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Spatial and temporal variations in subtidal fish assemblages of Xiaolanyu, Taiwan

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Abstract

A baseline assessment of marine biodiversity is essential for the establishment of a marine protected area (MPA). Three inshore and three offshore coral reef stations were surveyed on SCUBA around Xiaolanyu in the southeastern waters of Taiwan to assess spatio-temporal variation in fish assemblages. A total of 115 fish species belonging to 29 families was identified, and the most species-rich families were the Labridae (19.1% of the total species count), Chaetodontidae (12.2%), Pomacentridae (12.2%), Acanthuridae (9.6%), and Balistidae (7.0%). High fish diversity was seen at sites with greater rugosity and habitat complexity. The fish assemblage was not delineated seasonally, but it was distinct between the inshore and offshore sites. The average similarity for the inshore group was 30.5%, with *Thalassoma lutescens*, *Coris aygula*, *Halichoeres margaritaceus*, and *H. hortulanus* (Labridae) representing the most common fish species. The average similarity was 34.9% for the offshore group, in which *Chromis margaritifer* (Pomacentridae), *Forcipiger flavissimus* (Chaetodontidae), and *Pseudanthias squamipinnis* (Serranidae) were the most common species. Future works should attempt to determine the effects of local fishing pressures on the fish assemblage of Xiaolanyu and a long-term surveying and monitoring regime should potentially be enacted at Xiaolanyu in order to determine whether this high biodiversity region warrants protection in the form of an MPA.

Keywords: coral reef ecology, fish assemblage, subtidal zone, Taiwan, Xiaolanyu

Introduction

Sustainability of marine biodiversity is a fundamental tenant of marine ecosystem conservation, and baseline biodiversity assessments are warranted before establishing new marine protected areas (MPAs; Almeida 1996, Vacchi et al. 1998, Rocha and Rosa 2001, Tunesi et al. 2006, Rangel et al. 2007). In Taiwan, most hot spots of marine biodiversity, which can be found either along the coastline of Taiwan's mainland or its various offshore islands, have at least been preliminarily surveyed, with some featuring long-term ecological datasets (Shao et al. 1999, Chen et al. 2006, Chang et al. 2011, 2012).

Xiaolanyu is a volcanic island located five kilometers away from the southeastern coast of Lanyu (known as "Orchid Island" in English) in the southeastern waters of Taiwan. The isolated, unpopulated island is nearly square in shape and has an area of 1.57 km^2 and a coastline of 4.3 km (Fig. 1). In terms of the marine biodiversity classification schematic map of Spalding et al. (2007), both Lanyu and Xiaolanyu are in the "South Kuroshio ecoregion" of the South Kuroshio Province, which is distinct from 1) the East China Sea ecoregion of the Warm Temperate Northwest Pacific Province in the northern and eastern waters and 2) the Southern China ecoregion of the South China Sea Province in the southwestern waters of Taiwan. Yami, the local aboriginal tribe from Lanyu, call Xiaolanyu "ji-teiwan" or "ji-magawed", which means "mysterious island." The spectacular floral biodiversity of Xiaolanyu (known as "Shokotosho" in Japanese) was documented by the Japanese during their colonization of Taiwan, and they deemed it a Natural Monument in 1941 (Wu 2000).

The coastlines around Lanyu and Xiaolanyu are mainly abutted by coral reefs. The Kuroshio Current flows by the island throughout the year, and epipelagic and migratory fish predominate the coastal waters around the islands (Chiang et al. 2014). This area is both a traditional fishing area for the Yami and an important fishing ground for flying fish in southeastern Taiwan (Shao et al. 2007). Various studies on the marine biodiversity of Lanyu have been reported (Reigle 1963, Lee 1980, Shao 1988, Jung 2001, Chao 2002, Chao and Lee 2002, Huang 2006, Kao et al. 2007, Hsueh et al. 2009), and management program evaluations (Chen et al. 1982, Chang et al. 1989) and fisheries resource assessments (Chen et al. 2006, Shao et al. 2007) have been made. However, little work has been done around Xiaolanyu, despite its potentially rich fish and coral communities. In 2009, a comprehensive survey on the geographic landscape, flora, and fauna of Xiaolanyu was coordinated by Taiwan's National Museum of Marine Biology and

Aquarium (NMMBA; Ko et al. 2009). Updated checklists of the inland vegetation (Yeh et al. 2010), crustaceans (Li et al. 2010), and marine mollusks (Su et al. 2011) were subsequently created. In this study, species composition of the fish in the subtidal waters off Xiaolanyu was surveyed, and the driven factors structuring the fish assemblages around Xiaolanyu were evaluated.

