


Species richness and abundance of non-cryptic fish species in the Philippines: a global center of reef fish diversity

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Abstract The Philippines is dubbed the ‘global center of marine biodiversity’ for having the greatest number of reef fish species per unit area in the world, mainly based on analysis of museum collections. However, to date, there is no national assessment of the status of Philippine reef fish species based on species abundance and distribution. We conducted underwater visual census belt transect surveys of all non-cryptic reef fish, to explore spatial trends in fish biodiversity and to assess the national status of Philippine reef fish species. We found that most places in the Philippines still hold high numbers of non-cryptic reef fish species, with 54 % of the surveyed transects having ≥ 22 reef fish species per 100 m². However, only 13 % of all recorded species had high abundances (≥ 0.81 individuals per 100 m²) and wide distributions ($\geq 291,964$ km²) (category A species), while 33 % had either low abundances or restricted distributions (category B species), and 54 % exhibited both low abundances and restricted distributions (category C species). In addition, 97 % of the large-bodied species (maximum TL > 30.1 cm) were assigned to category B or C—a matter of concern, since 47 % of the recorded large-bodied species in our study are food-fish. The findings of our study present the most recent (2012–2013) national assessment for all non-cryptic reef fish species using standardized methods, and highlight the need for conservation action for many Philippine reef fish species, upon which many Filipinos derive benefits such as food, income, livelihood, and recreation.

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Introduction

The Philippines is recognized as one of the most biodiverse countries in the world in terms of reef fish species richness per unit area (Carpenter and Springer 2005; Allen 2008), parts of which contribute to the ‘Indo-Pacific Coral Triangle’, the epicenter of reef fish diversity. However, the country is also recognized as a marine biodiversity hotspot (Roberts et al. 2002) that is rapidly losing a lot of biodiversity due to habitat loss and various human-induced threats. Among these threats is increasing fishing effort, and the overexploitation of reef fish species populations (Watson and Pauly 2001; Pauly et al. 2002; Anticamara et al. 2011). Additionally, the coral reef habitats of the Philippines are heavily degraded—i.e., only about five percent of Philippine reefs are estimated to remain in excellent condition based on live coral cover estimates from the 1980s (Gomez et al. 1994), and to date no recent papers have reported on the national recovery of Philippine coral reef habitats.

Despite the degraded state of coral reefs and the depleted reef fish populations in the country, there is a general lack of systematic assessment of the current remaining biodiversity of reef fish species across the Philippines (Licuanan and Gomez 2000; Anticamara 2009; Tupper et al. 2011). For instance, species abundance and distribution are two metrics often used to describe the status of a particular species in relation to its susceptibility to extinction, but studies presenting the national status of Philippine reef fish species based on these two metrics are non-existent for many Philippine reef fish species. Previous studies on Philippine reef fish biodiversity only analyzed species richness based on museum collections or field surveys using variable methods (Carpenter and Springer 2005; Allen 2008; Nañola Jr. et al. 2011). While species richness can be used to determine the distribution of reef fish species, complementing this data with records of species abundance can be used to gauge species susceptibility to local extirpation, track species population status and trends, and estimate fish production in MRs and fishing grounds. In addition, most existing literature documenting Philippine reef fish abundance have focused on examining the effectiveness of a few no-take marine reserves (MRs) (Russ 1989; Russ and Alcala 1998a; Christie et al. 2002; Russ et al. 2003; Samoilyis et al. 2007), despite the existence of nearly 1000 Marine Protected Areas in the Philippines, over 90 % of which have a no-take MR zone (Weeks et al. 2010). Grey literature in the form of reports, guide-books, and atlases documenting Philippine reef fish abundance also exist, although commercially-important fish species or families are usually their main focus, and their field data collection methods are highly variable across different studies (Alino et al. 2002; Haribon Foundation 2005; Coral Reef Information Network of the Philippines (Philreefs) 2010).

The general lack of systematically-collected national and temporal species-level abundance and distribution data makes the assessment of Philippine reef fish species using the International Union for Conservation of Nature (IUCN) categories and criteria very difficult or impossible. The IUCN currently represents the global standard in making species status assessments, and has shifted from making species assessments based solely on expert opinion to using data-driven criteria to estimate species’ extinction risk (Rodrigues et al. 2006). However, only 6 % of all the world’s fish species (including freshwater fish) have been assessed by the IUCN (Baillie et al. 2004), and the global-scale assessments provided by the IUCN may not always appropriately represent the local status

of species (Gardenfors 2001). To address this issue, the IUCN recommends the use of guidelines to create national and regional assessments using IUCN categories and criteria (Gardenfors 2001; Milner-Gulland et al. 2006), but the limitations of existing national datasets make this impossible for reef fish species in the Philippines. As a result, the national status of the country's reef fish species—or the condition of reef fish species found in Philippine waters in terms of abundance and distribution—remains largely unknown. Despite these limitations, efforts to track the national status of Philippine reef fish species should not be forgone. Ignorance regarding the status of marine species has led to extinctions in the past, due to continued exploitation of depleted species and the degradation of species' habitats (Roberts and Hawkins 1999). Therefore, there is a great need to collect up-to-date, quantitative data per species using standardized methods in order to assess and update the current status of Philippine reef fish species throughout the country.

The objectives of the study were the following: (a) to present results of a systematic and standardized survey of reef fish species throughout the Philippines; (b) to examine patterns of total reef fish species richness, abundance, and biomass per unit area throughout the Philippines; (c) to quantify the current status of reef fish species in terms of their mean national abundance per unit area and national distribution; and (d) to provide our own status categorization for all non-cryptic reef fish species based on our collected quantitative data. The data collected will provide the most recent snapshot of the national status of Philippine reef fish species, and can serve as a baseline for future assessments tracking the status of these species.

Methods

Study sites and sampling

The Philippines is a tropical and archipelagic country composed of roughly 7107 islands, with an estimated total coral reef area of 25,819 km² (Burke et al. 2000). The country is geographically grouped into the three major island groups of Luzon, Visayas, and Mindanao. We used Google Earth to determine parts of the country that would most likely have coral reefs close to shore. We selected survey reef sites that would adequately represent the Philippines' three major island groups, and six marine biogeographic regions (BGRs) as proposed by Aliño and Gomez (1994), while accounting for certain budget and logistical constraints. For example, we took into account factors such as travel time, costs, issues of site accessibility, traveling with lots of equipment, and safety (i.e., it is dangerous to travel some reef sites in the Philippines, especially in the south, due to political instability).

