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Author(s)	Magdaong, Evangeline Tolentino
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LONG-TERM TRENDS OF CORAL COVER IN THE PHILIPPINES: TRAJECTORY, SPATIOTEMPORAL PATTERNS, AND THE EFFICACY OF MARINE PROTECTED AREAS

DOCTORAL DISSERTATION

Evangeline Tolentino Magdaong

Graduate School of Environmental Science

Hokkaido University

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Abstract

Coral reefs are reportedly degrading worldwide due to combined local human impacts and global impacts of climate change. However, region-specific trends remain unclear. This study shows the long-term trends of coral cover in one of the most important regions for biodiversity. The Philippines, located in the tropics, has the highest diversity of reef species in the global center of marine biodiversity known as the Coral Triangle. This biodiversity ‘hot spot’ has experienced reef degradation driven by intense anthropogenic pressures. This consequently led to the establishment of marine protected areas (MPAs) as a management and conservation strategy to arrest reef degradation in the country. This study examined the long-term trajectory and magnitude of coral cover change, spatiotemporal variability, and the role of marine protected areas in the Philippines. Percentage living hard coral cover was collated from existing studies and analyzed using quartile category and meta-analysis. Results based on quartile classification showed an increasing number of areas in “poor” condition (<25% coral cover) and a declining number of reefs in “excellent” condition (≥75% coral cover). On the other hand, meta-analysis showed coral cover increased at 1.3% yr^{-1} from 1981 to 2010. Protection against fishing contributed to the overall increase in coral cover as it significantly increased within MPAs than outside. However, coral cover change is independent of the level of protection, age and size of MPA. Chronic anthropogenic stress, thermal stress and the establishment of MPAs influence the temporal patterns of coral cover. Tubbataha reefs in Sulu Sea is most sensitive to positive thermal anomalies, while intense fishing is the dominant driver of coral cover loss in the Visayas region. This study shows that coral cover in the Philippines has increased for over three decades, remained stable outside MPAs and increased within

MPAs. Regionally, coral cover improved in West Philippine Sea and Celebes Sea while at risk is Visayas region that warrants immediate conservation and effective fisheries management strategy to mitigate reef overexploitation.

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Chapter I

Introduction

1.1 Background of the study

Coral reef ecosystems, the so-called the rainforest of the sea, are amongst the most productive and biologically diverse ecosystems on Earth (Bryant et al., 1998; Moberg & Folker, 1999). Although coral reefs comprise only 0.5% of the ocean floor (Cooper, 1994), it is home and nursery for 25% of all marine life (WMO, 2010). It hosts 250,000 known species including about 4,000 fish species and 800 species of reef building corals known to date (Burke et al., 2011). Coral reefs offer a wide range of goods and services to humans. An annual seafood catch valued at US$50 to $100 billion provides one-fifth of all animal protein consumed by human worldwide (Bryant et al., 1998). It also generates livelihood and income to coral reef communities in more than 100 countries through recreation and tourism. Coral reef species are also a source for potential treatments for many of the prevalent illnesses and diseases. Further, reefs also serve as a natural barrier protecting coastal cities, communities, and beaches from storm damage.

However, many coral reefs are in serious decline (Wilkinson, 1993; Bryant et al., 1998; Pandolfi et al., 2003; Wilkinson, 2008). Studies have shown that marine ecosystems have been greatly affected by local anthropogenic impacts and global impacts of climate change (Burke et al., 2002; Carpenter et al., 2008). It is predicted that, within 10 to 20 years, about 15% of world's reef will be "effectively lost" due to increasing human population pressures unless management interventions shall be enforced (Wilkinson, 2008). While, 75% of the reefs are estimated to be threatened by combined local threats and thermal stress (Burke et al., 2011). Coral declines are reported in major reef systems such as the Caribbean (Gardner et al., 2003), the Great Barrier Reef (De'ath et al., 2012), and the Indo-Pacific (Bruno & Selig, 2007). However, region-specific long-term trends still remain unknown particularly in a highly biodiverse are such as the Philippines.

1.1.1 Philippine reefs

The Philippines lies in the tropical Indo-West Pacific (4˚N–21˚N and 116˚E–127˚E) and consists of more than 7,100 islands. It has the third largest reef area in the world (Burke et al., 2011) and is a potential source of reef larvae for the northwest Pacific (Fujiwara, 1997; Burke et. al., 2002; Licuanan & Capili, 2003). It has a total coastline of 36,289 km (NAMRIA, cited by BFAR 2009), which includes an estimated 25,819 (Burke et al., 2002; Tun et al., 2008) to 27,000 km^2 (White & Trinidad, 1998; BFAR, 2009) of commonly fringing reefs. Atoll reefs are found near Tubbataha, Sulu Island, the northernmost islands of Babuyan and Batanes, and in the southeastern and western Negros and Guimaras. Barrier reefs appear near Palawan and Tawi-tawi and a double barrier is found in Danajon Bank, Bohol (Alcala et al., 1987). The Philippines is the epicenter of the region with high species richness and marine biodiversity worldwide, known as the Coral Triangle (Roberts et al., 2002; Carpenter and Springer, 2005). Approximately 468 species of scleractinian coral (Licuanan & Capili 2004; Veron & Fenner 2000), 915 reef fish species (Burke et al., 2002), 820 species of macrobenthic algae (Trono, 1999), 16 seagrass species (Fortes & Santos, 2004), and 44 mangrove species (Licuanan et al., 2011; Spalding et al., 2010) can be found in the Philippines (Nañola et al., 2006). The islands are regarded as the main source of coral larvae in the northwestern Pacific (Fujiwara, 1997, Burke et. al., 2002; Licuanan & Capili, 2003), as they are located in the upstream area of the Kuroshio Current. It is estimated that coral reef fisheries support more than a million small-scale fishermen who contributed almost US$1 billion annually to the Philippine economy (White, 2000). It is estimated that >80% of the population 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). As the population rapidly grows, the reefs are threatened with increasing impacts of human activities such as overfishing, destructive fishing methods, sedimentation, among others (Gomez et al., 1982; Gomez, 1991; Gomez, 1997; White, 2000; Burke et al., 2002; PhilReefs, 2003). Philippine reefs are identified as the hottest of the hotspots, highly threatened and highly vulnerable (Roberts et al., 2002; Carpenter et al., 2008; Burke et al., 2011). 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 particularly this important region for biodiversity and conservation. Although the state of coral cover has been regularly reported, there is no study on long-term trends of coral cover in the Philippines. In this study, living hard coral cover was used 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).

1.2 Objectives and overview of Dissertation

This study aims to assess the long-term temporal and spatial trends of coral cover in the Philippines. This describes the creation of long-term and large-scale database and examines the spatiotemporal condition of the reefs in two methods. Coral cover trends were assessed based on the percentage of absolute coral cover using quartile category and annual rates of coral cover change using meta-analysis. The use of quartile category has been an adopted method not only in the Philippines but also in Global Coral Reef Monitoring Network (GCRMN) in Southeast Asian countries (see Tun et al., 2008). This is also coupled by quantitative estimate of coral cover change using meta-analysis, a statistical method of integrating the findings of primary studies, to obtain a holistic information of the coral cover trends. This study is organized as follows: Chapter I states the background of the study, Chapter II discusses the collation of existing studies to develop a large-scale and long-term database of coral cover and reef disturbances. It also describes the spatiotemporal trends in coral cover based on quartile categories. Chapter III deals with the overall pattern and magnitude of the coral cover change through time and investigates the role of marine protected areas using meta-analysis. Chapter IV presents the spatiotemporal variability of coral cover change using meta-analysis in relation to the effect of protection and trends of absolute coral cover. Finally, the results in Chapters II through IV are summarized and concluded in Chapter V.

Chapter II

Development of a large-scale, long-term coral cover and reef disturbance database in the Philippines

2.1 Introduction

Nationwide coral reef assessment in the Philippines began in 1976 due to concerns of gathering of corals in the country (Gomez, 1991). Initial findings 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). A recent status report in 2000-2004 demonstrated a steady decline of “excellent” (≥75% living hard coral cover) and increase of "poor" (<25% living hard coral cover) reefs (Nañola et al., 2006).

Coral cover is a critical measure of habitat loss and degradation (Bruno & Selig, 2007), and because hard corals form the structural framework of the reef, the percentage cover of living hard corals is used as an index of reef condition in most studies (Sweatman et al., 2011). Licuanan & Gomez (2000) suggested that hard coral cover provides a better measure for comparison across sites than does living coral cover (hard and soft corals) because soft corals are not abundant in offshore reef areas. Moreover, percentage hard coral cover reflects (inversely) the amount of physical degradation through coral breakage from destructive fishing methods (White & Walmsley, 2003). Percent living hard coral cover classified in quartile category introduced by Gomez & Alcala (1979) has become the adopted method in reporting the condition of the reefs not only in the Philippines but also in Southeast Asian countries (see Tun et al., 2008).

Threats to Philippine reefs come primarily from human-related factors due to increasing population; the most significant disturbances are associated with fishing, particularly overfishing and destructive fishing (Gomez et al., 1982; Gomez, 1997; PhilReefs, 2003). It has been identified as highly at risk (Roberts et al., 2002) and has the highest level of vulnerable and threatened coral species (Carpenter et al., 2008) due to the combined effects of thermal stress and local anthropogenic impacts. In recent Reefs at Risk assessment, the Philippines was reported as highly vulnerable to reef degradation with very low adaptive capacity (Burke et al., 2011).

This study investigates the long-term trends in coral cover using percentage of absolute living hard coral cover classified in quartile category with an emphasis on the recent years. A large-scale and long-term database was developed by compiling coral cover data from existing studies. Reef disturbances were also compiled from disparate studies to create a timeline of stressors that have affected the Philippine reefs through the years.

2.2 Methodology

2.2.1 Coral cover data collation

Percentage living scleractinian covers were compiled from quantitative surveys obtained from scientific and gray literature available online and personal communications. Electronic searches involved browsing reef related websites such as ReefBase and OneOcean.org, search engines such as Google Scholar, and the online journals of Coral Reefs, Marine Pollution Bulletin, and Proceedings of the International Coral Reef Symposium. Personal communications were done initially by sending email requests to reef scientists who are conducting reef monitoring or had surveyed in the country. This also includes research institutes and non-governmental organizations such as Reef Check, Coral Cay Conservation (CCC) and Coastal Conservation and Education Foundation (CCEF). Positive responses were followed-up by personal meeting for an interview and manual search of published articles on locally published journals. This was also accompanied by visiting university libraries for journals, and reports not found online particularly reef-related papers in the 1970s. Information collated from each study include percentage living hard coral cover, number of transects, survey method used, site coordinates and location, depth, and observed disturbances if available.

2.2.2 Recording of reef disturbances

The historical timeline of coral disturbances was constructed based partly on the study of Melbourne-Thomas et al. (2011) in the western Philippines. Threats to the reef from published reports were reviewed, mostly included in coral status reports in the Philippines (Gomez & Alcala, 1979; Gomez et al., 1981; Gomez et al., 1994; Licuanan & Gomez, 2000; Nañola et al., 2006). For anthropogenic disturbances, a thorough literature search was conducted using ReefBase to determine when activities were initiated, increased, decreased, or ceased. Supplementary information was also obtained from the surveys conducted by Reef Check and interviews with reef scientists.

2.2.3 Coral cover analysis: Quartile Category

Percentage coral cover was classified according to quartile category as Poor (<25%), Fair (25 to <50%), Good (50 to <75%) and Excellent (≥75%) following Gomez & Alcala (1979). For each period, the quartile categories were presented as percentages of the total sites, for instance, 161 out of 372 sites are in Fair category, which makes up ~43% of all sites. Spatiotemporal trends were investigated for both overall and biogeographic sub-regions following the spatial classification of PhilReefs series (Philreefs 2003, 2005, 2008). The six biogeographic regions were delineated based on the distribution of coral reef and fish species affinities, geomorphology and major water circulation patterns (Aliño & Gomez, 1994; White et al., 2006). These major marine corridors are nursery, feeding and spawning grounds essential for biodiversity and larval connectivity of MPA network in the Philippines (White et al., 2006). These biogeographic regions are: (1) North Philippine Sea (NPS): (2) South Philippine Sea (SPS); (3) Visayan Sea (VS); (4) South China Sea, herein referred to as West Philippine Sea (WPS); (5) Sulu Sea (SS), and (6) Celebes Sea (CS, Fig. 1). Spatiotemporal trends were examined based on the disturbance events following Bruno & Selig (2007) for the Indo-Pacific, which coincided with strong El Niño Southern Oscillation (ENSO) events (1983, 1998, and 2010) during the following periods: 1978–1983, 1984–1996, 1997–2004, and 2005-2010.

2.3 Results

2.3.1 Data Collation

A total of 2,936 living hard coral cover surveys were collated from studies conducted at 1,523 sites, 178 cities/municipalities, and 44 provinces between 1978 and

2010. About 52% (789 out of 1523) of the study sites were obtained through personal communications while online search yielded the remaining 48% (734; Fig. 2.2). A total of 541 sites (36%) were surveyed by volunteer divers at Reef Check while 448 (29%) sites were sourced from biennial compilation of reef studies by various scientists in the Philippines of Philippine Coral Reef Information Network of the Philippines (PhilReefs) series (PhilReefs 2003, 2005, 2008). However, only 668 (44%) sites were surveyed more than once and 276 of these came from PhilReefs series. The survey depths ranged from 2 m to 12 m, and coral cover was estimated using various methods such as point intercept transects (PIT), line intercept transects (LIT), systematic snorkeling, phototransect, and video transect. Most of the sites were surveyed using PIT (48%), followed by LIT (11%), snorkeling (4%) and a combination of these methods (4%). Both PIT and LIT use a line transect typically 10, 20, 30, or 50 m measuring tape placed (randomly or permanently) on the reef along a constant depth contour. Measurement of lifeform is conducted *in situ* at specific intervals in PIT, for instance Reef Check uses four 20 m transect lines and samples points every 50 cm to determine the substrate type. While, in LIT, the coral cover is estimated as the proportion of the length of a line intercepted by a certain growth form expressed in percentage (English et al., 1997). Systematic snorkeling, on the other hand, is typically carried out on shallow reefs (typically 2-4 m) covering 1 to 1.5 km of the reef. The snorkeler stops for every 50 m interval to estimate one square meter of the bottom cover making a total of 100 to 200 stations (Uychiangco et al., 2001;White et al., 2002). Most of the data collected were recorded in 2000s, and data from this decade accounted for 74% of the data (Fig. 2.3). The largest number of surveys was in 2006, with 474 surveys (16% of the total) while no coral cover data is recorded in 1987.

More than half of the collected study sites (805) were in Visayas, that has 1,606 surveys between 1978 and 2010. About 21% (316 sites; 564 surveys) were surveyed in West Philippine Sea; 10% (145 sites; 343 surveys) in Sulu Sea, 8% (116 sites; 212 surveys) in Celebes Sea, 7% (104 sites; 145 surveys) in South Philippine Sea and 2% (37 sites; 66 surveys) in North Philippine Sea.

