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Exploitation-related reef fish species richness depletion in the epicenter of marine biodiversity

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Abstract The central Visayan region of the Philippines historically has the highest concentration of coral reef fishes than any other large marine area in the world. This well-supported biogeographic phenomenon is contradicted by recent transect observations on coral reefs that indicates that the Visayan region and the southern Philippine Sea region have the lowest species richness in the Philippines. The Visayan region has unusually low counts of species typically exploited in fisheries and the aquarium trade. This evidence, coupled with numerous reports of intense fishing and habitat degradation and subsequent species declines at local scales suggests that this exploitation is having a cumulative effect on the overall species richness of the Visayan region. Successes in Marine Protected Areas in this region in increasing species richness at local scales suggests that improved management of these protected areas coupled with much more intensive fisheries management will be key to reviving a healthy biodiversity in the Visayas.

Keywords Reef fish species richness · Species loss · Overexploitation · Biogeographic regions

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Introduction

The Philippine archipelago is at the apex of the Coral Triangle (Veron 1995; Allen and Werner 2002), the region with the highest concentration of marine species globally. This area also includes all or part of Indonesia, Malaysia, Brunei, Timor L'Este, Papua New Guinea, and the Solomon Islands. It has variously been referred as the East Indies Triangle (Briggs 1999; Reaka et al. 2008), the Indonesia-Philippine Region (Mora et al. 2003), and the Indo-Malay-Philippine Archipelago (Carpenter and Springer 2005). It is also erroneously referred to as the Indo-Australian Archipelago (e.g., Bellwood and Hughes 2001); the Coral Triangle does not include Australia (Veron et al. 2009) and, in addition to Indonesia, includes several other countries with diverse geological origins. Marine species richness decreases across the Indo-Pacific with distance from the Coral Triangle (Veron 1995; Bellwood and Hughes 2001; Mora et al. 2003). Carpenter and Springer (2005) used generalized distributions compiled and reviewed by over 100 taxonomic experts and identified the central Philippines as the area with the highest shore fish species diversity. Moreover, based on a re-analyses of Allen's (2008) historical generalized distribution data compiled from the literature and personal records, the highest concentration of reef species is found in the central Visayan region of the Philippines (Fig. 1). The generalized distributions in both these studies were based mostly on museum specimens collected throughout the last century. Therefore, much of the information is based on collection records several decades old and predates intensive periods of intensive fisheries exploitation and habitat degradation in the Philippines (Lavides et al. 2010).

Many hypotheses have been proposed to explain the peak of biodiversity in the Coral Triangle. These are sometimes grouped into the center of origin, area of overlap, area of refuge, area of accumulation, and other similar hypotheses (Bellwood and Wainwright 2002; Carpenter and Springer 2005). All these hypotheses are based on processes occurring in geological time. However, changes in biodiversity patterns can also take place at ecological time scales. Anthropogenic activities such as resource overexploitation and habitat destruction can cause extinction of marine populations (Dulvy et al. 2003), changes in reef fish assemblages (McClanahan and Arthur 2001; Grandcourt and Cesar 2003; Wilson et al. 2008) and species loss (Lavides et al. 2010). The Philippines in particular, is experiencing rapid declines in fish catch rates both at the commercial and municipal levels (Burke et al. 2002; Green et al. 2003; Aliño et al. 2004; Armada 2004). Standing stock estimates of less than 10mt/km^2 indicate overfishing in almost all coastal areas within the country (Nañola et al. 2006). Highest exploitation rates occur within the central Philippine Visayan Region (Yambao et al. 2001; Green et al. 2004; Campos 2007a; Campos and Armada 2009) and in some areas of the South China Sea (McManus et al. 1992) and Celebes Sea (Campos 2007b, c). Habitat degradation is also concentrated in the Visayan region and is a widespread problem throughout the country (White and Cruz-Trinidad 1998; McManus et al. 1992; Green et al. 2004).

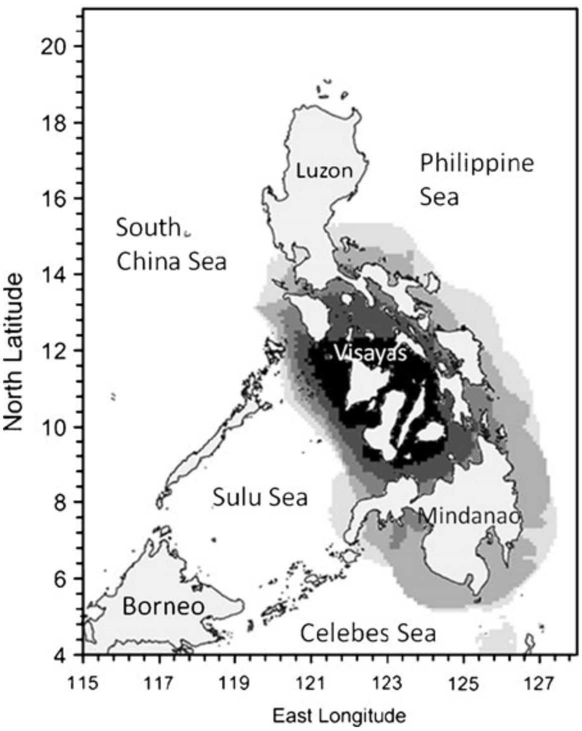


Fig. 1 Distribution of highest concentration of species richness of coral reef fishes in the Philippines. The darkest area in the central Philippines represents the area with the greatest 1% of species richness and is a unique global maxima. Successively lighter shades of grey represent successive 1% increments of decreasing concentration of species richness and this incremental decrease continues both east and west of the central Philippines (not shown). Analyses is based on Allen' s (2008) distributions using standardized base maps at the appropriate scale of 10 km by 10 km pixel size

Numerous marine protected areas (MPA) have been established to mitigate the effects of habitat degradation (Russ and Alcala 1999; Stockwell et al. 2009) and coral loss (Selig and Bruno 2010) to maintain integrity of fish-habitat interaction (Carpenter et al. 1981; Chabanet et al. 1997). Additionally MPAs are thought to contribute to fishery production through spill-over (Abesamis and Russ 2005) and to serve as a source of additional recruits (Abesamis and Russ 2010). Unfortunately, only somewhere between 10–15% in the 1990s and 30% in 2000s of these MPAs have been managed effectively (Alcala et al. 2008; Arceo et al. 2008). Effective management amounts to only around 3% of the total reef area of the Philippines and is insufficient to contribute significantly to the need to compensate for very high levels of exploitation (Weeks et al. 2009). In the Philippines, the legal mandate (Republic Act 8550) is to create MPAs that cover 15% of reef area and in the Visayas it is estimated that at least around 30% is needed to overcome the effects of intensive fishing levels (Licuanan et al. 2008).