We utilized an underwater visual census (UVC) belt transect method commonly used in reef fish field surveys to record diurnally-active, non-cryptic reef fish species (Brock 1982; Samoilys 1997; Samoilys and Carlos 2000). To conduct UVC belt transect surveys, a diver swam along the length of a 20 m transect, and recorded the count and length estimates (to the nearest cm) of all non-cryptic reef fish species encountered approximately 2.5 m on either side of the transect (total area per transect = 100 m²). The diver recorded all fish down to a minimum total length of 1 cm. Setting such a small minimum length may result in erroneous estimates of small-bodied fishes, because such species are hard to detect (Bellwood and Alcala 1988), and a minimum length of 10–11 cm is usually recommended in most UVC assessments. However, considering that most of the reef fishes that occurred in our study sites were small (i.e., damselfishes, cardinalfishes, and butterflyfishes), we considered that our 1 cm minimum total length recorded is appropriate and justifiable to be

able to capture most to the reef fish diversity within and across our study sites. The diver (and co-author of this paper, J. Anticamara) who conducted the surveys has had almost 20 years of experience conducting UVC surveys prior to the current study, and therefore did not need further training in the assessment method (Samoilys et al. 2007; Anticamara 2009; Anticamara et al. 2010). We assume that the diver or surveyor's error should be similar across all study sites, therefore, the spatial variations in reef fish diversity reported in this manuscript are real rather than simply a reflection of surveyor's error. Surveys were not timed, but generally each transect was surveyed for about 20 min, corresponding to a survey swim speed of about 5 m² transect area covered per minute. Around 3–4 transects were surveyed per site (or about 7–8 transects per municipality). Our choice of transect size (5 × 20 m), number of transects (3–4 transects per site, or about 7–8 transects per municipality), and surveyed area per site (300–400 m² per site or 700–800 m² per municipality) is comparable to methods used in previous studies assessing fish diversity

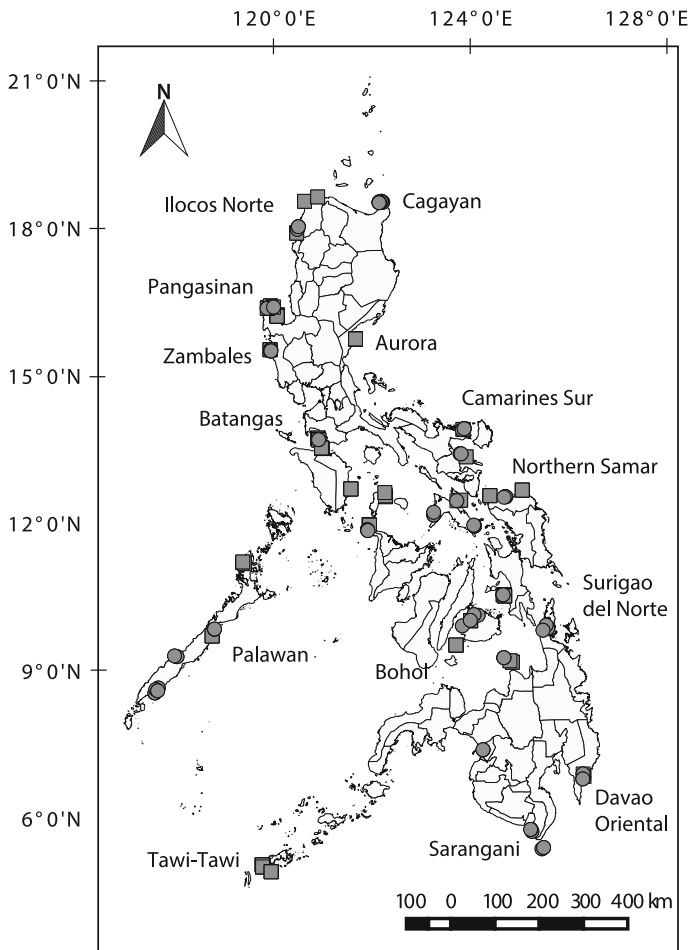


Fig. 1 Map showing all 313 transects surveyed throughout the Philippines. *Squares* represent transects located within MR boundaries, while *circles* represent transects located outside MR boundaries

(Brock 1982; Friedlander and Parrish 1998; Tissot et al. 2004; Nakamura and Tsuchiya 2008; Shibuno et al. 2008; Honda et al. 2013). All surveys were conducted during daylight hours, from around 9:00 am–2:00 pm. All surveyed transects were positioned parallel to reef slopes of survey sites at depths ranging from 3 to 6 m, a depth range where reef fish diversity and abundance is often high relative to other depth ranges (Friedlander and Parrish 1998; Friedlander et al. 2003). Abundance of cryptic reef fish species, such as certain species of blennies, gobies, dotybacks, and eels, are underestimated in our assessments (Brock 1982; Willis 2001) due to their tendency to avoid detection by hiding in reef crevices. Similarly, certain nocturnal species that remain hidden during the day (e.g., sweepers, soldierfishes, and priacanthids), and very well-camouflaged species (e.g., scorpionfishes), are also under-represented. While conducting the UVC surveys, we took underwater photographs of encountered reef fish species for identification verification using various fish identification resources and guides (Allen et al. 2003; Kuitert and Debelius 2006; Froese and Pauly 2014).

Overall, we surveyed a total of 313 belt transects (20×5 m or 100 m^2) in 97 reef sites from 42 different municipalities, from March 2012 to August 2013 (Fig. 1). Surveyed transects were located within MRs (163 transects) and outside MR boundaries (150 transects). Information on MR establishment, size, and ratings (based on an MR rating system proposed by White et al. (2006) and Maypa et al. (2012) was extracted from the Coastal Conservation and Education Foundation (CCEF) website (<http://coast.ph/our-work/mpadatabase>, data accessed: 07/31/13)—the authority on MR management and enforcement assessments in the Philippines. However, information on the MRs included in our survey was very limited—only 5 out of the 52 MRs had available information on the CCEF website—thereby making the assessment of enforcement status for most of our MR study sites very difficult (Online Appendix 1).

Data analysis

To quantify the current status of Philippine reef fish species, we examined the following: (a) patterns of total reef fish species richness, abundance, and biomass throughout the Philippines; (b) the national status of each reef fish species based on their abundance per transect; (c) the national status of each reef fish species based on their distribution throughout the country; and (d) the national status category assignments of each reef fish species based on our estimate of their abundance per transect and our record of their distribution throughout the Philippines.