2.3.2 Historical reef disturbances in the Philippines

Figure 2.3 presents the historical timeline of major reef disturbances in the Philippines from 1960 to 2010. The main causes of reef destruction during the 1970s to 1980s appear to be siltation or sedimentation due to deforestation and land developments, followed by illegal and destructive fishing and coral harvesting for trade and construction (Gomez et. al., 1981; Gomez & Alcala, 1979). Similar threats were also predominant at varying scales in the 1990s, including blast fishing, cyanide fishing, siltation leading to pollution, overfishing, and massive bleaching from 1998–1999 (Licuanan & Gomez, 2000). Reefs at Risk estimated that more than 80% of the reefs are threatened by overfishing and that overall, 98% of reefs are at risk because of factors related to combined anthropogenic impacts (Burke et al., 2002). Indicators included coastal development (mining of sand and coral, dredging, land filling, coastal construction, and discharge of sewage), marine-based pollution (pollution from ports, oil spills and leakage, ballast and bilge discharge, and dumping), sedimentation (erosion potential), overfishing, and destructive fishing. There are no updated reports on issues and threats published in the 2000s, with the exceptions of Tun et al. (2008) and Burke et al. (2011). Tun et al. (2008) identified an increase in coastal development and marine-based pollution and medium to high threats from overfishing and destructive fishing, and reported that sedimentation had changed from medium to a low threat in the Philippines. The local integrated threats (combined impacts of overfishing and destructive fishing, coastal development, marine-based pollution and damage, and watershed-based pollution) are reportedly most severe threats to Philippines reefs, particularly overfishing and destructive fishing because a large number of people are dependent on reefs (Burke et al., 2011).

2.3.2.1 Destructive fishing and overfishing

Various destructive fishing techniques have been used through the years, and destructive fishing practices have remained the major disturbance affecting the condition of the reefs in the country. *Muro-ami*, a Japanese fishing technique that was introduced to the Philippines before the Second World War, whereby swimmers pound the corals to drive fishes into nets. *Kayakas* is a modified form of *muro-ami* in which bamboo is used instead of rocks to frighten the fish; it is typically conducted in shallower reefs than *muro-ami* (Carpenter & Alcala, 1977; Gomez et al., 1987). Commercial *muro-ami* was the leading fish-producing sector from 1965–1970 and *kayakas* was regarded as equally productive (Carpenter & Alcala, 1977). However, studies have shown that both operations resulted in reductions to coral cover through coral breakage, and induced overfishing due to the slow recovery of damaged corals and replenishment of fish stocks frequently in fished areas (see review by Gomez et al., 1987). Alcala & Gomez (1985) reported four reefs that had been damaged by destructive fishing: Sumilon Island, Cebu was protected in 1970 until it was opened to fishing in 1984 and subsequently subjected to occasional *muro-ami* and blast fishing. The Selinog reef in Bohol Sea and Hulao-hulao in Panay Gulf also underwent occasional muro-ami, but at Apo Island, Negros Oriental. The activity ceased in 1983 and was banned in 1986 (Aliño et al., 2004).

Blast fishing and sedimentation were the two main causes of coral destruction in Southeast Asia (Yap & Gomez, 1985). Blast fishing is a destructive and wasteful method that damages the coral habitat, fish stocks, and non-target marine organisms (Alcala, 2000; Alcala & Gomez, 1987). It started in 1930s and became widely used after the Second World War due to the availability of ammunition. In Bolinao, Pangasinan, from late 1987 to mid-1989, the recorded frequency of blast fishing was 10 blasts per hour (McManus et al., 1992). The incidence of blast fishing was observed to decrease or cease in the 1990s; this was attributed largely because of the depleted fishery stocks rather than increased environmental awareness and enforcement of laws (Alcala, 2000). Alcala (2000) reviewed the occurrence of blast fishing in the Philippines until the 1990s. He mentioned blast fishing was still apparent in the following areas: northern Philippines (Babuyan Island group), western Philippines (Palawan except Puerto Princesa), Central Visayas (Danajon reef, Bohol and Mactan Island in 1997), Mindanao (Basilan and Zamboanga Peninsula, eastern Mindanao, Ozamis, Misamis Occidental), Sulu Archipelago (Turtle Islands), Sulu Sea (Tubbataha reef from 1991–1995). Areas with decreased activity or that were free of blast fishing included: Negros Oriental (since 1980), western Visayas (Sagay, Negros Occidental), northwestern Luzon (Masinloc, Zambales and Bolinao, Pangasinan), western Philippines (Puerto Princesa, Palawan), and northern Mindanao (Camiguin Island, Dapitan, Zamboanga del Norte; Misamis Oriental and Lopez Jaena, Misamis Occidental). Anecdotal evidence suggests that dynamite fishing still persists to the present but at a localized level.

Cyanide fishing became popular in the marine aquarium fish trade and live reef fish food trade. The use of cyanide began in Batangas and Central Visayas in 1962, when the Philippines dominated ornamental fish exports (Rubec, 2000). Sodium cyanide (NaCN) is a toxic chemical that is used to stun hard-to-catch fish that cannot be caught using nets. Approximately 70% of aquarium fish caught in the Philippines have been reported to contain cyanide, resulting in high rates of delayed mortality of exported ornamental fish (Ochavillo et al., 2004). The strong demand for live fish for food in Hong Kong, Taiwan, and China brought about the live reef food fish trade (LRFFT), which also involved using cyanide rather than hook-and-line to catch fish (Licuanan & Gomez, 2000). LRFFT collection areas included: Coron Island and the Calamianes Group of Islands in northern Palawan, Balabac in Palawan, Surigao, Catanduanes, Camarines, and the Polillo Islands in Quezon (Mamuag, 2004). Aquarium fish has been collected in Zambales, Ilocos region, Bohol, Leyte, Samar, Dipolog, Negros Oriental, Zamboanga, Siquijor, Polillo, Palawan, Bicol region, Masbate, Mindoro, Marinduque, Masbate, and Batangas (Albadejo and Corpuz, 1982). These highly selective fisheries significantly diminished the density of targeted species at collection sites in the Palawan and Cebu-Bohol areas (Ochavillo et al., 2004). Rubec et al. (2000) reported that the exposure of corals to low concentrations of cyanide impairs photosynthesis and causes a loss of zooxanthellae, resulting in coral mortality. In 1998, the percentage of ornamental fish testing positive for cyanide was reportedly reduced to 20% (Rubec et al., 2000).

Overfishing is a pervasive problem linked to the prevalence of destructive fishing in the Philippines. According to Pauly et al. (1989), the overfishing problem in the Philippines can be defined as Malthusian overfishing, whereby fishermen opt to fish destructively as fishery resources are depleted by increasing numbers of fishers in the community. The decline in species richness and the absence of target fish species in the Visayas region are proof over a short ecological timescale of a degrading ecosystem due to overfishing and overexploitation (Nañola et al., 2010).

2.3.2.2 Coral trade

The Philippines had been a major international supplier of stony corals for at least three decades (Mulliken and Nash, 1993); Wood and Wells (1984) traced the country's trade dominance back to the 1950s. More than 13,000 tons of corals had been exported for the aquarium, ornamental, and surgical purposes (Mulliken & Nash, 1993). In response to overexploitation and poaching of corals, the government issued a ban on the harvest and commercial export of corals in 1977 and a Presidential Decree 1698 in 1980 (Gomez et al., 1994; Wood & Wells,1984; Ross 1984). However, commercial trading did not cease until the early 1990s, and its documented peak was between 1986 and 1989 (Mulliken & Nash, 1993). This overexploitation reduced the abundance of harvested corals at collection sites (Ross, 1984). Presently, coral harvesting is still prevalent in the form of poaching. Poaching is a persistent problem in areas like Palawan, which has experienced high levels of foreign intrusion since the early 1970s. From 1995 to 2002 alone, 675 foreign fishers were caught illegally harvesting corals, giant clams, turtles, wrasses, and groupers, among other taxa (Benavente-Villena & Pido, 2004).

2.3.2.3 Crown-of-thorns seastar (COTS)

There has been no report of large-scale impact from infestation by *Acanthaster* *planci*, or crown-of-thorns seastar (COTS), and this emerging threat still remains unexplored. The first observation of COTS predation was in 1976 at the reef near Sumilon Island (Alcala, 1976). COTS devastation were observed in Alcoy, Cebu and Bantayan Island, Cebu in 1980s (Yap & Gomez, 1985). COTS feed on fast-growing corals and are responsible for the mass mortality of coral species in the Indo-Pacific (Miller, 2002). The mechanism that triggers COTS outbreaks are still unknown (Burke et al., 2011), but siltation through nutrient runoff (Brodie et al., 2005; Fabricius et al., 2010) and overharvesting of COTS predator (e.g Napoleon wrasses, Giant triton *Charonia tritonis*, puffer fish and triggerfish) may contribute to the problem (Dulvy et al., 2004; WWF, 2007). COTS are naturally present on the reefs but outbreak emerged during high nutrient level and sea water temperatures in 2007 in West Philippine Sea (Mabini,Batangas; Bolinao, Pangasinan; Apo Reef and Puerto Galera in Mindoro) and Celebes Sea (Kiamba and Glan in Saranggani; WWF, 2007). Nañola et al. (2004) reported COTS outbreaks in 1985 (El Nido, Palawan), 1998 (Batangas), 2003 (Davao Gulf), and 2004 (El Nido, Palawan). COTS collection was also undertaken in 2007-2008 during a severe outbreak in Dalaguete and Alcoy in Cebu (*Dean Apistar, pers. comm.*). To determine the frequency of COTS infestation, Reef Check COTS observations were used since its surveys began in 1997. Healthy reefs can sustain 30 COTS per hectare (10,000 m^2) or 0.30 per 100 m^2 of COTS but a density above this limit is considered an 'active outbreak' (CRC Reef Research Center, 2003). The mean abundance of COTS per 100 m^2 per site was categorized as either low (<0.3), medium (0.30–0.75), or high (>0.75) intensity. Here, it is considered 'high' category to represent a severe COTS outbreak and identified the years with the greatest impacts from COTS (Fig. 2.4). Severe COTS outbreaks occurred in 2004 and 2006, and Cebu was consistently observed to have high densities of COTS between 2002 and 2008. Other areas with severe outbreaks included Palawan (1998, 2008), Bohol (2005, 2007), Negros Oriental (2002), Negros Occidental (2005), and Leyte (2008).

2.3.2.4 Terrestrial influences

Sedimentation is a major limiting factor for coral growth and development (Hubbard, 1986). Reefs located near streams and rivers are most likely to be affected by episodes of perturbation due to high levels of exposure to suspended solids. Increased siltation due to ash fall and volcanic mudflows from the Mt. Pinatubo eruption in 1991 substantially affected coastal areas in Zambales, killing approximately 40% of corals near Capones Island (Pajaro et al., 1993). From 1997–1999, sedimentation caused by suspended solids from the river was a major threat reported in Sipalay, Negros Occidental (Beger & Harborne, 2000). Siltation caused by man-made activities also poses a deleterious threat (Gomez et al., 1994). In Bacuit Bay, Palawan, reductions in coral cover were highly correlated with siltation caused by logging activities in 1986 (Hodgson, 1989). High levels of mine tailing discharge caused the siltation stress and reduced diversity in coral communities on reefs located 9 km from the outfall in Toledo, Cebu (Aliño, 1984).

2.3.2.5 Anomalously high sea surface temperatures

Coral bleaching was unknown in the Philippines until the global mass bleaching event caused by ENSO in 1998. Extensive elevations in sea surface temperature (SST) related to ENSO were also reported in 1983–1984 and 1987–1988 (Arceo et al., 2001). However, only a single bleaching observation was reported in the

Philippines, in June 1983 in Pangasinan (Yap et al., 1992), and one comprehensive study (Arceo et al., 2001) focused on the 1998 mass coral bleaching in the Philippines. Arceo et al. (2001) reported that the thermal anomalies from April to November followed a southward movement, with initial bleaching reports from the northwestern part of the Philippines in June 1998, and proliferated all over the country in August. They also found *Acropora* species to be most susceptible to bleaching, with coral mortality rates reaching almost 50%. Since then, bleaching has been monitored, and approximately 47 bleaching observations were reported from May to September 2010 in the Philippines (http://phcoralbleaching.crowdmap.com/). According to the World Meteorological Organization (WMO), 2010 was one of the warmest global temperatures ever recorded, similar to those in 1998 and 2005 (WMO, 2010). Unlike the 1998 bleaching, the 2010 bleaching was observed to be patchy (W. Campos, *personal communication*).

2.3.2.6 Tropical cyclone

An average of 19 tropical cyclones annually visit the Philippine Area of Responsibility (PAR) (Quibilan & Aliño, 2006). These storms not only kill or damage corals but also directly or indirectly alter the physical and biological environment, affecting species recovery (Connell et al., 1997). On September 2, 1984, Typhoon Ike (local name: Nitang) with sustained winds of 220 km hr^{-1}, devastated the pristine reefs of Pescador Island, Cebu. The living coral cover on one reef was reduced from 52% before the storm to 4% two weeks after the typhoon (Alcala et al., 1986) which subsequently recovered to 45% after four years (Alcala & Gomez, 1990). Alcala & Gomez (1990) estimated that it would take five years for a typhoon-damaged reef to recover to a classification of “good” reef (at least 50% coral cover). Anecdotal accounts from scuba divers referred to uprooted and overturned branching and foliose corals after Tropical Storm Washi (local name: Sendong) hit Negros Oriental on December 17, 2011. The storm devastated the reefs at Apo Island, and the sanctuary was closed to tourism activity to ensure recovery. Similarly, dead corals smothered with silt were observed on Poblacion reef in Dauin, Negros Oriental, which was attributed to heavy flooding brought by Tropical Storm Washi (P.B. Tanangonan, *pers. comm.*).

2.3.3 Coral cover analysis

The mean absolute coral cover ranged from 20.19% in 1985 to 42.66% in 1995 from 2,936 reef surveys of 1,523 sites between 1978 and 2010 (excluding the year with <5 sites surveyed; Fig. 2.3). The estimated overall mean coral cover is 33.5% similar to 33% reported in the Indo-Pacific (Bruno et al., 2009).

For quartile category analyses, the initially collated 2,349 surveys between 1978 and 2010 from 1,387 sites were used in the analysis. For each study, sites from the same reef were pooled and averaged annually regardless of the depth. This reduced the total number of surveys to 1,270 from 571 sites. Fig. 2.5 shows the overall quartile category in each time period. A large proportion of the sites (40–70%) falls in the Fair category across time periods. Poor sites steadily increased from 23.5% in 1984–1996 to 39.8% in 2005–2010, while Good sites increased gradually from 13.8% in 1997–2004 to 16.4% in 2005–2010. A small percentage of sites belong to the Excellent category: 2.3% and 2.9% in 1984–1996 and 1997–2004, respectively, and declined significantly to 0.5% in 2005–2010. Reef condition varied per biogeographic region across periods, but the majority of the reefs was classified into the Fair category, except in Visayan Sea (Fig. 2.6). In Visayan Sea, the percentage of reefs in the Excellent condition increased from 1.9% to 3.4% between 1984–1996 and 1997–2004, concomitant with a slight increase and minimal decline of Fair and Poor categories, respectively. However, Poor reefs dominated at 58% during 2005–2010, with a three-fold reduction of reefs in Excellent condition. Visayan Sea is the only region to have reefs in Excellent category recorded in 2005–2010, which constitutes 0.5% of all sites. In contrast, West Philippine Sea exhibited improvements in 2005–2010 compared to early periods, when reefs in the Poor category increased from 20% to 47% in 1984–1996 and 1997–2004, respectively. In 2005–2010, Good reefs increased from 7.7% to 22% while the percentage of Poor reefs declined from 48% to 27% in West Philippine Sea. Similarly, both South Philippine Sea and Celebes Sea regions exhibited increases in in Fair and Good categories in 2005–2010, but none in Excellent category. In the same period, the proportion of Poor category reefs increased in both Sulu Sea and North Philippine Sea regions while fewer sites in Sulu Sea and slightly more sites in North Philippine Sea were classified as Good.

