). Although the above-mentioned species were benefited by these activities, a discrepancy on the population levels within a fish assemblage is considered a sign of historical environmental change, which is caused or, at least, enhanced by human activities. These discrepancies were also noticed elsewhere (see Milazzo *et al.* 2002) and have been related to recreational activities benefiting one or few species, with harsh consequences on others. Although in reefs worldwide, protected or non-protected, it is common to observe a pattern shifting from common abundant species and a progressive decline to rarer species (Magurran 1996), in no undisturbed natural system investigated up to date in Brazil, one single species prevail all other by 75% (e.g. Ferreira *et al.* 1995, Floeter *et al.* 2000, Feitosa *et al.* 2002, Rocha *et al.* 2001, Ferreira *et al.* 2004). Nonetheless, although only two species were less abundant at Picãozinho (see Figure 2), most other species did not seem to be negatively affected by the recreational activities and their abundances did not differ from those of the control reef. However, the increased population size of only a few species indicates a significant shift in fish assemblage structure at Picãozinho.

Nowadays, unregulated recreational activities are one the underlying anthropogenic factors responsible for causing several types of impacts on marine ecosystems and their living organisms (Sala *et al.* 1996, Harriot *et al.* 1997, Millazzo *et al.* 2002).

As a consequence of the uneven fish composition, due especially to the extremely high abundance of *A. saxatilis*, trophic structure was more homogenous in the control reef. Undisturbed tropical fish assemblages usually display a large trophic spectrum with many categories in the community (Hobson 1974). In a study conducted in another shallow reef of northeastern Brazil by Feitosa *et al.* (2002), fish trophic categories even showed a more homogenous distribution than the reefs evaluated in the present study (Figure 5).

Furthermore, highly diversified and undisturbed communities are usually characterized by the presence of few common species and a progressive decline to many occasional or rare species (Magurran 1996). Therefore, the great abundance of few species in such a diverse ecosystem is atypical and this progressive decline

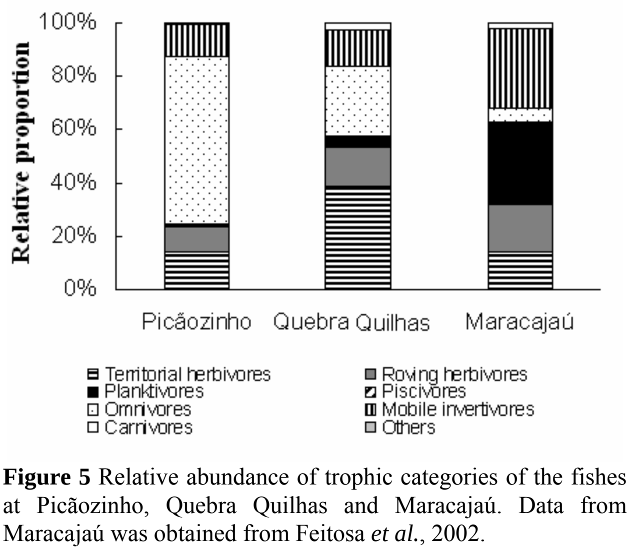

Figure 5 Relative abundance of trophic categories of the fishes at Picãozinho, Quebra Quilhas and Maracajaú. Data from Maracajaú was obtained from Feitosa *et al.*, 2002.

was observed on neither reef, but to a much less extent at Picãozinho. Thus, the observed structure of both reefs suggests that, besides tourism at Picãozinho, other external factors may have contributed to the current patterns observed. Nowadays, large predators in northeastern Brazil are restricted to deeper reefs as a consequence of a long history of overfishing that took place in the shallow reefs of this area (Feitoza *et al*. 2005). Thus, it is reasonable to consider that fishing has also played a major role in shaping the assemblage structure on these shallow reefs by altering the reef trophic dynamics over the decades. The removal of large predators is considered to have a major influence on the trophic structure of a reef, often leading to an increase in the population of their prey, which in turn, influences the whole base of the food web (Steneck 1998, Pace *et al.* 1999, Shears & Babcock 2002, Duffy 2003). For example, Ceccarelli *et al.* (2006) experimentally removed medium and large fishes, as a simulation of over-fishing, and found changes in the relative abundances of two species of damselfishes and on their overall dynamics.

