Long-term change in coral cover and the effectiveness of marine protected areas in the Philippines: a meta-analysis

Evangeline T. Magdaong[1*], Masahiko Fujii [2], Hiroya Yamano[3], Wilfredo Y. Licuanan[4], Aileen Maypa[5], Wilfredo L. Campos[6], Angel C. Alcala[7], Alan T. White[8], Dean Apistar[5], Rafael Martinez[5]

[1]Graduate School of Environmental Science, Hokkaido University, N10W5, Kita-ku, Sapporo, Hokkaido 060-0810, Japan

[2]Faculty of Environmental Earth Science, Hokkaido University, N10W5, Kita-ku, Sapporo, Hokkaido 060-0810, Japan

[3]Center for Environmental Biology and Ecosystem Studies, National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan

[4]Biology Department and the Br. Alfred Shields FSC Ocean Research Center, De La Salle University-Manila, 2401 Taft Avenue, Manila 1004, Philippines

[5] Coastal Conservation and Education Foundation, Banilad, Cebu City, Philippines

[6]OceanBio Laboratory, University of the Philippines in the Visayas, Miag-ao, Iloilo 5023, Philippines

[7]Silliman University Angleo King Center for Research and Environmental Management, Silliman University, Dumaguete City 6200, Philippines

[8] The Nature Conservancy, Honolulu, HI, USA

[*]Corresponding author: emagdaong@ees.hokudai.ac.jp

Abstract

Coral cover assessments have shown coral declines in major reefs of the world. However, region-specific trends still remain unclear, particularly in areas with high diversity such as the

Philippines. Although the state of Philippine reefs has been periodically reported, long-term trend in coral cover change has not been investigated. In this study, we examined the temporal patterns of the magnitude and trajectory of coral cover change in the Philippines using meta-analysis. We collated and analyzed quantitative surveys of living hard coral cover from 317 sites monitored between 1981 and 2010. We explored the rate of change in coral cover in terms of time, effect of bleaching and effect of protection on fishing. Accompanied with the history of reef assessment in the country is its almost four decades of experience in reef management and conservation. Here, we assessed the efficacy of marine protected areas (MPAs) on coral cover for over nearly three decades. Results showed an overall increase in coral cover in the Philippines from 1981 to 2010. Protection from fishing contributed to the overall increase in the mean annual rate of change as the coral cover significantly increased within MPAs than non-MPAs. The significant differences in the rate of change in coral cover across time periods were influenced by chronic anthropogenic stresses, coinciding with the timing of thermal stress and the establishment of MPAs. Our findings revealed however, that the pattern of the rate of change in coral cover is independent of the level of protection, age or size of MPA.

Keywords: Coral cover, meta-analysis, marine protected areas, bleaching, Philippines

Introduction

Long-term coral cover assessments have shown coral declines in major reefs of the world (Pandolfi et al., 2003), such as the Caribbean (Gardner et al., 2003), the Great Barrier Reef (Sweatman et al., 2011; De'ath et al., 2012), and the Indo-Pacific (Bruno & Selig, 2007). However, region-specific trends still remain unclear particularly in highly biodiverse areas such as the Philippines. The Philippines, located in the tropical Indo-Pacific, is the epicenter of species richness and marine biodiversity in the Coral Triangle (Roberts et al., 2002; Carpenter & Springer, 2005). It has the third largest reef area in the world and is a potential source of reef larvae for the northwest Pacific (Fujiwara, 1997, Burke et. al., 2002; Licuanan & Capili, 2003). More than 80% of the population is estimated to live within 50 km of the coast, deriving ecosystem benefits from the reef such as food, employment, coastal protection, and tourism (Burke et al., 2002, 2011). It is identified as the hottest of the hotspots, highly threatened and highly vulnerable (Roberts et al., 2002; Carpenter et al., 2008; Burke et al., 2011). Philippine reefs have been exposed to a plethora of local stresses, particularly destructive fishing, overfishing, siltation, pollution, crown-of-thorns seastar (COTS) predation, and recently, bleaching and diseases (see review of Magdaong et al., in press).

Nationwide coral reef assessment in the Philippines began in 1976 due to concerns of gathering of corals in the country (Gomez, 1991). Initial findings in 1978 showed that only 5% of the reefs were in "excellent" condition (>75% soft and hard coral cover; Gomez & Alcala, 1979). Since then, the status of Philippine reefs has been regularly reported in various periods (Gomez et al., 1981; Yap & Gomez, 1985; Gomez, 1991; Gomez et al., 1994; Licuanan & Gomez, 2000; Nañola et al., 2006; PhilReefs, 2003, 2005, 2008). However, there has been no long-term study of coral cover trend in the Philippines. In the face of the increasing impacts of climate change compounded by anthropogenic disturbances, it is imperative to assess the long-term trend of coral cover over time. Here, we assess the trajectory and magnitude of coral cover change in the Philippines through the integration of the previous studies and reports using meta-analysis.

Accompanied with the history of reef assessment in the country is its almost four decades of experience in reef management and conservation. The success of the early marine sanctuaries established in the 1970s in Sumilon and Apo Islands served as a model for biodiversity conservation and fisheries management in the country (Russ & Alcala, 1996; Alcala & Russ, 2006). Establishing marine protected areas (MPA) has been one of the implemented management interventions to curve habitat degradation (Walmsley & White, 2003; Nañola et al., 2006). Presently, there are more than 1200 MPAs across the country, and about 60% of these are located in the Visayas region (Arceo et al., 2008). Maliao et al., (2009) demonstrated the efficacy of Philippine marine reserves in increasing the overall reef fish density. We then explore whether coral cover exhibits a similar pattern and examine the role of MPAs on the trends of coral cover in the Philippines.

Meta-analysis has been a widely used method of assessing long-term trends in the state of coral reefs (e.g., Gardner et al., 2003; Côté et al., 2005; Gardner et al., 2005; Alvarez-Filip et al., 2011). It is a statistical method for quantitatively integrating research findings across studies and determines whether they share a common effect size (Hedges & Olkin, 1985; Gurevitch & Hedges, 1999; Côté et al., 2005). In this study, we used living hard coral cover as a reef health indicator because it forms the structural foundation of the reef ecosystem and constitutes the architectural complexity of the reef (Sweatman et al., 2011; Selig et al., 2012).