Figure 2.6 presents the distribution of reef conditions by city/municipality in four time periods. The reef condition of cities/municipalities that had been similarly monitored was compared between periods. Between 1978–1983 and 1984–1996, the sites in both Poor and Fair conditions remained the same in 9 municipalities. From 1984–1996 to 1997–2004, of the 42 municipalities that had been similarly monitored, 23 did not change, 12 improved and 7 declined. Of the 12 municipalities that improved, 9 sites were in Visayan Sea (4 in Negros Oriental; 1 in Bohol, 1 in Cebu, 1 in Misamis Occidental, and 1 in Siquijor). Another 2 municipalities in West Philippine Sea

(Pangasinan and Zambales) and 1 in Sulu Sea (Nueva Valencia, Guimaras) also exhibited improvement. Of the 7 municipalities that declined in 1997–2004, 3 sites were located in the Celebes Sea region (Davao del Norte, Davao del Sur, and Saranggani) while the rest were distributed in the Visayan Sea (Bantayan, Cebu), West Philippine Sea (El Nido, Palawan), and Sulu Sea (Culasi, Antique) regions. From the periods 1997–2004 to 2005–2010, 28 of 42 municipalities exhibited no change in reef condition, 6 improved, and 8 declined. Among the 6 municipalities that exhibited improvements, 3 were found in Palawan (2 in West Philippine Sea and 1 in Sulu Sea), 2 in Visayas (Bohol and Leyte), and 1 in Celebes Sea (Zamboanga del Sur). The 8 municipalities that declined included 3 municipalities in Tawi-tawi (Sulu Sea), 2 municipalities in Pangasinan and 1 in Zambales (West Philippine Sea), and 1 municipality each in North Philippine Sea (Aurora) and Visayan Sea (Negros Oriental).

2.4 Discussion and Conclusion

2.4.1 Data Collation

To date, the inventory includes 2,597 reef surveys more than a report on the Philippines or 49% of the total quantitative surveys obtained in the Indo-Pacific from 1968 to 2004 coral cover study of Bruno & Selig (2007). This is also almost six times more than the sites reported in the Caribbean (263 sites, Gardner et al., 2003) and 678 greater than the collected data for Great Barrier Reef study of De'ath et al. (2012). This is the largest data collection of living hard coral cover of combined periodic reports in the Philippines since 1979 (e.g. Gomez & Alcala, 1979; Gomez et al., 1981; Gomez et al., 1994; Licuanan & Gomez, 2000; Nañola et al., 2006). The number of data points increased in the early 1990s, which may be attributed to either an increase in data collection or the availability of online literature from this time (Fig. 2.3). Also, the early reef assessment reports in early 1980s were reported as living hard coral (combined hard and soft coral cover) consequently was not included in the database. All regions are represented in the 1990s up to recent years, particularly North Philippine Sea, South Philippine Sea, and Celebes Sea, for which 1980s data are lacking. Among the regions, Visayan Sea region is the most surveyed because a large number of marine protected areas (MPAs) have been established and monitored here. Further, it also favors that many research institutes and organizations are located in Visayas region that makes monitoring viable and less costly due to proximity. This is contrary to North Philippine Sea which is least reported or visited potentially because it is frequented by typhoon. Based on the major sources of data, the compilation of reef surveys through PhilReefs has contributed to the time series data. The caveat, however, in collecting data from compiled studies is the incomplete information reported for instance site coordinates, number of transects and the survey method used are inconsistently reported. This is the advantage of utilizing monitoring raw data through personal communications because the abovementioned information is available. On the other hand, raw data falls often short in including the qualitative description of the survey such as the threats and observations that could be helpful in identifying the factor for changes in coral cover. One good example of studies with both narrative and numerical information of the survey is the Saving Philippine Reefs study of CCEF.

Many of the surveys were also surveyed only once; thus it would be helpful that a database would be developed so that it can continuously update the surveys conducted on each site. Ecological surveys are costly and effort intensive, thus, repository of data for all benthic surveys undertaken is strongly recommended. As discussed by Côté et al., 2006, data sharing is difficult if researchers do not benefit from it. They cited that contributing the data to a repository should be allowed as project deliverables, citation of unpublished data for funding applications, and contributor must permit to where the data will be used. Coral cover data repository would be successful if initiated by funding agencies that will support the creation of a database and will require researchers to contribute their survey data as one of the project outputs. In this way, monitoring data will not be fragmented in disparate studies and will increase the understanding of the condition and dynamics of coral reef ecosystems by covering extensive areas particularly remote and isolated reefs. This study hopefully encourages reef scientists to monitor the reefs regularly, improve the reporting of survey information by both quantitative and narrative information (e.g observed threats, survey methods used, coordinates, date of surveys, number and length of transects, depth, etc.) and make the coral cover data publicly available through publication because this information is important for reconstructing long-term ecological studies.

2.4.2 Coral cover analysis

Since the first national state of the reefs report, Philippines reefs have been considered to be influenced primarily by man-induced disturbances. The greater number of reefs in Poor and Fair categories in the 1976 survey (Gomez et al., 1981) and a high percentage of reefs in the Fair category among the present data suggest that the trends are consistent. The historical timeline in Fig. 2.3 shows the predominant impact of anthropogenic activities through the years. Overfishing and destructive fishing still remain the most serious of the local threats to reefs (Burke et al., 2002, 2011). The combined effects of local impacts and climate change currently pose a significant threat. Thermal stress associated with ENSO was evident from 1996–2006 (Peñaflor et al., 2009). The massive bleaching event in 1998 resulted in a slight decline in average coral cover from 39% in 1997 to 32%, which was maintained for three years before recovering in 2001 to 39% (Fig. 2.3). Along with overfishing, destructive fishing, and thermal stress due to climate change, the last decade has also seen reefs threatened by siltation and pollution associated with sewage, mining, mariculture, land clearing, deforestation, and agricultural fertilizer run-off, among others (Tune et al., 2008). From 2002–2008, COTS outbreaks were reported in various areas; these were particularly large in 2004 and 2006, but the most significant impact was in 2004 when the mean overall coral cover was at its lowest during the 2000s (Fig. 2.3).

The overall annual means revealed that, on a nationwide scale, coral cover appears to be stable, with no major decline through the years. However, if Poor and Excellent coral cover categories are used as a measure of habitat degradation, this may indicate that Philippine reefs had experienced habitat loss, particularly from 2005–2010. The recent years had a five-fold reduction in the Excellent category and an increasing trend toward the Poor category, a trend that has continued since 1984–1996 (Fig. 2.5) This trend in Excellent and Poor categories can also be observed in the Visayan Sea region. The overall trends may have been influenced by trends in the well-surveyed Visayan Sea. The results may be skewed toward well-sampled areas and are dependent on the available data (Bruno & Selig, 2007; Nañola et al., 2006; Nakao et al., 2009; Omori, 2010), but the overall trends are consistent with previous reports at different areas in 1990s (Licuanan & Gomez, 2000) and 2000–2004 (Nañola et al., 2006).

As the number of Excellent reefs has declined recently, trends in the Poor and Good categories may provide a better comparison across regions (Fig. 2.6). From 2005–2010, the ratio of sites in the Poor category increased in the Visayan Sea and Sulu Sea regions while those in the Good category decreased. West Philippine Sea, South Philippine Sea, and Celebes Sea regions, in contrast had positive growth in the percentage of sites classified as Good and significant declines in reefs classified as Poor. For North Philippine Sea, both the Poor and Good categories increased, but the increase was more substantial in the Poor category than in the Good category. The dominance of reefs classified as Poor and the decline of all other categories (Fair, Good, and Excellent) from 2005–2010 suggest that VS is at high risk. Reefs are expected to be in better condition in the West Philippine Sea, South Philippine Sea, and Celebes Sea regions, particularly in South Philippine Sea, where no reefs were classified as Poor from 2005–2010.

As most of the surveys were undertaken MPAs, the observed increase in coral cover may be linked to improvements in MPAs in the surveyed regions. The 1998 Republic Act 8550 states that all coastal municipalities should set aside 15% of their coastal areas as fish sanctuaries (Licuanan & Gomez, 2000). The number of marine reserves, sanctuaries, and parks in the country grew from 565 in 2000 to 1,169 in 2007, concomitant with the observed expansion of the reserves from 10 ha to 11–100 ha (Arceo et al., 2008). However, these changes are still insufficient to ensure that more reefs can be categorized as Excellent In 2005–2010, 5 biogeographic regions had no reefs classified as Excellent. A similar trend appears in the timing of reef declines at the surveyed city/municipality level (Fig. 2.7). Insufficient data from 1978–1983 makes it difficult to draw conclusions for this period, but coral cover increased from

1984–1996 to 1997–2004. Although 55% (23 of 42 sites) of the reefs were stable, 28% (12 sites) increased and only 16% (7 sites) decreased in coral cover. From 1997–2004 to 2005–2010, stable reefs increased to 67%, but there was a higher proportion of declines (19%) compared to improved reefs (14%) and a substantial reduction in improved reefs, down from the previous 28% to 14%.

The results revealed that trends on national and biogeographic levels were not the same for all sites; hence it is worthwhile to investigate individual reef sites using time series data to clarify general trends statistically. Preliminary findings revealed that the Visayan Sea region is at high risk, which warrants immediate concern and conservation efforts. West Philippine Sea and South Philippine Sea have improved slightly, but in recent years, no reefs have been classified as Excellent.

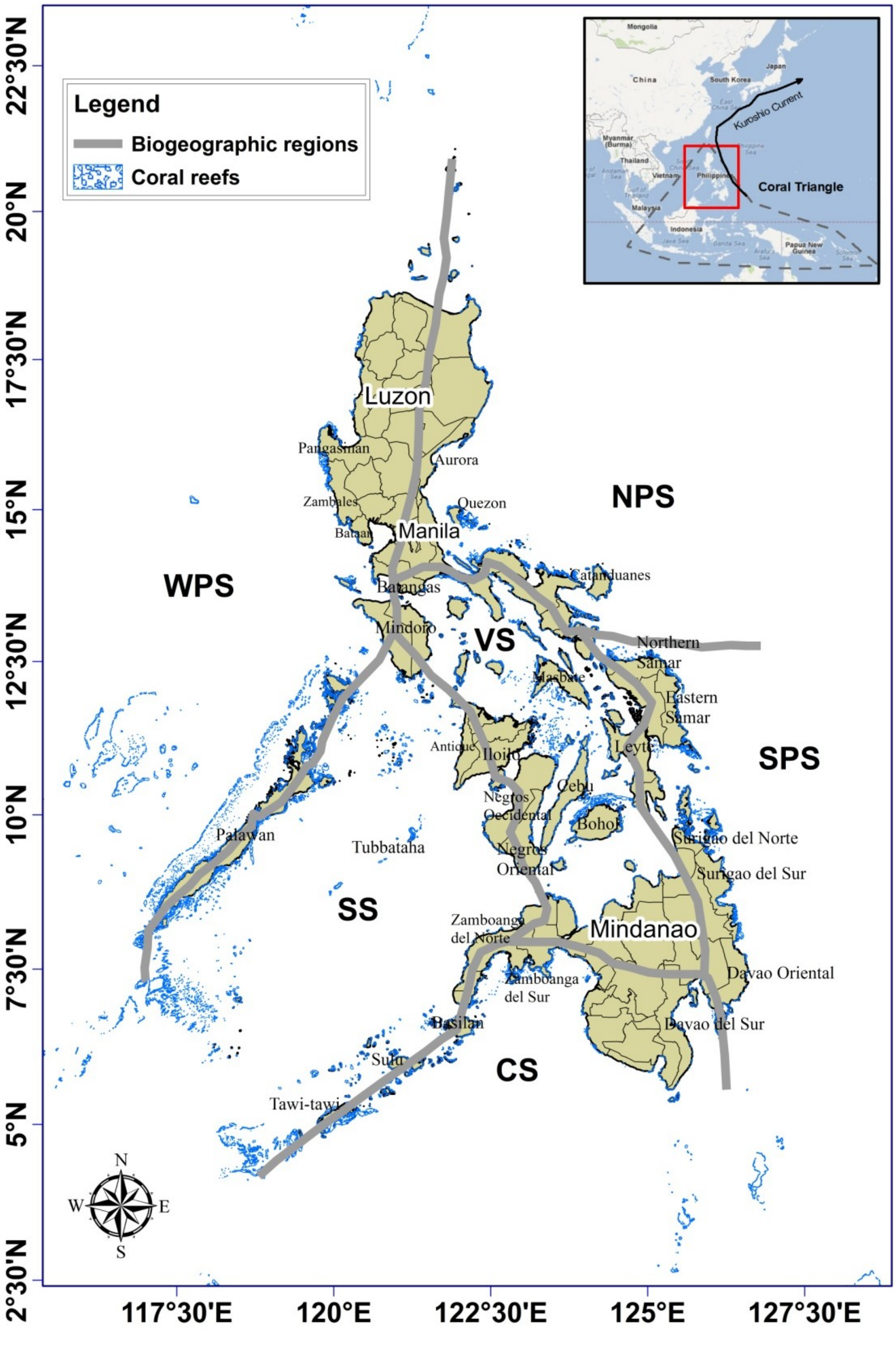


Figure 2.1 Map of the study site and the division of biogeographic regions. WPS-Western Philippine Sea, NPS-Northern Philippine Sea, SPS-Southern Philippine Sea, VS-Visayan Sea, SS-Sulu Sea, CS-Celebes Sea.

Figure 2.2 The number of collated sites through personal communications and online search.

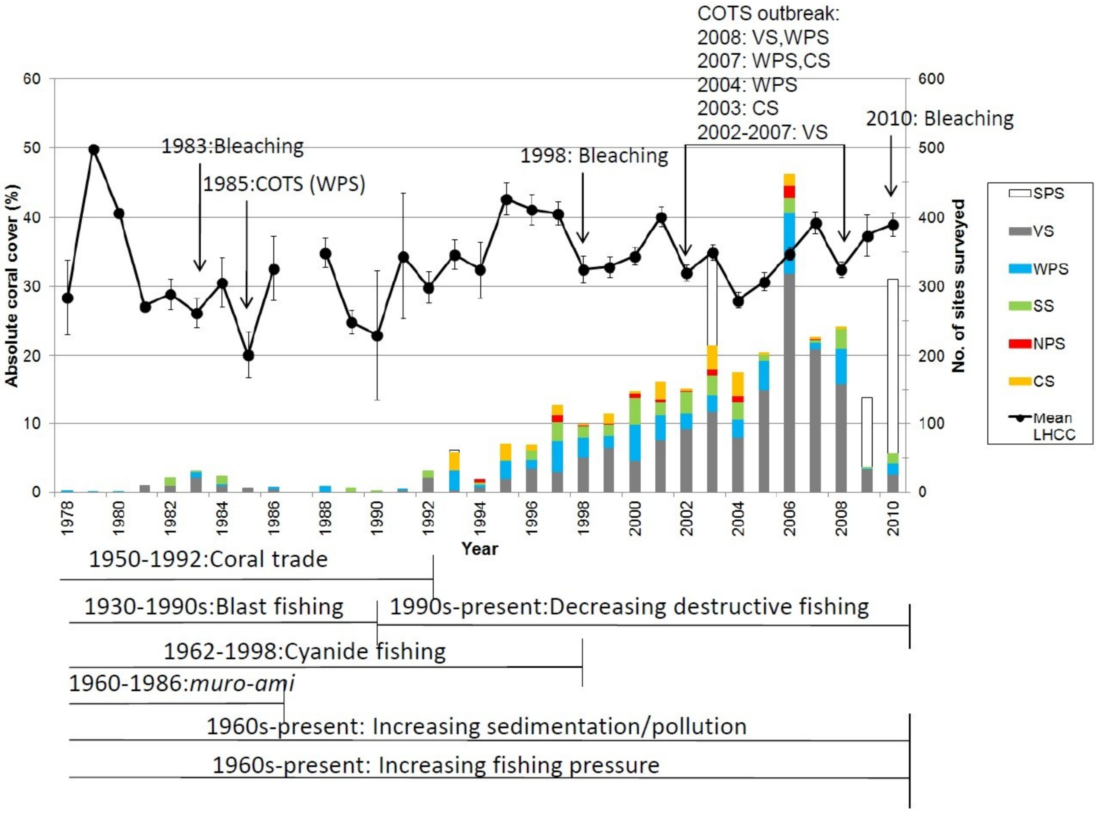


Figure 2.3 Annual mean hard coral cover (%) from 1978 to 2010 and the historical timeline of major disturbances to Philippine reefs. No data obtained in 1987. Error bars denote one standard error of the mean. Bars are the number of surveys per year from different biogeographic regions.

