RESEARCH ARTICLE

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Community Structure of Coral Reef Fishes at a Sink Reef in the Inner Gulf of Thailand

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ABSTRACT Reef fish assemblages in the inner Gulf of Thailand exist in a low salinity, high- sediment environment with limited connection to other reefs. Monitoring of reef fish assemblages at Khangkao Island from October 1997 to November 1998 revealed 83 species from 28 families. The pomacentridae family was dominant in terms of both number of species and abundance. Small water-column feeders (13 species, 40% abundance) and small herbivores (4 species, 39% abundance) dominated the assemblages. Invertebrate feeders and piscivores were less prominent, with a moderate number of species in low abundance. The differences in species composition between sites arose because habitat is a major source of variation, while the time of year of sampling and reef orientation with reference to seasonal winds were less important. Variation among stations was detected only in fish assemblages of the reef slope. Temporal variation was also detected but mainly on dominant fish taxa in each study site. Community parameters indicated a similar pattern where habitat was a major source of variation in species composition. The results suggest that fish assemblages on reef slopes have higher species and abundance than other habitats. The present structure of the fish assemblage of Khangkao Island illustrates a shift from the structure 10 years ago. Benthic invertebrate feeders declined severely while small plankton feeders and herbivores increased. This may reflect a pattern of increasing disturbance affecting reef fish assemblages in the inner Gulf of Thailand.

KEYWORDS: reef fishes, community structure, connectivity, Gulf of Thailand.

INTRODUCTION

Many marine organisms including reef fishes are assumed to have an open population.[1] For coral reefs, this assumption leads to the concept of connectivity where source reefs facilitate seeding of sink reefs.[2] This concept also leads to the question of how different reefs maintain their populations and communities of organisms. This question may also relate to disturbances influencing different reefs. The study of ecosystems at their environmental limits is ideal for examining ecological processes regulating populations and communities of reef organisms.[3]

Differences in reef fish assemblage structure have been recognized over different areas with different underlying causes. Different zoogeographic regions demonstrate very large-scale spatial variation due to evolutionary history and larval dispersal.[4, 5] The influences from land relating to reef development, such as run-off water, have been demonstrated for the Great Barrier Reef and Red Sea.[6-10] At smaller spatial scales, reef habitat variation due to geomorphological differences[8-10] and also human disturbance[11] are known. There has been little work, however, documenting the community structure of assemblages of individual reefs with limited connectivity in a low salinity and nutrient-rich environment.

The inner part of the Gulf of Thailand (inner Gulf) is the northwest apex of the Gulf of Thailand. It has a squarish shape covering an area of 10,360 km^2 fringed by 300 km of coastline (3.2% of the total area and 4.3% of the coastline of the entire Gulf of Thailand). Coral formations are found only on the East Coast of the inner Gulf, where a chain of islands known as the Sichang Islands are located inner-most. One of these, Khangkao Island, located in the southern-most part of the Sichang Islands, has the best-developed and largest area of coral formations. These coral formations are classified as coral assemblages and are characterized as poorly developed or with no reef framework.[12] Primary factors limiting reef development here are low salinity and high nutrient concentrations maintained by runoff from four major rivers.[13] Water circulation is also limited where tidal currents cause north-south movements

of water mass in the area.[14] The connection to other reefs is limited as the nearest coral reefs are found only in the south. These coral formations at Khangkao Island can be considered as sink reefs from their position at the downstream end of the Gulf of Thailand. This raises the question of how these reefs maintain their populations and community structure. Furthermore, their sensitivity to any sources of disturbance is also of interest.

In this study, we investigated reef fish assemblages on such a reef system in a low salinity environment with limited larval supply from other reefs. A description of reef fish assemblages at Khangkao Island was first provided in 1986. To date, there is little new information on fish assemblages from this area. During this time, anthropogenic disturbances to this area have increased, especially from port construction, rock mining and tapioca dust. The intention of this report is to provide an updated description of the community structure of reef fishes and to determine their spatial and temporal variations.

Materials and Methods

Study sites

Khangkao Island (13°06′ 30″ N, 100°48′ E) is located in the southern-most part of the Sichang Islands in the inner Gulf of Thailand (Fig 1). It is 7 km off the east coast of Sriracha District, Chonburi Province, and 30 km south of the mouth of the Bangpakong River. It is a small island (1.5 km x 0.8 km) with narrow strips of coral assemblages, generally 30-100 m in width and 3-5 m in depth. Reef development is generally limited. Structures of coral assemblages here were described in 1986.[16] Four localities around the island were selected for study: North reef (N), Northeast reef (NE), Southeast reef (SE), and Southwest reef (SW). The coral assemblages in each locality are subjected to different wind and wave actions. The SW reef is exposed to the southwest monsoon and experiences the strongest wave action, while N and NE reefs are exposed to the northeast monsoon and receive only moderate wind and wave action. The SE reef is sheltered and relatively free from monsoonal influence.

Sampling procedures

This study was conducted from October 1997 to November 1998. Fishes were censussed on 11 occasions spanning 14 months at 4 localities. These localities had 2 habitats, reef flat and reef slope, which differed in substrate types, depth and influence from wave action. The term "site" will be used to represent the sampling area of each habitat at each locality. At each site fish were counted along 5 random transects each 30 m long and 5 m wide. Transects were positioned with their long axes parallel to the shoreline and were separated by approximately 10-15 m. Instantaneous visual census[17] was employed by a SCUBA diver who simultaneously identified and counted fish during the deployment of the measuring tape. However, small and cryptic species, eg gobies and blennies, were excluded from the census, as they were difficult to see and count accurately. A previous study[15] showed that the proportion of these groups at Khangkao Island was small, and considered them to be only a minor component.