The purpose of this study is to use visual census data to examine patterns of reef fish biodiversity across the Philippines with respect to levels of resource exploitation and habitat degradation. Transect data is taken from the upper fore reef slope where reef fish species richness is concentrated and where both habitat degradation and resource exploitation is most intense. The extensive data set used in this study is also being analyzed for biogeographical and other ecological results and will be the subject of forthcoming papers.

Methods

Study area

Comparisons of biodiversity patterns are based on the six Philippine biogeographic regions proposed by Aliño and Gomez (1994) and Aliño (1994), namely: a) South China Sea (SCS); b) Sulu Sea (SS); c) Celebes Sea (CS); d) Internal Seas (Visayas Region, VR; e) Northern Philippine (NP) Sea; and f) Southern Philippine (SP) Sea (Fig. 2). Philippine coral reefs have been estimated to cover approximately 25 819 km^2 across 7100 islands and islets (Burke et al. 2002). A lower estimate of 10 749.86 km^2 was derived from satellite images (Ong et al. 2002). Philippine reef systems are mainly fringing and oceanic reefs. Most oceanic reefs are located to the west of the Palawan archipelago in the Kalayaan Islands of the SCS. Atolls and atoll-type reefs are found in Tubbataha of the Cagayancillo Island in SS and along the Sulu Island chain, an island arc situated between SS and CS. A double barrier reef system is found in the Danahon Banks north of the island of Bohol in VR (Fig. 2). Coral cover estimates (Ong et al. 2002) for each of these regions are as follows: CS=811.29 km^2; SCS=3732.56 km^2; SS=1057.58 km^2; NP=655.50 km^2; SP=1896.75 km^2 and VR=2596.07 km^2.

Fish visual census

Data were collected using a non-destructive underwater fish visual census method modified from English

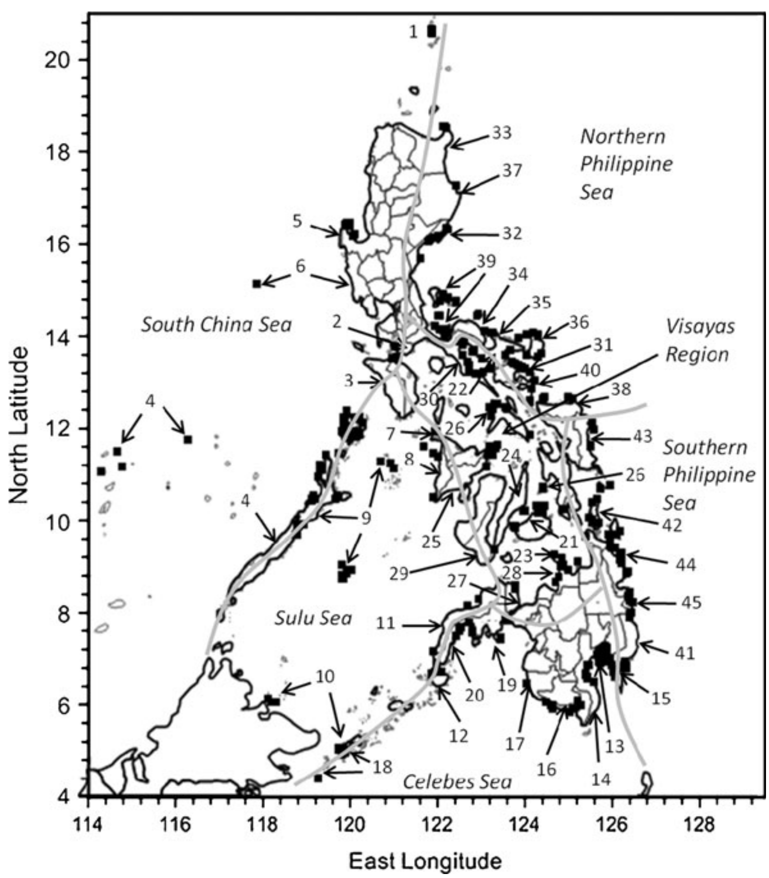


Fig. 2 Map of the study site, the Philippines. Thick light gray lines represents the divisions of the different biogeographic regions re-drawn from Aliño and Gomez (1994) by Rañola et al. (2002). Numbers represent the names of the political provinces surveyed as listed in Table 1. Filled squares represent location of the sites surveyed

et al. (1997). This method is highly efficient but has a bias towards the highly visible reef fishes that swim over and above the reef (Labrosse et al. 2002). Groups of fishes that are cryptic (e.g., some species of groupers, scorpionfishes, soldierfishes) and very small (e.g., blennies, cardinalfishes, gobies, and juveniles) are underrepresented in the data. To minimize observer bias that may stem from different abilities in spotting cryptic species and species identification, all data used in the analysis was collected by the senior author. Furthermore, our analyses include only fish data obtained after 3 years of fish census experience, after the senior author logged more than 300 fish transects (McManus et al. 1992). All species names were checked against a number of reliable taxonomic references (Randall et al. 1990; Myers 1991; Carpenter and Niem 1998–2001; Randall and Lim 2000; Allen et al. 2003).