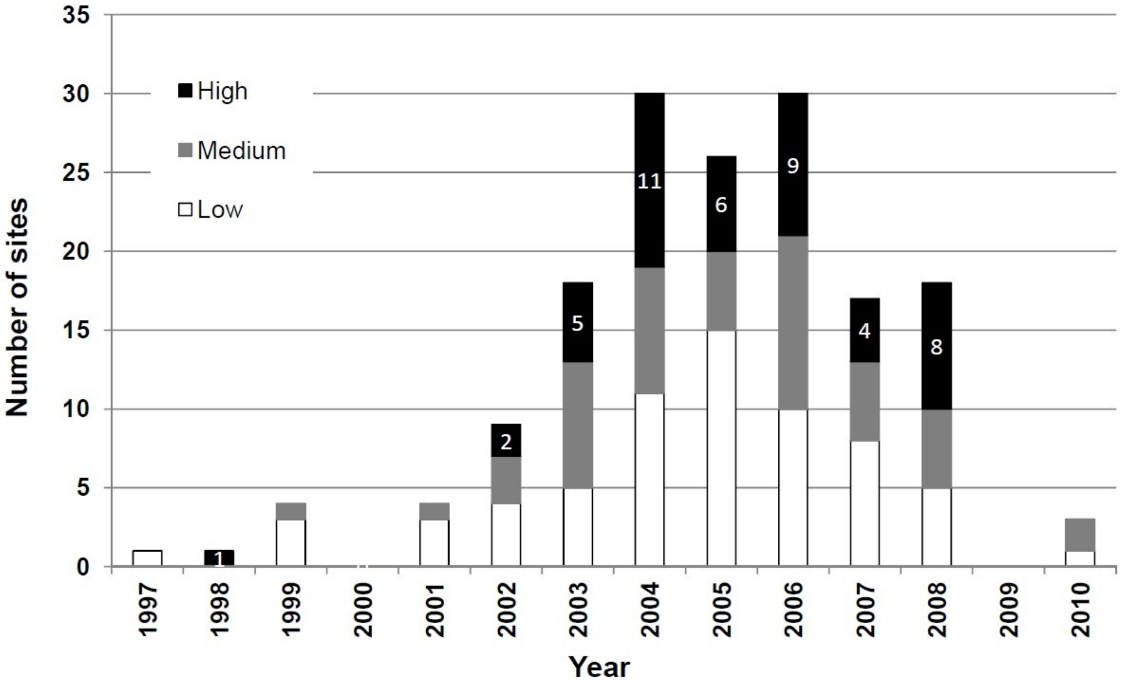


Figure 2.4 Frequency of crown-of-thorns starfish (COTS), Acanthaster planci outbreaks from 1997–2010. Values denote the occurrence of high densities of COTS observed in the surveys conducted by Reef Check.

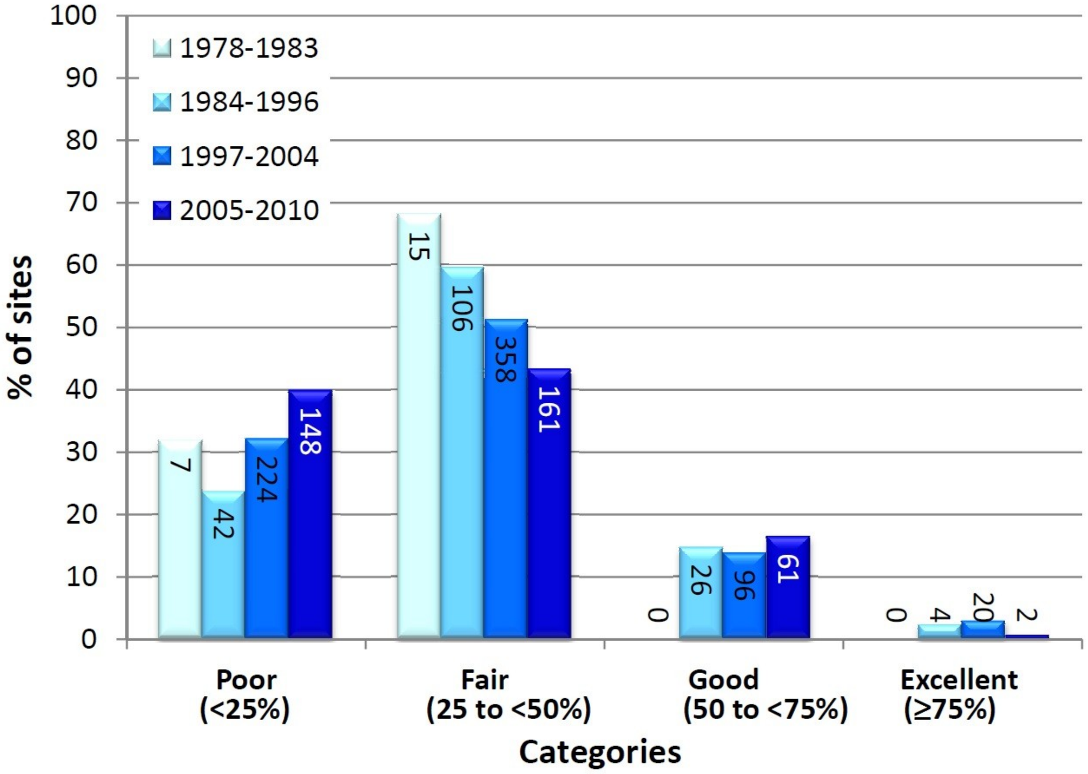


Figure 2.5. Overall reef condition based on the quartile categories over four time periods. Values denote the number of sites covered per period.

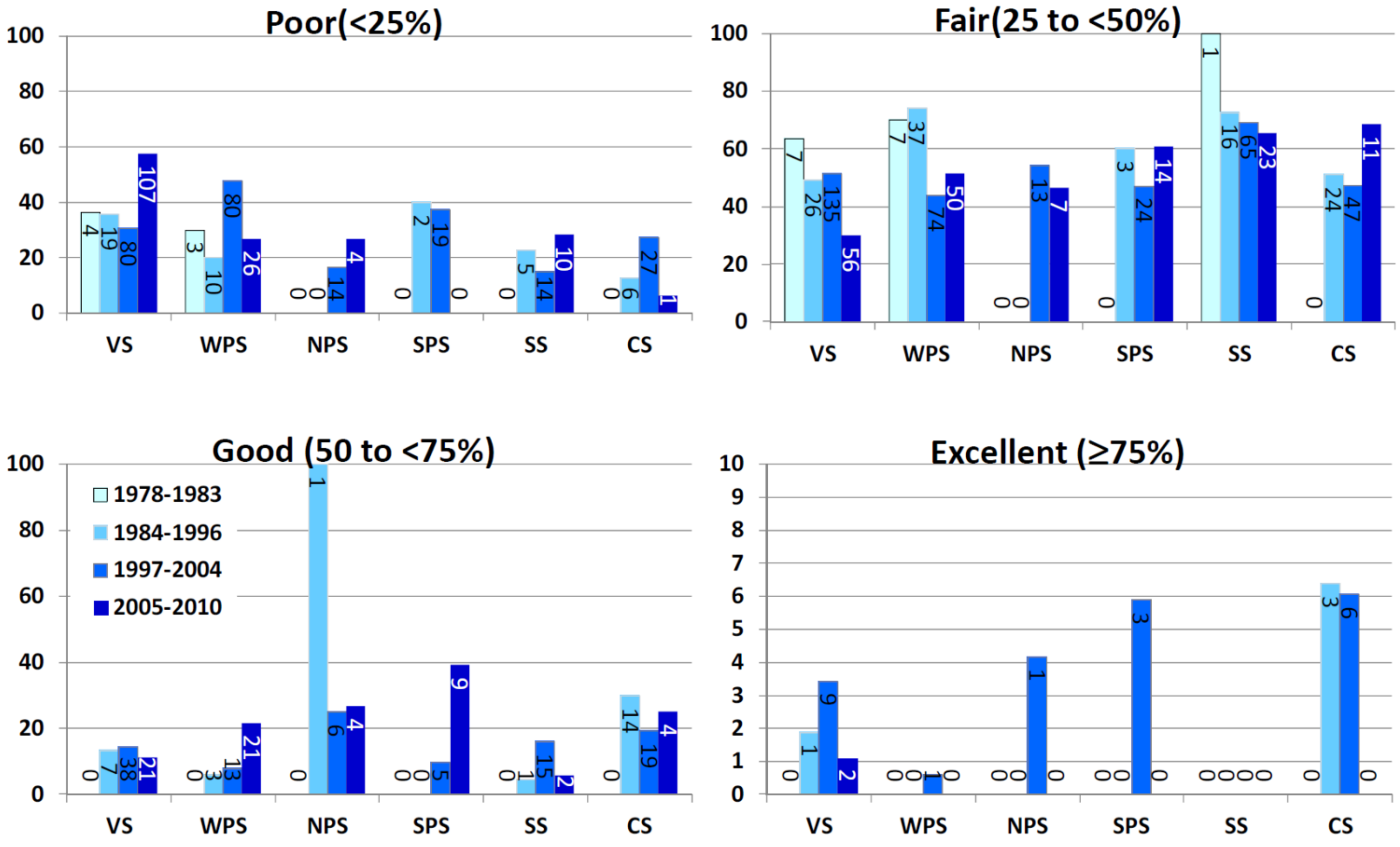
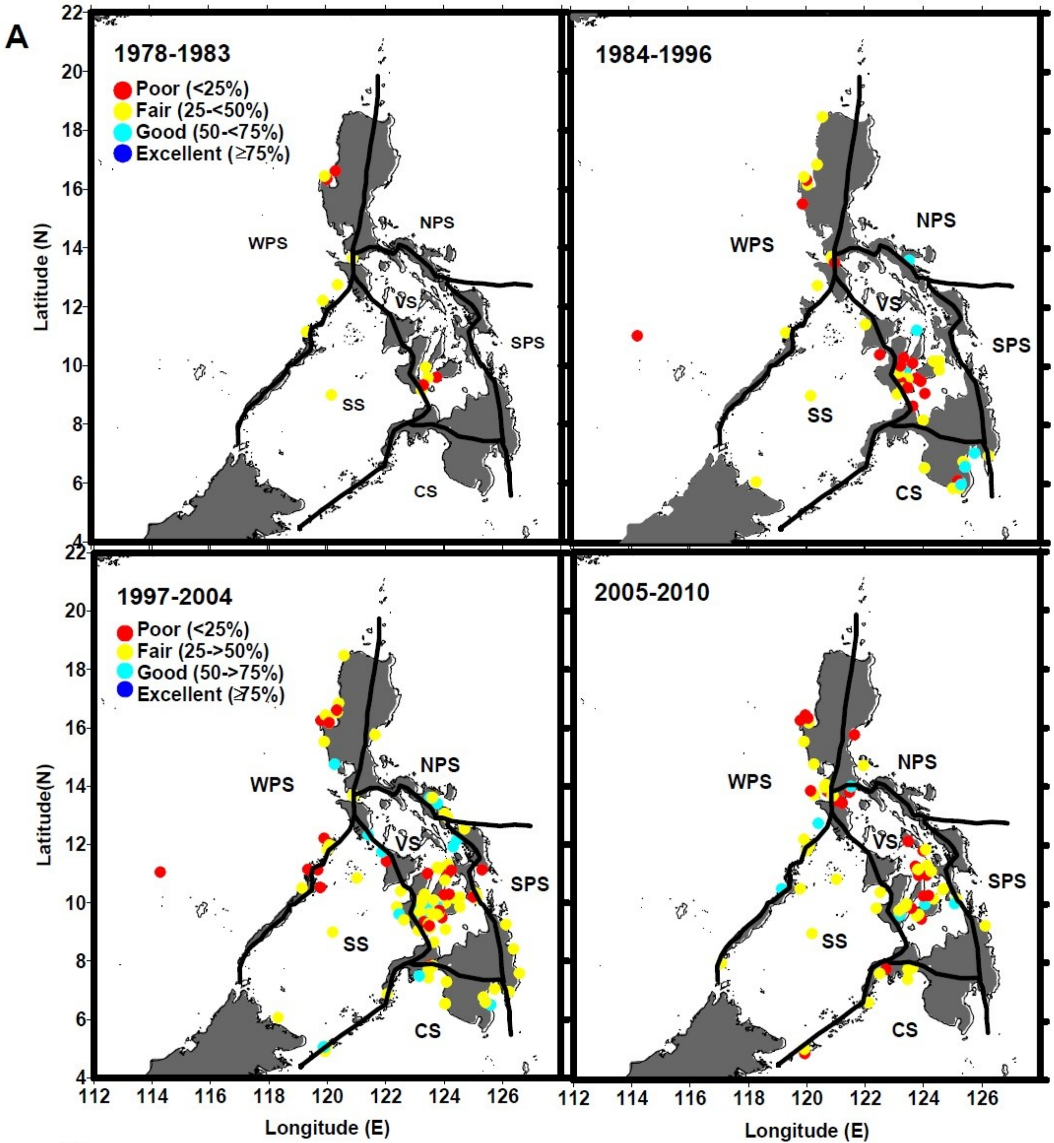


Figure 2.6. Coral condition based on the quartile categories per biogeographic region over four time periods. Values denote the number of surveys covered.



B

Change in condition	1978-1983 to 1984-1996	1984-1996 to 1997-2004	1997-2004 to 2005-2010
Stable	9	23	28
Improved	0	12	6
Decline	0	7	8
Total	9	42	42

Figure 2.7 A) Spatial distribution of reef condition based on quartile categories per city/municipality over four time periods. B) The change in reef condition of city/municipality monitored between the periods.

Appendix 1: Data Sources for Quartile category analyses in Chapter II

PhilReefs Series

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. ≥

Coral Reef Information Network of the Philippines (Philreefs), 2005. Reefs through Time: 2004 Biennial report on 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 Phillipine (PhilReefs), 2008. Reefs Through Time: Initiating the state of the coast report. Coral reef information network of the Philipines (PhilReefs), MPA support network, Marine Environment and Resources Foundation Inc and the Marine Science Institute. University of the Phillipines, Diliman,Quezon City.

