Distribution and factors influencing on structure of reef fish communities in Nha Trang Bay Marine Protected Area, South-Central Vietnam

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Abstract Visual censuses of coral reef fishes in Nha Trang Bay Marine Protected Area (MPA) were conducted during September–October 2005. Nha Trang Bay MPA is relatively rich in reef fishes compared to other areas in Vietnam and the Pacific Ocean outside the 'Coral Triangle,' consistent with its biogeographic location in the western South China Sea. A total of 266 species of 40 families of coral reef fishes formed five distinct assemblages. Spatial variations in distribution and structure of the assemblages were associated with eight significant biological and physical variables which were cover of living hard corals, encrusting corals, branching corals, *Acropora*, *Millepora*, *Montipora*, depth and distance from the coast of the mainland. The six factors in front are likely related to provision of shelter and nutrition, while the distance factor is likely to represent a gradient in disturbance and impacts from various mainland sources including sedimentation and pollution discharge from nearby rivers. Local species richness ranged from 35 to 70 species 500 m^{-2} (mean: 51±2 SE) for reef flat stations and from 23 to 68 species 500 m^{-2} (mean: 48±4 SE) for reef slope stations. Total species richness at each site averaged 76 species (±4 SE), ranging from 56 to 110 species, dominated by wrasses, damselfishes, butterflyfishes, parrotfishes, surgeonfishes, groupers and goatfishes. Density of total fishes at each station ranged from 348 to 1,444 individuals 500 m^{-2} (mean: 722±302 SE) for the reef flat stations and from 252 to 929 individuals 500 m^{-2} (mean: 536±215.7 SE) for the reef slope stations. Overall mean density at each site averaged 628.9 (±238.4 SE) individuals 500 m^{-2}. The highly protected sites supported higher mean density of fishes per site (ranged: 904.5–1,213 individuals 500 m^{-2} for Hon Mun and 1,167.5 individuals 500 m^{-2} for Hon Cau) compared to other sites (<800 individuals 500 m^{-2}). Of the families included in the census, densities were dominated throughout the MPA by damselfishes and wrasses. Many target species, particularly groupers, snappers and emperors, were rare or absent and the low abundance of big fishes was consistent with over-harvesting. Similarly a low density of butterfly fishes and angelfishes is likely related to the supply for marine aquaria in Vietnam and overseas. This study provides an important baseline against which the success of present and future MPA management initiatives may be assessed.

Keywords Spatial distribution and structure · Fish assemblages · Environmental factors · Canonical correspondence analysis · Vietnam

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Introduction

One of the main interests of coral reef ecologists is to determine the processes that influence the spatial distribution and structures of fish assemblages. Results from previous studies indicate that factors influencing fish communities are many and vary depending on the scale and methods applied. Some studies indicate that rugosity (Luckhurst and Luckhurst 1978; Jennings et al. 1996; Chabanet et al. 1997; Cadoret et al. 1999) significantly influences diversity and spatial distribution of coral reef fish communities, whereas other authors found no relationships (Roberts and Ormond 1987; Ault and Johnson 1998). Some authors found that amount of living hard coral cover was positively related with fish species richness (Carpenter et al. 1981; Bell and Galzin 1984; Cadoret et al. 1999) whereas others recorded no such relationship (Luckhurst and Luckhurst 1978; Roberts and Ormond 1987; Lecchini et al. 2003). Most recently, the spatial structure and distribution of fish assemblages have been related to water depth (Russ 1984a; Fowler 1990; Friedlander and Parrish 1998; Cadoret et al. 1999; Lecchini et al. 2003), exposure (Williams 1982; Victor 1986; Depczynski and Bellwood 2005), reef zone (Lecchini et al. 2003; Depczynski and Bellwood 2005), distance from the shoreline to offshore waters (Williams 1982; Green et al. 1987; Adjeroud et al. 1998; Lecchini et al. 2003) and geographical location (Travers et al. 2006). In general, findings from previous studies on relationships between the spatial distribution and structure of reef fish communities and environmental factors have provided conflicting conclusions.

In Nha Trang Bay Marine Protected Area (MPA), south-central Vietnam, recent biodiversity studies have described a total of about 800 species of corals, fish, molluscs, echinoderms, crustaceans and macro algae (Vo et al. 2004). Detailed information on biodiversity and conservation potential (Vo 1995), description of structure of reef-building coral communities (Vo et al. 2004), impacts to coral reefs (Vo and Pham 1997) have been considered in the Nha Trang Bay MPA. Some 15 species of butterflyfishes (Nguyen 1998) and 220 species of coral reef fishes (Vo et al. 2004) were listed for Nha Trang Bay. Although many other studies on reef fish communities have been done in Nha Trang Bay during recent decades, few have been published. Specifically, there are a lack of quantitative studies describing the structure of coral reef fish communities and factors that may influence the spatial distribution and structure of these communities in Nha Trang Bay MPA in particular and in Vietnam in general.

The aims of this study were (1) to provide baseline information on the distribution, abundance and species richness of coral reef fishes in Nha Trang Bay MPA, (2) to describe patterns of the spatial structure of fish communities on coral reefs, and (3) to determine any relationships of the structure of the fish communities to gradients in environmental variables.

Materials and methods

Study site

Nha Trang Bay Marine Protected Area (MPA), the first MPA in Vietnam, established in 2002, consists of ten islands (Hon Vung, Hon Cau, Hon Rua, Hon Tre, Hon Noc, Hon Mun, Hon Rom, Hon Mot, Hon Tam and Hon Mieu) from ~1 to ~15 km offshore, and is situated at 12° 00′–12° 45′ N to 109° 15′–109° 30 E, Khanh Hoa province, south-central Vietnam. The MPA encompasses some 160 km^2 in total (Fig. 1) and is recognized as being internationally important for its coral reefs and fish, and as a center of marine tourism in Vietnam.

The area is influenced by tropical monsoonal climate, with sea surface temperatures usually peaking at ca. 31°C (summer) and falling to 24°C in winter, and annual mean rainfall is 1,441 mm $year^{-1}$ (Le et al. 1979). The MPA is located immediately adjacent to the coastal city of Nha Trang and its port at Cau Da. Two Rivers, the Cai River in the north and the Cua Be River in the south, flow into Nha Trang Bay, with the potential to influence water quality in the Bay. The highest peak occurs from October to December, producing regular flooding of the Cai and Be Rivers, discharging waters of low salinity and high sediment content and nutrient loads into Nha Trang Bay, several kilometers to the north of the MPA. Resuspension of sediments from the rivers and dredging of the port during rough sea conditions also contributes to localized increases in turbidity and deposited on coral reefs of the islands nearshore. Parts of the island shorelines are eroded by episodic wave action, causing loss of terrigenous sediments into near-shore waters and increased turbidity and sediment deposition on nearshore benthic communities.

The islands and surrounding waters of the Bay provide the topographic basis for a wide range of coastal and marine habitat types, including coral reefs, soft bottom communities, seagrass beds, mangroves, sandy beaches and rocky shores. Coral reef communities occur in patches around most of the islands,