This fish census data was obtained from 1991 to 2008 (Table 1). All sites were visited opportunistically and haphazardly rather than according to a specific sampling regime. However, most transects were surveyed during the changeover from the northeast monsoon the southwest monsoon or vice versa because these periods offer the best weather for field work. Community composition of reef fishes is influenced by many factors but seasonality is not thought to substantially influence transect data in the Philippines (Hilomen and Gomez 1988; Nañola et al. 1994) particularly if one looks only at the species presence or absence. New recruits were included in census counts and noted as such and indicate that recruitment is influenced by spatio-temporal factors but these are not a factor in the results or conclusions of this study (Arceo et al. 2006).

At each sampling site (Fig. 2), one to two 50 m transect lines were haphazardly laid at the fore reef slope between 5 to 10 m depths. The observer swam along the transect line and recorded on a slate board all fishes that fall within the 5×50 m belt on both sides of the transect. This translates to 500 m^2 of reef area surveyed per transect. All fishes were identified to species level with less than 3% of the total number of species per survey identified only to genus (i.e. difficult to recognize parrotfishes and some wrasses, particularly from the genus *Halichoeres*). Individuals were counted and their total lengths (TL) were estimated to the nearest cm. Transects were completed on a variety of reef types (e.g., fringing, shoals, narrow and wide reefs, exposed and sheltered reefs, some atolls, and barrier reefs) in each of the biogeographic regions. Site specific data included the location of the site as determined by using the global positioning system (GPS) or by compass triangulation in the absence of GPS particularly in the earlier sampling period. The position of transects relative to proximity to MPA's was determined and the number of MPA's per biogeographic region was also noted (Table 1).

Data analyses

Only those species identified to the species level were included in the analyses. Species richness by geographic region was determined though the species-accumulation-plot by Jackknife2 option using the PRIMER v.6 software (Clarke and Warwick 2001). Jackknife estimator of species richness is based on presence-absence data. It is known to reduce bias for the theoretical estimates of species richness and is based on the amount of unique species information that is contained in each observation (Smith and Pontius 2006). Analysis of co-variance was used to test for significant difference of equality of slopes of regression lines from the log transformed species accumulation plots. This is an appropriate tool for comparisons among linear relationships (Sokal and Rohlf 1981). One-way analysis of variance (ANOVA) was used to determine significant differences of commercially important, ornamental and the other non-target species among the six biogeographic regions. A Tukey post-hoc test was performed for the pairwise comparisons. The latter two analyses were performed using MINITAB v.15 software. Species observed on transects were also classified as typical fisheries species depending on their frequency observed in fish markets or as typical aquarium fishes based on published records (Ochavillo et al. 2004 and references therein).

Results

A total of 1198 fish transects were surveyed from 1991 to 2008 covering 142 cities/municipalities and 40 coastal provinces representing 15.5% and 61.5% of the total coastal cities/municipalities and provinces, respectively (Fig. 2). The region with the most fish transects was in the CS with 241 and the least was in

Table 1 The biogeographic regions and the list of political provinces. The numbers inside the parentheses represent the number of transects and year surveyed by province respectively. See Fig. 1 for the location of the provinces in the map preceded by a number

Biogeographic region	Provinces	Total number of transects surveyed and numbers of MPAs present in the region
South China Sea (SCS)	1) Batanes (2) (1991) 2) Batangas (18) (2004)	219 transects (30% of the transects are in and/or within 2 km of a MPA)[a]
	3) Occidental Mindoro (24) (1993) 4) Palawan (141) (1996, 2002–04)	113 MPAs present in the region[b]
	5) Pangasinan (32) (1993, 1996)	
	6) Zambales (2) (1996)	
Sulu Sea (SS)	7) Aklan (2) (2004) 8) Antique (6) (2004)	200 transects (24% of the transects are in and/or within 2 km of a MPA)[a]
	9) Palawan (174) (1993, 1998–2000, 2002–04) 10) Tawi-Tawi (16) (1991)	76 MPAs present in the region[b]
	11) Zamboanga del Norte (2) (1998)	
Celebes Sea (CS)	12) Basilan (22) (2005, 2007, 2008)	
	13) Davao del Norte (47) (1998–99, 2001–02, 2008) 14) Davao del Sur (29) (1998–99, 2001, 2008)	241 transects (78% of the transects are in and/or within 2 km of a MPA)[a]
	15) Davao Oriental (16) (2001) 16) Sarangani (21) (1998, 2003)	88 MPAs present in the region[b]
	17) Sultan Kudarat (3) (2003)	
	18) Tawi-Tawi (35) (1991, 2004)	
	19) Zamboanga del Sur (20) (1998, 2004)	
	20) Zamboanga Sibugay (48) (2005–08)	
Visayas Region (VR)	21) Bohol (49) (2003–04) 22) Camarines Sur (36) (1994)	213 transects (61% of the transects are in and/or within 2 km of the MPA)[a]
	23) Camiguin (2) (2000) 24) Cebu (18) (2003, 2004)	717 MPAs present in the region[b]
	25) Iloilo (12) (2003)	
	26) Masbate (31) (1994–95, 2000)	
	27) Misamis Occidental (6) (1999)	
	28) Misamis Oriental (8) (2000, 2003)	
	29) Negros Oriental (8) (2003)	
	30) Quezon (43) (1992, 1994)	
Northern Philippine Sea (NP)	31) Albay (29) (1994, 2000)	
	32) Aurora (30) (2003–04)	
	33) Cagayan (12) (1995, 2001)	
	34) Camarines Norte (6) (2001) 35) Camarines Sur (13) (1994, 2001)	219 transects (51% of the transects are in and/or within 2 km of a MPA)[a]
	36) Catanduanes (29) (1994, 2000) 37) Isabela (2) (2001)	123 MPAs present in the region[b]
	38) Northern Samar (4) (2000)	
	39) Quezon (90) (1992–94, 2001)	
	40) Sorsogon (4) (2000)	
Southern Philippine Sea (SP)	41) Davao Oriental (18) (1995, 2000, 2002–03) 42) Dinagat Islands (6) (2000)	106 transects (33% of the transects are in and/or within 2 km of a MPA)[a]
	43) Eastern Samar (8) (2000)	52 MPAs present in the region[b]
	44) Surigao del Norte (13) (2000, 2003)	
	45) Surigao del Sur (61) (2001, 2003–04)	

[a] this study; [b] Arceo et al. 2008

SP with only 105 (Table 1). The region with the most transects in proximity to MPAs was the CS (78%), followed by the VR (61%), NP (51%), SP (33%), SCS (30%) and SS (24%). The VR has 717 MPAs which is far greater than any other region which all have less than 130 (Table 1).