Fish community structure was categorized according to the feeding niche of each species. These categories were defined on the basis of both visual observation and from a number of references.[7, 18-19]

Data analyses

Canonical Discriminant Analysis (CDA) was employed to test the hypothesis that time, locality, and habitat influenced fish community structure. *A priori* tests were performed on the data matrix to verify tha the data satisfy the assumptions of parametric statistical methods.[20] A log (x+1) transformation, therefore, was applied to stabilize the variance of the data set. This transformation was also used to reduce the chance that a few extremely dominant species would skew the results of CDA. The CDA analysis was performed on the centered data matrix using SPSS 7.5 for Windows.[21] The canonical structure of each species was used as the "responsive" factor for the discrimination of sites (ie the interpretation indicates fishes that would be the most different between two sites). Angular interpretation was thus used for the ordination plot produced by CDA.

Community characteristics were described by four parameters for the purpose of ANOVA: total abundance, species richness, diversity, and evenness indexes. The abundance of all fishes at each site was calculated as the mean abundance from five replicates. Therefore, mean abundance of all fishes was expressed as individuals per 150 m^2. Species richness was a count of total species found in each site. A Shannon-Wiener diversity index ($H' = -\Sigma p_i \ln p_i$) and evenness index ($E = H'/\ln S$) were calculated using natural logarithms throughout.[22, 23] Computation of these community parameters

(except total abundance) was executed on mean abundance at each site rather than abundance at each transect. These parameters were considered as semi-quantitative variables rather than quantitative. For example, the mean number of species of each site calculated from replicate transects tends to underestimate the actual number of species found at each site. The actual number of species of each site, therefore, should be the cumulative total from each replicate rather than averaged. This is also the problem when calculating the species diversity and evenness indices.

ANOVA was used to test the hypothesis that there are influences on community parameters by sampling time, locality and habitat. Full factorial three-way ANOVA was applied to the total abundance, while three-way ANOVA without replicates was applied to species richness, species diversity and

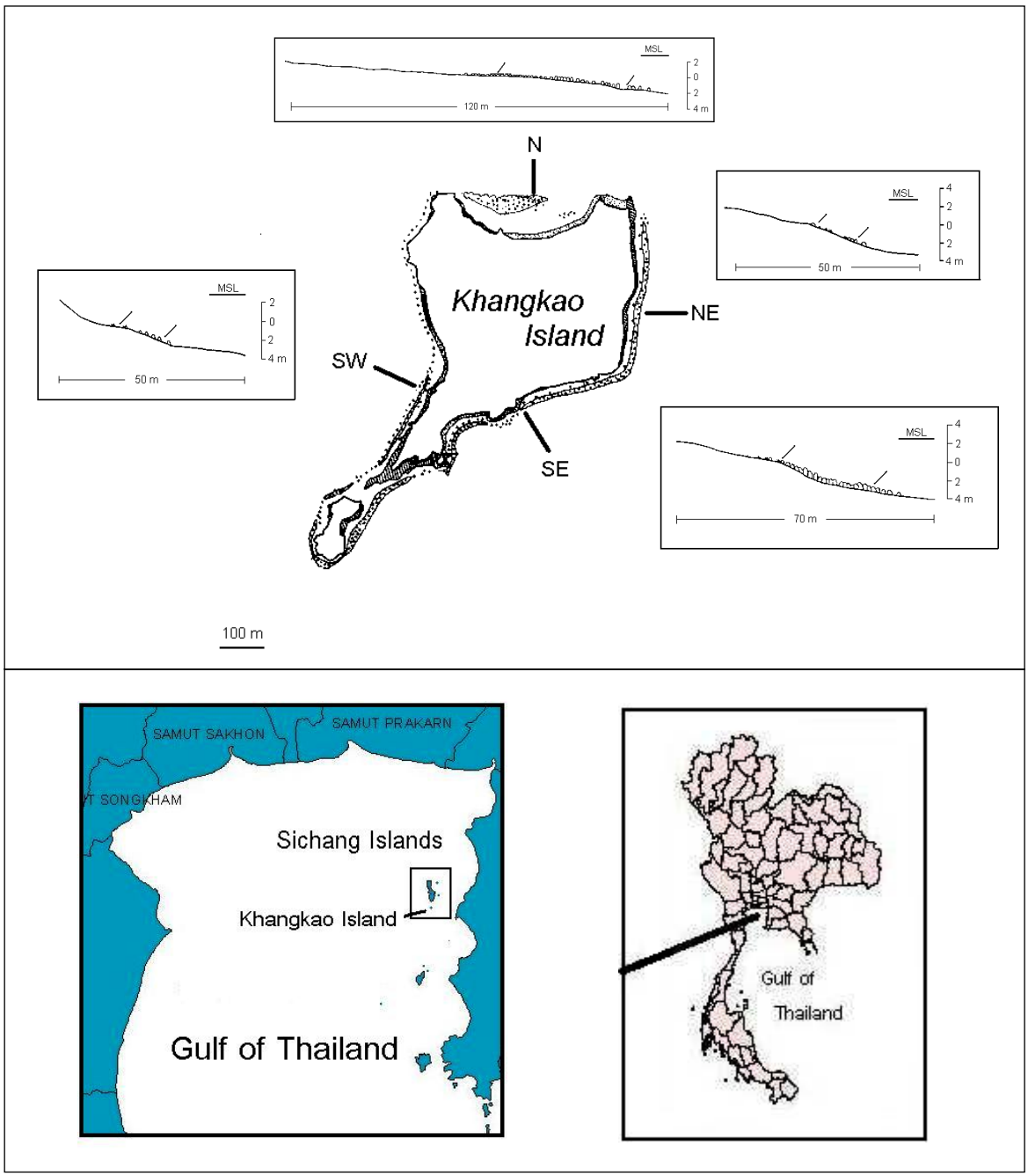

Fig 1. Map of Khangkao Island showing 4 study localities with profiles indicated 2 sampling habitats.

evenness indexes. This is because these community parameters are calculated from mean of each site, and therefore lack replication. In this case, error mean square does not exist and the second and third order interaction MS is used as F-denominator.[24] For statistical hypothesis testing, a decision level of 0.05 was used throughout the study, but the lowest probability level was also reported where appropriate.