The present study showed how one single species, *A. saxatilis*, was of major influence on species evenness and trophic structure on a reef with common tourist visitation. Therefore, the extremely high abundance of this species was the underlying feature responsible for the assemblage structure pattern observed on the reef. Due to uncontrolled recreational activities that take place in this reef since the mid 80's without regulation or authority supervision whatsoever, fish assemblage structure has been intensively modified. Whether by artificially feeding the fishes or by trampling over the substrate, humans represent potential threats to the reef. Nonetheless, the patterns observed on both reefs suggest that other external factors, such as the historical over-harvesting of large predators, may have also contributed to the current pattern observed nowadays.

Acknowledgments

We are grateful to CNPq, CAPES and Universidade Federal da Paraíba for essential assistance and two anonymous referees, whose comments were essential for the improvement of the manuscript. Thanks are also due to fisherman Dag for assistance during field trips.

References

Backhurst, M. K. & Cole, R. G. 2000. Biological impacts of boating at Kawau Island, northeastern New Zealand. **Journal of Environmental Management**, 60: 239-251.

Bell, J. D. 1983. Effects of depth and marine reserve fishing restrictions on the structure of a rocky reef fish assemblage in the North Western Mediterranean Sea. **Journal of Applied Ecology**, 20: 357-369.

Beauchamp, K. A., Gowing, M. M. 1982. A quantitative assessment of human trampling effects on a rocky intertidal community. **Marine Environmental Research**, 7: 279-283.

Bohnsack, J. A., Bannerot, S. P. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. **NOAA Technical Report**, 41: 1-15.

Brosnan, D. M., Crumrine, L. L. 1994. Effects of human trampling on marine rocky shore communities. **Journal of Experimental Marine Biology and Ecology**, 177: 79-97.

Brown, P. J., Taylor, R. B. 1999. Effects of trampling by humans on animals inhabiting coralline algal turf in the rocky intertidal. **Journal of Experimental Marine Biology and Ecology**, 235: 45-53.

Ceccarelli, D. M., Hughes, T. P., McCook, L. J. 2006. Impacts of simulated overfishing on the territoriality of coral reef damselfish. **Marine Ecology Progress Series**. 309: 255-262.

Chandrasekara, W. U., Frid, C. L. J. 1996. Effects of human trampling on tidalflat infauna. **Aquatic Conservation**, 6: 299-311.

Cole, R. G. 1994. Abundance, size structure and diver-oriented behaviour of three large benthic carnivorous fishes in a marine reserve in northeastern New Zealand. **Biological Conservation**, 70: 93-99.

Costa, C. F., Sassi, R., Costa M. A. J., Brito, A. C .L. 2007. Recifes costeiros da Paraíba, Brasil: usos, impactos e necessidades de manejo no contexto da sustentabilidade. **Gaia Scientia,** 1: 37-4.

Creed, J. C., Amado-Filho, G. M. 1999. Disturbance and recovery of the macroflora of a seagrass (*Halodule wrightii* Ascherson) meadow in the Abrolhos Marine National Park, Brazil: an experimental evaluation of anchor damage. **Journal of Experimental Marine Biology and Ecology**, 235: 285-306.

Davis, D., Tisdell, C. 1996. Economic management of recreational SCUBA diving and the environment. **Journal of Environmental Management**, 48: 229-248.

Dias, T. L. P., I. L. Rosa, and B. M. Feitoza. 2001. Food Resource and Habitat Sharing by the Three Western South Atlantic Surgeonfishes (Teleostei: Acanthuridae: Acanthurus) off

Paraíba Coast, North-eastern Brazil. Aqua Journal of Ichthyology and Aquatic Biology, no. 1, 5:1-10.

Duffy, J. E. 2003. Biodiversity loss, trophic skew and ecosystem functioning. **Ecology Letters**, 6: 680-687.

Eckrich, C. E., Holmquist, J. G. 2000. Trampling in a seagrass assemblage: direct effects, response of associated fauna, and the role of substrate characteristics. **Marine Ecology Progress Series**, 201: 199-209.