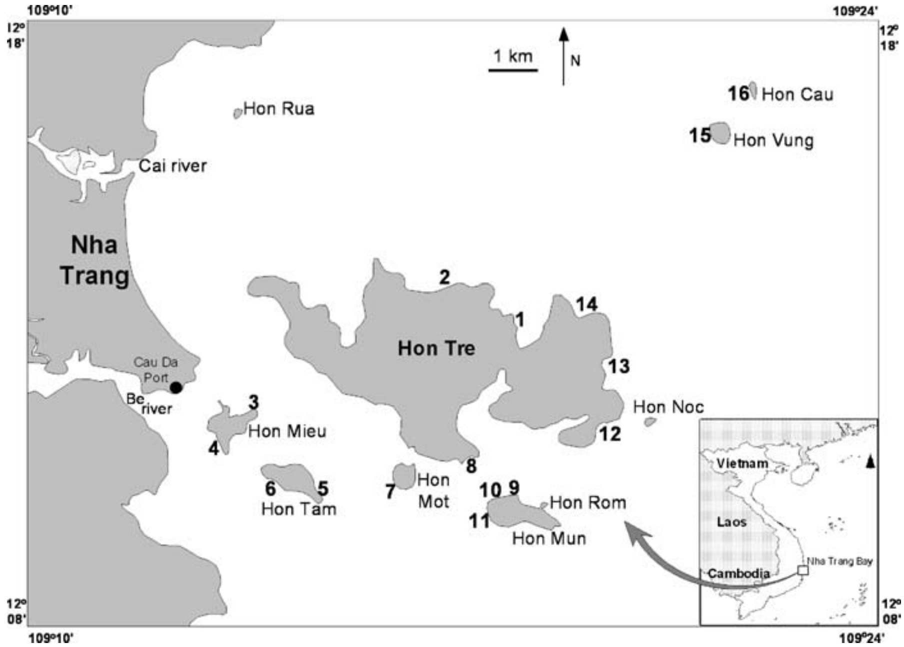

Fig. 1 Approximate location of study sites of coral reefs in Nha Trang Bay MPA surveyed in 2005

their structure varying in relation to the degree of physical exposure. With more than 350 species of reef building corals, the Nha Trang Bay MPA is recognized as one of the most diverse areas in Vietnam and the South China Sea (Vo et al. 2004).

Sampling sites and strategy

Survey sites were chosen to provide a representative range of coral reef communities in terms of the environmental gradients. A total of 32 transects at 16 sites around the islands of Nha Trang Bay with the exception of Hon Rua, Hon Noc and Hon Rom) were surveyed during September–October 2005 using SCUBA (Fig. 1). At each survey site, two transects, each 100 m long were placed at two reef zones parallel to the shoreline of the island. The reef flat transect (shallow station) was ca. 2–4 m deep and the reef slope transect (deep station) was 5–12 m below low tide level. Throughout this paper, the terms 'site' and 'station' are used consistently in the above manner.

To avoid disturbance from divers, fish surveys were conducted 15 min after the first transect was placed. The fish observer swam slowly along each transect of each station to identify and count fishes located within an area of 500 m^2, 100 m long (transect line) and 5 m wide and 5 m above by visual estimates following Hodgson and Waddell (1997), English et al. (1997). Fishes of all families were identified to species level following Randall et al. (1990), Myers (1991), Kuiter (1992) and Allen et al. (2003). Surveyed time at each station was about 60 min.

The percentage cover of hard corals, soft corals, recently killed corals, dead corals with algae, fleshy seaweeds, turf algae, coralline algae, coral rubble, sponges, rock, sand and others was also recorded along the transects using the point intercept transect method with an interval of 0.5 m (English et al. 1997; Hodgson and Waddell 1997). Hard corals were identified to type of colony (branching, tabular, encrusting, foliose, massive, sub-massive, mushroom) and to generic level following Veron and Pichon (1982), Veron and Wallace (1984), Veron (1986, 2000), Wallace and Wolstenholme (1998), Wallace (1999). Other factors such as depth, underwater visibility, distance from the coast of the mainland, and levels of exposure to waves were also recorded for each station during the surveys. Depth was determined as the mean of the starting point, middle and the end point of the transect. Visibility at each station was recorded by visual estimation of water transparency in the horizontal direction along the transect lines. Distance from the coast was measured from the map from Cau Da port (taken as the main source of sediments, freshwater or pollution) to each survey site, level of exposure to waves was ranked in four levels (exposed: sites that face into big waves;

semi-exposed: medium waves; sheltered: sites that never get large waves, i.e. very sheltered behind an island; and semi-sheltered: small waves) following Vo et al. (2004). The surveys were all carried out between 10:00 and 14:00 local time. This period is considered as the time with maximum light levels penetrating into the water column, when most reef-associated fishes become more active.

Data analysis

Data were transformed to improve normality, linearity, and homoscedasticity. To remove heterogeneity of variances, fish abundance (number of individuals 500 m^{-2}) was transformed log (X+1). Environmental variables including the percentage cover of hard corals, soft corals, recently killed corals, macro-algae, turf algae, coralline algae, rubble corals, sponges, rock, sand, silt/clay, others, branching corals, tubular corals, encrusting corals, foliose corals, massive corals, submassive corals, mushroom corals and some common genera *Acropora*, *Fungia*, *Montipora*, *Pachyseris*, *Porites*, *Millepora*, *Galaxea*, *Hydrogonia*) were transformed by acrsin of square root (X). Depth, visibility, distance from the coast of the mainland and exposure were transformed by log (X+1).

Among the 40 families recorded, eight most common families including Labridae, Pomacentridae, Chaetodontidae, Scaridae, Acanthuridae, Siganidae, Pomacanthidae, Zanclidae were used for Cluster Analysis and Correspondence Analysis (CA) based on the species composition and abundance of fishes for groups of spatial distribution of fish assemblages. Difference in fish assemblage structure was tested using ANOSIM randomization test (Analysis of Similarities) (Clarke 1993). SIMPER was used to identify which species best typify faunal assemblages and contribute most to any differences between each of two groups.

Relationship between fish assemblages of the eight most common families and environmental variables were examined using Canonical Correspondence Analysis (CCA) (ter Braak 1986). Environmental variables determined from the forward selection with Monte Carlo permutation test were added to the model and displayed in graphic biplots of species and environmental variables. Cluster Analysis, ANOSIM and SIMPER were performed using Primer Software 5.0 package, while Correspondence Analysis and Canonical Correspondence Analysis were performed by CANOCO Software 4.5 Package.

Results

Distribution and abundance of fish communities

A total of 20,126 individuals of 266 species in 40 families of coral reef fishes were recorded at the 32 stations in Nha Trang Bay MPA. Wrasses (Labridae) and damselfishes (Pomacentridae) were the richest families with 47 and 46 species respectively. Other predominant families were butterflyfishes (Chaetodontidae: 24 species), parrotfishes (Scaridae: 19 species), surgeonfishes (Acanthuridae: 13 species), groupers (Serranidae: nine species) and goatfishes (Mullidae: nine species). The 14 most common species that were counted at almost all of the study sites included *Canthigaster valentini*, *Dascyllus reticulatus*, *Scarus sordidus*, *Gomphosus varius*, *Cheilinus chlorourus*, *Thalassoma lunare*, *Chaetodon trifasciatus*, *Labroides dimidiatus*, *Stethojulis bandanensis*, *Parupeneus multifasciatus*, *Acanthurus nigrofuscus*, *Ctenochaetus strigosus*, *Pomacentrus chrysurus* and *Plectroglyphidodon lacrymanus*.

Number of species (species richness) and density of fishes at each station and site are shown in Fig. 2. Species richness at each station ranged from 35 to 70 species (mean: 51±2 SE) for reef flat stations and from 23 to 68 species (mean: 48±4 SE) for reef slope stations. Total species richness at each site averaged 76 species (±4 SE), ranging from 56 to 110 species. Density of total fishes at each station ranged from 348 to 1,444 individuals 500 m^{-2} (mean: 722±302 SE) for the reef flat stations and from 252 to 929 individuals 500 m^{-2} (mean: 536±215.7 SE) for the reef slope stations. The mean species richness at site 15 (65 species, Hon Vung) was relatively high and similar to that found at the other sites, whereas mean density of total fishes was very low. Species richness and fish density were general higher on the reef flat stations compared to the reef slope stations, and these values were lower at the sites closest to the mainland (site 1–6) compared to sites offshore, with the exception of site 15 (Hon Vung) and site 16 (Hon Cau) (Fig. 2).