To examine patterns of total reef fish species richness throughout the Philippines, we first obtained the national mean \pm SE of the total species richness per transect for all the 313 transects surveyed. We then used a Geographical Information System, Quantum GIS (Q-GIS) 2.4.0. (Q-GIS Development Team 2014), to map the total species richness of each surveyed transect, and presented all mapped transect data points as color codes with respect to the national mean species richness \pm SE values—i.e., black, grey, and white for those transects with total reef fish species richness above, within, and below the national mean \pm SE species richness, respectively. To supplement the species richness map, we plotted the frequency distribution of total reef fish species richness per transect for all transects. To further explore patterns of Philippine reef fish species richness, we plotted the total number of reef fish species versus the number of municipalities where those number of reef fish species were found.

To examine patterns of total reef fish abundance, we began by calculating the national mean \pm SE of the total reef fish abundance (in number of individuals) per transect for all

the 313 transects. Subsequently, we used Q-GIS to map the total reef fish abundance of each surveyed transect and presented all mapped transect data points as color codes with respect to the national mean abundance—i.e., black, grey, and white for those transects with total reef fish abundance above, within, and below the national mean \pm SE abundance, respectively. We also plotted the frequency distribution of total reef fish abundance per transect for all surveyed transects.

To examine patterns of total reef fish biomass, we first converted reef fish length estimates to biomass (g) using standard length-weight relationships from FishBase (Froese and Pauly 2014). For species with no length-weight relationships information, we used length-weight relationships from the closest congeneric in terms of body shape. We then calculated the national mean \pm SE of the total reef fish biomass (in grams, g) per transect for all the 313 transects. Then, we used Q-GIS to map the total reef fish biomass of each surveyed transect and presented all mapped transect data points as color codes with respect to the national mean biomass—i.e., black, grey, and white for those transects with total reef fish biomass above, within, and below the national mean \pm SE biomass, respectively. We also plotted the frequency distribution of total reef fish biomass per transect for all surveyed transects.

To further examine and compare spatial patterns of reef fish biodiversity throughout the country, we ran one-way ANOVA analyses among municipalities for all three biodiversity metrics—i.e., species richness, abundance, and biomass. We chose to compare these metrics between municipalities (rather than between sites, provinces, or BGRs), because coastal resource management in the Philippines is typically carried-out at the municipal level. We also compared each municipality's mean \pm SE species richness, abundance, and biomass with the national mean \pm SE species richness, abundance, and biomass, and determined which municipalities fell below, within, or above the national mean \pm SE for each metric. This was done in order to highlight potential 'hotspots' within the country, or areas that exhibited reef fish species richness, abundance, and biomass that fell below the national means. We also constructed maps for mean municipal species richness, abundance, and biomass per municipality using Q-GIS, to help us detect patterns for these metrics.

To test the potential effects of MR protection on reef fish biodiversity, we ran one-way ANOVA analyses of total reef fish species richness, abundance, and biomass between transects located within MR boundaries versus transects located outside MR boundaries. Although comparing biodiversity before and after MR establishment is preferable for measuring MR effects, comparing snapshot data of marine biodiversity inside versus outside MRs is a common alternative in many MR studies (Halpern 2003). The rationale behind using inside-outside data to assess MR effects is that reef fish biodiversity is expected to be higher inside an MR than outside (i.e., in the adjacent fishing grounds), if indeed an MR is properly enforced. However, we were unable to run further analyses on the effects of MR establishment, such as the effects of MR size, age, or enforcement ratings on reef fish biodiversity because of the limited data available on MRs included in our survey (Online Appendix 1).

To determine the national status categories of all reef fish species that we recorded during our national reef fish diversity surveys, we assigned each species to a status category based on our estimates of their abundance per transect and their distributions throughout the Philippines. To estimate abundance, we calculated the mean abundance of each reef fish species across all surveyed transects. To estimate distribution, we used the Convex Hull function in Q-GIS to construct actual minimum convex polygons (AMCP) for each reef fish species. A species' AMCP is defined as the smallest polygon with no internal

angle greater than 180 degrees that includes all points where a species was recorded. We then used a measurement tool in Q-GIS to obtain the total area of each species' AMCP. After calculating each species' abundance and distribution, each reef fish species was assigned to status category A, B, or C, defined as follows: (a) category A species were those with mean abundance and AMCP values (across all transects) that were both within or above the calculated mean \pm SE values for all species (i.e., species that exhibited both high abundance and wide distribution); (b) category B species are those with mean abundance and AMCP values that were within or above the calculated mean \pm SE values for either abundance or AMCP for all species (i.e., species that exhibited either high abundance or wide distribution only, while having low values in the other metric); and (c) category C species are those with mean abundance and AMCP values that were both below the calculated mean values \pm SE for all the species (i.e., species that exhibited both low abundance and restricted distribution).

We then examined patterns between our assigned reef fish status categories and the life-history information [e.g., maximum total length (TL) and trophic level (TrL)] obtained from FishBase (Froese and Pauly 2014) for all surveyed reef fish species. In terms of maximum TL, reef fish species were categorized as small-bodied (Max TL \leq 10 cm), medium-bodied (Max TL = 10.1–30 cm), and large-bodied (Max TL > 30.1 cm). In terms of trophic level, reef fish species were categorized as pure herbivores (TrL = 2.0–2.1), omnivores with a preference for plant material (TrL = 2.1–2.9), omnivores with a preference for animal material (TrL = 2.9–3.7), and carnivores (TrL = 3.7–4.5) based on gut content analysis and fish trophic level categorizations proposed by Stergiou and Karpouzi (2001).

We also compared our reef fish status categories with existing status assessments, namely: species vulnerability scores (VS) from FishBase (Froese and Pauly 2014), and conservation status categories from the IUCN (IUCN 2014), which were obtained from each organization's respective websites (www.fishbase.org and www.iucnredlist.org). FishBase VS is the intrinsic vulnerability of a species to fishing, and is based on species life history and ecological traits such as maximum length, age at first maturity, natural mortality, known geographic range, fecundity, and spatial behavior (Cheung et al. 2005). Because FishBase VS is represented as a numerical value, we assigned each species' FishBase VS to one of the following categories: low-moderate vulnerability (VS \leq 33.3), moderate-high vulnerability (VS between 33.3 and 66.6), and high-very high vulnerability (VS \geq 66.6) based on the fuzzy logic VS system developed by Cheung et al. (2005). The IUCN assigns species to conservation status categories, which are based on species population size, abundance, and range or distribution (IUCN 2012). IUCN conservation status categories, arranged in increasing order of extinction risk, are: least concern (LC), near threatened (NT), vulnerable (VU), endangered (EN), critically endangered (CR), extinct in the wild (EW), and extinct (EX). Species that lack data for a proper assessment are categorized as data deficient (DD), and species that remain un-assessed are categorized as not evaluated (NE).