We identified a total of 721 species of reef associated fishes on the transects in 205 genera belonging to 52 families, and 4 species of cartilaginous fishes in 3 genera in 2 families. The most speciose families were Pomacentridae (125 species), Labridae (105), Serranidae (48), Chaetodontidae (41), Acanthuridae (36), Scaridae (36), and Apogonidae (30). These families comprised 58% of the total number of species observed. Other important families observed with considerable number of species were Lutjanidae (21), Blenniidae (20), Balistidae (18), Pomacanthidae (18), Holocentridae (17), Nemipteridae (17), Carangidae (15) and Gobiidae (15) (Table 2).

An analysis of co-variance for testing equality of slopes of regression lines showed that there is significant difference among the species accumulation plots, F (5, 1192)=225.76, p=0.000. The species accumulation plot indicated that SS had the highest species richness, while VR and SP showed the lowest species richness (Fig. 3).

Results of the one-way ANOVA showed that there is a significant difference among the six biogeographic regions for commercially important species, F (5, 1192)=52.57, p=0.000; ornamental species F (5, 1192)=18.41, p=0.000 and the remaining other species, F (5, 1192)=23.95, p=0.000. Tukey post-hoc test comparisons for commercially important species showed that VR (M=7.00, 95% CI [6.29, 7.70]) had significantly the lowest species number than all other regions: CS (M=9.02, 95% CI [8.35, 9.69]), NP (M=10.79, 95% CI [10.13, 11.45]), SP (M=11.31, 95% CI [10.39, 12.23]), SCS (M=12.86, 95% CI [12.08, 13.63]) and SS (M=14.79, 95% CI [13.90, 15.68]) (Fig. 4). The considerable absence of or rarity of some commercially harvested species are noted, these include six species of surgeonfishes (*Acanthurus lineatus, A. nigricauda, A. olivaceus, A. xanthopterus, Naso annulatus* and *N. brevirostris*), a triggerfish (*Odonus niger*), a sweetlip (*Plectorhinchus lessonii*), two species of emperors typically common on reefs (*Gnathodentex aureolineatus* and *Monotaxis grandoculis*), a snapper (*Lutjanus bohar*), a goatfish (*Parupeneus pleurostigma*), five species of parrotfishes (*Bolbometopon muricatum, Scarus altipinnis, S. hypselopterus, S. javanicus,* and *S. ovifrons*), a grouper (*Plectropomus laevis*) and two species of rabbitfishes (*Siganus corallinus* and *S. doliatus*). In contrast, the region has a very high percentage occurrence of *Plotosus lineatus* (eeltail catfish) and *Cephalopholis boenak* (grouper) as compared to other regions (Table 3).

Moreover, Tukey post-hoc test for ornamental species showed that VR (M=10.12, 95% CI [9.28, 10.96]) together with SP (M=11.59, 95% CI [10.61, 12.58]) and NP (M=10.26, 95% CI [9.59, 10.93]) had lowest species number than SCS (M=11.79, 95% CI [10.99, 12.58]), CS (M=12.83, 95% CI [11.99, 13.66]) and SS (M=15.18, 95% CI [14.11, 16.25]) (Fig. 4). Some of the ornamental fish species that were markedly absent in the VR included one species of surgeonfish (*Zebrasoma flavescens*), nine species of butterflyfishes (*Chaetodon citrinellus, C. ephippium, C. mertensii, C. reticulatus,C. unimaculatus, Forcipiger longirostris, Hemitaurichthys polylepis, Heniochus monoceros* and *H. singularius*), a wrasse (*Labropsis micronesica*), three species of angelfishes (*Apolemichthys trimaculatus, Centropyge heraldi* and *C. nox*) and four species of damselfishes (*Amphiprion akindynos, Chromis atripectoralis, C. vanderbilti* and *Dascyllus melanurus*) (Table 3). Furthermore, results of the Tukey post-hoc test for the rest of non-targeted species also showed that VR (M=13.28, 95% CI [12.59, 13.96]) had the least species numbers than all other regions: SP (M=15.65, 95% CI [14.64, 16.66]), NP (M=15.67, 95% CI [15.00, 16.34]), CS (M=15.78, 95% CI [15.15, 16.41]), SS (M=17.83, 95% CI [17.08, 18.57]), SCS (M=18.64, 95% CI [17.66, 19.62]) (Fig. 4).

In addition to having consistently lower species richness for exploited fisheries and aquarium fishes, the VR also had from 5.6 to 30.9% fewer exploited species that span the East and West range of the VR (Fig. 5). These exploited species are missing in transect counts in the central part of the Philippines despite available appropriate habitat and their occurrence in surrounding regions.