Comparisons of overall mean densities of all families and the eight most common families are shown in Table 1. Overall mean density at each site

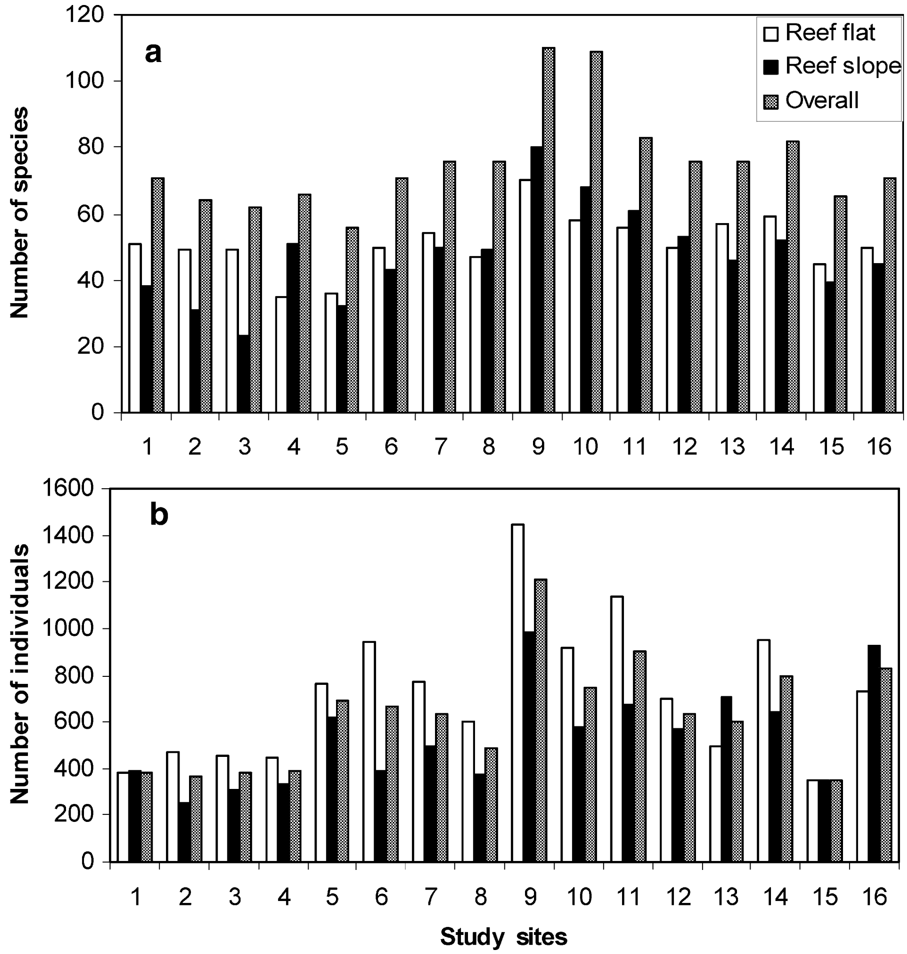

Fig. 2 Species richness (**a**) and density (**b**) of fish fauna 500 m^{-2} at reef stations and sites

averaged at 628.9 individuals 500 m^{-2} (±238.4 SE, ranged: 315–1,213 individuals 500 m^{-2}). Site 9 at North Hon Mun supported the highest density of total fishes (1,213±232.0 SE, individuals 500 m^{-2}) compared to the other islands. The highly protected sites supported higher mean density of fishes per site (ranged: 904.5–1,213 individuals 500 m^{-2} for Hon Mun and 1,167.5 individuals 500 m^{-2} for Hon Cau) compared to other sites (<800 individuals 500 m^{-2}). The families Pomacentridae and Labridae had higher density compared to the other families, with the highest densities being recorded 352.5±69.2 SE and 95.8±14.9 SE individuals 500 m^{-2} respectively. The highest density of the families Pomacentridae, Acanthuridae, Chaetodontidae and Pomacanthidae were found at the sites of Hon Mun (site 9–11) and Hon Cau (site 16) whereas Hon Tam (site 5–6), Hon Mieu (site 3–4) and Hon Mot (site 7) supported the highest density of the families Siganidae and Scaridae. The highest density of the family Zanclidae (4.0±0.5 SE, individuals 500 m^{-2}) was recorded at Hon Mun (site 9–11).

Substratum components

Percentage cover of some major substratum components are given in Table 1. Mean cover of living hard corals at each site was the highest at site 12 (Bai San: 61.3%±10.4 SE) and the lowest at site 2 (North Hon Tre: 2.2%±0.3 SE). The highest cover of soft corals was found at site 16 (Hon Cau: 9.4%±0.1 SE) whereas site 14 (Hon Vung) supported the highest cover of fleshy algae (11.9%±0.1 SE) and coral rubble (17.2±5.9 SE). Overall mean cover of living hard corals was 24.4% (±5.3 SE), in which cover of branching corals of three genera *Porites*, *Acropora*, *Millepora* and *Montipora* were dominant with mean cover at each site being 6.3% (±1.1 SE), 4.3% (±1.8 SE), 2.8% (±1.2 SE) and 1.5% (±1.1 SE) respectively (Table 1).

Table 1 Mean density and species richness in parenthesis of the eight most common families of fishes and all families of fishes (individuals 500 m^{-2}) and major substratum cover (%) at each study reef in Nha Trang Bay MPA

	Study site																Overall mean
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Fish families																	
Acanthuridae	8.5 (2)	11.0 (4)	1.0 (2)	7.5 (4)	9.0 (3)	4.5 (3)	40.5 (4)	14.0 (5)	**76.0** (**7**)	12.0 (5)	68.5 (**7**)	43.5 (**7**)	34.0 (5)	29.0 (6)	4.0 (2)	67.5 (4)	26.9 (4.4)
Chaetodontidae	8.5 (3)	7.0 (2)	1.5 (5)	2.0 (4)	2.0 (3)	12.0 (7)	5.5 (5)	9.0 (5)	30.5 (11)	29.0 (11)	**46.0** (**12**)	22.0 (7)	15.5 (7)	16.5 (6)	3.5 (2)	34.0 (5)	15.8 (5.9)
Labridae	51.5 (18)	56.5 (16)	35.0 (14)	134.5 (20)	49.0 (12)	128.0 (20)	104.0 (23)	49.5 (19)	100.0 (25)	168.5 (21)	99.5 (21)	61.0 (21)	39.0 (16)	**255.5** (23)	169.0 (20)	32.5 (7)	95.8 (19.1)
Pomacanthidae	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	4.0 (2)	4.5 (1)	1.0 (1)	8.0 (2)	7.0 (1)	6.5 (2)	7.0 (1)	13.0 (1)	**9.0** (1)	2.5 (2)	7.0 (**3**)	4.3 (1.1)
Pomacentridae	136.5 (16)	94.0 (15)	123.0 (16)	195.0 (18)	619.0 (13)	285.5 (15)	254.0 (18)	240.5 (17)	821.5 (**27**)	598.0 (25)	608.0 (21)	282.0 (16)	343.0 (24)	387.0 (21)	82.5 (14)	**956.0** (18)	325.5 (18.1)
Scaridae	61.0 (8)	35.0 (4)	25.0 (4)	**114.0** (6)	13.0 (2)	86.0 (7)	85.0 (8)	92.5 (6)	75.0 (**11**)	53.0 (12)	43.5 (7)	28.0 (5)	19.5 (4)	32.0 (7)	30.0 (4)	33.0 (4)	53.5 (6.2)
Siganidae	22.0 (2)	58.5 (**3**)	28.0 (1)	52.5 (2)	16.0 (**3**)	**89.5** (2)	18.0 (2)	6.5 (2)	5.5 (2)	1.0 (1)	2.0 (2)	0.0 (0)	0.0 (0)	6.0 (**3**)	9.5 (2)	0.0 (0)	20.3 (1.7)
Zanclidae	3.0 (1)	2.0 (1)	0.0 (0)	0.0 (0)	1.0 (1)	0.5 (1)	3.5 (1)	3.0 (1)	**4.0** (1)	3.5 (1)	**4.0** (1)	2.5 (1)	3.0 (1)	0.5 (1)	2.0 (1)	0.0 (0)	2.1 (0.8)
All families	416.5 (74)	315.0 (68)	349.0 (64)	551.0 (68)	794.0 (57)	665.5 (73)	550.0 (78)	489.5 (76)	**1,213.0** (**113**)	933.5 (105)	904.5 (88)	486.0 (76)	512.5 (78)	795.5 (86)	347.0 (67)	1167.5 (73)	628.9 (77.8)
Substratum cover																	
Hard corals	7.5	2.2	10.3	5.9	12.8	36.9	23.4	4.7	38.8	36.6	45.9	**61.3**	35.9	48.4	4.7	14.7	24.4
Encrusting corals	2.2	0.0	0.3	4.1	0.3	22.2	1.9	0.9	10.6	10.6	**26.3**	5.3	3.1	8.8	0.3	2.2	6.2
Branching corals	0.9	0.9	0.0	0.0	0.3	0.0	0.6	0.9	0.3	0.0	0.0	**13.4**	5.9	6.9	0.0	0.9	2.0
Acropora	0.0	0.0	0.3	0.0	0.0	21.6	0.6	1.6	6.3	3.4	**22.2**	6.9	2.2	2.5	1.6	0.0	4.3
Millepora	0.0	0.0	2.5	0.0	1.3	0.3	0.9	0.0	**13.3**	9.7	13.1	0.0	0.0	0.0	2.5	1.9	2.8
Montipora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	1.9	4.7	**16.9**	0.0	0.0	1.5
Porites	5.9	0.6	6.9	2.8	10.6	0.6	10.9	0.3	**13.8**	8.1	9.4	3.1	9.4	8.8	0.3	9.1	6.3
Level of exposure	SH	EX	SS	SE	SH	SE	SS	SE	SS	SS	SE	SE	EX	SE	EX	SE	