Materials and Methods

Six subtidal stations (Fig. 1c) spanning both inshore (ST-2, ST-3, and ST-5) and offshore (ST-1, ST-4, and ST-6) regions were chosen around Xiaolanyu (Ko et al. 2009). ST-1, with an average depth of 16 m, was approximately 600 m away from the southern part of the island and featured mainly sandy bottoms and ledges made by large rocks. ST-2 (10 m average depth), which was ~80 m off the southeastern shore, possessed a similar benthic structure as ST-1. ST-3 (12 m average depth) was ~80 m off the eastern shore and was characterized by an extended rocky slope and underwater sulphur springs (the only ones found in Southeastern Taiwan). ST-4 (average depth unknown; surveys conducted at 32 m) was ~700 m off the northeastern shore and had normally strong currents. ST-5 (9 m average depth) was ~70 m off the north shore and had a sandy bottom interspersed with abundant pebbles. ST-6 (20 m average depth) was ~400 m off the western shore and was characterized by high-relief coral reef. The coral composition for ST-1, ST-2, ST-3, and ST-5 was dominated by scleractinians of the families Pocilloporidae, Acroporidae, and Faviidae, whereas ST-4 and ST-6 were richen by non-scleractinian corals: families Milleporidae (Milleporida), Tubiporidae (Stolonifera), Gorgonacea, and Alcyonacea. Members of the families Poritidae (Scleractinia) and Helioporidae (Coenothecalia) were also common at ST-5. Percentages of coral cover by Scleractinia/Alcyonacea were 44.8/4.5% and 49.7/3.2% at ST-2, 55.6/0.1% at ST-3, 31.3/1.0% and 25.7/0% at ST-5, and 14.4/3.1% at ST-6 (Ko et al. 2009).

SCUBA diving-based visual censuses of fish diversity were conducted in a rectangular area of 50 m long and 20 m wide in Spring (May) and Autumn (September) of 2009. The surveys in May were conducted at each station, whereas those of September could not be completed at ST-1 and ST-4 due to unstable oceanographic conditions driven by frequent typhoons. Underwater voucher photographs of the fish were taken for identification as in Chen et al. (2010) and Shao (2016). Fish species unidentified during both surveys represented less than 1% of the voucher photographs and were excluded from analysis.