Materials and Methods

We estimated the rate of change of living scleractinian coral cover from quantitative surveys obtained from electronic and manual searches of the scientific and gray literature, including personal communications from reef scientists and non-governmental organizations. The electronic search consisted of browsing reef-related websites such as ReefBase and OneOcean.org, search engines such as

Google Scholar, and online publications. The process of data collation, compilation of the study database and review of historical disturbances on Philippine reefs are described in Magdaong et al. (in press). From the compiled database, we selected studies that reported (1) the percentage of living hard coral cover, (2) two or more surveys on the same reef, and (3) the number and length of transects covered. We included studies regardless of the purpose, survey method used, and the location of the survey (e.g., protected reefs). All sites defined by each study were treated as a separate site. A site defined here can be the average of transects of stations on the same reef but at different depths, within protected or unprotected reefs. The effect size chosen to measure the annual rate of change in percentage cover (ARC) of each site was

$$\mathrm{ARC} = \frac{(\log End - \log Start)}{d}, \qquad (1)$$

where *Start* and *End* are the coral cover (%) at the start and end of the time series, respectively, and d is the duration of the time series in years (Paddack et al., 2009; Alvarez-Filip et al., 2011). Paddack et al. (2009) used the survey area as a weighting measure which was suggested as a robust weighting method (Côté et al., 2005). However, 84% of the collated studies used point intercept transect (PIT) and line intercept transect (LIT) methods which used transect length in measuring percent coral cover and no surveyed area was reported. Alternatively, we used the transect length and the number of replicate transects for each survey similar to Alvarez-Filip et al. (2011). We took the average number of transects for studies with varying number of replicates. The mean effect size $\overline{\mathrm{ARC}}$ of all studies or categories was estimated as

$$\overline{\mathrm{ARC}} = \frac{\sum_{i=1}^{n}(W_i * \mathrm{ARC}_i)}{\sum_{i=1}^{n} W_i}. \qquad (2)$$

The effect size was considered significant if the 95% bias-corrected bootstrapped confidence interval (CI) did not include zero. The confidence interval (CI) is a range of values that encompasses the true value and indicates the magnitude, direction, and uncertainty of the effect (Greenfield et al., 1998;

Nakagawa & Cuthill, 2007). Variation in the rate of change in coral cover among categories or groups was evaluated by the Q_M statistic, analogous to analyses of variance (ANOVA; Hedges & Olkin, 1985; Rosenberg et al., 2000). A significant Q_M value denotes differences in effect size among the groups (e.g., MPA vs. non-MPA), tested against a distribution generated from 4999 iterations of a randomization test (Rosenberg et al., 2000). An individual group however, may have a significant effect size even given a non-significant Q_M (Paddack et al., 2009; Alvarez-Filip et al., 2011). We explored three main categorical groupings based on: time, effect of coral bleaching, and effect of protection from fishing. In all cases, data were pooled and maintained with a minimum sample size of 10 sites per group. All meta-analyses were performed using MetaWin Version 2.0 (Rosenberg et al., 2000). All ARC and CI were back transformed to an annual percentage change in coral cover for interpretation.

We examined the temporal heterogeneity in 5-year intervals for the overall dataset by including the replicate surveys that fell within the time period. Some years had longer (6 years instead of 5 years) intervals, to compensate for the low sample size and missing data during 1987–1988 and 1990–1991. We also assessed the impact of coral bleaching on the rate of change in coral cover. The elevated sea surface temperatures coinciding with the El Niño Southern Oscillation (ENSO) led to coral bleaching in years 1982–1983, 1987–1988, 1997–1998, and 2010 (Yap et al., 1992; Arceo et al., 2001). We only considered the massive coral bleaching in 1997–1998 because of the paucity of data in other bleaching years. According to anecdotal accounts, the extent and severity of the 2010 bleaching were patchy (W. Campos, unpublished data). All sites were assumed to be affected by bleaching hence, all sites surveyed in 1998 were included.

We assessed the effect of protection by comparing the overall mean rates of change in coral cover between MPAs and non-MPAs. For MPAs, we considered only sites with a known year of establishment and surveys following year designation to determine the rate of percentage change in coral cover since protection. We used the initial year of MPA designation in some areas which were established more than once because there were no differences in the general trend of rates of change between the first and second year of designation. Effect of protection however may be constrained by potential bias in site selection from placement of MPAs on reefs that were initially healthy resulting to positive reserve effect. In the absence of before and after surveys, the site selection bias was alternatively tested by comparing the initial coral cover between MPAs and non-MPAs within the first 5 years of protection following Selig & Bruno (2010). We further examined the effect of protection on rates of change in coral cover with level of protection, age and size of MPAs. We classified MPAs in terms of level of protection: fully protected (i.e., any form of extraction was prohibited) and partially protected MPAs (i.e., activity or the use of fishing gear was regulated). MPA age was estimated as the number of years between the year of the last monitoring and the year of designation. The official year of designation was assumed as the initial year of enforcement and was considered as the first year of protection (Claudet et al., 2008). We obtained MPA information, such as the official year of designation, size, status of protection from Coral Reef MPAs of East Asia and Micronesia of ReefBase, World Database on Protected Areas (IUCN & UNEP-WCMC, 2010), and Alcala et al. (2008) for MPAs in the Visayas region.

Results

Selected studies from the database generated 1119 monitoring surveys conducted in 317 sites, in 57 municipalities and 18 coastal provinces, from 36 studies and 1 monitoring program provided by the Coastal Conservation and Education Foundation (CCEF; Fig. 1). Details of the previous studies used and the result of methodological effects are described in Online Resource 1. Together, these studies spanned 29 years (mean = 6.4 ± 5.9 SD years) between 1981 and 2010, with the longest monitoring study covering the same period. Two of the most commonly used survey methods were PIT (204/317, or 64%) and LIT (~20%) (see Online Resource 1). The majority of sites (262/317, or 83%) was surveyed

コメント [EM1]: PIT and LIT were first defined in lines 110-111.

using a 50 m transect length at depths ranging from 2 m to 20 m. Figure 2 shows the pattern of percent hard coral cover from 1981 to 2010. Absolute coral cover showed an increasing trend from an average of 28% in 1981 to 37% in 2010, with an overall average of ~36% comparable to reported 33% in Indo-Pacific (Bruno et. al., 2009). A similar pattern can be observed across MPA and non-MPA sites. Although there is an inter-annual variability, MPA sites generally exhibited higher coral cover than non-MPA sites except in years with very low number of surveys on MPAs (i.e. in 1984, 1993 and 1995). The number of monitoring sites increased with the highest (150 sites) in 2006 and no data were obtained in years 1987-1988 and 1990-1991. A total of 162 sites monitored on non-MPA sites, and 137 of the 155 MPA sites had replicated surveys following establishment. This comparable number of sample sizes surveyed inside and outside of MPAs minimized the potential bias of protected reefs on the overall response of percentage change in coral cover.

コメント [EM2]: Except in 2004, because the number of MPA sites were not extremely low (22 MPA vs 19 non-MPA)

General trend

The overall meta-analysis also indicated an annual mean coral cover increase of 1.34% from 1981 to 2010 (bias-corrected 95% confidence interval, CI = 0.18 to 2.51%, which did not include 0 and was therefore significant). However, the division in 5-year intervals showed significant differences across time periods ($Q_M = 31.9$, $df = 4$, $P = 0.0002$) (Fig. 3). The overall rate of change in coral cover was strongly positive in time periods: 1989-1995 (ARC = 12.18%; CI = 6.73 to 18.79%) and 2001-2005 (ARC = 4.57%, CI = 1.08 to 8.32%) while significantly negative in periods 1981-1986 (ARC = -9.16%; CI = -15.95 to -2.08%) and 1996-2000 (ARC = -4.91%, CI = -8.04 to -1.22%). In 2006-2010, there was a negative change in coral cover although not statistically significant (ARC = -1.08%; CI = -3.91 to 1.61%). During the 1997–1998 massive bleaching, the absolute change in coral cover was estimated at -8.07% yr^{-1} (CI = -13.24 to -2.46%) (figure not shown).