Bold shows higher number.

EX Exposed, *SE* Semi-exposed, *SH* Sheltered, *SS* Semi-sheltered

Structure of fish assemblages

Cluster analysis and Correspondence analysis of the spatial distribution of fish assemblages of the eight most common families in Nha Trang Bay MPA show that there were five groups distributed among the islands (Fig. 3a,b). One-way ANOSIM tests demonstrated that there was a significant difference between these distinct groups of fish fauna (all $P<0.005$, Table 2). Correspondence analysis showed a strong separation between the reef flat stations from the reef slope stations on the second axis (Fig. 3b).

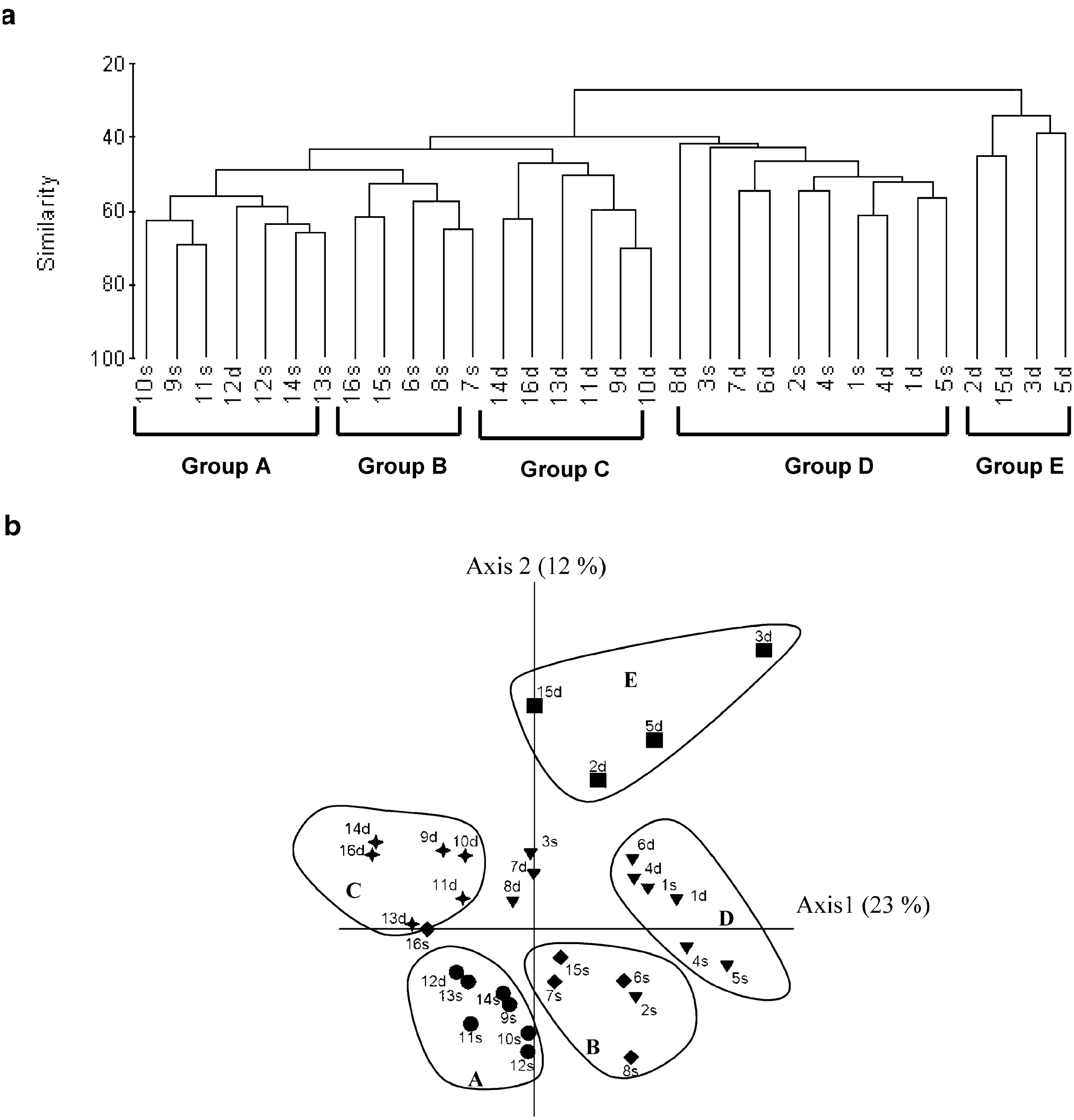

Fig. 3 Hierarchical cluster analysis (based on Bray–Curtis similarity; **a**) and correspondence analysis (CA; **b**) ordination showing the distribution of five distinct groups of the eight most common families of fish assemblages (Labridae, Pomacentridae, Chaetodontidae, Scaridae, Acanthuridae, Siganidae, Pomacanthidae, Zanclidae) in the Nha Trang Bay MPA. The *numbers* represent the site (from Fig. 1); *s* and *d* are shallow and deep stations. *A*, *B*, *C*, *D*, *E* are consistent with Group A, Group B, Group C, Group D and Group E in the cluster analysis

Table 2 Summary of one-way ANOSIM test performed on data of fish abundance of study stations at 16 sites in Nha Trang Bay MPA during September–October 2005

Group of fish assemblages	A	B	C	D
B	0.001 (0.631)			
C	0.001 (0.762)	0.002 (0.525)		
D	0.001 (0.679)	0.001 (0.913)	0.001 (0.954)	
E	0.003 (0.989)	0.003 (0.989)	0.003 (0.933)	0.003 (0.831)

Significance level and *R*-statistic values in parentheses.

Group A included six reef flat stations (site 9: N. Hon Mun; site 10: NW.Hon Mun; site 11: S.W.Hon Mun; site 12: Bai San; site 13: E.Hon Tre; site 14: Bai Bang) and 1 deep station (Bai San) in offshore sites listed. A total of 97 species was recorded for this group. *D. reticulatus* (Pomacentridae) was the most representative species of this group and mean density was 191 (±46.1 SE) individuals 500 m^{-2} per station. Of the 19 representative species selected by SIMPER, *D. reticulatus*, *Pomacentrus moluccensis*, *Pomacentrus lepidogenys* (Pomacentridae) and *Labrichthys unilineatus* (Labridae) were distinguished from the other groups.

Group B included five reef flat stations of both near and offshore sites (site 6: S.Hon Tam; site 7: Hon Mot; site 8: Bai Lan; site 15: Hon Vung and site 16: Hon Cau) with a total of 78 species. *Plectroglyphidodon lacrymanus* (Pomacentridae) was the most representative species and mean density was 44.2 (±17.2 SE) individuals 500 m^{-2} per station. Of the 18 representative species of this group selected by SIMPER, two species of *Chrysiptera* spp (Pomacentridae) and *Ctenochaetus binnotatus* (Acanthuridae) were distinguished from the other groups.