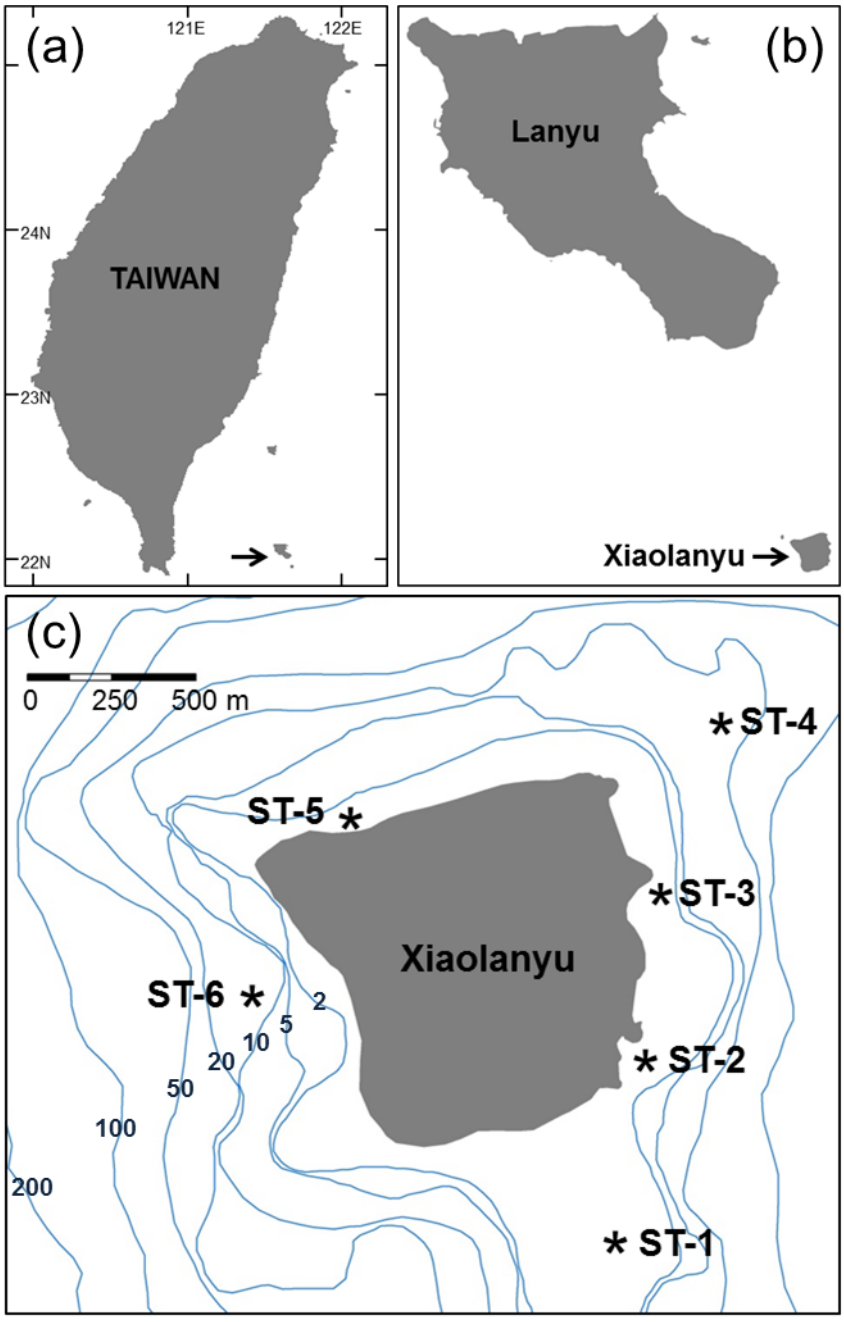

Fig. 1. The six subtidal stations (ST-1 to ST-6) of Xiaolanyu, Southeastern Taiwan surveyed in 2009 to document fish assemblages. In the map of Taiwan (a), an arrow denotes Lanyu (b); in the map of Lanyu (b), the arrow points to Xiaolanyu (c). Bathymetric charts in (c) were generated from data from Taiwan's Navy.

In order to characterize the spatio-temporal variation in the fish assemblages, species presence/absence data were analyzed with a Bray-Curtis similarity index (CLUSTER) using the PRIMER package (ver. 5). One-way analysis of similarity (ANOSIM) was employed to test for differences in species composition among groups, and the similarity and dissimilarity percentages for species contributions (SIMPER) were also calculated (*sensu* Clarke and Warwick 1994).

Results and Discussion

In total, 115 fish species belonging to 29 families were identified in the subtidal waters off Xiaolanyu (Table 1). The top five most species-rich families encompassed 60.0% of the total species inventoried: 22, 14, 14, 11, and 8 Labridae, Chaetodontidae, Pomacentridae, Acanthuridae, and Balistidae species, respectively, accounted for 19.1, 12.2, 12.2, 9.6, and 7.0%, respectively, of the total composition.

In terms of temporal variation, 90 species across 25 families and 76 species across 23 families were recorded in May and September, respectively. Amongst them, 48 species from 19 families were seen in both survey months. Six families (Carangidae, Lutjanidae, Caesionidae, Kyphosidae, Siganidae, and Ostraciidae) were recorded only in May, whereas four families (Muraenidae, Synodontidae, Aulostomidae, and Priacanthidae) were seen only in September (Table 1). Relatively higher family- and species-level diversity were documented in May, though this is due to the fact that more stations were surveyed in May than September. There was no significant effect of season on fish diversity (ANOSIM, global R=0.046, p=0.281).

Regarding spatial variation, high fish diversity was seen at sites with greater rugosity and habitat complexity. Low diversity was documented at sites characterized by predominantly sandy bottoms with the occasional large rock: ST-1 (25 species across 13 families) and ST-2 (33 species across 16 families). The fish diversity of ST-4 (25 species across 11 families) may have been underestimated due to relatively stronger current velocity at the time of surveying. At ST-3 (49 species across 21 families) and ST-5 (53 species across 20 families), wide rocky slopes and relatively higher coral diversity in both sites supported a higher diversity of fish species of the Labridae, Pomacentridae, and Chaetodontidae families (Table 1). ST-6 (36 species across 14 families), which was composed of coral reefs of high rugosity, was a common habitat for fishes of the families Chaetodontidae, Pomacanthidae, and Pomacentridae. For more rarely seen fish species, those of the families Lutjanidae and Caesionidae were restrictedly to ST-1, whereas

Table 1. Fish species recorded at the six subtidal stations off Xiaolanyu in 2009. "+" indicates presence.