Reboton, C., 2002. Apo Island.p.132-136. In: Aliño, P., .Miclat,E., Nañola, C. Jr., Roa-Quiaoit, H. and Campos, R. (eds) Atlas of Philippine Coral Reefs. Philippine Coral Reef Information (Philreefs). Goodwill Trading Co., Inc., Quezon City, Philippines.

ReefBase

Aliño, P., Banzon, V., Yap, H., Gomez, E., Morales, V. and Bayoneto, R., 1985. Recovery and recolonization on a damaged back reef area at Cangaluyan Is. (Northern Philippines). Proc. 5th Int. Coral Reef Congr. 4:279-284.

Arquiza, Y., 1999. Rhythm of the Sea: Coastal Environmental Profile of San Vicente, Palawan. Coastal Resource Management Project, Cebu City, Philippines.

De Jesus E., Diamante-Fabunan, D., Nañola, C., White, A. and Cabangon, H., 2001. Coastal Environmental Profile of the Sarangani Bay Area Mindanao, Philippines. Coastal Resource Management Project, Cebu City, Philippines.

Hodgson, G. and Dixon, J., 2000. El Nido revisited: ecotourism, logging and fisheries. In: Cesar, H. (ed) Collected essays on the economics of coral reefs. CORDIO, Kalmar University, Sweden.

Palaganas, V., Sy, J.and Aliño, P., 1985. Coral communities of the Tubbataha Atolls. Proc. 5th Int. Coral Reef Cong. 6:237-242.

Philippine Reef and Rainforest Conservation Foundation, Inc., 2004. Danjugan Island Marine Reserve and Sanctuaries (DIMRS) Reef Monitoring Program. In: UNEP (ed) Monitoring Coral Reefs for Better Management Schemes. UNEP EAS/RCU Small Grants Fund Programme, Bangkok, Thailand.

Reboton, C. and Calumpong, H., 2000. How much damage do divers and snorkelers do to corals? Proc. 9th Int. Coral Reef Symp. 2: 787-790.

Ross, M., White, A., Sitoy, A. and Menguito, T., 2000. Experience from improving management of an "Urban" marine protected area: Gilutongan marine sanctuary, Philippines. Proc. 9th Int. Coral Reef Symp. 2: 641-648.

Sotto F., Gatus, J., Ross, M., Portigo, M. and Freire, F., 2001. Coastal Environmental Profile of Olango Island, Cebu, Philippines. Coastal Resource Management Project, Cebu City, Philippines.

UNESCO, 2002. An ecological assessment of Ulugan Bay, Palawan, Philippines.. CSI info N° 12, UNESCO, Paris.

Coastal Conservation Education Foundation

Christie, P., White, A. and Deguit, E., 2002. Starting point or solution? Community-based marine protected areas in the Philippines. J. Environ. Manag. 66:441-454.

Christie, P., 2005. Observed and perceived environmental impacts of marine protected areas in two Southeast Asia sites. Ocean Coast. Manag. 48: 252-270.

White, A., Christie, P., Apurado, J. , Meneses, A., Ovenden, M. , Tesch, S. and White, E., 2002. Summary Field Report: Coral Reef Monitoring in Cebu, Negros and Siquijor, Philippines, March 23-31, 2002. The Coastal Conservation and Education Foundation,Inc. and Coastal Resource Management Project, Cebu City.

White, A., Christie, P., Meneses, A., Maypa, A., Stockwell, B., Tesch, S., White, E. and

Mueller, T., 2004. Summary Field Report: Coral Reef Monitoring Expedition to Tubbataha Reefs National Marine Park, Sulu Sea, Philippines, April 3-11, 2004. The Coastal Conservation and Education Foundation, Inc. and Coastal Resource Management Project, Cebu City.

White, A., Maypa, A., Tesch, S., Stockwell, B., Meneses, A., White, E. and Mueller, T., 2005. Summary Field Report: Coral Reef Monitoring Expedition to Mabini and Tingloy, Batangas, Philippines, March 19–27, 2005. The Coastal Conservation and Education Foundation, Inc. and the Fisheries Improved for Sustainable Harvest (FISH) Project, Cebu City.

White, A., Maypa, A., Tesch, S., Meneses, A., Stockwell, B. , White, E. and Martinez, R., 2006. Summary Field Report: Coral Reef Monitoring Expedition to Calamianes Islands, Palawan,Philippines, April 8-16, 2006. The Coastal Conservation and Education Foundation, Inc. and the Fisheries Improved for Sustainable Harvest (FISH) Project, Cebu City.

White, A., Meneses, A., Tesch, S. , Maypa, A., Stockwell, B., White, E. and Martinez, R., 2007. Summary Field Report: Coral Reef Monitoring in Bohol, Philippines,March 26-April 3, 2007. The Coastal Conservation and Education Foundation, Inc. and Fisheries Improved for Sustainable Harvest Project, Cebu City.

White, A., Maypa, A., Tesch, S., Diaz, R., Martinez, R. and White, E., 2008. Summary Field Report: Coral Reef Monitoring Expedition to Tubbataha Reefs Natural Park, Sulu Sea, Philippines, March 26 – April 1, 2008. The Coastal Conservation and Education

Foundation, Inc., Cebu City.

OneOcean.org

UPVFI, 2005. Baseline assessment of existing or potential MPA's in FISH Project focal areas: Tawi-tawi. Technical Report, University of the Philippines-Visayas, Miag-ao,Iloilo.

UPVFI, 2007. Monitoring and baseline assessment of marine protected areas in the Fish Project focal areas: Tawi-tawi. Technical Report, University of the Philippines-Visayas, Miag-ao,Iloilo.

USAID/DA-BFAR FISH Project, 2010. Consolidated Report: Monitoring of the capture fisheries and marine protected areas (reef habitats) in the FISH Project's focal areas: Coron Bay, Danajon Bank, Lanuza Bay and Tawi-tawi. FISH Project Final Report,Tetra Tech EM Inc., Ortigas Center, Pasig City. 143 p.

Valle, I.S., Cristobal, M.C.B., White, A.T. and Deguit, E., 2000. Coastal Environmental Profile of the Malalag Bay Area, Davao del Sur, Philippines. Coastal Resource Management Project, Cebu City, Philippines.

Coral Cay Conservation

Bochove, J., Wood, O., Holman, K., Head, C. and Raines, P., 2006. Coral Reef Resource Assessment and Management Recommendations, Polillo Islands, Philippines. Coral Conservation, London,UK.

Daly R., and Bochove, J.W.V., 2009. Napantao Fish Sanctuary Report 2009. Coral Cay Conservation, Southern Leyte, Philippines.

Solandt, J. -L., Harding, S. P., Beger, M., Dacles, T. P. and Raines, P. S., 2003. Effects of 1998 bleaching event on a large Pavona clavus colony in a Philippine marine protected area. Silliman J. 44:19-32.

Other studies

Boquiren, R., Di Carlo, G., and Quibilan, M., 2010. Climate Change Vulnerability Assessment of the Verde Island Passage, Philippines. Technical report. Conservation International, Arlington, Virginia, USA.

De Guzman, A., 2004. A Fishery in Transition: Impact of a Community Marine Reserve on a Coastal Fishery in Northern Mindanao, Philippines. Research Report 2004 RR6. EEPSEA, Singapore.

Dygico, M., 2006. Tubbataha reefs a marine protected area that works, a case study on the Philippines. WWF-Philippines, Quezon City, Philippines.

Raymundo, L., Maypa, A., Gomez, E., Pablina C., 2007. Can dynamite-blasted reefs recover? A novel, low-tech approach to stimulating natural recovery in fish and coral populations. Mar. Pollut. Bull. 54:1009-1019.

Reef Check MPA Report, 2006. Hambongan Marine Sanctuary Management Report. Marine Aquarium Council, Reef Check, Conservation and Community Investment Forum.

Russ, G. and Alcala, A., 1998. Natural fishing experiments in marine reserves 1983-1993: community and trophic responses. Coral Reefs 17:383-397.

Shuman, C., Hodgson, G. and Ambrose, R., 2005. Population impacts of collecting sea anemones and anemonefish for the marine aquarium trade in the Philippines. Coral Reefs 24:564-573.

The Louis Berger Group Inc., 2008. Regional Impacts Projects (RIP) R-04 Tawi-tawi Bridge /Road Partnership Environmental Assessment Report. USAID's Growth with Equity in Mindanao (GEM-3) Program, Manila, Philippines.

Vergara, M., 2009. Coral community structure of the Bolinao reef system, Northwestern Philippines. MS thesis, University of the Philippines, Quezon City, Philippines.

White, A., 1984. Marine parks and reserves: managament for Philippine, Indonesian and Malaysian coastal reef environments. PhD dissertation, Univ. Hawaii.

CHAPTER III

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

3.1 Introduction

In Chapter II, coral cover patterns were assessed based on the condition of coral cover. Another method offers a way to standardize and represent the results of primary studies on a common scale (i.e., effect size) so that results from individual studies can be compared and evaluated, is meta-analysis (Rosenberg et al., 2000). Meta-analysis is a statistical method used to integrate quantitatively research findings across studies and determines whether they share a common effect size (Hedges & Olkin, 1985; Gurevitch & Hedges, 1999; Côté et al., 2005). It offers several advantages over other quantitative research synthesis (Côté et al., 2006). First, it considers the results obtained by individual studies regardless of their statistical significance. Second, it overcomes the problem of low statistical power from low sample size as it considers the weighting of the outcome of each study in the analysis. In addition, the likelihood of committing Type II error (i.e., failing to reject the null hypothesis when it is false) is reduced. Côté et al., 2006 argued that a Type II error could show that the rates are not statistically significant which could have a negative impact for a declining trend. Finally, meta-analysis offers a quantitative estimate of the overall effect and its statistical significance. This method was used to validate the trends observed in snapshots surveys used in the quartile category analysis by estimating the change in coral cover of individual sites monitored over time. Annual rate of change in coral cover was chosen effect size to examine the pattern of change in coral cover across sites in relation to time, effect of bleaching and effect of protection against fishing. However, unlike the quartile category, this requires repeated measurement over time on the same reef, must report the number and length of transects used in the surveys. 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).

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 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 MPAs 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. This study then explores whether coral cover exhibits a similar pattern and examines the role of MPAs on the trends of coral cover in the Philippines.

3.2 Methodology

From the compiled database (Chapter 2.3.1), 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 were selected. Studies were included 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 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 estimated as:

$$\mathrm{ARC} = \frac{(\log End - \log Start)}{d}, \tag{3.2.1}$$

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, transect length and the number of replicate transects of each survey were used similar to Alvarez-Filip et al. (2011). The average number of transects for studies with varying number of replicates was used. The mean effect size $\overline{\mathrm{ARC}}$ of all studies or categories was estimated as:

$$\overline{\mathrm{ARC}} = \frac{\sum_{i=1}^{n}(W_i * \mathrm{ARC}_i)}{\sum_{i=1}^{n} W_i}. \tag{3.2.2}$$

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 rates 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). Three main categorical groupings were performed 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. To assess the impact of combining different studies and survey methods, methodological, non-independence and publication biases were tested.

The temporal heterogeneity in 5-year intervals for the overall dataset was examined by including the replicate surveys that fell within the period. Some years had longer (6 years instead of 5 years) intervals, to compensate for the low sample size and missing data in 1987–1988 and 1990–1991. The impact of coral bleaching was assessed 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). This study 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. All sites were assumed to be affected by bleaching thus surveys in the following time periods were included: 1996-1997 (before bleaching), 1997-1998 (during), 1998-1999 (1 year post-bleaching), 1998-2000 (2 years post-bleaching), 1998-2001 (3 years post-bleaching) and 1998-2002 (4 years post-bleaching).

The effect of protection was examined by comparing the overall mean rates of change in coral cover between MPAs and non-MPAs. For MPAs, sites with a known year of establishment with surveys after the year of designation were considered to estimate the rate of cover change since protection. Effect of protection, however, may be constrained by potential site selection bias for initially healthy reefs resulting to positive reserve effect. In the absence of before establishment surveys, 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). The effect of protection on rates of change in coral cover was further examined with the level of protection, age and size of MPAs. MPAs were classified in terms of level of protection: fully protected (i.e., any form of extraction is 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. MPA information was obtained 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.

3.3 Results

Selected studies from the database generated 1,096 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. 3.1). Details of the studies used are listed in Table 3.1. 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%). The majority of sites (262/317, or 83%) was surveyed using a 50 m transect length at depths ranging from 2 m to 20 m. Figure 3.2 shows the pattern of percent hard coral cover. From 1981 to 2010, the overall coral cover mean was ~36% comparable to the reported 33% in the Indo-Pacific (Bruno et al., 2009). There was a relatively higher coral cover beginning in 1995 than the early years of the time series with notable peaks in 1995-1997. 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 rate of change in coral cover.

3.3.1 Methodological, non-independence and publication bias tests

Annual rate of change in percentage cover did not vary significantly ($Q_M = 0.59$, df = 3, P = 0.74) among commonly used methods such as PIT, LIT, video transect and snorkeling. Similarly, no relationship was found between the overall rate of change in coral cover and duration of study (slope of Regression: <0.001, SE = 0.0005, P = 0.61).

There was also no publication bias observed in the collected data as confirmed graphically by funnel and normal quartile plots (Fig. 3.3). Studies with small sample size should have a large standard error compared to large sample size thus forming a funnel shape (Rosenberg et al., 2000). Alternative to funnel plot is normal quantile plot, two distributions are compared by plotting their quantiles (percentiles) with each other (Wang & Bushman, 1998). If two quantiles are the same then the two distributions are similar and the points will lie closely to the line X = Y (Wang & Bushmann, 1998; Rosenthal et al., 2000). The points on the normal quantile plot should look like a straight line and would coincide within the 95% confidence interval bands showing that the observed data come from a single normal population. Publication bias was further confirmed statistically by rank correlation tests. Significant correlation indicates a publication bias but both Kendall's Tau (τ= 0.05, Z = 1.14, P = 0.26) and Spearman Rank-Order Correlation (Rs = 0.07, P = 0.30) showed non-significant correlation indicating no bias in publication or "file-drawer problem" present in the data set (Rosenthal et al., 2000).

Data non-independence was also examined by removing the largest study (CCEF) in the analysis which had no effect in overall ARC (1.45%, CI= 0.12 to 2.72%). However, randomly choosing one site per study showed a positive rate of change but not different from zero (ARC = 1.07%, CI= -1.61 to 4.52%), probably due to geographical proximity of sites included in the analysis. Moreover, almost 70% of the sites were surveyed in the Visayas region thus, omitting Visayan Sea region yielded an overall annual percent cover of 1.26% (CI = -0.23 to 2.93%).

3.3.2 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 periods ($Q_M = 31.9$, $df = 4$, $P = 0.0002$) (Fig. 3.4). The overall rate of change in coral cover was strongly positive in 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%). Before the mass coral bleaching (1996-1997), coral cover was significantly positive (ARC= 3.95%, CI= 1.39 to 6.90%). During the 1997-1998 massive bleaching, coral cover decline was estimated at 8.07% yr^{-1} (CI= -13.24 to -2.46%) but positive rates were noted in all post bleaching years. Three years post-bleaching indicated significant recovery (ARC = 12.82%, CI = 4.51 to 23.32%) suggesting coral recovery in 2001 (figure not shown).

3.3.3 Marine Protected Areas

Assessing site selection bias revealed that coral cover within MPAs (mean = 36.0%, n = 56) were higher than non-MPAs (mean = 30.2%, n = 57), 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). All Cebu sites in 2000s were eliminated in the MPA 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).