Group C consisted of 90 species at the reef slope stations of offshore sites (site 9: N.Hon Mun; site 10: NW.Hon Mun; site 11: SW.Hon Mun; site 13: E.Hon Tre; site 14: Bai Bang and site 16: Hon Cau). *D. reticulatus* (Pomacentridae) was the most representative species and the mean density was 152.7 (±49.0 SE) individuals 500 m^{-2} per station of this group. Three species including *Scarus schlegeli* (Scaridae), *Chaetodon xanthura* (Chaetodontidae) and *Zebrasoma scopas* (Acanthuridae) were distinguished from the other groups.

Group D included four reef flat stations (site 1: Bai Ngheo; site 2: N.Hon Tre; site 3: N.Hon Mieu; site 5: N.Hon Tam) and five reef slope stations (site 1: Bai Ngheo; site 4: S.Hon Mieu; site 6: S.Hon Tam; site 7: Hon Mot and site 8: Bai Lan) in nearshore sites with a total of 100 species recorded. Of the 14 species listed as typified indicator species for this group, *S. sordidus* (Scaridae) was the most representative species and the mean density was 49 (±20.0 SE) individuals 500 m^{-2} per station. Four species *S. bandanensis* and *Halichoeres margaritaceus* (Labridae), *Siganus spinus* (Siganidae), *Hemiglyphidodon plagiometopon* (Pomacentridae) were distinguished from the other groups.

Group E included four deep stations of the nearshore and offshore sites (site 2: N. Hon Tre; site 3: NE. Hon Mieu; site 5: N. Hon Tam and site 15: Hon Vung). Among the six key indicator species selected by SIMPER, *Siganus canaliculatus* (Siganidae) was the most representative species and the mean density was 38.3 (±20.9 SE) individuals 500 m^{-2} per station. Four species distinguished from the other groups were *S. canaliculatus* (Siganidae), *Stethojulis strigiventer* (Labridae), *Pomacentrus* sp2 and *Pomacentrus* sp (Pomacentridae).

Comparison of the mean density of 11 species, in which each species occupied more than 2% of total of fishes showed that there were difference in mean density of these dominant species between groups. *D. reticulatus* was the most dominant species in the five groups. *Chromis weberi* was dominant for Group C and E, *S. sordidus* for Group A and D, *Cirrhilabrus punctatus* for Group C and E, *P. lacrymanus* for Group A and B, *Amblyglyphidodon curacao* for Group A and C, *Dascyllus trimaculatus* for Group A, C and E, *P. chrysurus* for Group D, *S. canaliculatus* for Group D and E, *Pomacentrus amboinensis* for Group C and *Chromis viridis* for Group A (Fig. 4).

Correlations between spatial structure and environmental variables

Correlations in the first analysis between fish assemblages of the eight common families (Labridae, Pomacentridae, Chaetodontidae, Scaridae, Acanthuridae, Siganidae, Pomacanthidae and Zanclidae) and environmental factors (the percentage cover of living hard corals, soft corals, recently killed corals, dead corals with algae, macro-algae, turf algae, coralline algae, coral rubble, sponges, rock, sand, other benthic covers,

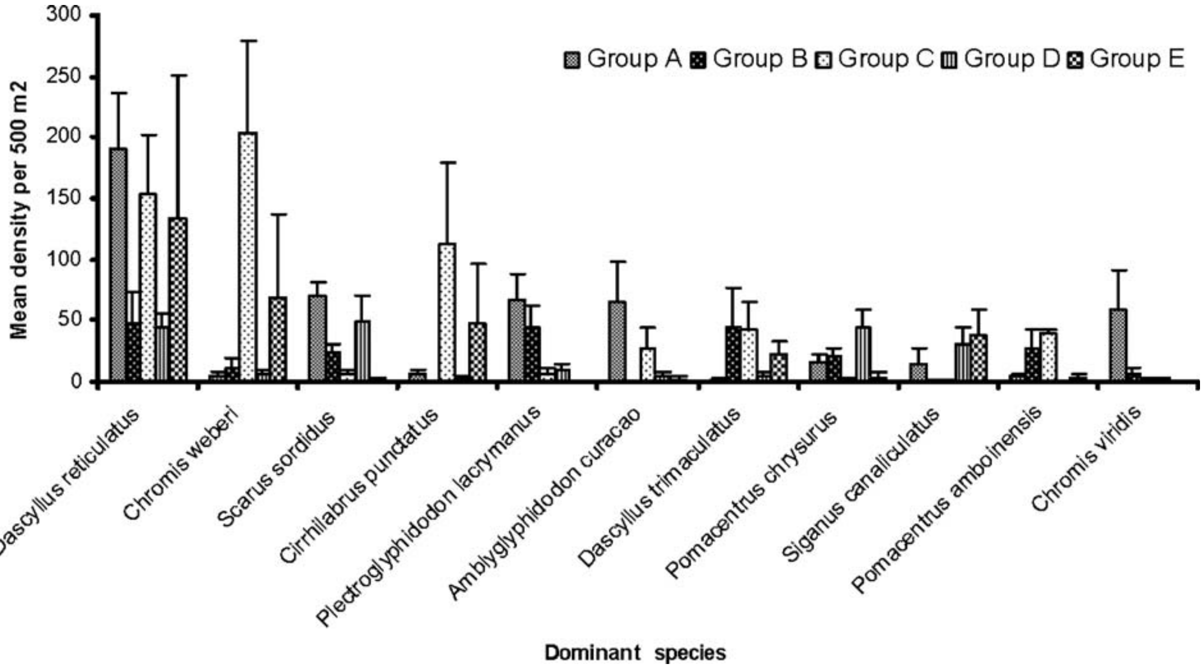

Fig. 4 Variation in mean density of the 11 most common species of the eight families in each of the five groups derived from cluster analysis and correspondence analysis. *Bar shows* standard error

exposure, visibility, depth, distance from the coast of the mainland) using CCA indicate that the percentage cover of living hard corals, depth and distance from the coast were the best at explaining spatial variation in community structure of fish fauna (Fig. 5). These three environmental variables explained 20.2% of the total variance in the species matrix for the eight common families (Table 3). Species such as *Chaetodon ornatissimus, Heniochus chrysostomus*, *Chaetodon trifascialis*, *Chaetodon baronessa*, *Centropyge heraldi*, *Naso lituratus*, *P. lepidogenys*, *Plectroglyphidodon dickii*, *Chromis margaritifer* and *C. viridis* were more abundant in shallow stations where high cover of living hard corals occurred. *Centropyge tibicen*, *Forcipiger flavissimus*, *Coris gaimard*, *C. punctatus*, *Acanthurus auranticavus*, *Choerodon schoenleinii* and *Halichoeres prosopeion* were more abundant at the deep stations. Species such as *Zebrasoma veliferum*, *C. binnotatus*, *Scarus forsteni*, *Scarus chameleon*, *Z. scopas*, *Centropyge vrolikii*, *Hemigymnus fasciatus* and *Chromis xanthura* were more abundant at the stations offshore, whereas *L. dimidiatus*, *Stegastes nigricans*, *C. chlorourus*, *Halichoeres melanurus*, *Abudefduf bengalensis*, *Hemiglyphidodon plagiometopon*, *S. canaliculatus*, *S. strigiventer*, *Pomacentrus* sp, *Siganus virgatus* and *Pomacentrus* sp2 were more abundant at the stations close to the coast of the mainland with low cover of living hard corals (Fig. 5).