Results

Assemblage structure

A total of 139,764 fish were counted during the study period. Eighty-three species belonging to 29 families were found. Species and mean abundances associated with each habitat at four localities around Khangkao Island are presented in Table 1. Pomacentridae dominated this assemblage with 20 species and represented 76.9% of total abundance (Table 2). Five families were represented as minor components: Labridae, Apogonidae, Nemipteridae, Carangidae and Chaetodontidae, each family contributing 2-6 species and representing 2-6% of total abundance. The families Serranidae, Siganidae and Lutjanidae were each represented by 5-6 species. Only 1 or 2 species from each of several families were recorded. The relative abundance of these poorly represented families was less than 1%.

According to ecological categories (Table 3), omnivores and herbivores dominated the assemblage represented by 32 species accounting for 81.5% of the total abundance. Within these categories, small site-attached herbivores (39.7%) and water column feeders (39.6%) were the most dominant groups. Remarkably, small site-attached fish were represented by only 4 species dominated solely by *Pomacentrus cuneatus*. In comparison, water column feeders were represented by 13 species, dominated by *Neopomacentrus filamentosus, N. anabantoides* and *N. cyanomos*. Invertebrate feeders had the highest species number, 35 species but representing only about 17.5% of total abundance. Among this group, *Scolopsis* spp. and *Halichoeres* spp. were the most abundant. For the piscivores, 16 species were sighted but their abundance was low, representing less than 1% of the total. Most of the piscivores found were small, certainly under 15 cm. in total length such as *Cephalopholis boenack*.

Species composition

The results from CDA illustrated spatio-temporal variability in community structure of fish in the study area (Fig 2). The first two discriminant functions explained 63.9% of total variance in the data set. It is clear that the community structure of fish on the reef flat and the reef slope is distinct. Community structure of fish on the reef flat at all localities showed less variation, and species characterizing this habitat were *Pomacentrus chrysurus*, *Abudefduf bengalensis* and *Gerres filamentosus*.

On the reef slope, by contrast, there were variations between localities where N and NE had similar structure while SW and SE had different structures. Fishes characterizing reef slopes of N and NE reefs were *Halichoeres purpurescens*, *Neopomacentrus filamentosus*, *N. cyanomos*, *N. bankerii*, *N. anabantoides*, *Cheilodipterus quinquelineatus* and *Diploprion bifasciatus*. The SE reef slope is characterized by *Neoglyphidodon nigroris*, *Hemiglyphidodon plagiometopon* and *Pomacentrus moluccensis*. *Apogon doederleini*, *A. cyanosoma* and *Halichoeres nigrescens* dominate the reef slope of the SW reef.

CDA of species composition over the entire sampling period showed a consistent pattern of the same site aggregated in the same group on different months. This result suggests that the community structure of each site varies temporally in the major fish components.

Community parameters

Total abundance varies over test factors, as there was significant Time x Locality x Habitat interaction (Table 4). Habitat, however, was a major source of variation accounting for 61.6% while Locality and Time explained less variation. As variation between localities was not prominent, total abundance was averaged across localities (Fig 3a). Fishes on reef slopes (300-600 indiviuals/150m^2) were more abundant than those on reef flats (200 indiviuals/150m^2). However, fish abundance on reef slopes exhibited fluctuations over sampling occasions, while fish abundance on reef flat remained relatively stable. Total abundance of fish on reef slopes was highest in December-January and in July-September; both maxima followed the influx of recruits the previous month.[25]

Results from ANOVA suggested some variation in species richness over test factors, significantly Time x Locality and Locality x Habitat interactions. The variance components, however, indicated that Habitat (24.9%) and Time (22.2%) were the major contributing sources of variation while other sources contributed less than 10%. Locality, therefore, was dropped and means are illustrated for Time and

Table 1. Mean abundance ±SE (no/150m^2) by species of reef fishes observed on 2 habitats of 4 localities at Khangkao Island, inner Gulf of Thailand, during 1997-1998. (* detail in Table 3, ** P – Permanent, V - Visitor)