Fig. 3.5a shows the annual absolute coral cover of MPA and non-MPA. Although there is an inter-annual variability, MPA sites exhibited higher coral cover than non-MPA sites except in years with very low number of surveys on MPAs (i.e. in 1982, 1993 and 1995). Pooling all the values annually by simple averaging, however, did not show the significant differences of MPA and non-MPA. In contrast, taking into consideration the rate of change in coral cover on individual sites revealed statistically significant variability between the two (Q_M = 2.27, P = 0.023) (Fig. 3.5b). Coral cover increased significantly within MPAs by 3.20% per year (CI = 1.65 to 4.95%) but did not change on 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. 3.6). There was 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%). Result 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 rate of change in coral cover is independent of MPA age and size (Fig. 3.7a). MPA age and size were classified into 3 groups covering the minimum, average and maximum values to assess the average responses in different groups of 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 coral cover showed no statistical differences across MPA age groups ($Q_M = 0.91$, $P = 0.64$) (Fig. 3.7b). 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%) which are municipal-based MPAs that 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 with the area of >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 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. 3.7b).

3.4 Discussion

3.4.1 General trend

The trend in absolute coral cover (Fig. 3.2) 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.

Temporal patterns of coral cover change showed the trajectory of decline and recovery, conservation efforts, and thermal anomalies through the years (Fig. 3.4). 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 activities, 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 predation were observed in the country although high incidences were reported in 2000s (Fig. 2.3).

Temporal trends suggest that major threats to Philippine reefs are local anthropogenic impacts and global impacts of climate change. About 8% absolute coral cover loss was estimated 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 is 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., 2007a; 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 were initially observed and persisted in the northwestern part of the Philippines (Arceo et al., 2001). While, some reefs in the Visayas suffered post-bleaching mortality in 1999 (Divinagracia et al., 2000; Raymundo & Maypa, 2002). In Zaragoza Marine Sanctuary, Cebu, coral loss was reported low because of the dominance of massive corals that 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, *Acropora* bleaching in Tubbataha reefs in the western Philippines was observed to vary spatially with exposure to wave action and current velocity on the reefs (Arceo et al., 2001).

3.4.2 Marine Protected Areas

Previous long-term studies of marine reserves showed 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 protection on the reef substrate (e.g Walmsley & White, 2003; Selig & Bruno, 2010; Alvarez-Filip et al., 2011) that can be compared with the results here. However, the responses of 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. 3.5b). 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 overall coral reef health by reducing anthropogenic pressure (primarily fishing, eliminating destructive fishing and anchor damage) that affects the substrate condition (Russ, 1991; Walmsley & White, 2003). Protection also helps in the recovery of key functional groups such as fish herbivores that control macroalgal growth after severe and acute disturbances; thus, contributing to reef resiliency (Mumby et al., 2006; Stockwell et al., 2009; Mumby & Harborne, 2010).

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 as a management strategy, as a compromise solution in resource use 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 and traditional fishing methods, such as gleaning or hook and line, and recreational activities (White et al., 2006). Result shows that partially protected areas did not differ in response from fully protected MPAs (Fig. 3.6). This is possibly because these partially protected MPAs 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. 3.7a). 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. 3.7b). The high variability of rates of coral cover change 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 destructive fishing activities 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. 3.7b). This 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 protect adequately 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.

The findings here 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. However, these results should be interpreted with caution since different species or species groups exhibit differential recovery rates (e.g., Russ & Alcala, 2004; McClanahan et al., 2007b) and it is likely that dominant species groups vary across MPAs. 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 siltation 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 t 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).

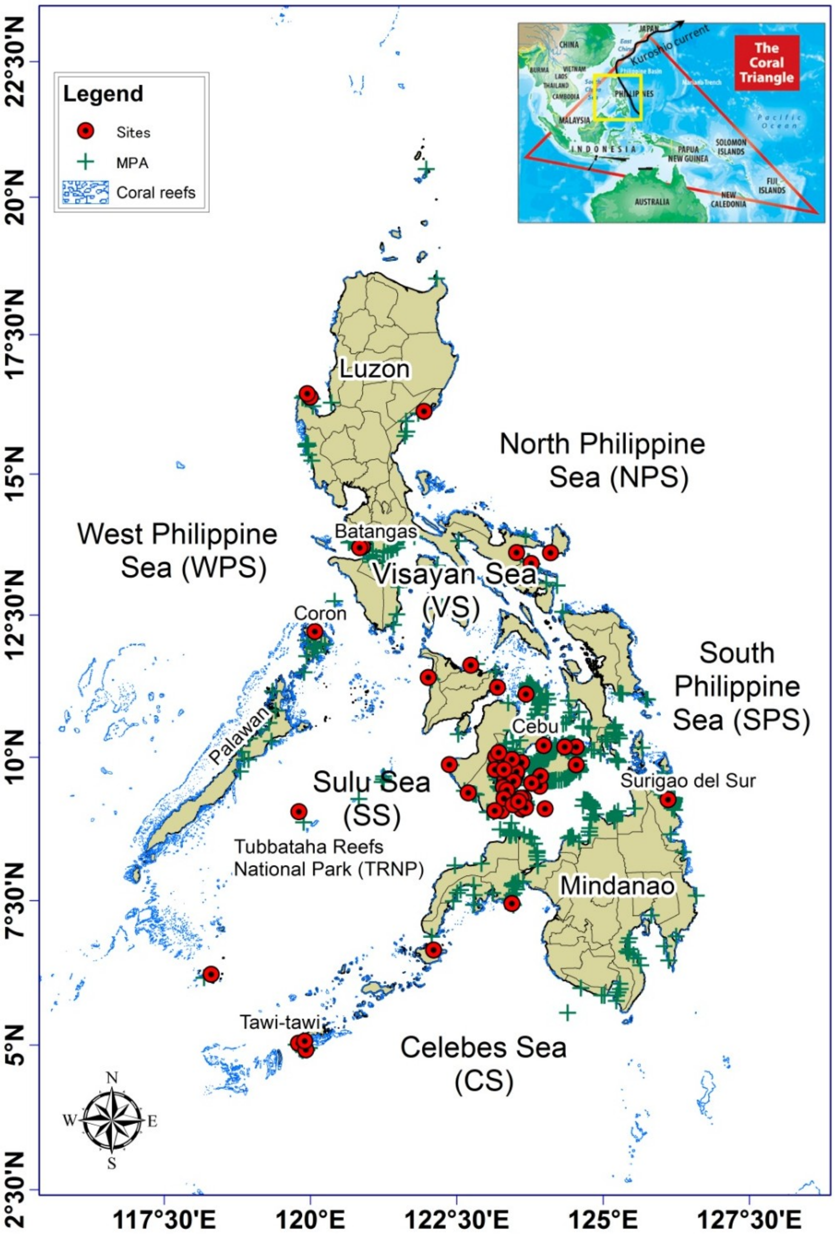


Figure 3.1 Distribution of the sites surveyed by different studies and marine protected areas (MPAs) throughout the Philippines. Each mark (⦿) may represent multiple sites. Most of the sites surveyed are confined in the Visayan Sea. The Philippine provincial map a nd boundaries were downloaded from www.philgis.org. The locations of coral reefs were sourced from the World Resources Institute (2011).

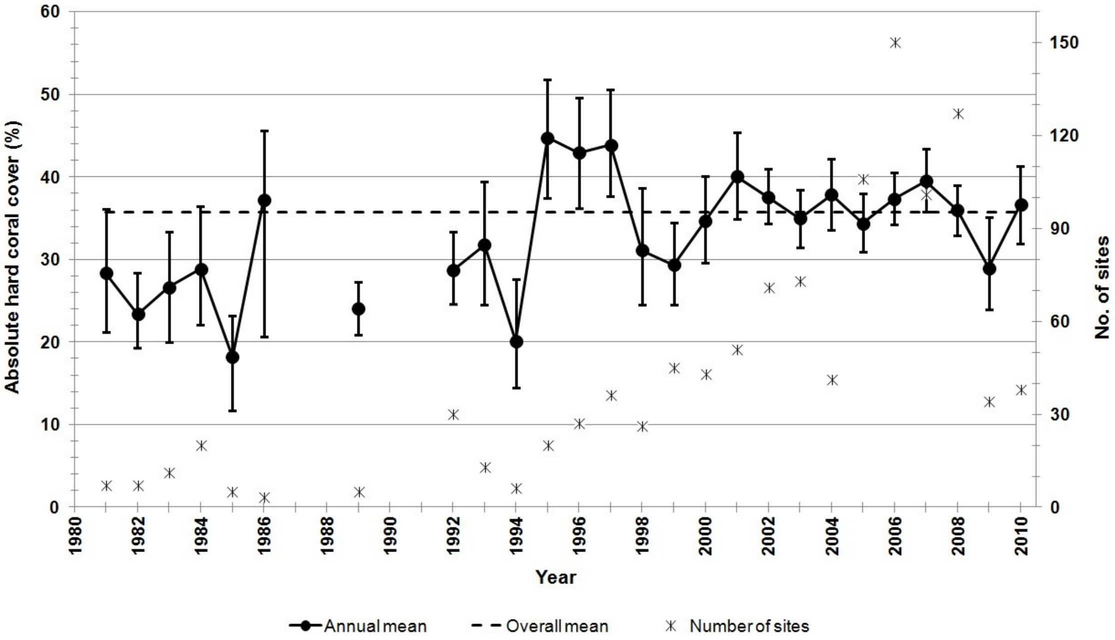


Figure 3.2 Annual absolute coral cover (%) of all sites (filled circle) and the overall mean (dashed line) from 1981 to 2010. Annual coral cover means are weighted means with 95% bias-corrected confidence intervalss. Asterisk denotes number of sites in each year. No data were obtained in years 1987-1988 and 1990-1991.

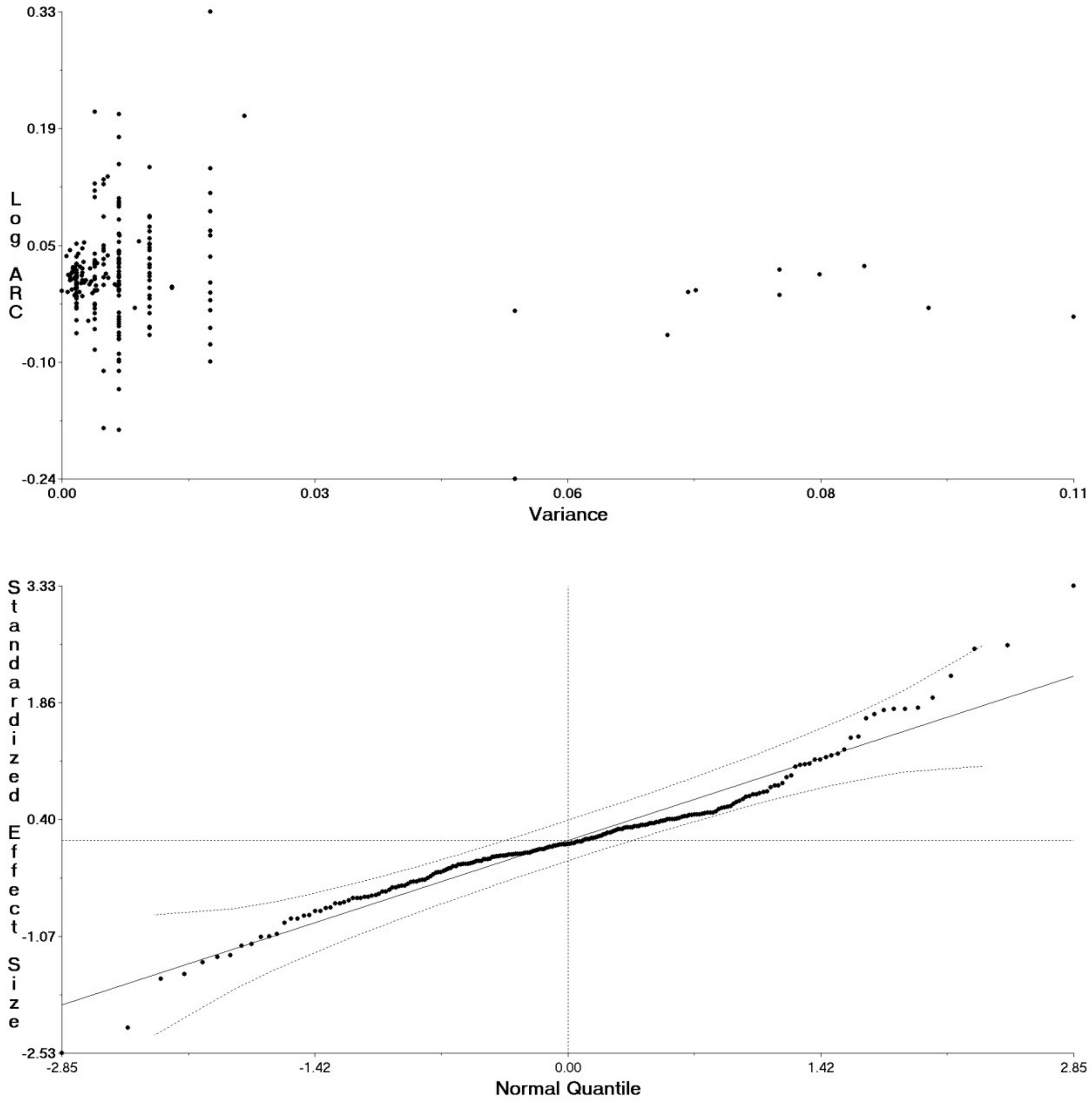


Figure 3.3 Graphical confirmation of no publication bias in the data set. Top: Funnel plot showing large opening at the smallest variance. Bottom: Normal quantile plot, the points coincide within the 95% confidence interval bands showing that the observed data ori ginate from a single normal population.

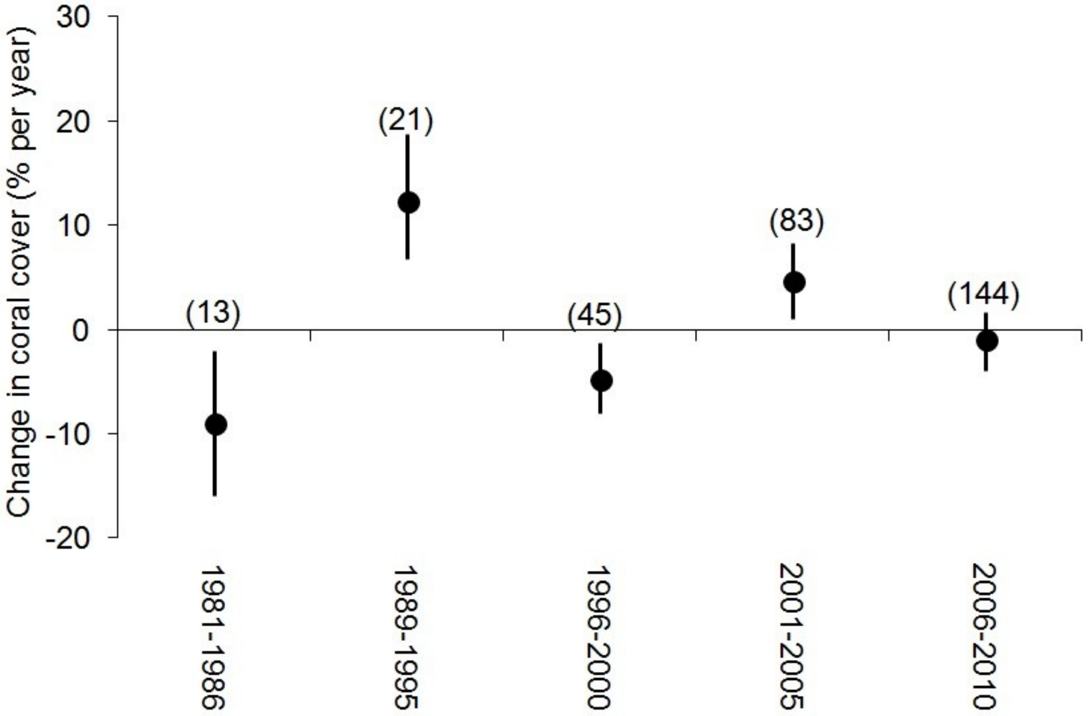


Figure 3.4 Annual rates of change in coral cover in 5-year time periods. Bars are 95% bias-corrected bootstrapped confidence intervals. Periods 1981–1986 and 1989–1995 covered 6 and 7 years, respectively to compensate the paucity of data in years 1987–88 and 1990–91. Sample sizes are given in parentheses.