Results

We identified a total of 367 non-cryptic reef fish species belonging to 44 families across the 313 transects surveyed throughout the duration of the study. This figure represents around 50 % of the total number of reef fish species recorded by Nañola et al. (2011), who analyzed compilations of UVC survey data throughout the country from 1991–2008 (over a 17-year period).

Surveyed Philippine reef sites generally exhibited high reef fish species richness. Of the 313 transects surveyed, 145 transects (47 %) had total species richness above the national mean \pm SE (22–23 reef fish species per 100 m²), and 23 transects (7 %) had total species richness within the range values of the national mean \pm SE (Fig. 2a). Reef fish species richness per transect showed approximately normal-distribution patterns (Fig. 2b). However, while Philippine reef sites generally exhibited high species richness, many of the reef fish species encountered during our surveys were restricted to only a few Philippine reef sites. In fact, 89 % of all 367 reef fish species were restricted to less than half of the municipalities surveyed, and 31 % were restricted to just one or two municipalities (Fig. 3).

Most Philippine reef sites had low reef fish abundance. Two hundred and twenty-six transects (72 %) had reef fish abundance below the national mean \pm SE (326–394 reef fish individuals per 100 m²), while only 63 (20 %) and 24 (8 %) transects had reef fish

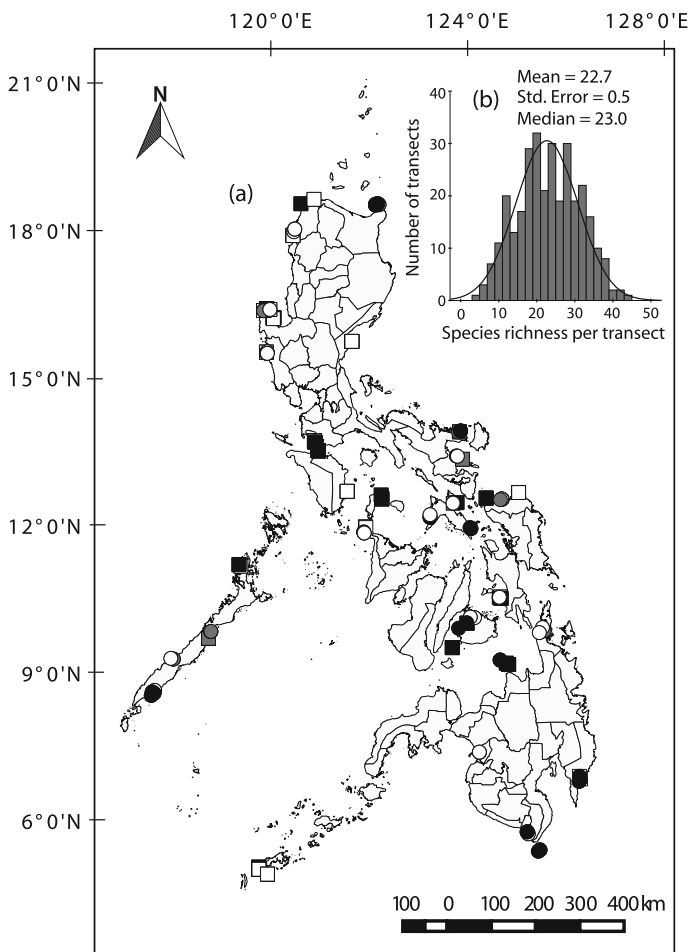


Fig. 2 Distribution map showing total reef fish species richness per transect. *Squares* represent transects located within MR boundaries, while *circles* represent transects located outside MR boundaries (a). *Histogram* with normal curve showing the mean fish species richness per transect (b)

abundance within and above the national mean \pm SE, respectively (Fig. 4a). Reef fish abundance per transect showed skewed distribution patterns (Fig. 4b).

Most Philippine reef sites exhibited low reef fish biomass. Two hundred and twenty-two transects (71 %) had reef fish biomass below the national mean \pm SE (8394–10,263 g per 100 m²), while only 74 (24 %) and 17 (5 %) transects had reef fish biomass within and above the national mean \pm SE, respectively (Fig. 5a). Reef fish biomass per transect showed skewed distribution patterns (Fig. 5b).

We found significant differences among municipalities for all three biodiversity metrics—i.e., reef fish species richness (one-way ANOVA, $F = 6.229$, $P < 0.001$), abundance (one Way ANOVA, $F = 6.411$, $P < 0.001$), and biomass (one-way ANOVA, $F = 3.036$, $P < 0.001$). When we compared municipalities based on their mean species richness, abundance, and biomass with respect to the national means, we found no clear spatial patterns. Municipalities that exhibited species richness, abundance, and biomass below the national means were generally spread throughout the country (Online Appendix 2). However, we noted that 11 of the 41 municipalities (26 %) fell below the national means for all three biodiversity metrics.

We observed no significant difference in reef fish species richness (one-way ANOVA, $F = 1.344$, $P = 0.247$), abundance (one-way ANOVA, $F = 3.097$, $P = 0.079$), or biomass (one-way ANOVA, $F = 3.635$, $P = 0.058$) between transects inside MR boundaries versus transects outside MR boundaries.

Quantitative data per species showed that most Philippine reef fish species exhibited low abundances and restricted distributions (Online Appendix 3). In terms of abundance, 305 of the 367 species recorded (83.1 %) had abundances below the calculated mean \pm SE abundance

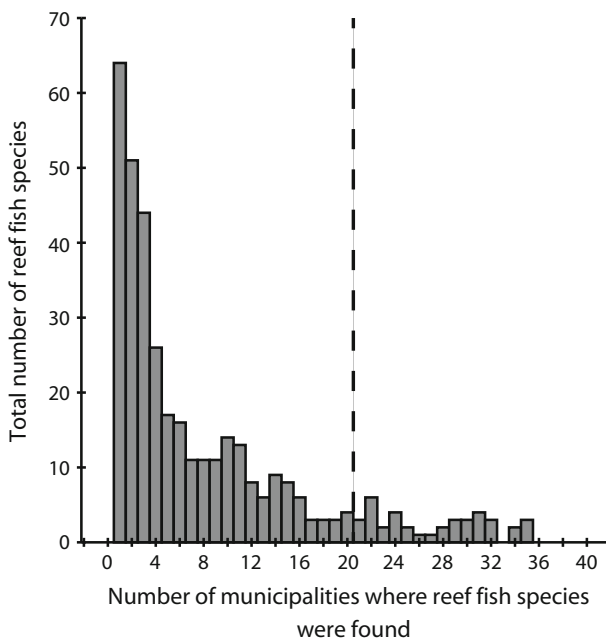


Fig. 3 Bar-plot showing the number of species found in a given number of municipalities. 89 % of all 367 reef fish species were found in less than half of all the municipalities surveyed throughout the Philippines (represented by the dashed line)