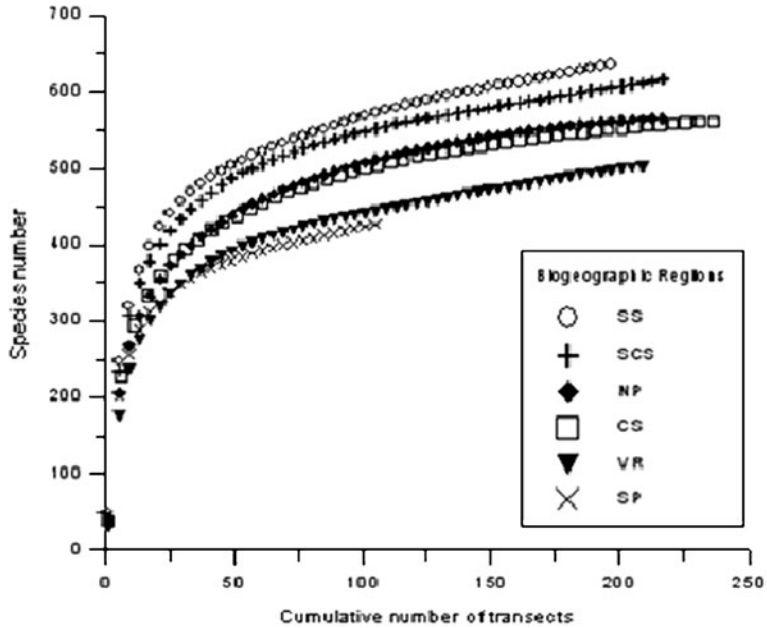
Discussion

This paper uses extensive recent fish transect data to describe for the first time the pattern of species-area richness of reef fishes across the entire Philippines. It

Table 2 Total number of species observed by family and biogeographic region. The list excludes all families with only one species observed (i.e., Alopiidae, Aulostomidae, Callionymidae, Carcharhinidae, Centriscidae, Centropomidae, Clupeidae, Echeneidae, Fistulariidae, Gobiosocidae, Kyphosidae, Leiognathidae, Malacanthidae, Platycephalidae, Plotosidae, Zanclidae)

Number	Family	CS	NP	SCS	SP	SS	VR	All regions
Class Osteichthys								
1.	Acanthuridae	26	28	27	21	24	18	36
2.	Apogonidae	14	16	15	11	13	21	30
3.	Balistidae	13	7	10	5	11	6	17
4.	Blenniidae	8	9	15	7	9	7	21
5.	Caesionidae	7	11	10	5	11	7	12
6.	Carangidae	5	5	6	1	11	3	15
7.	Chaetodontidae	32	35	30	34	34	27	41
8.	Cirrhitidae	3	3	4	3	4	3	5
9.	Diodontidae	2	1	1	0	1	1	3
10.	Ephippidae	2	1	1	0	3	2	3
11.	Gobiidae	2	6	9	1	3	6	15
12.	Haemulidae	5	5	7	6	8	6	9
13.	Holocentridae	8	10	8	9	13	2	18
14.	Labridae	75	70	82	57	84	69	105
15.	Lethrinidae	3	3	6	3	5	2	7
16.	Lutjanidae	14	11	12	9	14	7	21
17.	Microdesmidae	2	3	4	2	3	3	6
18.	Monacanthidae	11	8	9	6	5	8	13
19.	Mullidae	9	9	8	7	11	7	12
20.	Muraenidae	2	0	1	1	2	0	4
21.	Nemipteridae	11	8	14	5	13	12	17
22.	Ostraciidae	4	3	4	3	3	4	4
23.	Pempheridae	1	1	1	1	1	2	2
24.	Pinguipedidae	5	4	5	2	6	3	6
25.	Pomacanthidae	11	15	14	11	13	10	18
26.	Pomacentridae	83	85	79	64	87	72	125
27.	Priacanthidae	0	1	1	0	2	1	3
28.	Pseudochromidae	2	3	4	3	2	2	5
29.	Scaridae	23	27	29	19	28	23	36
30.	Scombridae	1	1	2	0	0	0	3
31.	Scorpaenidae	3	3	3	1	3	3	7
32.	Serranidae	26	16	31	12	33	19	48
33.	Siganidae	9	10	8	9	10	8	11
34.	Sphyraenidae	2	1	2	0	3	2	3
35.	Syngnathidae	1	2	2	1	0	2	3
36.	Synodontidae	3	4	4	2	3	3	5
37.	Tetraodontidae	9	9	10	5	6	8	13
	Other families	8	7	6	5	9	7	16
Class Chondrichthys								
1.	Dasyatidae	0	0	0	0	3	0	3
	Total species	445	441	484	331	494	386	721

Fig. 3 Species accumulation plot of the different biogeographic regions derived from Jacknife estimates using PRIMER v.6 software



shows a different pattern of species richness from historical data sets (Fig. 1; Carpenter and Springer 2005; Allen 2008) in that unlike the recent transect data, historical data shows the VR with the highest species richness. Although the types of data in these two studies are different and direct comparison may not be valid, indirect evidence suggests that the VR has undergone recent loses in species richness. In this study, the SS and SCS biogeographic regions (sensu Aliño and Gomez 1994) have the highest reef fish species-area richness while the VR and SP had significantly lower species-area richness (Fig. 3). The lower species richness counts in the VR occur despite this region has, by far, the greatest number of MPAs and a very high percentage of transects were completed in close proximity to MPAs (Table 1). The significantly lower species-area richness on the Pacific side (NP and SP) as compared to the western side (SCS and SS) is consistent with historical distribution evidence (Fig. 1) and the general findings that species richness declines eastward and westward from the Coral Triangle (Veron 1995; Briggs 1999; Bellwood and Hughes 2001; Mora et al. 2003; Reaka et al. 2008). Furthermore, a large number of the species not found on transects in the VR are found in surrounding areas, despite the existence of abundant suitable similar habitat in the VR (Fig. 5). Each of the species missing in the VR but found in surrounding regions (Table 3) are indicated as being present in the VR according to generalized distribution maps based on historical data (Carpenter and Niem 1998–2001). Although historical species specific landing records are not available, the fact that the species primarily missing in the VR are exploited species indicates that exploitation levels are influencing species-area richness.