In the second analysis between fish assemblages of eight families and the percentage cover of branching corals, tubular corals, encrusting corals, foliose corals, massive corals, sub-massive corals and mushroom corals show that factors of encrusting and branching corals, produced significant correlations with the fish species matrix with 23.3% of the total variance (Fig. 6 and Table 4). Species such as *Chaetodon unimaculatus*, *Chaetodon wiebeli*, *C. baronessa*, *Chaetodon speculum*, *Chaetodon refflesi*, *C. ornatissimus*, *C. heraldi*, *P. moluccensis*, *C. viridis*, *Z. veliferum*, *C. trifascialis*, *Chrysiptera* sp, *P. dickii*, *C. binnotatus*, *Neoglyphidodon melas* and *Thalassoma quinquevittatum* were associated with branching corals. *Z. scopas*, *Thalassoma hardwicke*, *S. spinus*, *Chaetodon punctatofasciatus*, *H. chrysostomus*, *H. plagiometopon* and *Scarus altipinnis* were correlated with encrusting corals (Fig. 6).

In the third analysis, the percentage cover of three factors (*Acropora*, *Millepora* and *Montipora*) among the eight most common genera including *Acropora*, *Fungia*, *Montipora*, *Pachyseris*, *Porites*, *Millepora*, *Galaxea*, *Hydrogonia* produced significant correlations with the fish species matrix with 21.3% of the

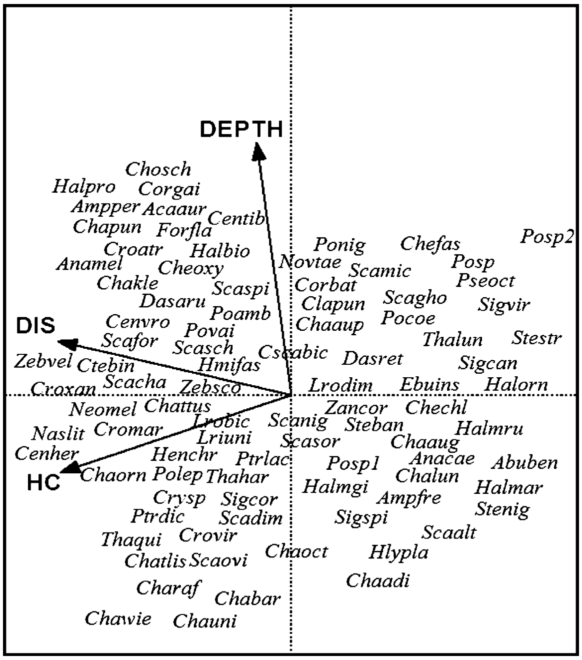

Fig. 5 Canonical Correspondence Analysis (CCA) of fish abundance of eight common families (Acanthuridae, Chaetodontidae, Pomacentridae, Pomacanthidae, Scaridae, Zanclidae, Labridae, Siganidae) and three significant environmental variables. *HC*: Hard coral cover (%); *Depth*: Depth of stations; *DIS*: Distance from the shore (mainland). Species overlapped in the centre were deleted. *Code* is given for the species explained in the text (Chaorn: *Chaetodon ornatissimus*, Henchr: *Heniochus chrysostomus*, Chatlis: *Chaetodon trifascialis*, Chabar: *Chaetodon baronessa*, Cenher: *Centropyge heraldi*, Naslit: *Naso lituratus*, Polep: *Pomacentrus lepidogenys*, Ptrdic: *Plectroglyphidodon dickii*, Cromar: *Chromis margaritifer*, Crovir: *Chromis viridis*, Centib: *Centropyge tibicen*, Forfla: *Forcipiger flavissimus*, Corgai: *Coris gaimard*, Clapun: *Cirrhilabrus punctatus*, Acaaur: *Acanthurus auranticavus*, Chosch: *Choerodon schoenleinii*, Halpro: *Halichoeres prosopeion*, Zebvel: *Zebrasoma veliferum*, Ctebin: *Ctenochaetus binnotatus*, Scafor: *Scarus forsteni*, Scacha: *Scarus chameleon*, Zebsco: *Zebrasoma scopas*, Cenvro: *Centropyge vrolikii*, Hemfas: *Hemigymnus fasciatus*, Croxan: *Chromis xanthura*, Lrodim: *Labroides dimidiatus*, Stenig: *Stegastes nigricans*, Chechl: *Cheilinus chlorourus*, Halmru: *Halichoeres melanurus*, Abuben: *Abudefduf bengalensis*, Hlypla: *Hemiglyphidodon plagiometopon*, Sigcan: *Siganus canaliculatus*, Stestr: *Stethojulis strigiventer*, Posp: *Pomacentrus* sp, Sigvir: *Siganus virgatus* and Posp2: *Pomacentrus* sp2)

total variance (Fig. 7, Table 5). Species such as *C. unimaculatus*, *C. wiebeli*, *C. ornatissimus*, *C. trifascialis*, *C. baronessa*, *T. quinquevittatum*, *Z. veliferum*, *P. dickii*, *P. moluccensis*, *C. viridis* and *C. binnotatus* were associated with *Acropora*. *C. strigosus*, *Z. scopas*, *Chromis xanthura* and *Labroides bicolor* were correlated with *Montipora*. *F. flavissimus*, *Chaetodon kleinii*, *Amblyglyphidodon leucogaster*, *C. tibicen*, *Bodianus loxozonus* and *P. amboinensis* were associated with *Millepora* (Fig. 7).

Discussion

Distribution and abundance

The total of 266 species of reef fishes recorded in the Nha Trang Bay MPA is very high compared to that found in some other areas around the Pacific Ocean such as Ryukyu Islands, southern Japan (156 species, Lecchini et al. 2003), Moorea—the central Pacific (98 species, Galzin 1987), Mauritius—Indian Ocean (107 species; Adjeroud et al. 1998) and Gulf of Thailand (241 species, Satapoomin 2000). Richness was, however, much lower than that found in the “Coral Triangle” of southeastern Asia, home of the world’s richest marine biodiversity, including Milne Bay—Papua New Guinea (1,040 species), Calamianes Islands—Palawan Philippines (736 species), Togean Banggai Islands—Sulawesi Indonesia (819 species) and Weh Island—Sumatra Indonesia (533 species) (Allen and Werner 2000) and Spratly Archipelagos (424 species, Chen et al. 1997).

Comparison of some common families of fishes also indicated that number of species of Labridae (47 species), Pomacentridae (46 species), Chaetodontidae (24 species), Scaridae (19 species), Acanthuridae (12 species), Siganidae (seven species) in Nha Trang Bay MPA was higher than that in the Gulf of Thailand (Satapoomin 2000), similar to the Ryukyu islands (Lecchini et al. 2003), lower than in Spratly Islands (Chen et al. 1997) and much lower than in Milne Bay—Papua New Guinea, Calamianes Islands—Palawan Philippines, Togean Banggai Islands—Sulawesi Indonesia and Weh Island—Sumatra Indonesia (Allen and Werner 2000). The difference in methods between studies may make some difference in the total species between Nha Trang Bay MPA and other areas in the “coral triangle” of southeastern Asia. For example, Allen and Werner (2000) used both visual census and rotenone collection and recorded very high numbers of species of gobiids (53–90 species), apogonids (26–56 species) and blennids (18–35 species) while very low species numbers in these families were recorded in the present study due to difficulties in identification to species underwater by

Table 3 Summary of the CCA performed on the abundance of fish species and significant environmental variables

	Axes $f1$	$f2$	$f3$
Correlations of environmental variables with ordination axes			
(1) Hard coral cover	−0.803	−0.297	−0.516
(2) Depth	−0.121	0.971	−0.205
(3) Distance from the mainland	−0.813	−0.208	0.544
Summary statistic for ordination axes			
Eigenvalues	0.181	0.141	0.076
Species–environmental correlations	0.912	0.872	0.890
Cumulative percentage variance			
of species data	9.2	16.3	20.2
of species–environmental relation	45.0	80.9	100
Sum of all unconstrained eigenvalues			1.969
Sum of all canonical eigenvalues			0.390
Monte Carlo probability for significance of the sum of all eigenvalues: 0.002			

Environmental factors were selected by forward selection.

visual census. These differences in methodology notwithstanding, the relatively high diversity in the reef fish community in this study indicates that Nha Trang Bay MPA is rich in species of coral reef fishes compared to other areas in Vietnam (Nguyen unpublished data) and around the Pacific Ocean. The comparatively high diversity of fishes (the present study) and reef building corals (Vo et al. 2004) on coral reefs in Nha Trang Bay MPA may be explained by the favourable conditions for reef development and recruitment from the "center of marine biodiversity" through dispersal of larvae in the South China Sea (Vo 1995), although the total area of coral reefs in the Nha Trang Bay MPA is much smaller than that to most typical coral reefs in "the Coral Triangle" of Southeast Asia.