Marine Protected Areas

Assessing site selection bias revealed that coral cover within MPAs (mean = 36.0%) were higher than non-MPAs (mean = 30.2%), and the difference is significant (Q_M = 4.16, P = 0.048). Among the seven provinces, MPA sites (mean = 39.2%, n = 32) established in 2000s in Cebu had a significant higher coral cover within the reserve (Q_M = 14.9, P = 0.0006) compared to its adjacent fishing ground (mean = 25.9%, n = 31). These MPAs with potential site selection bias were eliminated in the subsequent analyses to determine the reserve effect on the rate of change in coral cover. Omitting these sites suggests no further substantial bias due to differences in the initial percent coral cover between inside and outside of MPAs (Q_M = 0.63, P = 0.43).

Comparison of rate of change in coral cover between MPA and non-MPA sites showed significant differences between the two (Q_M = 2.27, P = 0.023), with an overall positive change in coral cover of 1.65% (CI = 0.42 to 2.94%) (Fig. 4). Coral cover increased significantly within MPAs by 3.20% per year (CI = 1.65 to 4.95%) but did not change in non-MPAs (ARC = 0.32%, CI = -1.37 to 2.09%). On the other hand, the rate of change in coral cover revealed no significant differences in level of protection (Q_M = 0.89, P = 0.12) (Fig. 5). We found a significant positive rate of coral cover change within partially protected MPAs (ARC = 6.00%, CI = 1.55 to 13.42%), comparable to that in fully protected MPAs (ARC = 2.52%, CI = 0.90 to 4.09%). We also did not detect a strong linear relationship between rates of change and MPA age (slope < 0.0001, P = 0.31) or coral cover change and MPA size (slope < 0.0001, P = 0.83), suggesting that the variability in the rate of change coral cover is independent of MPA age and size (Fig. 6a). MPA age and size were classified into 3 groups covering the minimum, average and maximum values to assess the average responses in different group age and size of MPAs. In terms of MPA age, duration of protection ranged from 2 to 37 years with an overall average of ~14 years. A total of 21 sites were ≤ 5 years old (mean = 3.86; range = 2-5) while 41 sites were 6-20 years of age (mean = 12.3; range = 6-20) and 37 sites were >20 years old (mean = 22.8; range = 21-37). Rates of change in

コメント [EM3]: It is statistically significant (P=0.023). Based on meta-anlysis articles Ive seen so far its common to use the word significant for statistically significant results.

コメント [藤井賢彦4]: Not statistically significant, and better to use a different word to express the large difference.

coral cover showed no statistical differences across MPA age groups (Q_M = 0.91, P = 0.64) (Fig. 6b). However, coral cover improved significantly in 6-20 years (ARC = 3.37%, CI = 0.95 to 5.78%) and >20 years (ARC = 1.91%, CI = 0.42 to 3.56%) while did not significantly increase in ≤ 5 years old MPAs (ARC = 6.10%, CI = -0.23 to 13.5%). With regard to MPA size, there was a large disparity between Tubbataha Reefs Marine National Park, a nationally designated MPA, which had 33,200 ha and the majority (82%) of municipal-based MPAs which had <40 ha. A total of 29 MPAs covering ≤10 ha had sizes ranging from 3.18 to 10.00 ha (mean = 6.50), while 52 sites were >10-40 ha with areas from 10.78 to 40.00 ha (mean = 18.8) and 18 MPAs of area with >40 ha ranged from 43.28 to 33,200 ha (mean: 25, 847), including Tubbataha reefs. This large difference, on the contrary, did not indicate statistical variation on the rates of change in coral cover among groups (Q_M = 0.64, P = 0.40). However, coral cover significantly improved across both >10-40 ha (ARC = 4.18%, CI = 1.63 to 7.37%) and >40 ha MPAs (ARC = 1.55%, CI = 0.25 to 2.75%) but did not show statistically significant improvement in ≤10 ha (ARC = 3.28%, CI = -1.10 to 6.88%) (Fig. 6b).

コメント [EM5]: I retained the word significant but mentioned it increased but not significant increase.

Discussion

General trend

The trend in absolute coral cover (Fig. 2) and the overall mean annual rates of change in coral cover (~1% yr^{-1}) both showed a general increase in coral cover over time. Unlike the Caribbean reefs, the Philippine reefs represented in this analysis have not suffered continuous coral cover decline as coral cover improved from 1981 to 2010. The resiliency of reefs in Indo-Pacific is attributed to the presence of high diversity and functional redundancy of species that can promote stability of ecosystem processes and capacity to recover despite the increase in disturbances (Bellwood et al., 2004; Hooper et al., 2005; Roff & Mumby, 2012). Moreover, the four decades of reef management in the country contributed to the overall increase in coral cover as the rate of change increased significantly within MPAs compared to non-MPAs (Fig.4).

Temporal patterns of coral cover change showed the trajectory of decline and recovery, conservation efforts, and thermal anomalies through the years (Fig. 3). In 1981-1986, coral cover significantly declined as confirmed by the reports in the 1980s. Signs of reef degradation had already been apparent since the early reef assessment due to predominant destructive fishing methods, overfishing, sedimentation from forest denudation and mining, coral harvesting, among others (Gomez et al., 1981; Yap et al., 1985). This consequently led to initiation of reef protection as management intervention to conserve coral reefs and prevent extractive exploitation (Alcala, 1988; Aliño et al., 2002). The occurrence of coral bleaching due to high sea surface temperatures was first reported in the country during the severe 1982–1983 ENSO (Yap et al., 1992). The coral cover increase in 1989–1995 coincided with the timing of the exponential growth in the number of established MPAs after 1991 (Weeks et al., 2009). This period also had little or minimal observed thermal stress (Peñaflor et al., 2009). Beginning in 1996, more bleach-inducing thermal stress events occurred in the Coral Triangle (Peñaflor et al., 2009; fig. 6). The anomalous high sea surface temperature during the strong ENSO in 1997–1998 resulted in large-scale bleaching, which could have influenced the coral decline in the period 1996–2000. Coral cover increased in 2001–2005 concomitant to continual increase in the number of established MPAs until early to mid 2000s (Alcala et al., 2008; Weeks et al., 2009). In 2006-2010, despite the large number of existing MPAs, coral cover did not increase but remained constant. About 48 incidences of bleaching were reported by the Philippine Coral Bleaching Watch (https://phcoralbleaching.crowdmap.com/) in 2010, although it was observed to be patchy compared to the 1998 bleaching episode. In recent years, coastal development and marine-based pollution were reportedly increasing while medium to high threats in terms of overfishing and destructive fishing practices (Tun et al., 2008; Burke et al., 2011). Unlike the Great Barrier Reef which had persistent outbreaks of COTS (Sweatman et al., 2011; De'ath et al., 2012), no large scale outbreaks of COTS

コメント [EM6]: This is based on the format of the journal predation were observed in the country although high incidences were reported in 2000s (Magdaong et al., in press).