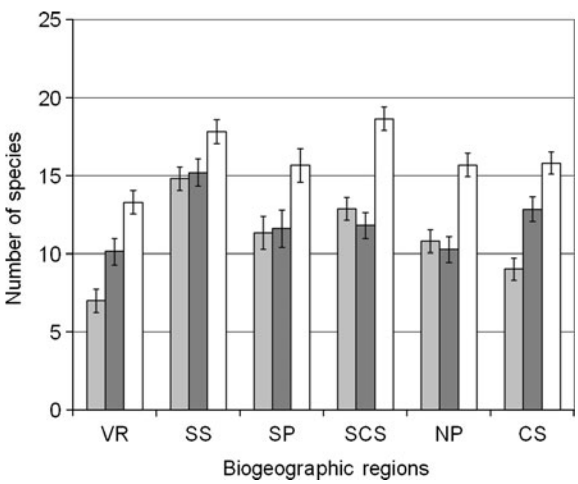


Fig. 4 Mean numbers of commercial (*light grey*), aquarium fishes (*darker grey*) and other non-target reef fishes (*blank*) per transect in each of the biogeographic regions. Error bars indicate 95% confidence intervals

Overexploitation of resources may lead to extinction of species (Dulvy et al. 2003) and localized species loss (Lavides et al. 2010). The municipal

Table 3 Abbreviated list of commercially important and ornamental species with an emphasis on the absence or high occurrence of species (e.g. *Plotosus lineatus* and *Cephalopholis boenak*) in the Visayas Region and de-emphasizing species common to all regions and species that do not occur in majority of the regions. Numbers represent the frequency of occurrence

	Family/species	CS	NP	SCS	SP	SS	VR
Acanthuridae (surgeonfishes)							
1.	*Acanthurus lineatus*[a]	1.24	4.57	1.83	3.77	0	0
2.	*Acanthurus nigricauda*[a]	0	5.94	2.28	0	1.50	0
3.	*Acanthurus olivaceus*[a]	2.49	1.83	6.39	0	0.50	0
4.	*Acanthurus xanthopterus*[a]	1.24	2.28	0	2.83	3.50	0
5.	*Naso annulatus*[a]	0.41	1.83	2.74	5.66	2.50	0
6.	*Naso brevirostris*[a]	0.83	0.91	2.74	0	0	0
7.	*Zebrasoma flavescens*[b]	0	3.65	0.91	0	0.50	0
Balistidae (triggerfishes)							
8.	*Odonus niger*[a]	0.83	0	3.65	0	10.50	0
Chaetodontidae (butterflyfishes)							
9.	*Chaetodon citrinellus*[b]	4.56	8.68	3.20	6.60	0.50	0
10.	*Chaetodon ephippium* [b]	0.83	0	0	8.49	7.00	0
11.	*Chaetodon mertensii* [b]	0	0.91	0.91	2.83	0	0
12.	*Chaetodon reticulatus* [b]	1.24	9.13	0	25.47	2.00	0
13.	*Chaetodon unimaculatus* [b]	1.24	0.91	2.74	2.83	1.00	0
14.	*Forcipiger longirostris* [b]	2.07	2.28	1.37	0	0.50	0
15.	*Hemitaurichthys polylepis* [b]	2.90	0.91	5.48	1.89	7.50	0
16.	*Heniochus monoceros* [b]	0	4.11	1.83	4.72	1.50	0
17.	*Heniochus singularius* [b]	0	1.83	1.37	2.83	1.50	0
Haemulidae (sweetlips)							
18.	*Plectorhinchus lessonii*[a]	3.32	0	0.46	1.89	0.50	0
Holocentridae (squirrelfishes)							
19.	*Myripristis adusta* [a]	0.41	0	0.46	0.94	2.00	0
20.	*Neoniphon samara* [a]	2.07	2.74	1.83	14.15	6.00	0
21.	*Sargocentron diadema* [a]	0	0.46	0	0.94	1.00	0
22.	*Sargocentron spiniferum* [a]	1.24	1.37	1.37	0	1.50	0
Labridae (wrasses)							
23.	*Labropsis micronesica*[b]	0.41	4.57	2.74	1.89	2.50	0
Lethrinidae (emperors)							
24.	*Gnathodentex aureolineatus* [a]	0	0.46	3.65	0	6.00	0
25.	*Monotaxis grandoculis* [a]	11.20	0.91	9.59	21.70	10.00	0
Lutjanidae (snappers)							
26.	*Lutjanus bohar* [a]	0.83	0.91	2.74	0.94	5.00	0
Mullidae (goatfishes)							
27.	*Parupeneus pleurostigma* [a]	1.66	0	3.20	3.77	3.00	0
Plotosidae (eeltail catfish)							
28.	*Plotosus lineatus* [a]	7.88	13.70	7.31	12.26	8.50	27.70
Pomacanthidae (angelfishes)							
29.	*Apolemichthys trimaculatus* [b]	1.66	0	1.37	0	1.50	0
30.	*Centropyge heraldi* [b]	1.66	1.37	6.39	0	4.50	0
31.	*Centropyge nox* [b]	2.90	0.46	1.37	1.89	5.00	0
Pomacentridae (damselfishes)							
32.	*Amphiprion akindynos* [b]	0.83	1.37	0.46	0.94	0	0
33.	*Chromis atripectoralis* [b]	2.07	1.37	0.46	0	2.50	0
34.	*Chromis vanderbilti* [b]	0.41	0.91	3.65	0	2.00	0

Table 3 (continued)