Feitosa, C. V., Pimenta, D. A. S., Araújo, M. A. 2002. Ictiofauna recifal dos parranchos de Maracajaú (RN): inventário, estrutura da comunidade e interferência antrópica. **Arquivos de Ciências do Mar**, 35: 39-50.

Feitoza, B. M., Rosa, R. S., Rocha, L. A. 2005. Ecology and zoogeography of deep reef fishes in northeastern Brazil. **Bulletin of Marine Science**, 76: 725-742.

Ferreira, B. P., Maida, M., Souza, A. E. 1995. Levantamento inicial das comunidades de peixes recifais da região de Tamandaré-PE. **Boletim Técnico e Científico do CEPENE**, 3: 211-230.

Ferreira, C. E. L., Floeter, S. R., Gasparini, J. L., Ferreira, B. P., Joyeux, J. C. 2004. Trophic structure patterns of Brazilian reef fishes: a latitudinal comparison. **Journal of Biogeography**, 31: 1093-1106.

Floeter, S. R., Gasparini, J. L. 2000. The southwestern Atlantic reef fish fauna: composition and zoogeographic patterns. **Journal of Fish Biology**, 56: 1099-1114.

Garcia-Rubies, A. 1999. Effects of fishing on community structure and on selected populations of Mediterranean coastal reef fish. **Naturalista Siciliano**, 23: 59-81.

Garcia-Rubies, A, Zabala, M. 1990. Effects of total fishing prohibition on the rocky fish assemblages of Medes Island marine reserve (NW Mediterranean). **Scientia Marina**, 54: 317-328.

Harriot, V. J., Davis, D., Banks, S. A. 1997. Recreational diving and its impact in marine protected areas in eastern Australia. **Ambio**, 26: 173-179.

Hastings, K., Hesp, P., Kendrick, G. A. 1995. Seagrass loss associated with boat moorings at Rottnest Island, Western Australia. **Ocean and Coastal Management**, 26: 225-246.

Hawkins, J. P., Roberts, C. M. 1992. Effects of recreational SCUBA diving on fore-reef slope communities of coral reefs. **Biological Conservation**, 62: 171-178.

Hawkins, J. P., Roberts, C. M., Van't Hof, T., De Meyer, K., Tratalos, J., Aldam, C. 1999. Effects of recreational SCUBA diving on Caribbean coral and fish communities. **Conservation Biology**, 13: 888-897.

Hobson, E. S. 1974. Feeding relationships of teleostean fishes on coral reefs in Kona, Hawaii. **Fisheries Bulletin**. 72:915-1031.

Hobson, E. S. 1975. Feeding patterns among tropical reef fishes. **American Scientist**, 63: 382-392.

Hunnam, P. 1987. Management of anchoring in marine parks. **Fringing Reef Workshop**, Townsville, 256-264

Jackson, J. B. C., Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J. 2001. Historical overfishing and the recent collapse of coastal ecosystems. **Science**, 293: 629-638.

Leão, Z. M. A. N., Dominguez, J. M. L. 2000. Tropical coast of Brazil. **Marine Pollution Bulletin**, 41: 112-122.

Liddle, M. J., Kay, A. M. 1987. Resistance, survival and recovery of trampled corals on the Great Barrier Reef. **Biological Conservation**, 42: 1-18.

Liddle, M. J. 1991. Recreation ecology: effects of trampling on plants and corals. **Trends in Ecology and Evolution**, 6: 13-17.

Magurran, A. E. 1996. **Ecological Diversity and its Measurements**. Princeton University Press, London, 179 p.

Maida, M., Ferreira, B. P. 1997. Coral reefs of Brazil: an overview. **Proceedings of the 8th International Coral Reef Symposium**, Panama, 263-274.

McClanahan, T. R., Kaunda Arara, B. 1996. Fishery recovery in a coral-reef marine park and its effects on the adjacent fishery. **Conservation Biology**, 10: 1187-1199.

Medio, D., Ormond, R. F. G., Pearson, M. 1997. Effects of briefings on rates of damage to corals by SCUBA divers. **Biological Conservation**, 79: 91-95.