Temporal trends suggest that major threats to Philippine reefs are local anthropogenic impacts and global impacts of climate change. We have captured an 8% absolute loss of coral cover during the 1997-1998 coral bleaching (a 22% relative coral cover loss given the overall average coral cover was 36%). This estimate however represents the reefs of central and southwestern Philippines and was lower than the observed coral cover loss (up to 46%) in the western Philippines (Arceo et al., 2001). Impacts of bleaching on habitat could vary depending on the timing and duration, dominant bleaching-sensitive coral population (McClanahan et al., 2007; Côté and Darling, 2010; Selig et al., 2012; Barshis et al., 2013) and current speeds on the reef (Nakamura & van Woesik, 2001). Bleaching was widely observed in August 1998 however, positive thermal anomalies initially developed and prevailed for an extended period of time in the northwestern Philippines compared to other parts of the country (Arceo et al., 2001). Some areas in the Visayas suffered post-bleaching event mortality in 1999 (Divinagracia et al., 2000; Raymundo and Maypa, 2002). In Zaragoza Marine Sanctuary in Cebu, for instance, coral loss was reported low because of the dominance of massive corals which are considered to be tolerant to thermal stress (Alcaria & Bagalihog, 2003) while branching *Acropora* was found to be most susceptible in the western Philippines (Arceo et al., 2001). On the other hand, the observed spatial pattern of *Acropora* bleaching in Tubbataha reefs in the western Philippines also varied with exposure to wave action, and current velocity on the reefs (Arceo et al., 2001).

Marine Protected Areas

Previous long-term studies of marine reserves showed an overall maintenance of coral cover over time in the Philippines (Walmsley & White, 2003) and on a global scale (Selig & Bruno, 2010). Some studies reported no difference in coral cover between inside and outside of MPAs (Jones et al., 2004;

Tyler et al., 2011; Huntington et al., 2011). There are few long-term studies elsewhere of the effects of the protection on the reef substrate that can be compared with our results (e.g Walmsley & White, 2003; Selig & Bruno, 2010; Alvarez-Filip et al., 2011). However, the responses of the organisms to protection vary in magnitude and trajectory with theoretical and empirical studies (Halpern & Warner, 2002). This study demonstrated an overall increase in coral cover across the reefs within MPAs over nearly three decades (Fig. 4). Although the trend in absolute coral cover showed that coral cover increased both inside and outside of MPAs, the mean annual rates of change revealed that coral cover increased significantly within MPAs compared with non-MPAs. This is most likely due to protection which helps in the improvement of the biological condition of the reefs by reducing fishing pressure (such as overfishing and destructive fishing methods) that affect the substrate condition (Russ, 1991; Walmsley & White, 2003). Protection also helps in the recovery of key functional groups such as fish herbivores that are important in climate change resilience (Mumby et al., 2006; Stockwell et al., 2009; Mumby & Harborne, 2010). Macroalgae compete in space with corals (McCook et al., 2001; Barott et al., 2012). Fish herbivores inhibit the growth of macroalgae consequently facilitate coral recruitment and survival (Mumby et al., 2007).

Despite the documented benefits of no-take marine reserves (e.g., Russ & Alcala, 1996; Kelly et al., 2000; Roberts et al., 2001; Halpern, 2003; Russ et al., 2004), partially protected MPAs are typically adopted management approach as a compromise solution in zoning conflicts (Shears et al., 2006, Lester & Halpern, 2008); especially if fishers oppose the allocation of protected areas because of their perceived negative impacts on their livelihoods (Halpern & Warner, 2003; Lester & Halpern, 2008; Horigue et al., 2012). Tyler et al. (2011) found no difference in coral cover between partially protected MPAs and unprotected reefs. A typical partially protected area consists of a sanctuary or no-take (core) zone with traditional use (buffer) zone wherein destructive fishing activities (e.g. use of explosives and poison, *muro-ami* drive-in net) are prohibited. Commonly, buffer zones only allow relatively low-impact extraction methods, such as gleaning or hook and line, and recreational activities (White et al., 2006). Our result indicates that partially protected areas did not differ in response from fully protected MPAs (Fig. 5). This is possibly because partially protected MPAs considered here were no-fishing areas with buffer zones that regulate recreational activities and non-destructive fishing inside the reserve. Further, buffer zone potentially benefits from spillover from the adjacent core or no-take zone. In addition, the cessation of rampant illegal fishing (such as blast fishing and the use of poison) which severely impacts the coral reef may be sufficient to allow the reef to recover as fast as fully protected areas.

Duration of protection has been suggested as a critical factor in the resiliency of the reef (Selig & Bruno, 2010). Stockwell et al. (2009) found no significant correlation between the benthic cover and duration of protection in 15 no-take marine reserves in the Philippines. Our results also suggest that MPA age did not explain a significant portion of the variation in rates of change in coral cover (Fig. 6a). Likewise, the rates of change in coral cover did not differ among age groups. Nevertheless, coral cover remained constant within young MPAs (≤5 yrs) while significantly increased within mid-age (6 to 20 yrs) and old (>20 yrs) MPAs (Fig. 6b). The high variability of rates of change in coral cover in young reserves may be attributed to recovery after closure to fishing. MPAs considered here are typically former fishing grounds and were heavily exploited prior to protection (White et al., 2000; White & Vogt, 2000; Alcala & Russ, 2002; Raymundo et al., 2007; Maliao et al., 2009). The absence of illegal fishing (e.g. blast fishing and use of poison) on the reefs allowed rapid recovery or stabilization of coral conditions within the initial years of protection. Coral recovery was found to be nonlinear, slower for extreme and small coral losses but immediate recovery at medium to high levels of coral decline (Graham et al., 2011). Moreover, some reefs may be dominated by fast growing *Acropora* species (Licuanan, 2002), thus allowing fast recovery following establishment.

Similarly, although the annual rates of change in coral cover were similar across MPA size, coral cover was observed to improve in mid to large sizes of MPAs but not in small MPAs (Fig. 6b). This

コメント [EM7]: Based on White et al., 2006, typically partially protected areas have no-take zone and traditional fishing zone/muti-use zone. I don’t know with other sites but 16/17 of our sites were confirmed strictly no fishing inside the core zone while some had recreational activities allowed inside the no-take zone (e.g. Mabini Batangas MPAs). There is little information about the operation of partially protected sites, it largely depends on municipal ordinance.

indicates that on the average, MPA size of >10 ha may be sufficient to protect the habitat. However for biodiversity conservation, large MPAs may be needed. Reserve sizes of 10–100 km^2 (1000–10,000 ha) are suggested to adequately protect and maintain the associated species within the MPA and facilitate larval export to fished areas (Halpern & Warner, 2003; Mora et al., 2006). Moreover, in case of large scale disturbance, large MPAs may help coral populations to provide new recruits to affected reefs (Selig et al., 2012). Most of the surveyed MPAs in this study fall short of the optimum size but large MPAs on the contrary may also be difficult to manage (Webb et al., 2004; Maliao et al., 2009) indicating the urgent need in the Philippines to establish more MPAs and design, manage them as part of networks.