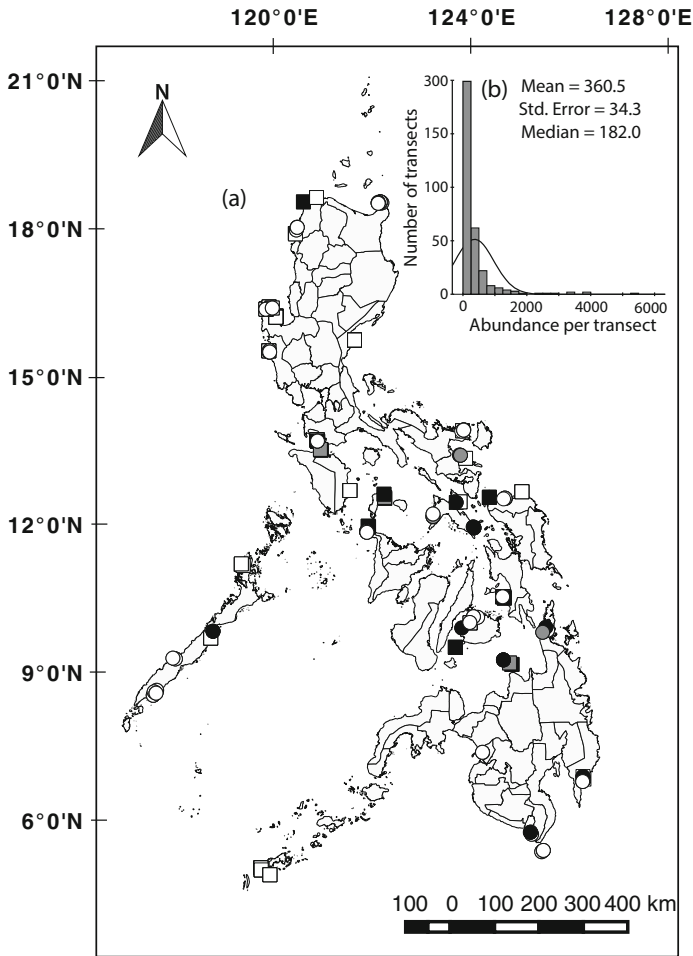


Fig. 4 Distribution map showing total reef fish abundance per transect. *Squares* represent transects located within MR boundaries, while *circles* represent transect located outside MR boundaries (a). *Histogram* with normal curve showing the mean fish abundance per transect (b)

for all recorded fish species (i.e., 0.98 ± 0.17 individuals per species per 100 m^2), 9 species (2.5 %) were within the mean \pm SE abundance for all reef fish species, and only 53 species (14.4 %) were above the mean \pm SE abundance for all encountered reef fish species. In terms of distribution, 215 species (58.6 %) had AMCPs below the calculated mean \pm SE AMCP area for all recorded fish species (mean AMCP = $310,022 \pm 18,058 \text{ km}^2$), 5 species (1.4 %) were within the mean AMCP \pm SE, and 147 species (40.0 %) were above the mean AMCP \pm SE.

Since most Philippine reef fish species showed mean abundance and AMCP values that were below the mean values for all the species, most reef fish species were assigned to category B or C (Fig. 6). Of the 367 reef fish species that we recorded, 54 % fell under status category C, while 33 % fell under status category B. Only 13 % of reef fish species that we recorded throughout the Philippines fell under category A, or those species that

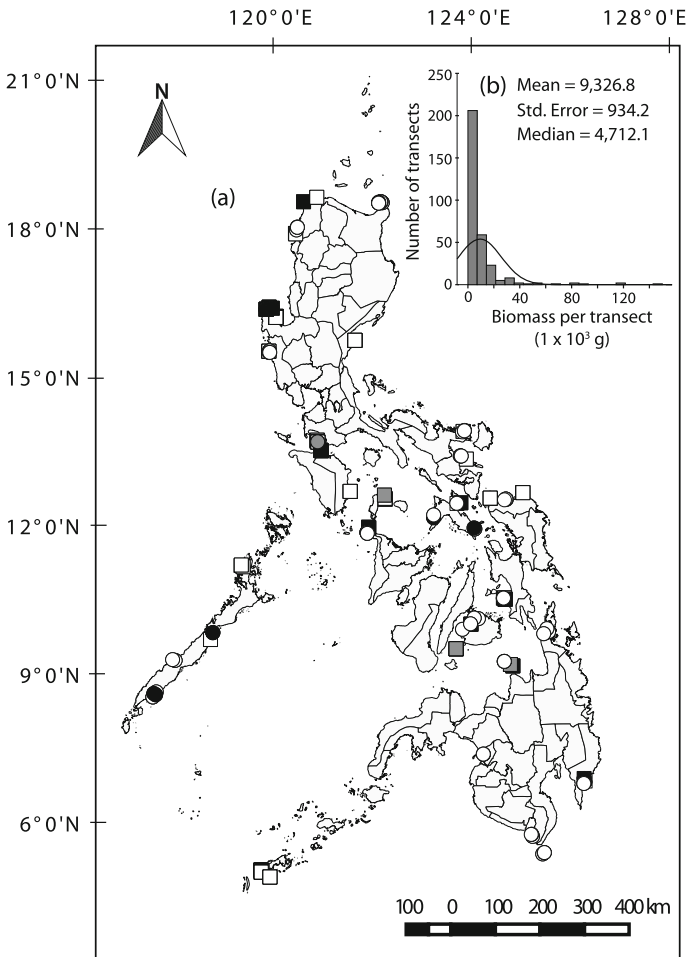
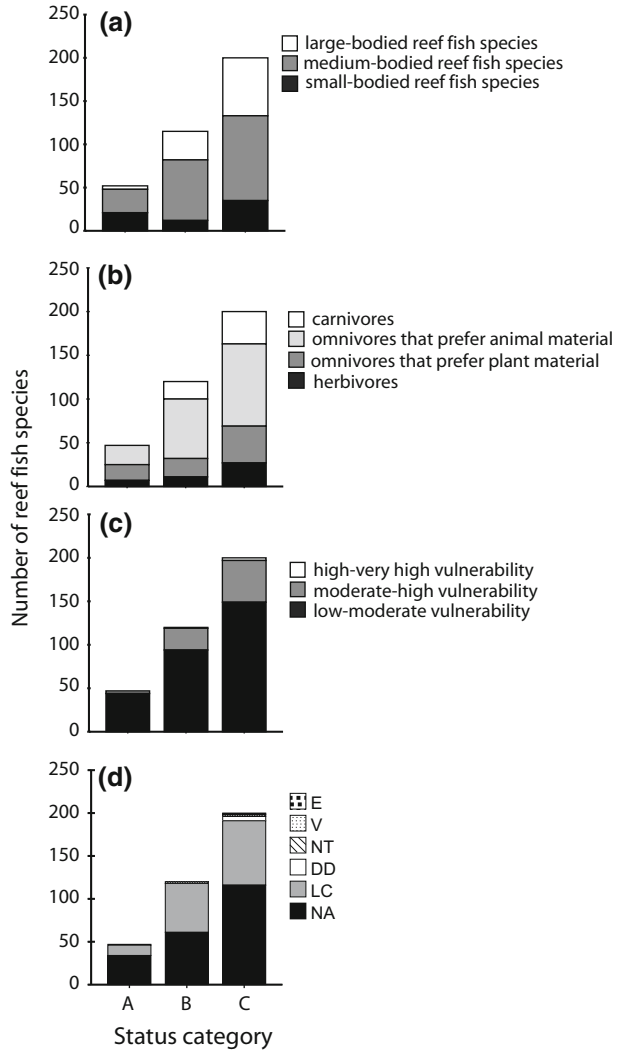