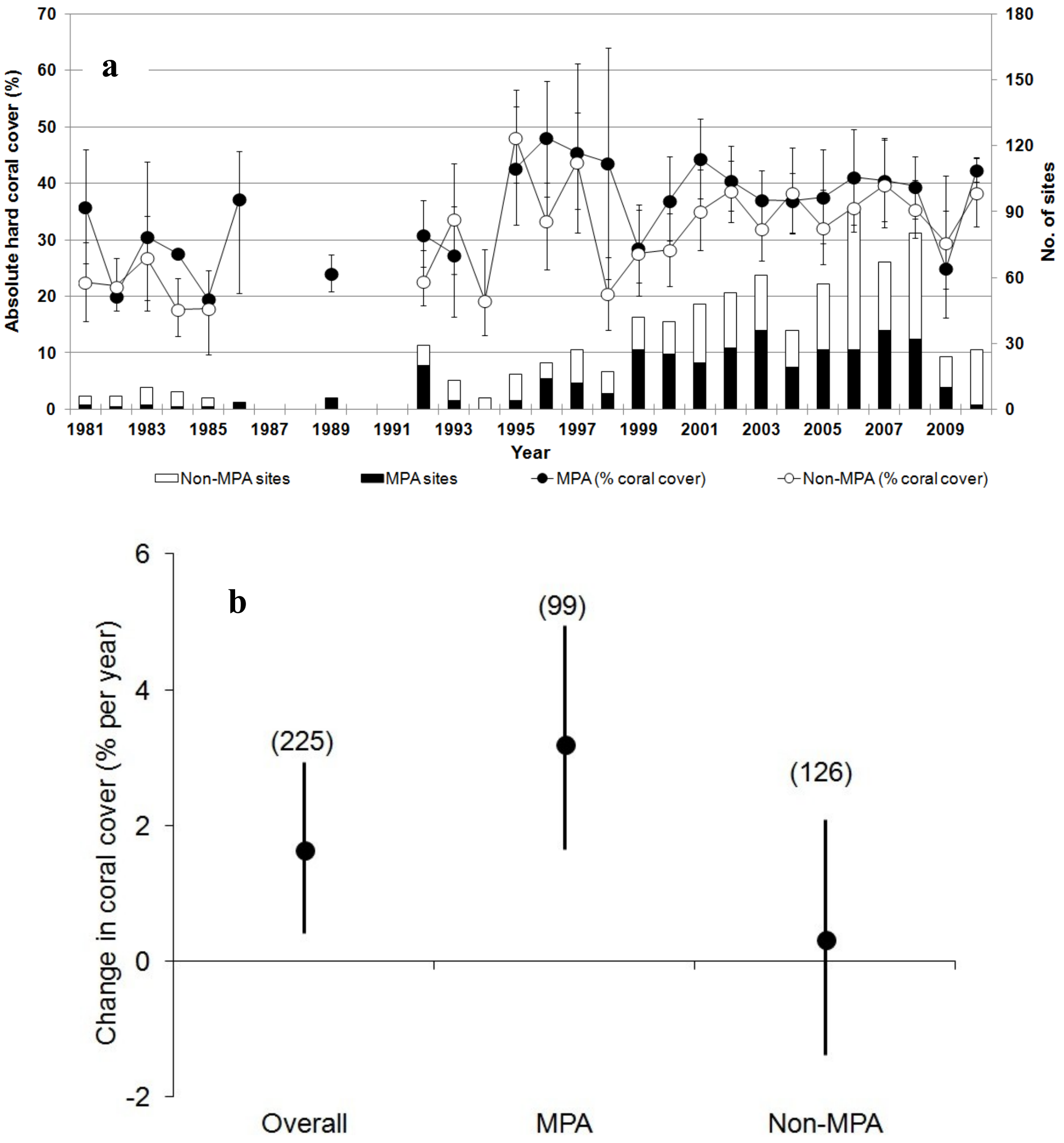


Figure 3.5 a. Absolute coral cover trend of MPA and non-MPA sites from 1981 to 2010. Means are shown in 95% bias-corrected bootstrapped confidence interval. b. Annual rates of change in coral cover (overall), MPAs and non-MPAs from 1981 to 2010. Bars are 95% bias corrected bootstrapped confidence interval. b. Annual rates of change in coral cover (overall), MPAs and non-MPAs from 1981 to 2010. Bars are 95% bias-corrected bootstrapped confidence interval. Sample sizes are given in parentheses.

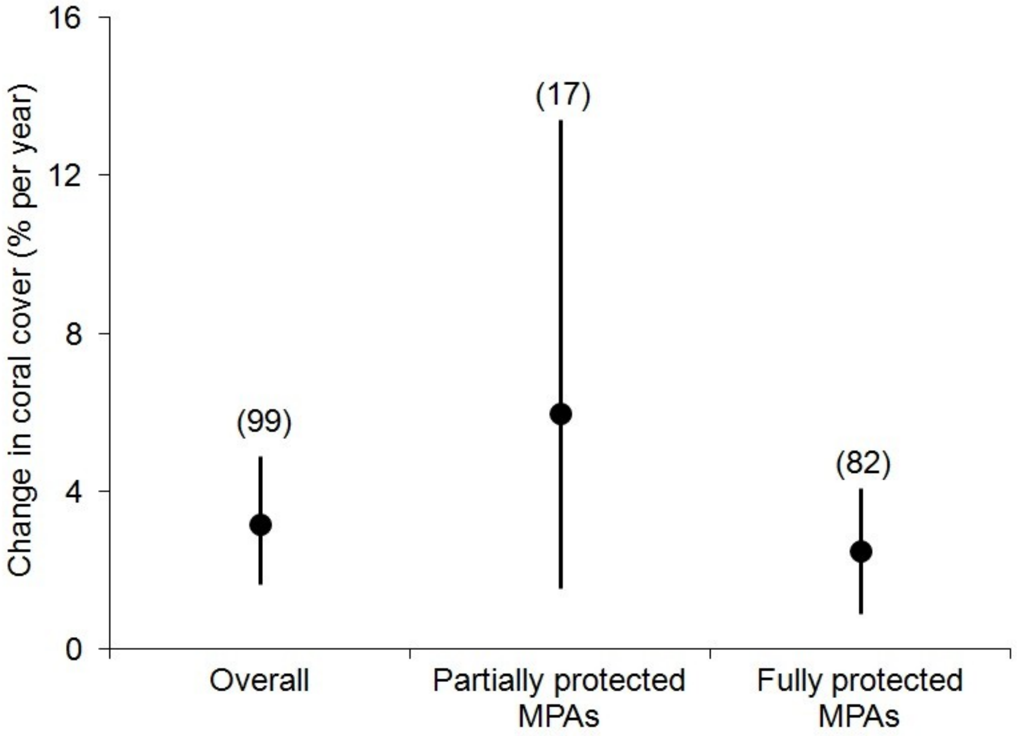


Figure 3.6 Annual rates of change in coral cover for all data, no-take MPAs, and partially protected MPAs since establishment. Bars are 95% bias-corrected bootstrapped confidence intervals. Sample sizes are in parentheses.

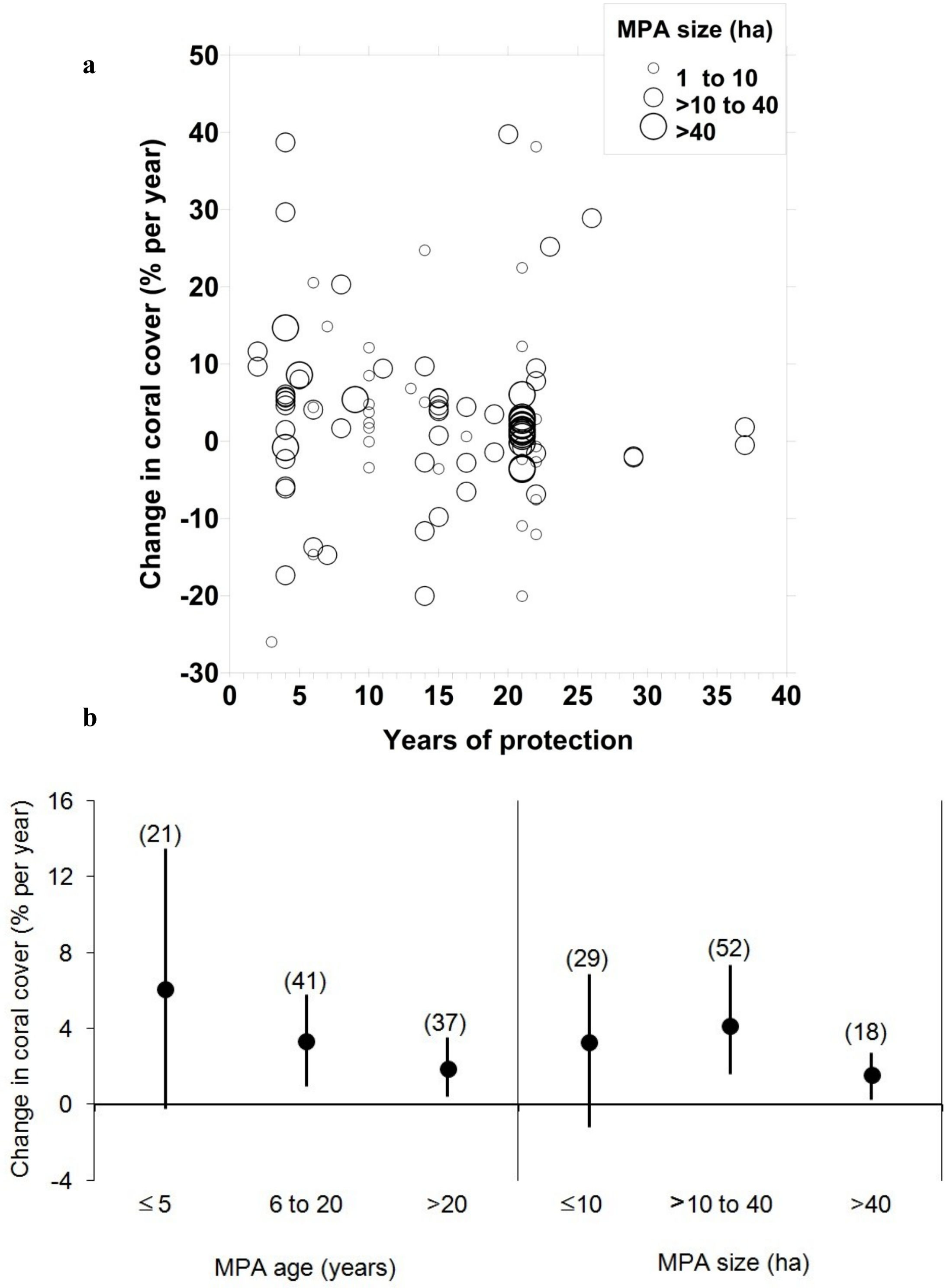


Figure 3.7 a. Relationship between annual rate of change in coral cover and MPA age. The size of the circle represents the corresponding size of MPAs at a given age. b. Annual rate of change in coral cover of age and size of MPAs classified in groups.

Table 3.1 Collated studies used for meta-analysis in this study. LIT: Line Intercept Transect; PIT: Point Intercept Transect; VT: Video Transect; PT: Photo transect; TQ: Transect quadrat; NA: Not available

Site	**Study**	**Reef**	**Location**	**Biogeo region**	**Mean #Transects**	**Transect Length**	**Survey Method**	**Depth (m)**	**Period**
1	The Local Governance for Coastal Management Project, 2005	Daang Lungsod-Guiwang Marine Sanctuary-inside	Alcoy, Cebu	VR	3	50 m	PIT	NA	2002-2003
2	The Local Governance for Coastal Management Project, 2005	Daang Lungsod-Guiwang non-sanctuary	Alcoy, Cebu	VR	2	50 m	PIT	NA	2002-2003
3	CCEF; White et al., 2010	Daanlungsod-Guiwang Marine Sanctuary inside	Alcoy, Cebu	VR	4	50 m	PIT	6 - 8	2005-2010
4	CCEF; White et al., 2010	Daanlungsod-Guiwang Marine Sanctuary outside	Alcoy, Cebu	VR	4	50 m	PIT	6 - 8	2005-2010
5	CCEF	Poblacion Marine Sanctuary - inside	Alcoy, Cebu	VR	3	50 m	PIT	6 - 8	2007-2008
6	CCEF	Poblacion Marine Sanctuary - outside	Alcoy, Cebu	VR	3	50 m	PIT	6 - 8	2007-2008
7	CCEF	Legaspi Marine Sanctuary - inside	Alegria, Cebu	VR	3	50 m	PIT	6 - 8	2006-2008

8	CCEF	Legaspi Marine Sanctuary - outside	Alegria, Cebu	VR	3	50 m	PIT	6 - 8	2006-2008
9	CCEF	Madridejos Marine Sanctuary - inside	Alegria, Cebu	VR	3	50 m	PIT	6 - 8	2006-2008
10	CCEF	Madridejos Marine Sanctuary - outside	Alegria, Cebu	VR	3	50 m	PIT	6 - 8	2006-2008
11	CCEF	Sta. Filomena Marine Sanctuary - inside	Alegria, Cebu	VR	3	50 m	PIT	6 - 8	2006-2008
12	CCEF	Sta. Filomena Marine Sanctuary - outside	Alegria, Cebu	VR	3	50 m	PIT	6 - 8	2006-2008
13	Aliño, 1985	Cangaluyan Is. -site I	Anda, Pangasinan	WPS	20	1 m^2	TQ	NA	1983-1984
14	Aliño, 1985	Cangaluyan Is. -site II	Anda, Pangasinan	WPS	20	1 m^2	TQ	NA	1983-1984
15	Philreefs, 2003	Carot Fish Sanctuary-in	Anda, Pangasinan	WPS	4	50 m	LIT/VT	5-7	2001-2003
16	Philreefs, 2003	Carot Fish Sanctuary-out	Anda, Pangasinan	WPS	4	50 m	LIT/VT	5-7	2001-2003
17	CCEF	Binlod Marine Sanctuary - inside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
18	CCEF	Binlod Marine Sanctuary - outside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
19	CCEF	Bogo Marine Sanctuary - inside	Argao,Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
20	CCEF	Bogo Marine Sanctuary - outside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008