Species	May 2009						September 2009			
	ST-1	ST-2	ST-3	ST-4	ST-5	ST-6	ST-2	ST-3	ST-5	ST-6
Family Muraenidae										
Gymnothorax favagineus									+	
Gymnothorax javanicus							+			
Family Synodontidae										
Synodus variegatus							+	+		+
Family Holocentridae										
Myripristis kunte			+					+		+
Sargocentron caudimaculatum				+						
Family Aulostomidae										
Aulostomus chinensis								+		
Family Scorpaenidae										
Sebastapistes cyanostigma					+			+		
Family Serranidae										
Cephalopholis urodeta					+	+		+		
Epinephelus hexagonatus		+					+		+	
Pseudanthias pleurotaenia				+						
Pseudanthias squamipinnis	+			+	+	+				+
Family Priacanthidae										
Priacanthus macracanthus								+		
Family Carangidae										
Caranx lugubris		+								
Trachinotus baillonii			+							
Family Lutjanidae										
Aphareus furca	+									
Family Caesionidae										
Caesio teres	+									
Family Lethrinidae										
Gnathodentex aureolineatus			+		+			+		
Family Mullidae										
Mulloidichthys vanicolensis		+	+		+			+		
Parupeneus barberinus								+		
Parupeneus cyclostomus	+	+								
Parupeneus multifasciatus					+	+	+	+	+	+
Family Kyphosidae										
Kyphosus cinerascens			+							
Family Chaetodontidae										
Chaetodon argentatus		+				+				
Chaetodon auriga		+			+					
Chaetodon auripes		+	+		+					+
Chaetodon ephippium	+		+		+				+	
Chaetodon kleinii	+			+						
Chaetodon lunula					+					
Chaetodon ornatissimus	+			+						
Chaetodon punctatofasciatus				+						+
Chaetodon speculum		+			+			+		
Chaetodon trifascialis			+				+	+		+
Chaetodon unimaculatus	+				+					
Forcipiger flavissimus	+		+	+	+	+		+		+
Hemitaurichthys polylepis	+					+				+
Heniochus monoceros								+		

Table 1. (continued)

Species	May 2009						September 2009			
	ST-1	ST-2	ST-3	ST-4	ST-5	ST-6	ST-2	ST-3	ST-5	ST-6
Family Pomacanthidae										
Centropyge heraldi				+		+				+
Centropyge vrolikii						+				+
Pomacanthus imperator				+	+					+
Pomacanthus semicirculatus							+			
Pygoplites diacanthus				+		+				+
Family Pomacentridae										
Abudefduf vaigiensis					+					
Amphiprion clarkii				+		+				
Amphiprion frenatus				+						
Chromis lepidolepis										+
Chromis margaritifer	+		+	+		+		+		+
Chromis ternatensis								+		
Chromis vanderbilti								+		
Chrysiptera starcki				+						
Dascyllus reticulatus	+			+		+				
Dascyllus trimaculatus				+						
Plectroglyphidodon dickii					+			+	+	
Plectroglyphidodon johnstonianus		+								+
Pomacentrus philippinus	+									
Stegastes fasciolatus							+	+		+
Family Cirrhitidae										
Cirrhitichthys falco				+						
Cirrhitus pinnulatus					+			+		
Paracirrhites arcatus	+							+		
Paracirrhites forsteri			+							+
Family Labridae										
Anampses caeruleopunctatus					+			+		
Anampses melanurus									+	
Anampses meleagrides					+					
Bodianus anthioides				+						
Bodianus axillaris				+		+				
Cirrhilabrus cyanopleura	+									
Coris aygula			+		+		+	+	+	
Coris gaimard							+	+		
Gomphosus varius					+			+		
Halichoeres hortulanus		+			+		+	+	+	
Halichoeres margaritaceus			+		+		+	+	+	
Halichoeres nebulosus									+	+
Hemigymnus melapterus	+									
Hologymnosus annulatus								+		
Labroides dimidiatus			+	+	+			+	+	
Macropharyngodon meleagris								+	+	
Oxycheilinus unifasciatus	+				+			+		
Pteragogus aurigarius										+
Stethojulis bandanensis									+	+
Thalassoma amblycephalum	+				+				+	
Thalassoma lutescens	+	+	+		+	+	+	+	+	+
Thalassoma quinquevittatum					+				+	