Family/species		CS	NP	SCS	SP	SS	VR
35.	*Dascyllus melanurus* [b]	2.90	0.46	0	0.94	3.00	0
Scaridae (parrotfishes)							
36.	*Bolbometopon muricatum* [a]	0	0.46	0.46	0	0.50	0
37.	*Scarus altipinnis* [a]	0	0	2.28	0.94	1.50	0
38.	*Scarus hypselopterus* [a]	0	0.46	2.74	0	2.50	0
39.	*Scarus javanicus* [a]	0	0.46	2.74	0	2.50	0
40.	*Scarus ovifrons* [a]	0.41	0.91	0	0	0.50	0
Serranidae (groupers)							
41.	*Cephalopholis boenak* [a]	7.47	8.22	14.16	1.89	27.50	35.68
42.	*Plectropomus laevis* [a]	0.41	2.74	0.46	0	0	0
Siganidae (rabbitfishes)							
43.	*Siganus corallinus* [a]	0	2.28	1.83	0.94	3.00	0
44.	*Siganus doliatus*[a]	0.41	0.46	0.46	2.83	2.00	0
Total number of commercial species		171	161	188	120	207	136
Total number of ornamental species		94	102	99	82	102	80
Total number of species		445	441	484	331	494	386

[a] commercially important species; [b] ornamental species

fishery data for some of the coastal towns in this region showed a significant decline in fish catch (Yambao et al. 2001; Green et al. 2004) and in some areas the present catch per unit effort (CPUE) is as low as 2.6 kg·fisher^{-1}·day^{-1} (Campos 2007a) while other regions (e.g., CS) have CPUE of about 5.0 kg·fisher^{-1}·day^{-1} (Campos 2007b, c; Watts et al. 2007). Two decades ago, catch rates in some reef

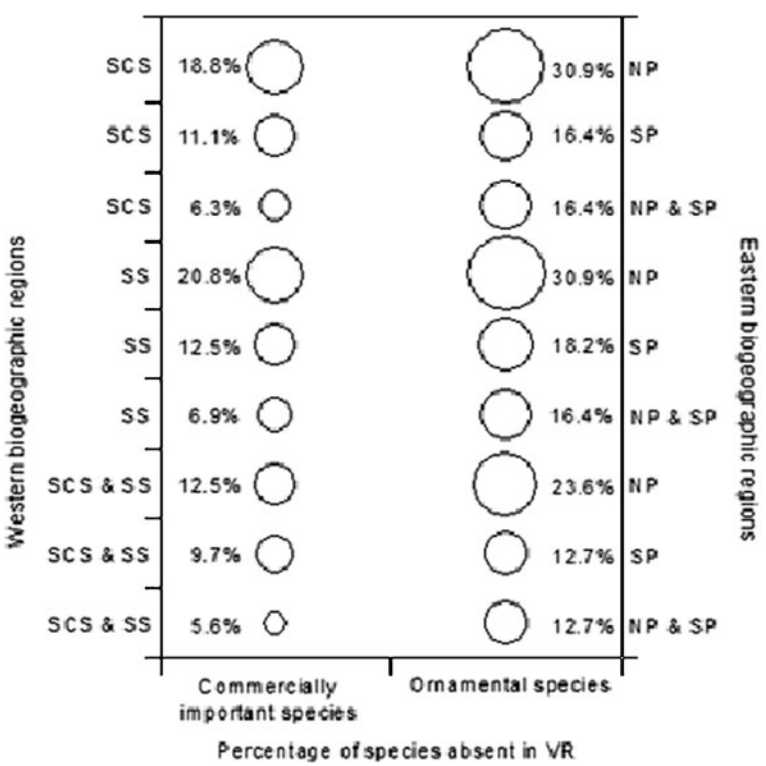


Fig. 5 Bubble diagram showing that both commercially important species and ornamental species are consistently absent in the VR although present in surrounding regions. Percentage composition was computed from a total of 144 commercially important species and 55 ornamental species that were not observed in VR. An example on how this diagram is read using the uppermost pair of bubbles: 18.8% of commercial species and 30.9% of ornamental species that are found both in the surrounding SCS and NP regions are absent in VR

areas in VR ranged from 5 to 37mt/km^2/year (Alcala and Gomez 1985). Sustainable reef fisheries on a well managed reef in the VR ranged from 15 to 20 mt·km^{-2}·yr^{-1} while reef fisheries on degraded reefs range from 4 to 5 mt·km^{-2}·yr^{-1} (Alcala and Russ 2002). A high percentage of reef areas in the VR have been classified as degraded i.e., showing poor coral cover with high proportions of dead coral and rubble (Gomez et al. 1994; Nañola et al. 2006). Nañola et al. (2006) also observed low fish biomass throughout most of the VR indicating a heavily overfished state. The highest density of municipal fishers in the Philippines occurs in the central (VR) region (Alcala and Russ 2002; Green et al. 2003). Moreover, Lavides et al. (2010) have shown that intense fishing pressure caused species loss in the Bohol area of the VR (Table 1, Fig. 2). High levels of exploitation are present in each of the other biogeographic regions of the Philippines, however, high levels of exploitation appear to be pervasive across most of the VR (Alcala and Russ 2002; Green et al. 2003). This may be due to the central location of the VR and proximity to, and being surrounded by, population centers.

Non-reef demersal fishery catches have steadily declined with rising fishing effort (Armada 2004). Catch records in the Visayan Sea was already low at 6.03 mt·km^{-2} in 1948 (Warfel and Manacop 1950) and went down further to 2.58 mt·km^{-2} in 2003 (Armada and Campos 2009). A sudden decline was observed in the 1970s and showed a change in the species composition (Armada 2004). For example, trawl catch composition records in the Visayan Sea conducted in 2003, showed *Plotosus lineatus* ranked 2nd and 3rd in terms of catch (mt·km^{-2}) by family and species, respectively (Campos and Armada 2009). However, in 1948 (Warfel and Manacop, 1950) and 1977 (Aprieto and Villoso, 1979), this species was not part of the catch in the same area (Armada and Campos 2009). This change in community composition may also be responsible for the unusually high observation rates of *P. lineatus* in the VR in this study (Table 3). Other reef areas in the Philippines that showed changes in the catch composition due to overfishing were in the Lingayen Gulf (Silvestre et al. 1991) and Manila Bay (Silvestre et al. 1987). These are both located in the SCS region where diversity of reef associated fishes is still high at a regional level although threats are significant in both these localities. This is evidence of the larger species pool of the SCS. It has been postulated that the species pool is largely determined by evolutionary and historical large scale processes (McManus 1985).