Milazzo, M., Chemello, R., Badalamenti, F., Camarda, R., Riggio, S. 2002. The impact of human recreational activities in marine protected areas: what lessons should be learnt in the Mediterranean sea? **Marine Ecology**, 23: 280-290.

Millazzo, M., Badalamenti, F., Vega-Fernández, T., Chemello, R. 2005. Effects of fish feeding by snorkellers on the density and size distribution of fishes in a Mediterranean marine protected area. **Marine Biology**, 146: 1213-1222.

Myers, R., Worm, B. 2003. Rapid worldwide depletion of predatory fish communities. **Nature**, 423: 280-283.

Pace, M. L., Cole, J. J., Carpenter, S. R., Kitchell, J. F. 1999. Trophic cascades revealed in diverse ecosystems. **Trends in Ecology and Evolution**, 14: 483-488.

Perrine, D. 1989. Reef fish feeding: amusement or nuisance? **Sea Frontier**, 35: 272-279.

Pinnegar, J. K., Polunin, N. V. C., Francour, P., Badalamenti, F., Chemello, R., Harmelin-Vivien, M. L., Hereu, B., Milazzo, M., Zabala, M., D'Anna, G., Pipitone, C. 2000. Trophic cascades in benthic marine ecosystems: lessons for fisheries and protected-area management. **Environmental Conservation**, 27: 179-200.

Polunin, N. V. C., Roberts, C. M. 1993. Greater biomass and value of target-coral reef fishes in two small Caribbean marine reserves. **Marine Ecology Progress Series**, 100: 167-176.

Quinn, N. J., Kojis, B. L. 1990. Are divers destroying the Great Barrier Reef's cod hole? **Diving Science**, 5: 303-309.

Randall, J. E. 1967. Food habits of reef fishes of the West Indies. **Studies in Tropical Oceanography**, 5: 665-847.

Rocha, L. A. 2003. Patterns of distribution and processes of speciation in Brazilian reef fishes. **Journal of Biogeography**, 30: 1161-1171.

Rocha, L. A., Rosa, I. L. 2001. Baseline assessment of reef fish assemblages of Parcel Manuel Luiz Marine State Park, Maranhão, north-east Brazil. **Journal of Fish Biology**, 58: 985-998.

Rocha, L. A., Rosa, I. L., Rosa, R. S. 1998. Peixes recifais da costa da Paraíba, Brasil. **Revista Brasileira de Zoologia**, 15: 553-566.

Rogers, C. S., Beets, J. 2001. Degradation of marine ecosystems and decline of fishery resources in marine protected areas in the US Virgin Islands. **Environmental Conservation**, 28: 312-322.

Rouphael, A. B., Inglis, G. J. 1997. Impacts of recreational SCUBA diving at sites with different reef topographies. **Biological Conservation**, 82: 329-336.

Sala, E., Garrabou, J., Cabala, M. 1996. Effects of diver frequentation on Mediterranean sublittoral populations of the bryozoan *Pentapora fascialis*. **Marine Biology**, 126: 451-459.

Sala, E., Boudouresque, C. F., Harmelin-Vivien, M. 1998. Fishing, trophic cascades, and the structure of algal assemblages: evaluation of an old but untested paradigm. **Oikos**, 82: 425-439.

Shears, N. T., Babcock, R. C. 2002. Marine reserves demonstrate topdown control of community structure on temperate reefs. **Oecologia**, 132: 131-142.

Steneck, R. S. 1998. Human influences on coastal ecosystems: Does overfishing create trophic cascades? **Trends in Ecology and Evolution**, 13: 429-430.

Sweatman, H. P. A. 1996. Impact of tourist pontoons on fish assemblages on the Great Barrier Reef. **Technical Report 5**, Townsville, CRC Reef Research Centre.

Vuelta, C.B. 2000. Influência do Turismo sobre a ictiofauna do Recife de Picãozinho, Paraíba, Brasil. Dissertação de Mestrado, Universidade Federal da Paraíba, João Pessoa, 102 pp.

Walker, D. I., Lukatelich, R. J., Bastyan, G., McComb, A. J. 1989. Effect of boat moorings on seagrass beds near Perth, Western Australia. **Aquatic Botany**, 36: 69-77.

Received August 2007
Accepted November 2007
Published online November 2007