Our findings revealed no apparent relationship with the pattern of coral cover change and the reserve characteristics examined (i.e., level of protection, age and size of MPA). This is consistent with results of Maliao et al. (2009), suggesting that the overall response of coral cover and reef fish within Philippine marine reserves is independent of the reserve size and the duration of protection. Several factors may have contributed to the variability of reserve response. The initial condition of the MPA upon establishment may play a role in the trajectory of coral cover change over time. Although there was no difference in the coral cover initially between the MPA and the adjacent fishing ground, some areas were in poor to fair (<50%) condition to begin with, while some were good to excellent (>50%) in coral cover. Further, the dominant lifeform or coral morphology, and species in the area may also affect the rates of change in cover. Reefs dominated by branching corals have higher growth rates compared to massive corals (Dullo, 2005). Also, site specific environmental conditions such as situation can have an adverse impact on coral growth and reef development (Hubbard, 1986; Rogers, 1990; Crabbe & Smith, 2005; Fabricius, 2005; Wilson et al., 2005). Effective enforcement and good management practices may also be a determining factor.

Walmsley & White (2003) demonstrated that management and enforcement factors were significantly related to ecological variables in Philippine marine reserves. While Maypa et al. (2012)

who used coral cover and fish density to compare with MPA rating, reported that high management ratings were likely to have better reef health conditions. However, this was not accounted in our analyses because the timing of the last monitoring did not coincide with the year of MPA rating in many sites. The positive change in coral cover within MPAs is an indication that many MPAs included here had enforcement and management in place. Management efforts should be sustained because reefs with reduced anthropogenic impacts (e.g., blast fishing) have a higher resilience after natural disturbance than reefs suffering from multiple stressors (West & Salm, 2003).

Conclusion

We first describe the long-term pattern and magnitude of change in coral cover in the Philippines. Our analyses revealed an overall increase in the rate of change in coral cover for almost three decades. Temporal trends showed that chronic human induced disturbances and thermal stress are major threats to the Philippine reefs. The four decades of conservation efforts contributed to the overall positive change in coral cover as the rate of change increased within MPAs compared with non-MPAs. Protection from fishing therefore helps improve the coral cover compared with unprotected reefs. However, we found no relationship between the rate of change in coral cover with level of protection, age or size of MPA.

The analyses in this study are limited to quantitative changes in coral cover. Changes in species composition through time should also be investigated because coral taxa may vary following disturbance and recovery (Berumen & Pratchett, 2006; McClanahan et al., 2007). Estimates of rates of change in coral cover, however, may be constrained to potential biases arising from preferences for surveying good sites on the reef or the inability to maintain fixed stations over time. Nonetheless, this comprehensive study revealed the overall trend and rates of coral cover change over time across the reefs in the Philippines. Our results provide useful information on the response of coral reefs to protection, which will help improve the design and management of MPA networks to optimize the benefits of protection. We hope this helps encourage and sustain efforts to establish more MPAs to protect a larger proportion of Philippine reefs, especially those around the larger islands of Luzon and Mindanao (that are less represented in this work).

Acknowledgments

We would like to thank the Coastal Conservation and Education Foundation (CCEF), the MPA Database Project of CCEF supported by the National Geographic Society, the Local Governance Coastal Management Project of CCEF supported by the David and Lucille Packard Foundation, Saving Philippine Reefs Project of CCEF, ReefBase, IUCN, UNEP-WCMC, PhilReefs, and the University of the Philippines-Marine Science Institute for the sources of the studies collated; World Resources Institute (WRI) and www.philgis.org for the maps used. We are also grateful to Perry Aliño for providing MSN reports, Mark Vergara for providing a copy of his thesis, Rene Abesamis, Maricar Samson, and Emily Layos for their help in obtaining the data, and Hokkaido University's Sustainable Low Carbon Society Project for funding this research. EM is indebted to Lorenzo Alvarez-Filip, Joseph Dominic Palermo and Koji Oba, who kindly assisted in the meta-analysis. We would also like to express our gratitude to Editor Mutsunori Tokeshi and two anonymous reviewers for their valuable comments and suggestions. This study would not have been possible without the dedication of the reef scientists and divers for conducting coral cover surveys in the Philippines. This paper is a contribution to the S-9 Project supported by the Environment Research and Technology Development Fund of the Ministry of the Environment and Program for Risk Information on Climate Change of the Ministry of Education, Culture, Sports, Science and Technology, Japan.

References

Alcala, A.C., 1988. Effects of marine reserves on coral fish abundances and yields of Philippine coral reefs. Ambio 17: 194-199.

Alcala, A.C., A.A. Bucol, & P. Nillos-Kleiven, 2008. Directory of Marine Reserves in the Visayas, Philippines. Foundation for the Philippine Environment and Silliman University-Angelo King Center for Research and Environmental Management (SUAKCREM), Dumaguete City, Philippines.

Alcala, A.C. & G.R. Russ, 2002. Status of Philippine coral reef fisheries. Asian Fisheries Science 15: 177–192.

Alcala, A.C. & G. R. Russ, 2006. No-take Marine Reserves and Reef Fisheries Management in the Philippines: A New People Power Revolution. Ambio 35: 245-254.

Alcaria, J.F. & S.D. Bagalihog, 2003. Chapter 11 Central Visayas. In Aliño, P., A. Uychiaoco, M. Deocadez, D. Ochavillo, & C. Collantes (eds), Philippine Coral Reefs through Time (2003): Workshop Proceedings. Second of the Atlas of Philippine Coral Reefs Series. Coral Reef Information Network of the Philippines (PhilReefs), University of the Philippines Marine Science Institute, Quezon City, Philippines and the Marine Parks Center, Tokyo, Japan: 47-54.

Aliño, P.M., N.E. Palomar, H.O. Arceo, & A.T. Uychiaoco, 2002. Challenges and opportunities for marine protected area (MPA) management in the Philippines. In Moosa, M.K., S. Soemodihardjo, A. Soegiarto, K. Romimohtarto, A. Nontji, Soekarno & Suharsono (eds), Proceedings of the Ninth International Coral Reef Symposium 2: 635-641.

Alvarez-Filip, L., J.A. Gill, N.K. Dulvy, A.L. Perry, A.R. Watkinson & I. M. Côté, 2011. Drivers of region-wide declines in architectural complexity on Caribbean reefs. Coral Reefs 30: 1051-1060.

Arceo, H.O., M.C. Quibilan, P.M. Aliño, G. Lim & W.Y. Licuanan, 2001. Coral bleaching in the Philippines reefs: coincident evidences with mesoscale thermal anomalies. Bulletin of Marine Science 69: 579-593.

Arceo, H.O., P. M. Aliño, & R.M. Gonzales, 2008. Where are we now with marine protected areas? In Aliño, P.M., R.C. Geronimo, S.S. Mamauag & R.M. Gonzales (eds), Reefs through time 2008: Initiating the State of the Coasts Reports. PhilReefs, MPA Support Network, Marine Environment and Resources Foundation, Inc. (MERF) and UP-MSI, Diliman, Quezon City.

Barott, K.,G. J. Williams, M.J. Vermej, J. Harris, J. Smith, F. Rohwer, S. Sandin, 2012. Natural history of coral−algae competition across a gradient of human activity in the Line Islands. Marine Ecology Progress Series 460: 1-12.

Barshis, D.J., J.T. Ladner, T. A. Oliver, F.O. Seneca, N. Taylor-Knowles & S.R. Palumbi, 2012. Genomic bias for coral resilience to climate change.

Bellwood, D. R., T.P. Hughes, C. Folke, M. Nyström, 2004. Confronting the coral reef crisis. Nature 429: 827–833.