Fig. 5 Distribution map showing total reef fish biomass per transect. *Squares* represent transects located within MR boundaries, while *circles* represent transect located outside MR boundaries (a). *Histogram* with normal curve showing the mean fish biomass per transect (b)

showed mean abundance and AMCP distribution that were above the mean values for all the recorded species.

Category B and C species included reef fish species from all size classes and trophic levels, but were mostly composed of large and medium-bodied species, and carnivorous or omnivorous species (Fig. 6a, b). Category C species were made up of mostly medium-bodied (49 %, $n = 200$) and large-bodied (33 %) species, omnivores with a preference for animal material (46 %), carnivores (21 %) or omnivores with a preference for plant material (20 %). Category B species were made up of mostly medium-bodied (60 %, $n = 120$) and large-bodied (28 %) species, omnivores with a preference for animal material (58 %), carnivores (17 %), or omnivores with a preference for plant material (16 %). In contrast, Category A species were mostly made up of medium-bodied (55 %, $n = 47$) and small-bodied (38 %) species, and omnivores with a preference for animal material (51 %) or plant material (34 %). We noted that 95 % of the 104 large-bodied reef fish

Fig. 6 Bar plots comparing reef fish species status categories with the species' maximum total length (a), trophic level (b), FishBase vulnerability score (c), and IUCN conservation status categories (d). Definitions of species' status and life history categories are found in the methods section of this paper



species were classified in either category B or C (33 species (31 %) were in category B, and 67 species (64 %) were in category C) (Fig. 6a).

Our current findings showing generally low mean reef fish species abundance and limited AMCP distribution do not match with existing FishBase vulnerability scores (Fig. 6c; Online Appendix 3) or IUCN status categories (Fig. 6d; Online Appendix 3). Of the 320 reef fish species in category B and C, 243 species (75 %) were given low-moderate vulnerability scores by FishBase. In addition, compared with the status categories of reef fish species given by the IUCN, we found that 211 (57 %) of the 367 reef fish species included in our study were un-assessed (NE), six species were labeled as data deficient (DD), 144 species (39 %) were categorized as least concern (LC), four species were classified as near threatened (NT), one species was classified vulnerable (VU) (*Cromileptes altivelis*), and only one species was classified as Endangered (EN) (*Cheilinus undulatus*).

Discussion

This paper presents the first account of Philippine reef fish biodiversity using standardized methods in quantifying abundance and distribution per species. Our findings demonstrated that, despite the Philippines generally exhibiting high reef fish species richness, most reef sites in the country had low reef fish abundance and biomass. In addition, many reef fish species exhibited either low abundance or distribution, or both low abundance and distribution—i.e., category B and C status. Another important finding was that most large-bodied carnivorous reef fish species fell under categories B and C—a matter of economic concern for the Philippine municipal fishing industry, which generally targets these groups in fisheries. However, despite the poor status of Philippine reef fish species, many species remain un-assessed or under-assessed by well-established conservation authorities such as IUCN to date, because of the lack of national reef fish species assessment data tracked over time.

Comparisons with existing conservation assessments

Prior to this study, existing data on Philippine reef fish species were generally available for only commercially-important reef fish species (i.e., large predatory fish species), limited to a few sites throughout the country, and presented reef fish abundance per family rather than per species (Russ 1989; Russ and Alcala 1998a; Alino et al. 2002; Christie et al. 2002; Russ et al. 2003; Haribon Foundation 2005; Samoilyts et al. 2007; Coral Reef Information Network of the Philippines (Philreefs) 2010). National assessments using IUCN categories and criteria have been done in other countries (Milner-Gulland et al. 2006; Miller et al. 2007), but in the Philippines, the lack of species-specific data on reef fish abundance and distribution has made national assessments impossible. As a result, many of the reef fish species recorded in our study remain un-assessed by conservation authorities such as the IUCN, or were given assessments that potentially underestimate their current status in the Philippines—a matter of great conservation importance, especially for reef fish species occurring in low local abundances and restricted distributions (i.e., species assigned to categories B and C). For example, many Philippine reef fish species that fell under category B and C in our study were actually assessed as LC or NE by the IUCN (Fig. 6d; Online Appendix3). Similarly, many reef fish species assigned to category B and C were assigned low-medium vulnerability scores and wide geographic distributions by FishBase (Fig. 6c; Online Appendix 3). The discrepancies between our own assessments and those of the IUCN and FishBase suggest that global-scale assessments may not adequately represent the national status of species—i.e., species recognized as globally stable in terms of population size and distribution may actually be exhibiting low national abundances or restricted distributions. This means that there is a great need to improve the national assessment and monitoring of Philippine reef fish species, to aid the management and conservation efforts in the country by providing constant and up-to-date information on the local status of species.

Patterns of reef fish diversity throughout the Philippines

Reef fish species richness throughout Philippine coral reefs was generally high throughout the country (Fig. 2). Our national mean species richness of 22–23 reef fish species per 100 m² is comparable to species richness levels recorded in previous studies conducted in the Philippines (Alcala 1988; Russ and Alcala 1989, 1998a; Christie et al. 2002; Walmsley

and White 2003; Nañola et al. 2011). Only a few places showed exceptionally high or low reef fish diversity (Fig. 2), and did not show peak diversity values in central Philippines as demonstrated in the findings of Carpenter and Springer (2005), which were mainly based on fewer sample sites or museum species collections from the Philippines. This implies that there is a great need to improve current assessments of biodiversity patterns throughout the Philippines and not just rely on previous collections and records, which may no longer represent current diversity.