Ornamental fishes are also heavily exploited in the VR (Albaladejo and Corpuz 1981; Nañola and Aliño 1999; Green et al. 2004; Ochavillo et al. 2004). In the 1970s, the most intense collection sites were in the Central Visayas, including Southern Luzon, Cebu, Bohol, Leyte, Samar, Negros Oriental, and Siquijor (Albaladejo and Corpuz 1981). More recently the volume of aquarium fish catch from Cebu and Bohol has notably declined with indications of both growth and ecosystem overfishing related ornamental fish collection (Ochavillo et al. 2004). Overfishing of ornamentals in the central Philippines has also led to a geographic shift in effort to Palawan and Tawi-Tawi provinces (Pomeroy et al. 2008; Nañola pers obs.).

Intense exploitation in the VR as a result of the “live reef fish food trade”, such as those targeting groupers and some parrotfishes, further contribute to the decline of fish abundance in the area (Mamauag 2004). Destructive collection methods that include cyanide and overturning coral heads for both the live reef fish food trade and ornamental fishes indirectly affects fish populations through habitat degradation (Robinson 1986; Rubec 1988; Barber and Pratt 1997; Jones and Hoegh-Guldberg 1999; Mamauag 2004; Ochavillo et al. 2004; Jones et al. 2004; Pratchett et al. 2008). Increased use of cyanide beginning in the 1970’s also presumably caused declines in landings of reef fisheries in the VR, particularly in the Cebu area (White and Cruz-Trinidad 1998). Another indication that the VR suffers from unusually high habitat degradation is from the high percentage of transects that record the grouper *Cephalopholis boenak* (Table 3) which is a species particularly adapted to disturbed coral reefs (Heemstra and Randall 1993).

Both destructive (i.e. blast fishing) and normal fishing patterns across the Philippines clearly indicate that the VR experiences the most intense exploitation levels in the country. The significantly lower species richness both for target and non-target species in this region (Fig. 4) further suggests reef degradation. Reef fishes are closely associated with their habitat and an altered habitat will reflect changes in the fish assemblages (Carpenter et al. 1981; Aliño 1994; Chabanet et al. 1997). The fact that historical patterns indicate the VR should have the highest species richness (Fig. 1) and that a large percentage of exploited species found in surrounding areas are absent in the VR, despite abundant available and varied habitat indicates that this exploitation level is leading to species richness reductions in this epicenter of marine biodiversity. This results in a "hole in the donut" pattern (Fig. 5) in which species are present in transects in all surrounding areas but absent in the middle or VR region. This is the exact opposite of the pattern from the historical data (Fig. 1). Assuming exploitation over 50 years and that the VR should have at least as high a species richness as the SS (Table 2) prior to this period, the VR has lost about 2% of its reef fish species richness per decade. This represents about 10% of the total species richness represented by the habitats sampled by this underwater fish visual census belt transect methodology. This observation of species loss by exploitation in the VR is corroborated by Lavides et al. (2010) who used traditional ecological knowledge in the area of Bohol Island Province in the VR area to document the loss of 21 species over 5 decades due to intense fishing. Unfortunately, the scale and data collection methods differ markedly between our transect data and the Lavides et al. (2010) study making it difficult to directly compare species losses. Nevertheless, both these studies are an indication that the slow process of evolutionary change can be altered by human activities such overfishing over shorter ecological time scales. Whether the changes are reversible or not remains to be seen.

The Philippines was identified as the region with the highest threat level to coral reefs of any other center of marine endemism (Roberts et al. 2002). Exploitation related species richness loss in the VR, purported as the historical epicenter of marine biodiversity, indicates an urgent need for increased and effective conservation and fisheries management in this region. The earliest establishment of Marine Protected Areas (MPAs) in the 1970s in the Philippines was in the VR (Russ and Alcala 1999). In 2004, about 60 no-take marine reserves were established in the southern Central Visayas (Alcala and Russ 2006). At present, the VR has 717 MPAs (61% of the country's total MPAs) (Table 1) but only very few of them are enforced effectively and most remain very small in size (Alcala et al. 2008; Arceo et al. 2008). Despite this, there remains significant gaps in conservation and fisheries management (Weeks et al. 2009). The gaps can be overcome by finding synergies in the development needs of sustainable fisheries and biodiversity conservation vis-à-vis effective measures such as having functionally larger MPA sizes and with improved good governance (Arceo et al. 2008). The Apo Island MPA in the VR remains one of the best managed in the Philippines (Alcala and Russ 2006) and long-term no-take marine reserves in the region have been shown to enhance coral reef resilience (Stockwell et al. 2009). Moreover, MPAs increase nearby local abundances through a spillover effect (Abesamis and Russ 2005) and may also serve as sources of new recruits to replenish fish populations (Abesamis and Russ 2010), as well as to prevent further loss in coral cover (Selig and Bruno 2010). Various fisheries management recommendations have been presented specifically for the VR, including catch quotas in terms of weight and fish size, closing of fishing grounds, and general effort reduction (Green et al. 2003; Licuanan et al. 2008). An integrated ecosystem approach to fisheries management together with the utilization of the value added benefits of MPA efforts through MPA networking can help accelerate these efforts (Aliño et al. 2002, 2006). The present Coral Triangle Initiative Philippine National Plan of Action can also provides a framework on how the complementation of efforts at local, seascape and at the entire Philippine archipelagic context (CTI-Phil NPOA 2009).

Despite the promise of improved conservation and fisheries management, habitat degradation and over-exploitation remains extensive throughout the VR. Unless these threats are effectively reduced, further declines in species richness can be expected (Alcala and Russ 2006). The Philippines urgently needs to focus on removing these threats so that the VR will no longer be the epicenter of conservation adversity in the "center of the center" (Carpenter and Springer 2005) of marine biodiversity.

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