		Ecological		N		NE		SE		SW	
Family	Species	Guild*	Residency**	Flat	Slope	Flat	Slope	Flat	Slope	Flat	Slope
Pomacentridae	*Abudefduf bengalensis*	4	P	3.6±0.5	3.8±0.4	10.6±1.3	7.0±0.9	24.4±2.7	7.2±1.4	30.4±3.1	26.4±2.5
	Abudefduf sexfasciatus	4	P	0.9±0.3	0.51±0.2	-	0.4±0.2	<0.1	0.2±0.1	3.5±0.9	4.0±1.0
	Abudefduf vaigiensis	4	P	-	-	-	-	<0.1	-	0.1±0.1	0.3±0.1
	Amblyglyphidodon curacao	4	P	0.2±0.1	0.2±0.1	<0.1	0.3±0.1	0.2±0.1	0.4±0.1	<0.1	-
	Amphiprion perideraion	6	P	0.1±0.1	0.1±0.1	0.2 ±0.1	0.3±0.2	0.4±0.1	0.3±0.2	0.5±0.1	0.3±0.1
	Chromis cinerascens	4	P	0.9±0.9	9.8±4.8	-	0.8±0.5	-	0.9±0.8	-	-
	Hemiglyphidodon plagiometopon	2	P	0.2±0.1	0.4±0.1	0.1±0.03	0.7±0.1	0.5±0.1	1.4±0.2	-	-
	Neoglyphidodon melas	6	P	0.1±0.1	<0.1	-	-	0.2±0.1	<0.1	<0.1	0.2±0.1
	Neoglyphidodon nigroris	6	P	0.1±0.1	0.4±0.1	<0.1	0.4±0.1	0.5±0.1	3.3±0.3	<0.1	0.1±0.1
	Neopomacentrus anabatoides	4	P	12.0±4.4	72.4±12.7	2.0±0.9	61.2±14.2	0.2±0.2	94.6±16.5	1.8±1.3	46.1±9.5
	Neopomacentrus cyanomos	4	P	0.6±0.6	34.0±6.3	0.6±0.6	44.1±6.7	-	27.9±5.9	-	15.1±4.6
	Neopomacentrus bankieri	4	P	0.4±0.4	23.2±3.5	-	18.0±3.3	-	32.6±4.3	-	2.5±0.6
	Neopomacentrus filamentosus	4	P	22.3±4.7	156.2±19.7	2.4±1.3	90.6±10.4	-	70.0±13.2	<0.1	16.2±3.8
	Pomacentrus cuneatus	1	P	116±7	139±9	120±4	83±6	99±5	130±7	135±6	156±10
	Pomacentrus chrysurus	1	P	1.8±0.2	0.1±0.1	0.1±0.1	12.2±5.3	3.8±0.4	<0.1	0.5±0.2	0.5±0.3
	Pomacentrus moluccensis	1	P	-	0.1±0.1	-	0.7±0.2	-	0.9±0.2	-	-
	Pomacentrus tripunctatus	1	P	0.2±0.2	-	0.1±0.1	-	0.1±0.1	-	<0.1	-
	Plectroglyphidodon lacrymatus	6	P	-	<0.1	-	-	-	-	-	-
	Cheiloprion labiatus	6	P	-	-	-	<0.1	-	-	<0.1	-
	Stegastes obreptus	2	P	<0.1	0.4±0.1	0.2±0.1	<0.1	0.4±0.1	0.1±0.1	0.2±0.1	-
Labridae	*Halichoeres chloropterus*	6	P	10.8±0.8	8.6±0.8	9.6±0.9	9.7±0.7	8.5±0.8	9.9±0.7	9.4±0.7	11.2±0.8
	Halichoeres purpurascens	6	P	1.3+0.2	5.4+0.5	0.2+0.1	3.2+0.4	0.3+0.1	5.0+0.5	0.2±0.1	3.4+0.4
	Halichoeres nigrescens	6	P	3.6±0.4	5.1±0.5	6.3±0.5	4.9±0.3	4.1±0.3	4.3±0.4	6.7±0.5	9.7±0.7
	Halichoeres vrolikii	6	P	0.3±0.2	0.6±0.2	-	-	0.1±0.1	0.9±0.3	-	0.3±0.1
	Halichoeres poecilopterus	6	P	0.3±0.1	0.1±0.1	-	<0.1	-	0.1±0.1	-	0.3±0.1
	Hemigymnus melapterus	6	P	-	-	-	<0.1	<0.1	<0.1	-	-
	Cheilinus fasciatus	6	P	-	-	-	-	-	<0.1	-	-
	Choerodon schoenleinii	6	P	-	-	-	-	-	-	-	<0.1
Apogonidae	*Apogon doederleini*	7	P	0.6±0.4	1.6±0.9	-	5.6±2.2	-	2.2±1.1	0.6±0.6	35.5±6.3
	Apogon cyanosoma	7	P	-	5.3±2.2	-	2.6±1.0	-	0.6±0.6	0.1±0.1	11.8±3.0
	Archamia fucata	7	P	-	-	-	0.3±0.2	-	0.1±0.1	-	-
	Cheilodipterus quinquelineatus	7	P	0.1±0.1	10.7±1.8	-	4.0±0.9	-	6.8±1.6	-	11.2±4.6
	Cheilodipterus macrodon	7	P	-	3.3±1.0	-	0.3±0.2	-	1.8±0.9	-	-
	Cheilodipterus artus	7	P	-	3.4±1.7	-	0.4±0.4	-	-	-	-
Serranidae	*Cephalopholis boenak*	8	P	0.9±0.2	1.3±0.2	1.8 ±0.3	0.3±0.1	0.6±0.1	1.5±0.2	2.1±0.3	2.8±0.3
	Cephalopholis formosa	8	P	<0.1	0.4±0.1	0.1±0.1	0.2±0.1	<0.1	0.4±0.1	<0.1	0.4±0.1
	Cephalopholis cyanostigma	8	P	-	-	-	-	<0.1	-	-	-
	Epinephelus merra	8	P	<0.1	-	-	-	<0.1	-	<0.1	<0.1
	Epinephelus fasciatus	8	P	-	-	-	-	-	-	-	<0.1
	Epinephelus malabricus	8	P	-	<0.1	-	<0.1	-	-	-	-
Siganidae	*Siganus guttatus*	3	V	0.6±0.2	2.2±0.5	0.3±0.1	5.3±1.0	2.5±0.9	3.1±0.5	0.5±0.2	1.2±0.6
	Siganus javus	3	V	<0.1	1.0±0.7	<0.1	0.7±0.3	1.2±0.9	0.1±0.1	0.2±0.1	2.3±1.0
	Siganus virgatus	3	V	-	-	-	<0.1	<0.1	-	-	-
	Siganus canaliculatus	3	V	-	-	-	0.6±0.3	0.3±0.3	0.6±0.4	<0.1	0.1±0.1
	Siganus corallinus	3	V	-	-	<0.1	-	-	<0.1	-	-

Table 1. Cont'd.