Table 1. (continued)

Species	May 2009						September 2009			
	ST-1	ST-2	ST-3	ST-4	ST-5	ST-6	ST-2	ST-3	ST-5	ST-6
Family Scaridae										
Calotomus carolinus					+					
Chlorurus microrhinos								+		
Scarus ovifrons								+		
Family Pinguipedidae										
Parapercis millepunctata		+			+					+
Family Tripterygiidae										
Enneapterygius rubicauda			+						+	
Enneapterygius vexillarius							+			
Family Blenniidae										
Exallias brevis								+	+	
Plagiotremus rhinorhynchos	+									
Plagiotremus tapeinosoma			+						+	
Family Pterelеotridae										
Nemateleotris magnifica				+		+				+
Pterelеotris evides		+						+		
Family Zanclidae										
Zanclus cornutus	+	+		+	+					+
Family Siganidae										
Siganus argenteus	+				+					
Family Acanthuridae										
Acanthurus japonicus	+						+	+		
Acanthurus leucopareius		+								
Acanthurus lineatus		+	+					+	+	
Acanthurus nigrofuscus			+		+		+			+
Acanthurus olivaceus		+							+	
Acanthurus pyroferus				+		+				
Ctenochaetus binotatus		+				+				+
Ctenochaetus striatus					+					
Naso lituratus					+			+		+
Naso tonganus					+					
Zebrasoma scopas										+
Family Balistidae										
Balistoides conspicillum	+	+								
Balistapus undulatus					+					
Balistoides viridescens					+					
Melichthys vidua	+							+		
Rhinecanthus rectangulus									+	
Sufflamen bursa				+						+
Sufflamen chrysopterum					+		+		+	
Xanthichthys auromarginatus				+						
Family Monacanthidae										
Cantherhines dumerilii		+			+			+		
Family Ostraciidae										
Ostracion meleagris					+					
Number of families	13	12	12	11	17	8	11	18	10	14
Number of species	29	22	21	27	43	19	20	43	25	32

Aulostomidae, Priacanthidae, and Kyphosidae species were restricted to ST-3; finally ostraciids were only seen at ST-5.

Fish assemblages were significantly different between the inshore and offshore sites (global R=0.530, p=0.047; Fig. 2). Species contributing to similarities within spatial groups are listed in Table 2. The average similarity for the inshore group (ST-2, ST-3, and ST-5) was 30.5%. The 10 most common species contributed 65.6% of the total average similarity, with 37.9% accounted for by the top four most common labrids: *Thalassoma lutescens*, *Coris aygula*, *Halichoeres margaritaceus*, and *H. hortulanus*. Average similarity for the offshore group (ST-1, ST-4, and ST-6) was 34.9%. The 10 most common species contributed 78.1% of the total average similarity, with 35.9% accounted for by the top three most commonly observed fish species: *Chromis margaritifer* (Pomacentridae), *Forcipiger flavissimus* (Chaetodontidae), and *Pseudanthias squamipinnis* (Serranidae). Average dissimilarity between inshore and offshore groups was 83.9% (Table 2). Species accounting for the dissimilarity between the two groups included many less commonly observed species; the accumulative percentage of the average dissimilarity for the top 10 species was only 19.3%.