Mean density of total fishes and some common families on coral reefs in Nha Trang Bay MPA were lower than that observed in some other areas in tropical waters. Mean density of total fishes was 628.9 individuals 500 m^{-2} and this value was lower than that found in the Ryukyu islands (1,129.5 individuals 500 m^{-2}; Lecchini et al. 2003). Mean density of Chaetodontidae in this study (15.8 individuals 500 m^{-2}) was similar to that in the Ryukyu islands (Lecchini et al. 2003) and the Caribbean (Findley and Findley 1985) but was lower than that in French Polynesia (115 individuals 500 m^{-2}; Findley and Findley 1985), southern Great Barrier Reef (65 individuals 500 m^{-2}; Fowler 1990) and the Red Sea (70 individuals 500 m^{-2}; Bouchon-Navaro 1981; Bouchon-Navaro and Bouchon 1989). Many species of target species of Serranidae, Lethrinidae, Lutjanidae, Carangidae, Haemulidae, Balistidae have become rare or absent from most surveyed reefs in this study. Furthermore, the low density of chaetodontids may be related to the high catch of these species to supply for marine aquaria in Vietnam and overseas during recent decades. Some high value ornamental and commercial species, for example angelfishes (*Pomacanthus imperator* and *Pomacanthus annularis*) and emperors (*Lethrinus nebulosus* and *Lethrinus miniatus*) were recorded in previous surveys but more recently these were mostly absent or extremely rare in Nha Trang Bay MPA (Vo et al. 2004). These reflect lower mean density of coral reef fishes in the Nha Trang Bay MPA.

Species richness and density of coral reef fishes in Nha Trang Bay MPA differed between sites and islands. Stations close to the mainland supported lower species richness and density compared to offshore stations, with the exception of Hon Vung. Although Hon Vung is located offshore and is not influenced by sedimentation, pollution, freshwater discharge from the mainland, the mean density of fishes was much lower than that at nearby Hon Cau, and sites close to the mainland. The low value at Hon Vung may be explained by extremely low cover of living hard corals caused by dynamite fishing, high numbers of coral feeding crown-of-thorns seastars *Acanthaster planci* and careless anchoring from fishing boats (Nguyen, personal observation). The low values of species richness and density at the sites close to the mainland are explained by low cover of living hard corals and habitat degradation through various impacts such as sedimentation, dynamite

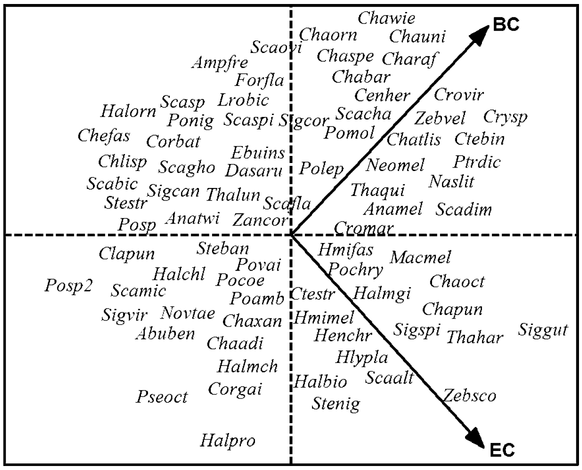

Fig. 6 Canonical Correspondence Analysis (CCA) showing correlations between fish abundance of the eight most common families of fishes (Acanthuridae, Chaetodontidae, Pomacentridae, Pomacanthidae, Scaridae, Zanclidae, Labridae, Siganidae) and two significant environmental variables (*BC*: Branching Corals and *EC*: Encrusting Corals). Species overlapped in the centre were deleted. *Code* is given for the species explained in the text (Chauni: *Chaetodon unimaculatus*, Chawie: *Chaetodon wiebeli*, Chabar: *Chaetodon baronessa*, Chaspe: *Chaetodon speculum*, Charaf: *Chaetodon rafflesi*, Chaorn: *Chaetodon ornatissimus*, Chatlis: *Chaetodon trifascialis*, Chapun: *Chaetodon punctatofasciatus*, Henchr: *Heniochus chrysostomus*, Zebvel: *Zebrasoma veliferum*, Ptrdic: *Plectroglyphidodon dickii*, Neomel: *Neoglyphidodon melas*, Pomol: *Pomacentrus moluccensis*, Crovir: *Chromis viridis*, Crysp: *Chrysiptera* sp, Hlypla: *Hemiglyphidodon plagiometopon*, Ctebin: *Ctenochaetus binnotatus*, Ctesgo: *Ctenochaetus strigosus*, Zebsco: *Zebrasoma scopas*, Lrobic: *Labroides bicolor*, Thaqui: *Thalassoma quinquevittatum*, Thahar: *Thalassoma hardwicke*, Forfla: *Forcipiger flavissimus*, Ambleu: *Amblyglyphidodon leucogaster*, Centib: *Centropyge tibicen*, Sigspi: *Siganus spinus* and Scaalt: *Scarus altipinnis*

fishing, pollution, freshwater discharge and outbreak of *A. planci* (Vo 1995; Vo et al. 2004). Habitat degradation is one of the main causes of reduced diversity of fish (Sano 2001).

Conversely, the high density of Pomacentridae, Acanthuridae, Chaetodontidae and Pomacanthidae at Hon Mun and Hon Cau may be explained by the good condition of coral reefs there. Most surveyed sites at Hon Mun and Hon Cau supported high cover of living corals, high visibility and fewer impacts from the mainland. Moreover, the high density of the families Siganidae and Scaridae at the sites on Hon Mieu, Hon Tam and Hon Mot, where coral reefs have been degraded due to various impacts from the mainland and annual dredging of the port, may be related to the high abundance of algae. Overgrowth by fleshy seaweeds, especially *Chnoospora implexa* enhanced by nutrient inputs from river discharge and dredge spoils occurred at south-west Hon Mieu, north Hon Tam, Hon Mot (Vo et al. unpublished data). High abundance of macro-algae likely provide more food for herbivorous fishes such as Siganidae and Scaridae at these sites.

Structure of fish assemblages

Five distinct groups of fish assemblages included shallow offshore assemblage, shallow nearshore and offshore assemblage, deep offshore assemblage, shallow and deep assemblage of nearshore and degraded reefs, and deep nearshore and offshore assemblage

Table 4 Summary of the CCA performed on the abundance of fish species and significant environmental variables (colonies of living corals)

	Axes	
	*f*1	*f*2
Correlations of environmental variables with ordination axes		
(1) Encrusting corals	0.688	0.726
(2) Branching corals	0.673	−0.739
Summary statistic for ordination axes		
Eigenvalues	0.138	0.092
Species–environmental correlations	0.866	0.888
Cumulative percentage variance		
of species data	11.7	23.3
of species–environmental relation	60.0	100.0
Sum of all unconstrained eigenvalues		1.969
Sum of all canonical eigenvalues		0.230
Monte Carlo probability for significance of the sum of all eigenvalues: 0.002		

Environmental factors were selected by forward selection.