Family	Species	Ecological Guild*	Residency**	N Flat	N Slope	NE Flat	NE Slope	SE Flat	SE Slope	SW Flat	SW Slope
Lutjanidae	*Lutjanus argentimaculatus*	9	P	-	-	-	-	-	< 0.1	-	-
	Lutjanus russelli	9	P	-	0.4 ± 0.2	-	0.5 ± 0.3	-	2.9 ± 1.9	< 0.1	< 0.1
	Lutjanus vitta	9	P	-	0.1 ± 0.1	-	1.8 ± 0.7	-	1.3 ± 0.7	-	0.5 ± 0.2
	Lutjanus carponotatus	9	P	-	0.1 ± 0.1	-	-	-	0.5 ± 0.2	-	-
	Lutjanus fulviflamma	9	P	< 0.1	< 0.1	-	-	-	< 0.1	-	-
Nemipteridae	*Scolopsis dubiosus*	6	V	1.0 ± 0.2	0.6 ± 0.2	0.1 ± 0.1	1.1 ± 0.3	0.4 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	0.9 ± 0.2
	Scolopsis margaritifer	6	V	2.2 ± 0.4	1.2 ± 0.2	2.3 ± 0.4	1.7 ± 0.3	1.4 ± 0.3	1.5 ± 0.3	0.2 ± 0.1	1.1 ± 0.3
	Scolopsis ciliatus	6	V	5.7 ± 1.0	5.7 ± 1.0	4.0 ± 0.5	20.0 ± 2.9	1.2 ± 0.3	8.6 ± 1.4	5.5 ± 0.8	17.1 ± 1.9
	Scolopsis vosmeri	6	V	-	-	-	0.02 ± 0.02	-	0.04 ± 0.03	-	-
Carangidae	*Atule mate*	5	V	1.8 ± 0.8	4.5 ± 1.4	0.5 ± 0.3	4.5 ± 1.3	1.6 ± 1.0	6.7 ± 2.3	1.5 ± 0.7	17.4 ± 4.5
	Selaroides leptolepis	5	V	0.3 ± 0.2	1.2 ± 1.0	< 0.1	0.1 ± 0.1	-	0.3 ± 0.2	0.3 ± 0.2	2.0 ± 1.0
	Gnathanodon speciosus	5	V	< 0.1	-	-	-	-	-	< 0.1	< 0.1
Haemulidae	*Plectorhynchus chaetodonoides*	9	P	-	-	-	< 0.1	-	< 0.1	-	-
	Plectorhynchus gibbosus	9	P	-	0.1 ± 0.1	-	< 0.1	-	< 0.1	-	-
	Diagramma pictum	9	P	-	0.2 ± 0.1	-	< 0.1	-	< 0.1	-	< 0.1
Chaetodontidae	*Chaetodon octofasciatus*	6	P	8.0 ± 1.6	7.6 ± 0.9	6.0 ± 0.7	6.5 ± 0.7	6.6 ± 0.6	6.0 ± 0.6	5.2 ± 0.5	6.5 ± 0.7
	Chelmon rostratus	6	P	0.2 ± 0.1	0.3 ± 0.1	-	0.1 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.1 ± 0.1	0.3 ± 0.1
Mugilidae	*Ellochelon vaigiensis*	3	V	-	-	-	0.1 ± 0.1	0.2 ± 0.2	-	0.1 ± 0.1	-
	Moolgarda seheli	3	V	-	-	-	1.4 ± 0.7	0.4 ± 0.2	0.7 ± 0.6	< 0.1	0.5 ± 0.4
Pomacanthidae	*Pomacanthus annularis*	6	P	-	< 0.1	-	-	-	< 0.1	-	-
	Pomacanthus sexstriatus	6	P	< 0.1	0.2 ± 0.1	< 0.1	< 0.1	0.2 ± 0.1	0.4 ± 0.1	-	0.3 ± 0.1
Dasyatidae	*Taeniura lymma*	6	P	< 0.1	< 0.1	-	-	-	-	-	-
Gobiesocidae	*Diademaichthys lineatus*	4	P	< 0.1	0.6 ± 0.1	< 0.1	0.1 ± 0.1	-	0.3 ± 0.1	< 0.1	0.6 ± 0.1
Holocentridae	*Sargocentron rubrum*	7	P	< 0.1	4.6 ± 1.0	< 0.1	2.7 ± 0.8	< 0.1	0.2 ± 0.1	0.2 ± 0.1	1.1 ± 0.3
Centropomidae	Psammoperca waigiensis	8	P	< 0.1	< 0.1	< 0.1	< 0.1	-	< 0.1	-	-
Grammistidae	*Diploprion bifasciatus*	6	P	0.4 ± 0.1	1.7 ± 0.2	0.5 ± 0.2	1.7 ± 0.2	0.2 ± 0.1	1.6 ± 0.3	0.1 ± 0.1	1.8 ± 0.3
Leiognathidae	*Leiognathus equulus*	6	V	-	-	-	-	-	-	< 0.1	-
Caesionidae	*Caesio cuning*	5	V	0.1 ± 0.1	0.8 ± 0.4	-	1.8 ± 0.8	-	3.7 ± 1.2	-	7.1 ± 1.9
Gerreidae	Gerres filamentosus	6	V	< 0.1	-	0.2 ± 0.2	0.1 ± 0.1	1.8 ± 0.8	0.3 ± 0.2	11.8 ± 3.4	0.9 ± 0.4
Mullidae	*Upeneus tragula*	6	V	0.2 ± 0.1	< 0.1	0.2 ± 0.1	4.3 ± 2.0	0.2 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.5 ± 0.1
Pempheridae	*Pempheris oualensis*	7	P	-	4.2 ± 1.4	-	2.3 ± 0.7	-	5.3 ± 1.3	-	9.6 ± 2.6
Kyphosidae	*Kyphosus vaigiensis*	3	V	-	-	-	< 0.1	0.3 ± 0.1	0.2 ± 0.1	< 0.1	-
Sphyraenidae	*Sphyraena obtusata*	9	V	1.5 ± 1.1	0.2 ± 0.2	-	-	-	-	-	-
Scaridae	*Scarus ghobban*	3	V	-	-	-	-	< 0.1	< 0.1	-	-
Microdesmidae	*Ptereleotris* sp.	4	P	0.9 ± 0.9	9.5 ± 4.0	1.6 ± 1.6	28.0 ± 6.5	-	-	0.1 ± 0.1	-
Monacanthidae	Monacanthus chinensis	6	V	< 0.1	< 0.1	-	-	-	-	< 0.1	< 0.1
Ostraciidae	*Ostracion cubicus*	6	P	< 0.1	< 0.1	< 0.1	0.14 ± 0.06	-	< 0.1	0.11 ± 0.05	0.18 ± 0.05
Diodontidae	*Diodon liturosus*	6	P	< 0.1	-	< 0.1	< 0.1	-	-	-	< 0.1