Berumen, M.L., & M.S. Pratchett, 2006. Recovery without resilience: persistent disturbance and long-term shifts in the structure of fish and coral communities at Tiahura Reef, Moorea. Coral Reefs 25: 647–653.

Bruno, J.F. & E. R. Selig, 2007. Regional decline of coral cover in the Indo-Pacific: Timing, extent, and subregional comparisons. PLoS ONE 2: e711. doi:10.1371/journal.pone.0000711.

Bruno, J.F., H. Sweatman, W.F. Precht, E.R. Selig &V.G.W. Schutte, 2009. Assessing evidence of phase shifts from coral to macroalgal dominance on coral reefs. Ecology 90: 1478-1484.

Burke, L., E. L. Selig & M. Spalding, 2002. Reefs at risk in South-East Asia. The World Resource Institute. London.

Burke, L., K., Reytar, M. Spalding, & A. Perry, 2011. Reefs at Risk revisited. World Resources Institute, Washington.

Carpenter, K.E., M. Abrar, , G. Aeby, R. Aronson, S. Banks, A. Bruckner, A. Chiriboga, J. Cortés, J. Delbeek, L. DeVantier, G. Edgar, A. Edwards, D. Fenner, H. Guzmán, B. Hoeksema, G. Hodgson, O. Johan, W. Licuanan, S. Livingstone, E. Lovell, J. Moore, D. Obura, D. Ochavillo, B. Polidoro, W. Precht, M. Quibilan, C. Reboton, Z. Richards, A. Rogers, J. Sanciangco, A. Sheppard, C. Sheppard, J. Smith, S. Stuart, E. Turak, J. Veron, C. Wallace, E. Weil & E. Wood, 2008. One-third of reef-building corals face elevated extinction risk from climate change and local impacts. Science 321: 560-563.

Carpenter, K.E & V. G. Springer, 2005. The center of the center of marine shorefish biodiversity: the Philippine Islands. Environmental Biology of Fishes. 72: 467-480.

Claudet J., C.W. Osenberg, L. Benedetti-Cecchi, P. Domenici, J-A. García-Charton, Á. Pérez-Ruzafa, F. Badalamenti, J. Bayle-Sempere, A. Brito, F. Bulleri, J-M. Culioli, M. Dimech, J.M. Falcón, I. Guala, M. Milazzo, J. Sánchez-Meca, P. J. Somerfield, B. Stobart, F. Vandeperre, C. Valle, S. Planes, 2008. Marine reserves: Size and age do matter. Ecology Letters 11: 481-489.

Coral Reef Information Network of the Philippines (PhilReefs), 2003. Philippine Coral Reefs through Time (2003): Workshop Proceedings. Second of the Atlas of Philippine Coral Reefs Series. Coral Reef Information Network of the Philippines (PhilReefs), University of the Philippines Marine Science Institute, Quezon City, Philippines and the Marine Parks Center, Tokyo, Japan.

Coral Reef Information Network of the Philippines (PhilReefs), 2005. Reefs Through Time: 2004 Biennial report of the status of Philippine coral reefs. Coral Reef Information Network of the Philippines (PhilReefs) and the Marine Science Institute, University of the Philippines, Diliman, Quezon City, Philippines.

Coral Reef Information Network of the Philippines (PhilReefs), 2008. Reefs Through Time 2008; Initiating the State of the Coasts Reports. Coral Reef Information Network of the Philippines (PhilReefs), MPA Support Network, Marine Environmenta & Resources Foundation, Inc. and the Marine Science Institute, University of the Philippines, Diliman, Quezon City.

Côté, I.M. & E.S. Darling, 2010. Rethinking ecosystem resilience in the face of climate change. PLoS Biology 8: e1000438. doi:10.1371/journal.pbio.1000438.

Côté, I.M., J.A. Gill, T.A. Gardner & A.R. Watkinson, 2005. Measuring coral reef decline through meta-analyses. Philosophical Transactions of The Royal Society B 360: 385–395.

Crabbe, M.J. & D. Smith, 2005. Sediment impacts on growth rates of Acropora and Porites corals from fringing reefs of Sulawesi, Indonesia. Coral Reefs 24: 437-441.

De'ath G, K.E. Fabricius, H. Sweatman & M. Puotinen, 2012. The 27-year decline of coral cover on the Great Barrier Reef and its causes. Proceedings of the National Academy of Sciences. doi:10.1073/pnas.1208909109.

Divinagracia, M.F., H.P. Calumpong & A. White, 2000. Extent and Degree of Coral Bleaching in Selected Reefs in Central Philippines. (Abstract) In D. Hopley, M. Hopley, J. Tamelander & T. Done (eds). Proceedings of 9th International Coral Reef Symposium, Bali, Indonesia.

Fabricius, K.E., 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. Marine Pollution Bulletin 50: 125-146.

Fujiwara, S., 1997. Coral Reefs in Japan. Marine Parks Center of Japan, Tokyo.

Gardner, T. A., I.M. Côté, J.A. Gill,A. Grant & A.R. Watkinson, 2003. Longterm region-wide declines in Caribbean corals. Science 301: 958–960.

Gardner, T.A., I.M. Côté, J.A. Gill, A.Grant & A.R. Watkinson, 2005. Hurricanes and Caribbean coral reefs: impacts, recovery, patterns and role in long-term decline. Ecology 86: 174-184.

Gomez, E.D. & A.C. Alcala, 1979. Status of Philippine coral reefs – 1978. Proceedings International Symposium on Marine Biogeography and Evolution in the Southern Hemisphere 137: 645-661.

Gomez, E.D., A.C. Alcala & A.C. San Diego, 1981. Status of Philippines coral reefs-1981. Proceedings of 4th International Coral Reef Symposium I: 275-282.

Gomez, E.D.,1991. Coral reef ecosystems and resources of the Philippines. Canopy International 16: 1, 6–7, 10–12.

Gomez, E.D., P.M. Aliño, H.T. Yap & W.Y. Licuanan, 1994. A review of the status of Philippine reefs. Marine Pollution Bulletin 29: 62–68.

Graham, N., K. Nash & J. Kool, 2011. Coral reef recovery dynamics in a changing world. Coral Reefs 30: 283–294.

Greenfield, M.L., J.E. Kuhn & E.M.Wojtys, 1998. A statistics primer: Confidence intervals. The American Journal of Sports Medicine 26: 145-149.

Gurevitch, H. & L.V. Hedges, 1999. Statistical issues in ecological meta-analyses. Ecology 80: 1142-1149.

Halpern, B.S., 2003. The impact of marine reserves: do reserves work and does reserve size matter? Ecological Applications 13: S117–S137.

Halpern, B.S. & R.R. Warner, 2002. Marine reserves have rapid and lasting effects. Ecology Letters 5: 361–366.

Halpern, B. S., & R. R. Warner, 2003. Matching marine reserve design to reserve objectives. Proceedings of the Royal Society of London Series B-Biological Sciences 270:1871–1878.

Hedges, L. V. & I. Olkin, 1985. Statistical methods for meta-analysis. Academic Press, New York.

Hooper, D.U., F.S. Chapin, J.J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J.H. Lawton, D. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Setälä, A.J. Symstad, J. Vandermeer, D.A. Wardle, 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecological Monograph 75: 3–35.