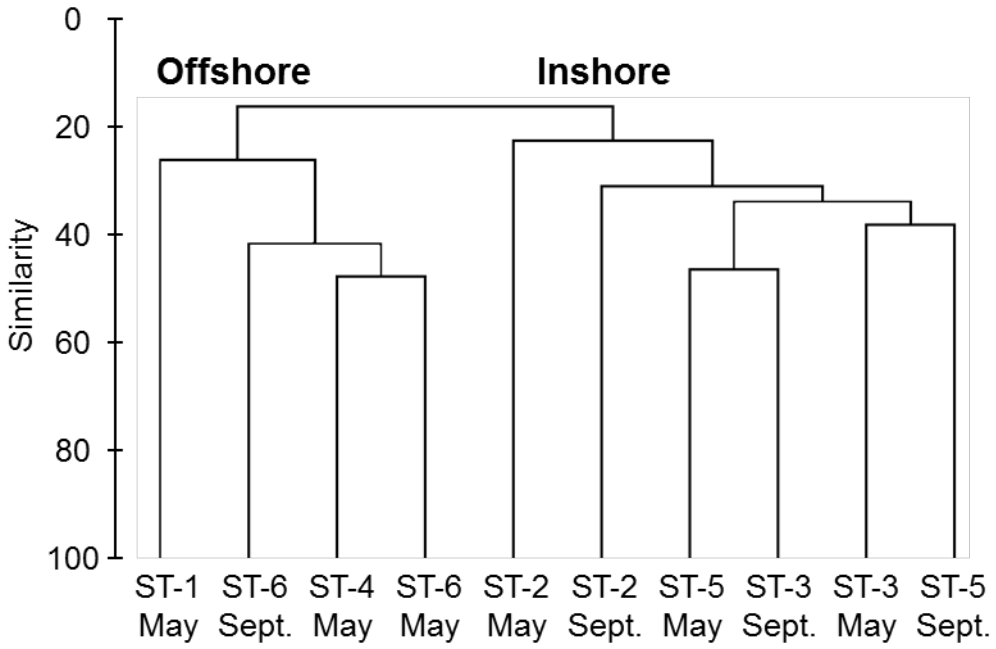

Fig. 2. Cluster dendrogram based on a Bray-Curtis similarity matrix of fish assemblages surveyed across six subtidal stations off Xiaolanyu in 2009.

Table 2. Average similarity and dissimilarity percentages contributed by the top 10 species within and between groups, respectively, for the six subtidal stations surveyed for fish assemblages off Xiaolanyu in 2009.

Rank	Family	Species	%
Within inshore groups (ST-2, ST-3, and ST-5)			
1	Labridae	*Thalassoma lutescens*	13.10
2	Labridae	*Coris aygula*	8.31
2	Labridae	*Halichoeres margaritaceus*	8.31
4	Labridae	*Halichoeres hortulanus*	8.23
5	Acanthuridae	*Acanthurus lineatus*	5.31
6	Mullidae	*Parupeneus multifasciatus*	4.56
7	Mullidae	*Mulloidichthys vanicolensis*	4.55
8	Labridae	*Labroides dimidiatus*	4.40
9	Serranidae	*Epinephelus hexagonatus*	3.36
10	Acanthuridae	*Acanthurus nigrofuscus*	2.75
10	Chaetodontidae	*Chaetodon trifascialis*	2.75
	Accumulated percentage		65.63
Within offshore groups (ST-1, ST-4, and ST-6)			
1	Pomacentridae	*Chromis margaritifer*	11.98
1	Chaetodontidae	*Forcipiger flavissimus*	11.98
1	Serranidae	*Pseudanthias squamipinnis*	11.98
4	Pomacentridae	*Dascyllus reticulatus*	6.47
5	Ptereleotridae	*Nemateleotris magnifica*	6.05
5	Labridae	*Thalassoma lutescens*	6.05
5	Chaetodontidae	*Hemitaurichthys polylepis*	6.05
5	Pomacanthidae	*Centropyge heraldi*	6.05
5	Pomacanthidae	*Pygoplites diacanthus*	6.05
10	Zanclidae	*Zanclus cornutus*	5.39
	Accumulated percentage		78.05
Between inshore and offshore groups			
1	Serranidae	*Pseudanthias squamipinnis*	2.16
2	Labridae	*Coris aygula*	2.01
2	Labridae	*Halichoeres margaritaceus*	2.01
4	Labridae	*Halichoeres hortulanus*	2.00
5	Pomacentridae	*Dascyllus reticulatus*	1.92
6	Ptereleotridae	*Nemateleotris magnifica*	1.87
6	Chaetodontidae	*Hemitaurichthys polylepis*	1.87
6	Pomacanthidae	*Centropyge heraldi*	1.87
6	Pomacanthidae	*Pygoplites diacanthus*	1.87
10	Pomacentridae	*Chromis margaritifer*	1.69
	Accumulated percentage		19.27

At least 407 coral reef, coastal, and migratory fish species belonging to 54 families have been documented around Lanyu (Shao 1988, Chen et al. 2006, Shao et al. 2007, Ho et al. 2013), though no new records were uncovered herein. However, our surveys did gather convincing information on the variation between offshore and inshore sites; such spatial variation was also characteristic of coral fish community structuring in New Caledonia (Wantiez et al. 1997). Future works should attempt to determine the effects of local fishing pressures on the fish assemblage of Xiaolanyu and a long-term surveying and monitoring regime should potentially be enacted at Xiaolanyu in order to determine whether this high biodiversity region warrants protection in the form of an MPA.

Acknowledgements

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