Habitat (Fig 3b). It is clear that species richness on reef slopes (22-32 species) was higher than that on reef flats (15-20 species). The number of species at both habitats over time had a similar pattern (non-significant interaction for Time x Habitat). There was some fluctuation over sampling times with species richness being highest in December, keeping stable until dropping sharply in May, before increasing again with little fluctuation.

Habitat was also a major source of variation in species diversity and evenness indices, with their variance components representing 80.6% and 69.8% of total variance, respectively (Table 3). There was a significant Locality x Habitat interaction on

Table 2. Major coral reef fish families found at Khangkao Island during 1997-1998 compare with 1984[15] .

	1997/98		1984	
Family	**No. species**	**% abundance**	**No. species***	**% abundance**
Pomacentridae	20	76.9	10	54.1
Labridae	8	5.6	4	1.6
Apogonidae	6	4.2	5	15.5
Serranidae	6	0.5	2	2.9
Siganidae	5	0.9	-	-
Lutjanidae	5	0.3	4	<1
Nemipteridae	4	3.2	-	-
Carangidae	3	1.7	1	<1
Haemulidae	3	0.02	-	-
Chaetodontidae	2	2.1	2	6.9
Mugilidae	2	0.1	-	-
Pomacanthidae	2	0.05	-	-
Others	17	4.5	42	ca. 19
Total	**83**	**100**	**70**	**100**

* including cryptic species

Table 3. Composition of fish assemblage on coral reef of Khangkao Island classified based on ecological guild.

Ecological guilds	**No. species**	**% abundance**
A) Herbivores	15	39.7
1. Site attach	4	38.5
2. Gardener	2	0.2
3. Homerange	9	1.0
B) Omnivores	17	41.8
4. Water column	13	39.6
5. Pelagic	4	2.2
C) Invertebrate feeders	35	17.5
6. Substrate feeders	27	12.1
7. Nocturnal feeders	8	5.4
D) Predators	16	0.9
8. Site attach	7	0.6
9. Homerange	9	0.4
Total	**83**	**100**

species diversity and evenness indices (Table 1). Fig 3b and 3c illustrate that reef slope had higher fish diversity and more evenness than reef flat. Species diversity at both habitats showed the same pattern of fluctuations over time. The species diversity index increased from October to a peak in January before decreasing slightly to July and then increasing again. For the evenness index, the fluctuation over time was less prominent (no significant effects relevant to Time were detected).

Discussion

The prominent features of Khangkao's reef fish assemblages, in general, are low species richness and absence of many reef fish taxa eg Acanthuridae. In the previous records in 1986, fishes at Khangkao Island were 49 species from 18 families.[25] In 1986, 70 species from 31 families, including some cryptic species, were reported.[15] This study in 1998 reports 83 species from 29 families. Thus, the total species pool of reef fishes at Khangkao Island is estimated at around 100 species. The reason for this low diversity is its geographic location in the innermost part of the Gulf of Thailand. The location of this reef is comparable to near-shore reefs where the structure of reef fish assemblages is less complicated compared with offshore reefs.[7-9] Furthermore, this reef also has limited connection to nearby reefs. The area of reef is also important, estimated at only 0.5 km^2, while the total reef area of the Sichang Islands is less than 1 km^2. Species and area relationships have been pointed out as important ecological factors.[27, 28]

Most significant in the reef fish assemblages at Khangkao Island is the dominance of individuals of the family Pomacentridae, which is consistent with the results from 1986.[15] However, the representation of other families differed between the two studies. Individuals of Pomacentridae and Labridae were more abundant in the present study, while those of Apogonidae, Chaetodontidae, Pempheridae,

Atherinidae, and Serranidae were less abundant (Table 3). This result suggests a shift in trophic structure from benthic invertebrate feeders to small herbivorous and plankton feeders.

Cross-shelf variability across the central Great Barrier Reef has also been illustrated, in which planktivores and benthivores form a major component of inshore reefs while algal feeders represent less than 10%.[7] In contrast, reef fish assemblages from pristine reefs of Hawaii had benthic invertebrate feeders as the major component (57%) while algal and plankton feeders represented 22% and 10%, respectively.[11] The three most species-rich families were Labridae, Acanthuridae and Chaetodontidae, and the three most abundant families were Gobiidae, Apogonidae and Pomacentridae. Food availability is also a factor structuring fish assemblage in each reef system at Hawaii.[11] The assemblage structure of fishes at Khangkao Island is quite different from that in Hawaian reefs. The geographical position and influences from land may contribute to this difference.