Horigue, V., P. Aliño, A. White, & R. Pressey, 2012. Marine protected area networks in the Philippines: Trends and challenges for establishment and governance. Ocean and Coastal Management 64: 15-26.

Hubbard, D.K., 1986. Sedimentation as a control of reef development: St. Croix, U.S.V.I. Coral Reefs 5: 117-125.

Huntington, B., M. Karnauskas & D. Lirman, 2011. Corals fail to recover at a Caribbean marine reserve despite ten years of reserve designation. Coral Reefs 30:1077–1085.

IUCN & UNEP-WCMC, 2010. The World Database on Protected Areas (WDPA) On-line. Cambridge, UK: UNEP-WCMC. Available at: www.protectedplanet.net .Accessed 07/07/2012.

Jones, G.P., M.I. McCormick, M. Srinivasan & J.V. Eagle, 2004. Coral decline threatens fish biodiversity in marine reserves. Proceedings of National Academy of Sciences 101: 8251–8253.

Kelly, S., D. Scott, A. MacDiarmid & R.C. Babcock, 2000. Spiny lobster, Jasus edwardsii, recovery in New Zealand marine reserves. Biological Conservation 92: 359–369.

Lester, S.E. & B.S. Halpern, 2008. Biological responses in marine no-take reserves versus partially protected areas. Marine Ecology Progress Series 367: 49–56.

Licuanan, W.Y., 2002. Regularities and generalities of Philippine Coral Reefs In Aliño, P.M., E.F.B .Miclat, C.L. Nanola Jr, R. Quiaoit & R. T. Campos (eds.) Atlas of Philippine Coral Reefs. Goodwill Trading Co., Inc. Manila, Philippines.

Licuanan, W.Y. & E. Capili, 2003. Range of extensions of Japanese Scleractinia to the Philippines. Galaxea, Journal of Coral Reef Studies 5: 63-67.

Licuanan, W.Y. & E.D. Gomez, 2000. Philippine coral reefs: Status and the role of the academe to improve their management. In Moosa, M.K., S. Soemodihardjo, A. Soegiarto, K. Romimohtarto, A. Nontji, Soekarno & Suharsono (eds). Proceedings of the Ninth International Coral Reef Symposium 2: 835-840.

Magdaong, E., H. Yamano, & M. Fujii, (in press) Development of a large-scale, long-term coral cover and disturbance database in the Philippines. In Nakano, S., T. Yahara & T. Nakashizuka (eds.) The biodiversity observation network in the Asia-Pacific region: Integrative observations and assessments of Asian biodiversity. Springer.

Maliao, R.J., A.T. White, A.T. Maypa & A.G. Turingan, 2009. Trajectories and magnitude of change in coral reef fish populations in Philippine marine reserves: a meta-analysis. Coral Reefs 28: 809-822.

Maypa, A.P., A.T. White, E. Cañares, R. Martinez, R.L. Eisma-Osorio, P. Aliño & D. Apistar, 2012. Marine Protected Area Management Effectiveness: Progress and Lessons in the Philippines. Coastal Management 40: 510-524.

McClanahan, T.R., M. Ateweberhan, C.A. Muhando, J. Maina & M.S. Mohammed, 2007. Effects of climate and seawater temperature variation on coral bleaching and mortality. Ecological Monographs 77: 503–525.

McCook, L.J., 2001. Competition between corals and algal turfs along a gradient of terrestrial influence in the nearshore central Great Barrier Reef. Coral Reefs 19: 419-425.

Mora, C., S. Andréfouët, M. J. Costello, C. Kranenburg, A. Rollo, J. Veron, K. J. Gaston & R. A. Myers, 2006. Coral Reefs and the Global Network of Marine Protected Areas. Science 312: 1750-1751.

Mumby, P. & A. Harborne, 2010. Marine reserves enhance the recovery of corals on Caribbean reefs. Plos One 5: e8657. doi:10.1371/journal.pone.0008657.

Mumby, P., A. Harborne, J. Williams, D. Brumbaugh, F. Micheli, K. Holmes, C. Dahlgren, C. Paris & P. Blackwell, 2007. Trophic cascade facilitates coral recruitment in a marine reserve. Proceedings of National Academy of Sciences 104: 8362-8367.

Mumby, P., C. Dahlgren, A. Harborne, C. Kappel, F. Micheli, D. Brumbaugh, K. Holmes, J. Mendes, K. Broad, J. Sanchirico, K. Buch, S. Box, R. Stoffle & A. Gill, 2006. Fishing, Tropic Cascades, and the Process of Grazing on Coral Reefs. Science 311: 98-101. doi: 10.1126/science.1121129.

Nañola, C.L., Jr., A.C. Alcala, P.M. Alino, H.Z. Arceo, W.L Campos, E.D. Gomez, W.Y. Licuanan, MC. Quibilan, A.J. Uychiaoco & A.T. White, 2006. Status report of the coral reefs in the Philippines. Proceedings of 10th International Coral Reef Symposium 4: 1055–1061.

Nakagawa, S. & I.C. Cuthill, 2007. Effect size, confidence interval and statistical significance: a practical guide for biologists. Biological Reviews 82: 591-605.

Nakamura, T. & R. van Woesik, 2001. Water-flow rates and passive diffusion partially explain differential survival of corals during the 1998 bleaching event. Marine Ecology Progress Series 212: 301–304.

Paddack, M.J., J. D. Reynolds, C. Aguilar, R.S. Appeldoorn, J. Beets, E.W. Burkett, P.M. Chittaro, K. Clarke, R. Esteves, A.C. Fonseca, G.E. Forrester, A.M. Friedlander, J. Garcia-Sais, G. Gonzalez-Sanson, L.K.B. Jordan, D.B. McClellan, M.W. Miller, P.P. Molloy, P.J. Mumby, I. Nagelkerken, M. Nemeth, R. Navas-Camacho, J. Pitt, N.V.C. Polunin, M.C. Reyes-Nivia, D.R. Robertson, A. Rodriguez-Ramirez, E. Salas, S.R. Smith, R.E. Spieler, M.A. Steele, I.D. Williams, C.L. Wormald, A.R .Watkinson & I.M .Côté, 2009. Recent Region-wide Declines in Caribbean Reef Fish Abundance. Current Biology 19: 1-6.

Pandolfi, J.M., R.H. Bradbury, E. Sala, T.P. Hughes, K.A. Bjorndal, R.G. Cooke, D. McArdle, L. McClenachan, M.J.H. Newman, G. Paredes, R.R. Warner & J.B.C. Jackson, 2003. Global trajectories of the long-term decline of coral reef ecosystems. Science 301: 955-958.

Peñaflor, E., W. Skirving, A. Strong, S. Heron & L. David, 2009. Sea-surface temperature and thermal stress in the Coral Triangle over the past two decades. Coral Reefs 28: 841-850.

Raymundo, L.J. & A.P. Maypa, 2002. Recovery of the Apo Island Marine Reserve, Philippines, 2 years after the El Niño bleaching event. Coral Reefs 21: 260-261.

Raymundo, L.J., A.P. Maypa, E.D. Gomez & Pablina Cadiz, 2007. Can dynamite-blasted reefs recover? A novel, low-tech approach to stimulating natural recovery in fish and coral populations. Marine Pollution Bulletin 54: 1009-1019.