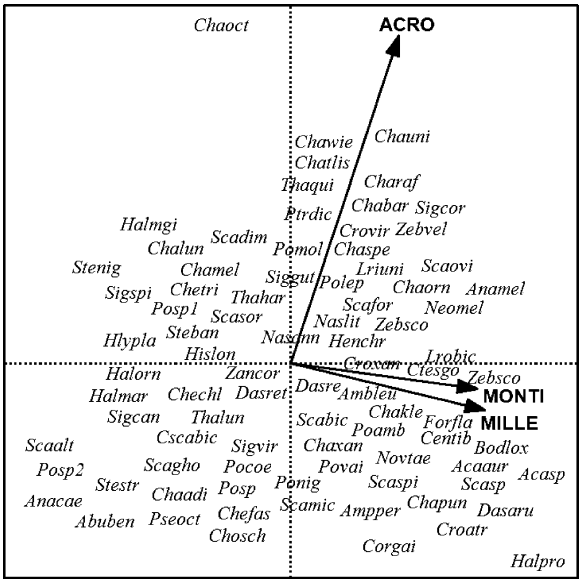

Fig. 7 Canonical Correspondence Analysis (CCA) showing correlations between fish abundance of the eight most common families of fishes (Acanthuridae, Chaetodontidae, Pomacentridae, Pomacanthidae, Scaridae, Zanclidae, Labridae, Siganidae) and three significant environmental variables (ACRO: *Acropora*; MON: *Montipora* and MILLE: *Millepora*). Species overlapped in the centre were deleted. *Code* is given for the species explained in the text (Chauni: *Chaetodon unimaculatus*, Chawie: *Chaetodon wiebeli*, Chaorn: *Chaetodon ornatissimus*, Chatlis: *Chaetodon trifascialis*, Chabar: *Chaetodon baronessa*, Thaqui: *Thalassoma quinquevittatum*, Zebvel: *Zebrasoma veliferum*, Pledic: *Plectroglyphidodon dickii*, Pomol: *Pomacentrus moluccensis*, Crovir: *Chromis viridis*, Ctebin: *Ctenochaetus binnotatus*, Ctesgo: *Ctenochaetus strigosus*, Zebsco: *Zebrasoma scopas*, Croxan: *Chromis xanthura*, Lrobic: *Labroides bicolor*, Forfla: *Forcipiger flavissimus*, Chakle: *Chaetodon kleinii*, Ambleu: *Amblyglyphidodon leucogaster*, Centib: *Centropyge tibicen*, Bodlox: *Bodianus loxozonus* and Poamb: *Pomacentrus amboinensis*)

were related to ecological (coral cover) and biophysical (distance from mainland) factors in Nha Trang Bay MPA. The station 3s, 7d and 8d located in the center and far from the Group D in correspondence analysis (Fig. 3b) compared to cluster analysis (Fig. 3a) is due to difference in data treatment between the two analyses, and these stations are actually included in the Group D. The distinction of fish assemblages displayed restricted patterns of zonation, especially at offshore sites where morphology and structure of the reefs and change in depth were different between reef flat and reef slope, consistent with numerous findings (Lecchini et al. 2003; see review by Williams 1991). Findings from this study also show that species richness and density of total fishes of the common families at the reef flat stations were higher than those at the reef slope stations. Many species were only found on the reef flat (i.e. *Pomacentrus* sp1, *P. moluccensis*, *C. viridis, P. lepidogenys*, *Chrysiptera* sp, *S. nigricans*, *P. dickii,* and *C. binnotatus*) or only on the reef slope (*C. punctatus*, *Pomacentrus* sp, *Pomacentrus* sp2, *F. flavissimus* and *C. tibicen*).

The distinction of the shallow and deep community of nearshore and degraded reefs at the sites close to the mainland is consistent with fishes forming specific disturbance-mediated assemblages. Dynamite fishing, sedimentation, pollution, river discharge and outbreak of crown-of-thorns seastars have been recently reported as main causes to damage and degradation of the coral reefs in Nha Trang Bay MPA (Vo 1995, Vo et al. 2004), Discharge of waters with low salinity, high sediments and nutrients during flooding has clearly influenced the coral reefs on the north coast of Hon Tre and Hon Mieu, Hon Tam and Hon Mot, as currents from Cai River travel down the channel between Hon Tre and Hon Mieu/Hon Tam/Hon Mot, and with an extra component from Be River. Furthermore, dredge spoils during dredging for Cau Da port expansion initially were dumped in close proximity to Hon Mieu, Hon Tam and Hon Mot, with transport of fine silts onto reefs there (Vo et al. unpublished data). More than 30,000 crown-of-thorns seastars have been collected and removed from the MPA and adjacent areas by local stakeholders since 2002, but seastars were still present in many areas such as Hon Tam and Hon Mieu, Hon Mot and even Hon Mun, although usually in low densities.

Correlations between spatial structure and environmental variables

Among 31 biological and physical factors, only three factors (living hard coral cover, depth and distance from the impacted sources in the mainland) in the first analysis, two factors (encrusting and branching corals) in the second analysis and three factors (*Acropora, Montipora* and *Millepora*) in the third analysis accounted for a significant proportion of variation of fish communities in Nha Trang Bay MPA. These factors accounted for relatively low proportions of the total variation of fish communities in the three analyses (20.2, 23.3 and 21.3% respectively). The small amounts of total variation in fish communities means that other factors not measured in

Table 5 Summary of the CCA performed on the abundance of fish species and significant environmental variables (genera of living corals)

	Axes		
	*f*1	*f*2	*f*3
Correlations of environmental variables with ordination axes			
(1) *Acropora*	−0.716	−0.684	0.139
(2) *Millepora*	0.106	−0.598	−0.794
(3) *Montipora*	0.533	−0.321	0.782
Summary statistic for ordination axes			
Eigenvalues	0.309	0.274	0.120
Species–environmental correlations	0.825	0.917	0.661
Cumulative percentage variance			
of species data	9.4	17.7	21.3
of species–environmental relation	43.9	82.9	100.0
Sum of all unconstrained eigenvalues			3.293
Sum of all canonical eigenvalues			0.702
Monte Carlo probability for significance of the sum of all eigenvalues: 0.002			

Environmental factors were selected by forward selection.

this study, such as reef complexity (rugosity), coral abundance, coral richness, species interactions, sedimentation and pollution, may also be important influences on the spatial structure of fish communities in Nha Trang Bay. As introduced above, results from previous studies have shown that the spatial structure of reef fish communities was correlated with rugosity (Luckhurst and Luckhurst 1978; Jennings et al. 1996; Chabanet et al. 1997; Cadoret et al. 1999), coral abundance and richness (Fowler 1990; Galzin et al. 1994; Chabanet et al. 1997). The remaining factors that were not selected by CCA in this study does not mean that these factors are unimportant in structuring fish communities elsewhere. Some previous studies have demonstrated that structure of fish communities or specific families may be correlated with reef zone (Lecchini et al. 2003), or wave exposure (Gust et al. 2001).

The biological factors associated with the spatial distribution and abundance of fish communities in Nha Trang Bay were cover of living hard corals, encrusting corals, branching corals, *Acropora*, *Montipora* and *Millepora*. These results are consistent with many previous studies which have demonstrated positive correlations between living coral cover and fish diversity and abundance (e.g. Carpenter et al. 1981; Bell and Galzin 1984; Cadoret et al. 1999). The encrusting corals, branching corals, *Acropora*, *Montipora* and *Millepora* provide shelter and food for highly specialized species like corallivorous chaetodontids (Cadoret et al. 1999), and provide shelter for pomacentrid species (Ohman and Rajasuriya 1998).

Of the biophysical factors, distance from the coast of the mainland (source of impacts from the mainland) was also important in structuring fish communities. This factor is likely to represent levels of disturbance and impacts from various sources on the mainland, for example: sedimentation, pollution, and discharge from the rivers. It is clear that coral reefs at the sites close to the coast of the mainland have been degraded (Vo 1995; Vo et al. 2004) and waters were very turbid compared to the offshore sites during the survey. These findings are consistent with previous studies which demonstrated that high sedimentation and low transparency indirectly influence fish distribution (Letourneur et al. 1998) or directly reduce coral diversity and coverage (Loya 1976).

Conclusions

The results from this study showed that fish assemblages of coral reefs in Nha Trang Bay MPA were diverse in terms of species richness compared to many other areas of the Indo-Pacific outside the 'Coral Triangle.' Fish communities were not homogeneous in spatial distribution and structure, with five distinct assemblages present among islands in Nha

Trang Bay MPA. The spatial distribution and structure of the fish assemblages were associated with eight significant biological and physical variables (cover of living hard coral, encrusting corals, branching corals, *Acropora*, *Montipora*, *Millepora*, depth and distance from the coast of the mainland).

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