Spatial variation

Zonation patterns of fish assemblages on coral reefs are common.[8-9, 29] This study indicated that reef habitat is the main contributing factor to zonation pattern. Although the reef framework is less developed, and distance and depth ranges among habitats are relatively short, the assemblages of fish on the reef

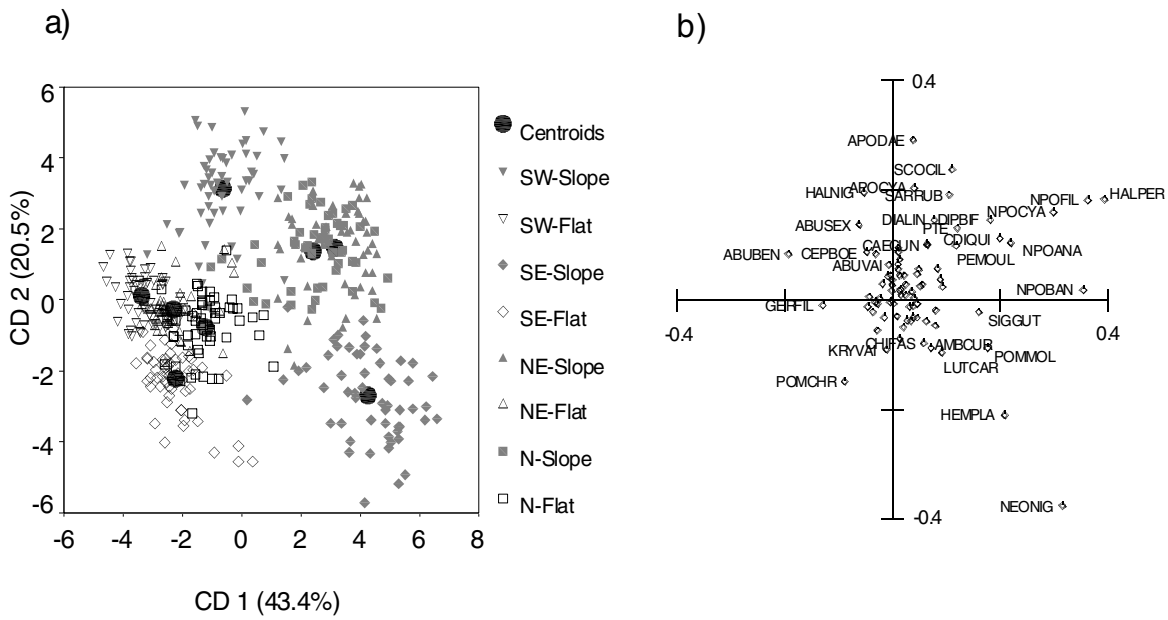

Fig 2. Ordination plots from Canonical Discriminant Analysis illustrated spatio-temporal variability of fish assemblages on coral reef at Khangkao Island; a) Site scores and b) Canonical structures of species (only some species are labeled due to overcrowding).

Table 4. ANOVA table showing testing factors effect on four community parameters. ABC interaction is used as F denominator for species richness, Diversity and Evenness Index. * significant at P <0.05 and ns – not significant.

SOV	Total abundance				Species richness			Diversity			Evenness		
	Df	MS	F	%VC	MS	F	%VC	MS	F	%VC	MS	F	%VC
Time (A)	10	0.18	10.43*	3.7	69.88	8.95*	22.2	11.80	3.38*	0.34	6.10	2.12^{ns}	2.48
Locality (B)	3	0.12	7.12*	0.1	80.76	10.34*	9.5	2.20	0.63^{ns}	-	1.38	0.48^{ns}	-
Habitat (C)	1	15.03	871.44*	61.6	3052.57	390.95*	24.9	1253.60	358.99*	80.57	504.00	175.61*	69.84
AB	29	0.14	7.93*	10.8	15.43	1.98*	10.9	5.41	1.56^{ns}	2.85	4.03	1.41^{ns}	3.57
AC	10	0.09	5.43*	3.5	9.74	1.25^{ns}	1.4	1.40	0.40^{ns}	-	1.81	0.63^{ns}	-
BC	3	0.11	6.27*	1.5	42.02	5.38*	8.9	28.10	8.05*	6.34	14.20	4.95*	7.76
ABC	29	0.04	2.08*	3.4	7.81		22.3	3.49		9.90	2.88		17.75
Error	344	0.02		15.6	-	-	-	-	-	-	-	-	-

flat are distinct from those on the slope with respect to both species composition and community parameters. Results from CDA illustrated that patterns of species composition of fish on the reef flat were similar over four localities. In the ANOVA, locality variation was detected only for total abundance and species richness, but this factor contributed less variation than habitat and month.

In general, the assemblages of fish on the reef flat have relatively few individuals and numbers of species, in agreement with several other studies.[8-9, 29] Low species diversity and evenness indices suggest that fish assemblages on the reef flat are dominated by a few species. This is shown by data on species composition where only *P. cuneatus* was very abundant on the reef flat (80-150 individual/150m^2), but was not detected by CDA because of its wide distribution over both habitats. The consistent pattern of fish assemblages on the reef flat over four localities can be explained by habitat structure, as all localities have a sandstone platform with boulders, except North reef which has some sandy bottom.[16] Coral cover is relatively low and dominated by massive or submassive forms especially *Porites lutea* and *Pavona* spp.. This also suggests that wind and wave action from monsoons have lettle influence on variability of fish assemblage on reef flats.

On reef slopes, in contrast, fish assemblages have relatively higher community parameter values than on reef flats. Overall, locality difference influenced species richness and abundance, but the effect was not significant. Species composition, however, was a more obvious indication of locality difference. Species composition on reef slope at North and Northeast reefs was similar, with *Halichoeres purpurescens* and *Neopomacentrus* spp. in the greatest abundance. Both reefs have the highest wave influence during the NE monsoon in winter. The Southeast reef receives waves from the south wind during summer. The main fishes characterizing reef slope assemblages were *Neoglyphidodon melas* and *Hemiglyphidodon plagiometopon*. The Southwest reef receives waves from the influence of SW monsoon during summer and its reef slope had more *Apogon doederleini, A. cyanosoma* and *Scolopsis ciliatus* than other reefs.