Roberts, C., C. McClean, J. Veron, J. Hawkins, G. Allen, D. McAllister, C. Mittermeier, F. Schueler, M. Spalding, F. Wells, C. Vynne & T. Werner, 2002. Marine biodiversity hotspots and conservation priorities for tropical reefs. Science 295: 1280-1284.

Roberts, C.M., J.A. Bohnsack, F. Gell, J.P. Hawkins & R. Goodridge, 2001. Effects of marine reserves on adjacent fisheries. Science 294: 1920–1923.

Roff, G. & P. J. Mumby, 2012. Global disparity in the resilience of coral reefs. Trends in Ecology and Evolution 27:404-413.

Rogers, C.S., 1990. Responses of coral reefs and organisms to sedimentation. Marine Ecology Progress Series 62: 185-202.

Rosenberg, M. S., D. C. Adams & J. Gurevitch, 2000. METAWIN version 2: statistical software for meta-analysis. Sinauer Associates, Boston, Massachusetts.

Russ, G.R., 1991. Coral reef fisheries: effects and yields. In Sale, P.F. (ed), The Ecology of Fishes on Coral Reefs. Academic Press, San Diego: 601–635.

Russ, G. R. & A.C. Alcala, 1996. Marine reserves: rates and patterns of recovery and decline of large predatory fish. Ecological Applications 6: 947–961.

Russ, G.R., A.C. Alcala, A.P. Maypa, H.P. Calumpong & A.T. White, 2004. Marine reserve benefits local fisheries. Ecological Applications 14: 597–606.

Selig, E.R. & J.F. Bruno, 2010. A global analysis of the effectiveness of marine protectedareas in preventing coral loss. PLoS ONE 5: e9278. doi:10.1371/journal.pone.0009278.

Selig, E., K. Casey & J. Bruno, 2012. Temperature-driven coral decline: the role of marine protected areas. Global Change Biology doi: 10.1111/j.1365-2486.2012.02658.x

Shears, N.T., R.V. Grace, N.R. Usmar,V. Kerr & R.C. Babcock, 2006. Long-term trends in lobster populations in a partially protected vs. no-take marine park. Biological Conservation 132: 222–231.

Stockwell, B., C.R. Jadloc, R. Abesamis, A. Alcala & G. Russ, 2009. Trophic and benthic responses to no-take marine reserve protection in the Philippines. Marine Ecology Progress Series 389: 1-15.

Sweatman, H., S. Delean & C. Syms, 2011. Assessing loss of coral cover on Australia's Great Barrier Reef over two decades, with implications for longer-term trends. Coral Reefs 30: 521-531.

Tyler, E., A. Manica, N. Jiddawi & M. Speight, 2011. A role for partially protected areas on coral reefs: maintaining fish diversity? Aquatic Conservation: Marine and Freshwater Ecosystems 21: 231–238.

Tun, K., L. Chou, T. Yeemin, N. Phongsuwan, A. Amri, N. Ho, K. Sour, N. Long, C. Nañola, D. Lane & Y. Tuti, 2008. Status of the coral reefs in Southeast Asia. In: Wilkinson, C. (ed) Status of coral reefs of the world: 2008. Global Coral Reef Monitoring Network and Reef and Rainforest Research Center, Townsville, Australia.

Walmsley, S.F. & A.T. White, 2003. Influence of social, management and enforcement factors on the long-term ecological effects of marine sanctuaries. Environmental Conservation 30: 388–407.

Webb, E.L., R.J. Maliao, S.V. Siar, 2004. Using local user perceptions to evaluate outcomes of protected area management in the Sagay marine reserve, Philippines. Environmental Conservation 31: 138–148.

Weeks, R., G. Russ, A. Alcala & A. White, 2009. Effectiveness of Marine Protected Areas in the Philippines for Biodiversity Conservation. Conservation Biology 24: 531-540.

West, J.M. & R.V. Salm, 2003. Resistance and resilience to coral bleaching: implications for coral reef conservation and management. Conservation Biology 17: 956–967.

White, A.T. & H.P. Vogt, 2000. Philippine coral reefs under threat: lessons learned after 25 years of community-based reef conservation. Marine Pollution Bulletin 40: 537-550.

White, A.T., H.P. Vogt & T. Arin, 2000. Philippine coral reefs under threat: the economic losses caused by reef destruction. Marine Pollution Bulletin 40: 598–605.

White, A., P. Aliño & A. Meneses, 2006. Creating and managing protected areas in the Philippines. Fisheries Improved for Sustainable Harvest Project. Coastal Conservation and Education Foundation, Inc., and University of the Philippines, Marine Science Institute, Cebu City, Philippines.

Wilson, J., N. Marimuthu, & A.K. Kumaraguru, Sedimentation of silt in the coral reef environment of Palk Bay, India. Journal of Marine Biological Association of India 47: 83-87.

World Resources Institute, Reefs at Risk Revisited, 2011. http://www.wri.org/publication/reefs-at-risk-revisited

Yap, H., P. Aliño & E. Gomez, 1992. Trends in growth and mortality of three coral species (anthozoa: Scleractinia), including effects of transplantation. Marine Ecology Progress Series 83: 91-101.

Yap, H.T. & E.D. Gomez, 1985. Coral reef degradation and pollution in East Asian Seas Region. In Dahl, A.L. & J. Carew-Reid (eds), Environment and Resources in the Pacific. UNEP Regional Sales Rep. and Studies No. 69: 185-207.

Figure Captions

Fig. 1 Distribution of the sites surveyed by different studies and marine protected areas (MPAs) throughout the Philippines. Each mark (☉) may represent multiple sites. Most of the sites surveyed are confined in the Visayan Sea. The Philippine provincial map and boundaries were downloaded from www.philgis.org. The locations of coral reefs were sourced from the World Resources Institute (2011).

Fig. 2 Annual absolute coral cover (%) of MPA (●), non-MPA (○) and the average of all sites (gray line) from 1981 to 2010. The average coral cover for each year are weighted means with 95% bias-corrected confidence intervals.The number of MPA (filled bar) and non-MPA (empty bar) sites per year are denoted by bar graph. No data were obtained in years 1987-88 and 1990-91.

Fig. 3 Annual rates of change in coral cover in 5-year time periods. Bars are 95% bias-corrected bootstrapped confidence intervals. Time periods 1981–1986 and 1989–1995 covered 6 and 7 years, respectively to compensate the paucity of data in years 1987–88 and 1990–91. Sample sizes are given in parentheses.

Fig. 4 Annual rates of change in coral cover (overall), MPAs and non-MPAs from 1981 to 2010. Bars are 95% bias-corrected bootstrapped confidence intervals. Sample sizes are given in parentheses.

Fig. 5 Annual rates of change in coral cover for all data, no-take MPAs, and partially protected MPAs since establishment. Bars are 95% bias-corrected bootstrapped confidence intervals. Sample sizes are given in parentheses.

Fig. 6 a. Relationship between annual rate of change in coral cover and MPA age of 99 sites. The size of the circle represents the corresponding size of MPAs at a given age. **b.** Annual rate of change in coral cover of age and size of MPAs classified in groups.