Most places in the Philippines exhibited low reef fish abundance per unit area (Fig. 4). Over 70 % of the surveyed transects had total reef fish abundances below the national mean abundance (326–394 reef fish individuals per 100 m²). In fact, our national mean abundance value itself was relatively low when compared to mean fish abundances recorded from previous studies (Alcala 1988; Russ and Alcala 1989, 1998a, b; Christie et al. 2002; Walmsley and White 2003). For example, Alcala (1988) estimated a density of about 18,000 reef fish individuals per 500 m² in Sumilon Reserve, a well-enforced MR in the Philippines. In a more recent study, Walmsley and White (2003) recorded a mean of 5214 ± 1580 fish individuals per 500 m² in the Apo Island sanctuary, after the implementation of MR management and enforcement. While such studies only represent a few localities throughout the country, they demonstrate the levels of fish abundance Philippine reefs may achieve with proper management and enforcement (Samoilys et al. 2007). However, our comparably low national mean abundance value, together with the disproportionate number of transects exhibiting extremely low reef fish abundance (Fig. 4b), further emphasizes the generally poor state of Philippine reef fish abundance levels to date.

Similarly, reef fish biomass per unit area was low throughout most of the surveyed reef sites (Fig. 5), with over 70 % of all surveyed transects falling below the national mean \pm SE biomass (8394–10,263 g per 100 m²). Estimates of fish biomass is often used in fisheries management (for example, to set fishing quotas), because it represents the potential amount of yield or production from fishing. In conjunction, our data estimates that most places in the Philippines hold less than 8.4 kg of fish per 100 m². This figure falls well below previous estimates of reef fish biomass in certain Philippine localities, such as the ~ 29.7 kg per 100 m² inside Sumilon MR, ~ 26.9 kg per 100 m² outside Sumilon MR, and ~ 26.8 kg per 100 m² inside Apo Island MR recorded by Russ and Alcala (1998b) during the year 1991.

Reef fish species richness, abundance, and biomass significantly differed among the surveyed municipalities, suggesting that reef fish community structure may vary at spatial scales of tens of kilometers (the typical area of territorial waters per municipality in the Philippines). Variations among reef fish communities have been shown at similar scales (e.g., tens of kilometers), and have been attributed to differences in habitat complexity, habitat quality, and patchiness of habitat types between sites (Anderson and Millar 2004; Garcia Charton et al. 2004). However, community variation may also be due to differences in conditions of water quality, pollution, and protection from exploitation—anthropogenic drivers which can be regulated by local management and enforcement. Such drivers may affect the differences in reef fish community structure between municipalities, given the variable levels of coastal resource management in Philippine municipalities (Weeks et al. 2010; Muallil et al. 2014).

The current status of Philippine reef fish species

Based on our abundance and distribution data per species, most Philippine reef fish species fell under status categories B and C (Fig. 5). Category C reef fish species exhibited both

low local population sizes and restricted distributions, putting them at the greatest risk of local extirpation, considering the continued high and often destructive exploitation of these species in many parts of the Philippines. However, category B species could also be at risk of local extirpation. For example, the failure to adapt to sudden changes in environment or resource availability (brought about by either natural or anthropogenic causes) could lead to the extirpation of restricted-range species, regardless of high local abundance (Hawkins et al. 2000). In addition, wide species distribution may not be a guarantee of safety from local extirpation, particularly for highly-exploited reef fish species with low local abundances (Morris et al. 2000). Only the 47 category A reef fish species exhibited both high abundances and wide distributions—qualities that make them less susceptible to local extirpation than the other 320 potentially imperiled reef fish species.

Category A species were made up of mostly small-bodied and medium-bodied, and omnivorous species. The abundance and distribution of these species may be due to their generalist lifestyle, which gives them access to a wider range of utilizable resources. For example, damselfishes (which made up 61 % of all category A species) can occupy reef and non-reef habitats, obtaining food from reef-associated organisms or other sources (Bell and Galzin 1984). Similarly, all six wrasse species in category A (the second most-represented family in category A, at 12 %) are carnivorous or omnivorous generalists (Froese and Pauly 2014). Additionally, generalist species are more resilient than specialists, and show smaller declines in abundance following disturbance (Wilson et al. 2008)—this could explain the abundance of generalists in many of our study reef sites, considering the degraded state of many Philippine coral reefs (Gomez et al. 1994).

We noted that over 90 % of all large-bodied reef fish species recorded in our study fell under category B or C (Fig. 6). The low local abundances and restricted distributions of large-bodied species may be expected, since commercially-valuable large-bodied species tend to be more targeted for exploitation than small-bodied species (Dulvy et al. 2003). Nevertheless, we found that categories B and C included reef fish species from all size classes and trophic levels. Some studies speculate that the absence of large predatory fish might result in increased abundances of smaller prey species such as damselfish—i.e., predator release (Christie et al. 2002). However, our study showed that many small-bodied and medium-bodied species also fell under category B and C, despite the rarity of large predators in most of the Philippine reefs. This suggests that many Philippine fisheries are non-selective, targeting fish species of all sizes (Pauly 1996; Bundy and Pauly 2001), and that even some small-bodied species may not escape intense fishing impacts (Olden et al. 2007) that include destructive fishing practices such as dynamite and cyanide fishing (Rubec 1986; Samoily 1988).

Caveats and limitations of reef fish species assessment methods: using UVC and MCP

The UVC belt transect method has been criticized as underestimating the diversity and abundance of species possessing certain behavioral or life history traits. For example, UVC belt transects may fail to detect many cryptic or nocturnal fish species, which remain hidden in reef crevices during the day, and are therefore missed by the divers conducting the census (Brock 1982; Willis 2001). Similarly, records of species that exhibit diver-avoidance behavior may also be underestimated, since these species hide upon the approach of a diver (Edgar et al. 2004). Conversely, highly mobile species may be overestimated, since they are highly conspicuous and their movement in and out of the transect and the diver's field of view may result in double-counting (Smith 1988). Furthermore, the

behavior of fish individuals can vary with conditions or experiences brought about by human impacts—fish found outside MRs may tend to avoid divers, possibly as a behavioral response to previous experience with spear-fishers (Jouvenel and Pollard 2001).

While a number of biases have been associated with the UVC belt transect method, it is a commonly-used method in reef fish biodiversity assessments that require species abundance estimates (Thresher and Gunn 1986). The method has a number of advantages, such as its non-destructive nature, high replication and power, accuracy and precision, and minimal post-processing after the survey (Murphy and Jenkins 2010). In addition, we minimize some biases by conducting surveys at slow swim speeds (we surveyed transects at a speed of about $5 \text{ m}^2 \text{ min}^{-1}$), which improves counting accuracy and search efficiency of reef fish (Samoilys and Carlos 2000). Conducting the surveys slowly and calmly was also done to avoid scaring away skittish fish (and therefore, underestimating counts), which may include some large-bodied species such as groupers, snappers, and sweetlips.