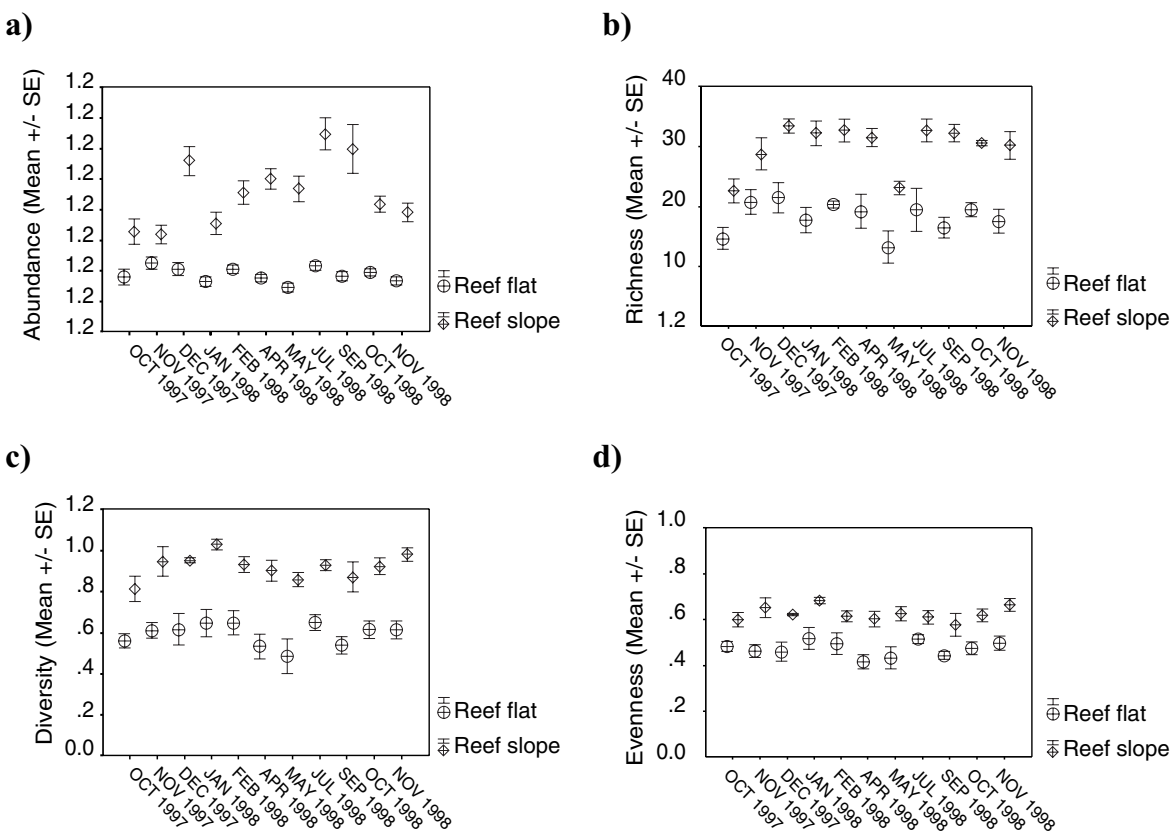

Fig 3. Community parameters: a) Total Abundance, b) Species Richness, c) Species diversity, and d) Eveness Index, of fish on coral reefs at Khangkao Island indicated variation through time and between habitats.

Temporal variation

There were no dramatic changes in the fish assemblages during 14 months of this study. It should be noted that widespread coral reef bleaching occurred in the Gulf of Thailand during the study (April – June 1998). At Khangkao Island, bleaching resulted in the decline of living coral, especially *Acropora* spp. and *Porites lutea*. About 40% of living coral died after 6 months of the bleaching event (unpublished data). The impact on coral feeders was not prominent, as their diversity and abundance in the study area were already low. There was also no prominent change on other groups of fish. This can be explained as the effect was relatively short and physical structure of habitat did not change during the study period. In Japan, after two years of the destruction of coral reefs by *Acanthaster planci*, coral feeders disappeared completely from the impact area due to shortage of food supply.[18] Other reef fishes also decreased in both numbers of species and abundance due to destruction of habitat.[18] The effect of coral reef bleaching is comparable to that from *A. planci* infestation. However, long term monitoring is needed to clarify the effect of habitat structure on fish assemblage at Khangkao Island.

The most prominent fluctuation, however, was in the total abundance of reef slope fishes. Most studies have revealed that population changes through time in reef fishes tend to be species specific[29], and some have found this to be less significant than spatial variability.[30] In this study, members of two genera of the family Pomacentridae, *Pomacentrus* and *Neopomacentrus,* contributed the most to change in total abundance at the reef slope. This result agrees with the conclusion made from CDA that the variation of total abundance over time is the result of relatively few fish species dominating at each site.

In conclusion, small site-attached herbivores and small water-column feeders dominated the assemblage structure of fishes on coral reefs at Khangkao Island. Pomacentrids characterized these fish assemblages, with the highest number of species and abundance. This indicates the influence from terrestrial runoff, which supplies nutrients and suspended food materials to the reef. Habitat or reef zonation is the main contributing factor to variability of fish assemblage structure. Spatial and seasonal variations are less prominent. The absence or rarity of piscivores may indicate intense fishing pressure and also limited recruitment. Community parameters suggest the fish assemblages to be relatively stable, although the present structure is different from that of earlier reports. This indicates a shift in the status of fish assemblages present over the past 10 -15 years, as disturbances have increased. Processes determining this shift include habitat structure, food supply, predation, and recruitment. There is little information on the recruitment of reef fishes in this area. Study of the role of recruitment in structuring fish communities in this area is necessary to show whether or not the larvae supply is limited by its geographical position.

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