Although widely-used in the assessment of species distributions, the MCP method has also received criticism, due to its tendency to overestimate species range (Burgman and Fox 2003). Because the MCP method accounts for only the outermost points of a species' occurrence, it utilizes only a very small sample of the species' occurrence data to estimate distribution. Other methods, such as kernel density estimators (KDEs) and application of α -hulls, provide a more accurate representation of species distribution (Burgman and Fox 2003). These methods allow the omission of outliers or 'rare occurrences' of a species, because the spatial density of species occurrence records is taken into account when plotting distribution (something the MCP method fails to do).

Despite the limitations of MCP, we feel that it is still an appropriate method in addressing the objectives of our study regarding species distribution. In our study, we wish to avoid omitting species of rare occurrences, since we want to provide estimates of the entire possible national distribution of each species (rather than estimates of species 'likelihood of occurrence' and 'core areas' throughout the country provided by the KDE and α -hull methods). Furthermore, the overestimation of species range is unlikely for most of the reef fish species included in our study, because many of these species are expected to be found throughout the Philippines (and in fact, throughout the Indo-Pacific Region and Coral Triangle) (Allen et al. 1999, 2003; Froese and Pauly 2014).

Implications for Philippine reef fish management and recommendations

The low abundance and restricted distributions of many Philippine reef fish species can have significant implications on the future trajectories of fish species declines, and the associated declines in reef fish biodiversity benefits derived from those species. Species with low abundance and distributions are generally prone to local extinctions, which have already been documented in marine environments (Dulvy et al. 2003; Edgar et al. 2005; Luiz and Edwards 2011; Stierhoff et al. 2012), despite claims that the natural extensive ranges and dispersal capabilities of marine organisms cushion them against extinction (Roberts and Hawkins 1999). The low abundances of many Philippine reef fish species may have detrimental ecological effects, including trophic cascades and changes in reef fish assemblages brought about by the loss of top predators (Pace et al. 1999; Friedlander and DeMartini 2002; Myers et al. 2007), and even shifts from coral-dominated reefs to algae-dominated reefs accompanying the loss of grazing, herbivorous fish species (Mumby et al. 2006; Stockwell et al. 2009). Furthermore, local extirpations of many reef fish species in the Philippines will negatively affect the socio-economic value of Philippine coral reefs, including the 70 Billion-Peso annual landed value of the Philippines' municipal fishing

industry (BFAR 2011). The rarity of large-bodied carnivorous fish species observed throughout our study is of particular concern. About 47 % of the large-bodied species recorded in our study are considered food-fish by FishBase (Froese and Pauly 2014), although this figure may still be an underestimate, given the non-selective nature of many Philippine fisheries (Bundy and Pauly 2001). Therefore, large-bodied fish species play a key role in the food security of Filipinos, who rely on fish protein for a significant portion of their diet (White et al. 2000; BFAR 2011).

Marine Reserve establishment is the most well-known and widely-implemented form of marine conservation in the Philippines. Philippine MRs have already been shown to increase levels of fish abundance and biomass (particularly of large, commercially-targeted predator species), both inside MR boundaries for a few MRs in the country (Alcala 1988; Samoilys et al. 2007), and outside MR boundaries via spill-over effects (Russ et al. 2003; Russ and Alcala 2011). However, we observed a lack of a significant effect of MR protection on reef fish species richness and abundance, and this, together with personal observations regarding the quality of MRs included in our study, lead us to speculate the following: (a) many of the MRs included in our study are poorly enforced (e.g., lacking boundary demarcations or patrolling officers), offering little difference in terms of protection and recovery from the adjacent fishing grounds; and (b) MRs included in our survey were not established in the best possible reef sites (i.e., areas with high coral cover), with the best reef sites being designated fishing grounds instead. Our observations regarding MR enforcement and placement are corroborated by an extensive review of Philippine MRs by Weeks et al. (2010), who found that only 0.5 % of municipal waters and 2.7–3.4 % of Philippine coral reef areas were protected in no-take zones, and that 90 % of Philippine MRs are <1 km². Inadequate MR size, connectivity, and site selection may compromise MR effectiveness, since reef fish species may utilize a wide range of habitats such as sea grass and mangrove areas (Honda et al. 2013). For such species, MR networks that do not include utilized habitats may not offer sufficient protection from exploitation. Furthermore, MR size and habitat requirements may vary with fish species that exhibit different life history traits and home range sizes, and such factors need to be considered when establishing MR size and placement (Moffitt et al. 2009; Claudet et al. 2010). Unfortunately, the lack of available information on the majority of MRs in our study (Online Appendix 1) makes it impossible to test the effects of MR age, size, or enforcement rating on reef fish biodiversity. However, there have been recent efforts to construct a centralized and publicly-accessible database of all Philippine MRs, called the Philippine marine protected area (MPA) Database (Cabral et al. 2014). The Philippine MPA Database (accessible at: <http://www.mpa.msi.upd.edu.ph/>) had collected information on 1800 Philippine MRs as of 12 July 2014, but was offline during the writing of this paper's revisions (October–December 2014). The construction of the Philippine MPA Database represents increasing efforts to standardize data collection in Philippine coastal resource management, and would complement national assessments and monitoring of Philippine marine biodiversity, such as the kind presented in this paper. Nevertheless, there is still a great need to ensure the effective enforcement of many MRs in the Philippines, in order to make MR effects consistent throughout the country. In addition, there is a great need to improve the selection of high-quality habitat in MR establishment to avoid the selection of only degraded habitats as MRs. Moreover, there is a great need to ensure that other reefs outside small MRs are put under some forms of management (e.g., selective fishing or close seasons) to ensure that large reef areas that are not under MRs are not over-exploited and heavily degraded.

While existing Philippine datasets make it difficult to assess the national status of many Philippine reef fish species using the internationally-accepted IUCN categories and criteria,

Jelks et al. (2008) suggested that conservation efforts should not be delayed while waiting for assessments that coincide with the IUCN's standards. The findings of our study present the most up-to-date national assessment for all non-cryptic reef fish species using standardized methods, and highlight the need for conservation action for many Philippine reef fish species. Furthermore, our findings demonstrate the great need for species-specific, standardized, and long-term reef monitoring in the Philippines to be able to quantitatively track species status, monitor the trajectories of reef fish species populations, aid management decisions, and improve public understanding of Philippine reef fish status.

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