21	CCEF	Bulasa Marine Sanctuary - inside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
22	CCEF	Bulasa Marine Sanctuary - outside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
23	CCEF	Casay Shoal Marine Sanctuary - inside	Argao, Cebu	VR	4	50 m	PIT	6 - 8	2005-2008
24	CCEF	Guiwanon Marine Sanctuary - inside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
25	CCEF	Guiwanon Marine Sanctuary - outside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
26	CCEF	Langtad Marine Sanctuary -inside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
27	CCEF	Langtad Marine Sanctuary -outside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
28	CCEF	Poblacion Marine Sanctuary - inside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
29	CCEF	Poblacion Marine Sanctuary -outside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
30	CCEF	Talaga Marine Sanctuary - inside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
31	CCEF	Talaga Marine Sanctuary - outside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008

32	CCEF	Taloot Marine Sanctuary - inside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
33	CCEF	Taloot Marine Sanctuary - outside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
34	CCEF	Tulic Marine Sanctuary - inside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
35	CCEF	Tulic Marine Sanctuary - outside	Argao, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
36	Alcaria & Bacalihog, 2003	Calag-calag Marine Sanctuary	Ayungon, Negros Oriental	VR	2	50 m	LIT	NA	1996-2001
37	White et al., 2007	Pamilacan Marine Sanctuary,	Baclayon, Bohol	VR	11	1 m^2	snorkel	2 - 4	1992-2007
38	White et al., 2007	Pamilacan Marine Sanctuary,	Baclayon, Bohol	VR	12	50 m	PIT	7 - 8	1984-2007
39	Christie et al., 2002	Pamilacan Marine Sanctuary,Baclayon,Bohol	Baclayon, Bohol	VR	10	50 m	LIT	5 - 7	1984-1999
40	Christie et al., 2002	Pamilacan non sactuary	Baclayon, Bohol	VR	10	50 m	LIT	5 - 7	1984-1999
41	White et al., 2007	Pamilacan non-sanctuary	Baclayon, Bohol	VR	5	50 m	PIT	7 - 8	1984-2007
42	White et al., 2007	Pamilacan non-sanctuary	Baclayon, Bohol	VR	9	1 m^2	snorkel	2 - 4	1992-2003
43	Delizo et al., 2007	Bato Fish sanctuary inside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
44	Delizo et al., 2007	Bato Fish Sanctuary-outside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
45	CCEF	Bato Seagrass and Fish Sanctuary -inside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007

46	CCEF	Bato Seagrass and Fish Sanctuary -outside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
47	Alcaria & Bagalihog, 2003, 2005	Bugas	Badian, Cebu	VR	2	50 m	LIT	NA	1995-2003
48	CCEF	Hinablan Marine Sanctuary - inside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
49	Delizo et al., 2007	Hinablan Marine Sanctuary - inside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2006-2007
50	CCEF	Hinablan Marine Sanctuary -outside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
51	Delizo et al., 2007	Hinablan Marine Sanctuary -outside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2006-2007
52	CCEF	Lambog Seagrass and Fish Sanctuary - inside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
53	Delizo et al., 2007	Lambog Seagrass and Fish Sanctuary - inside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
54	CCEF	Lambog Seagrass and Fish Sanctuary - outside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2006-2007
55	Delizo et al., 2007	Lambog Seagrass and Fish Sanctuary - outside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
56	CCEF	Matutinao Marine Sanctuary - inside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2006-2007

57	Delizo et al., 2007	Matutinao Marine Sanctuary - inside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
58	CCEF	Matutinao Marine Sanctuary - outside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2006-2007
59	Delizo et al., 2007	Matutinao Marine Sanctuary - outside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
60	CCEF	Zaragosa Fish Sanctuary -inside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
61	Delizo et al., 2007	Zaragosa Fish Sanctuary -inside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
62	CCEF	Zaragosa Fish Sanctuary -outside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
63	Delizo et al., 2007	Zaragosa Fish Sanctuary -outside	Badian, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
64	Alcaria & Bagalihog, 2003, 2005	Zaragosa Marine Sanctuary	Badian, Cebu	VR	2	50 m	LIT	NA	1996-2003
65	Raymundo et al., 2006a	Zaragosa MPA inside	Badian, Cebu	VR	3	20 m	LIT	NA	2006-2008
66	Raymundo et al., 2006a	Zaragosa MPA outside	Badian, Cebu	VR	3	20 m	LIT	NA	2006-2008
67	Alcaria & Bacalihog, 2003	Sulangan-inside sanctuary	Bantayan, Cebu	VR	2	50 m	LIT	NA	1995-1997
68	Alcaria & Bacalihog, 2003	Sulangan-outside sanctuary	Bantayan, Cebu	VR	2	50 m	LIT	NA	1998-2001

69	Alcaria & Bacalihog, 2003	Actin	Basay, Negros Oriental	VR	2	50 m	LIT	NA	1999-2001
70	Alcaria & Bacalihog, 2003	Bungalonan Marine Sanctuary	Basay, Negros Oriental	VR	2	50 m	LIT	NA	2000-2001
71	Alcaria & Bacalihog, 2003	Tinaogan	Bindoy, Negros Oriental	VR	2	50 m	LIT	NA	1996-2001
72	Arceo et al., 2005; Geronimo et al., 2008	Balingasay MPRA-inside	Bolinao, Pangasinan	WPS	5	50 m	LIT/VT/PIT	NA	1999-2006
73	Philreefs, 2003	Balingasay MPRA-inside	Bolinao, Pangasinan	WPS	4	50 m	LIT/VT	6-8	2001-2002
74	Arceo et al., 2005; Geronimo et al., 2008	Balingasay MPRA-outside	Bolinao, Pangasinan	WPS	5	50 m	LIT/VT/PIT	NA	1999-2006
75	Philreefs, 2003	Balingasay MPRA-outside	Bolinao, Pangasinan	WPS	4	50 m	LIT/VT	6-8	2001-2002
76	Vergara, 2009	Malilnep	Bolinao, Pangasinan	WPS	5	20 m	PT	3	2006-2009
77	CCEF; White et al., 2010	Arbor Fish Sanctuary - inside	Boljoon, Cebu	VR	4	50 m	PIT	6 - 8	2005-2010
78	CCEF; White et al., 2010	Arbor Fish Sanctuary - outside	Boljoon, Cebu	VR	4	50 m	PIT	6 - 8	2005-2010
79	The Local Governance for Coastal Management Project, 2005	Arbor Marine non-sanctuary	Boljoon, Cebu	VR	2	50 m	PIT	NA	2002-2003
80	The Local Governance	Arbor Marine non-sanctuary	Boljoon, Cebu	VR	2	50 m	PIT	NA	2002-2003

	for Coastal Management Project, 2005								
81	The Local Governance for Coastal Management Project, 2005	Arbor Marine Sanctuary-inside	Boljoon, Cebu	VR	3	50 m	PIT	NA	2002-2003
82	The Local Governance for Coastal Management Project, 2005	Arbor Marine Sanctuary-inside	Boljoon, Cebu	VR	3	50 m	PIT	NA	2002-2003
83	CCEF; White et al., 2010	Granada Fish Sanctuary - inside	Boljoon, Cebu	VR	4	50 m	PIT	6 - 8	2004-2010
84	CCEF; White et al., 2010	Granada Fish Sanctuary - outside	Boljoon, Cebu	VR	3	50 m	PIT	6 - 8	2005-2010
85	UPVFI 2007; FISH 2010	Pababag Is., Bongao	Bongao, Tawi-tawi	SS	10	50 m	PIT	3 - 6	2004-2010
86	UPVFI 2007; FISH 2010	Ungos-ungos,Bongao	Bongao, Tawi-tawi	SS	10	50 m	PIT	NA	2006-2010
87	White et al., 2008	Jessie Beazley Reef,Tubbataha	Cagayancillo, Palawan	SS	13	50 m	snorkel	2 - 4	1984-2008
88	White et al., 2008	Jessie Beazley Reef,Tubbataha	Cagayancillo, Palawan	SS	18	50 m	PIT	6 - 8	2004-2008
89	White et al., 2008	North Reef 1,Tubbataha	Cagayancillo, Palawan	SS	8	50 m	snorkel	2 - 4	1984-2008
90	White et al., 2008	North Reef 1,Tubbataha	Cagayancillo, Palawan	SS	11	50 m	PIT	6 - 8	1984-2008

91	White et al., 2008	North Reef 2,Tubbataha	Cagayancillo, Palawan	SS	10	50 m	snorkel	2 - 4	1992-2008
92	White et al., 2008	North Reef 2,Tubbataha	Cagayancillo, Palawan	SS	13	50 m	PIT	6 - 8	1992-2008
93	White et al., 2008	North Reef 5,Tubbataha	Cagayancillo, Palawan	SS	8	50 m	snorkel	2 - 4	1984-2008
94	White et al., 2008	North Reef 5,Tubbataha	Cagayancillo, Palawan	SS	11	50 m	PIT	6 - 8	1984-2008
95	White et al., 2008	South Reef 1,Tubbataha	Cagayancillo, Palawan	SS	7	50 m	snorkel	2 - 4	1984-2008
96	White et al., 2008	South Reef 1,Tubbataha	Cagayancillo, Palawan	SS	11	50 m	PIT	6 - 8	1984-2008
97	White et al., 2008	South Reef 3 Black Rock, Tubbataha	Cagayancillo, Palawan	SS	7	50 m	snorkel	2 - 4	1984-2008
98	White et al., 2008	South Reef 3 Black Rock, Tubbataha	Cagayancillo, Palawan	SS	12	50 m	PIT	6 - 8	1992-2008
99	White et al., 2008	South Reef 4,Tubbataha	Cagayancillo, Palawan	SS	11	50 m	snorkel	2 - 4	1992-2008
100	White et al., 2008	South Reef 4,Tubbataha	Cagayancillo, Palawan	SS	14	50 m	PIT	6 - 8	1992-2008
101	Alcaria & Bagalihog, 2003, 2005	Lomboy Marine Sanctuary	Calape, Bohol	VR	2	50 m	LIT	NA	1997-2003

102	Alcaria & Bagalihog, 2003, 2005	Magtongtong Marine Sanctuary	Calape, Bohol	VR	2	50 m	LIT	NA	1995-2003
103	Alcaria & Bagalihog, 2003, 2005	Bolinawan	Carcar, Cebu	VR	2	50 m	LIT	NA	1996-2003
104	Alcaria & Bagalihog, 2003, 2005	Tuyom	Carcar, Cebu	VR	2	50 m	LIT	NA	1996-2003
105	UNEP, 2004	AG1-Agutayan Is-outside_reserve	Cauayan, Negros Occidental	SS	5	50 m	PIT	12	2002-2003
106	UNEP, 2004	AG2-Agutayan Is-outside_reserve	Cauayan, Negros Occidental	SS	5	50 m	PIT	6	2002-2003
107	UNEP, 2004	AG3-Agutayan Is-outside_reserve	Cauayan, Negros Occidental	SS	5	50 m	PIT	12	2002-2003
108	UNEP, 2004	AG4-Agutayan Is-outside_reserve	Cauayan, Negros Occidental	SS	5	50 m	PIT	6	2002-2003
109	UNEP, 2004	AG5-Agutayan Is-outside_reserve	Cauayan, Negros Occidental	SS	5	50 m	PIT	12	2002-2003
110	UNEP, 2004	AG6-Agutayan Is-outside_reserve	Cauayan, Negros Occidental	SS	5	50 m	PIT	6	2002-2003
111	UNEP, 2004	Brgy Elihan-in,Danjugan	Cauayan, Negros Occidental	SS	5	50 m	PIT	6	2002-2003
112	UNEP, 2004	Brgy Elihan-in,Danjugan	Cauayan, Negros Occidental	SS	5	50 m	PIT	12	2002-2003

113	UNEP, 2004	Brgy Elihan-out,Danjugan	Cauayan, Negros Occidental	SS	5	50 m	PIT	6	2002-2003
114	UNEP, 2004	Brgy Elihan-out,Danjugan	Cauayan, Negros Occidental	SS	5	50 m	PIT	12	2002-2003
115	UNEP, 2004	CO1-reserve,Danjugan Is.	Cauayan, Negros Occidental	SS	5	50 m	PIT	6	2002-2003
116	UNEP, 2004	CO1-reserve,Danjugan Is.	Cauayan, Negros Occidental	SS	5	50 m	PIT	12	2002-2003
117	UNEP, 2004	CO2-reserve,Danjugan Is.	Cauayan, Negros Occidental	SS	5	50 m	PIT	6	2002-2003
118	UNEP, 2004	CO2-reserve,Danjugan Is.	Cauayan, Negros Occidental	SS	5	50 m	PIT	12	2002-2003
119	UNEP, 2004	CO3-reserve,Danjugan Is.	Cauayan, Negros Occidental	SS	5	50 m	PIT	6	2002-2003
120	UNEP, 2004	CO3-reserve,Danjugan Is.	Cauayan, Negros Occidental	SS	5	50 m	PIT	12	2002-2003
121	Dacles et al., 2003	Danjugan Island Marine reserve and sanctuaries-inside	Cauayan, Negros Occidental	SS	15	50 m	PIT	15	2000-2001
122	Dacles et al., 2003	Danjugan Island Marine reserve and sanctuaries-outside	Cauayan, Negros Occidental	SS	15	50 m	PIT	15	2000-2001

123	UNEP, 2004	SMA1-sanctuary,Danjugan Is.	Cauayan, Negros Occidental	SS	5	50 m	PIT	6	2002-2003
124	UNEP, 2004	SMA1-sanctuary,Danjugan Is.	Cauayan, Negros Occidental	SS	5	50 m	PIT	12	2002-2003
125	UNEP, 2004	SMA2-sanctuary,Danjugan Is.	Cauayan, Negros Occidental	SS	5	50 m	PIT	6	2002-2003
126	UNEP, 2004	SMA2-sanctuary,Danjugan Is.	Cauayan, Negros Occidental	SS	5	50 m	PIT	12	2002-2003
127	UNEP, 2004	SMA3-sanctuary,Danjugan Is.	Cauayan, Negros Occidental	SS	5	50 m	PIT	6	2002-2003
128	UNEP, 2004	SMA3-sanctuary,Danjugan Is.	Cauayan, Negros Occidental	SS	5	50 m	PIT	12	2002-2003
129	UPVFI	Agho Is.(Stn 6)	Concepcion, Iloilo	VR	2	50 m	LIT	NA	2002-2006
130	UPVFI	BagoAbo (Stn 12)	Concepcion, Iloilo	VR	2	50 m	LIT	NA	2002-2006
131	UPVFI	BagoAbo (Stn 9)	Concepcion, Iloilo	VR	2	50 m	LIT	NA	2002-2006
132	UPVFI	Botlog Dako (STn 11)	Concepcion, Iloilo	VR	2	50 m	LIT	NA	2002-2006
133	UPVFI	Malangaban Is. (Stn 4)	Concepcion, Iloilo	VR	2	50 m	LIT	NA	2002-2006
134	CCEF	Gilutongan Marine Sanctuary-inside	Cordova, Cebu	VR	10	50 m	PIT	5 - 7	1999-2009
135	CCEF	Gilutongan Marine Sanctuary-outside	Cordova, Cebu	VR	10	50 m	PIT	5 - 7	1999-2009
136	Raymundo et al., 2006a;	Gilutungan MPA inside	Cordova, Cebu	VR	3	20 m	LIT	NA	2006-2007

	Raymundo et al., 2008								
137	Raymundo et al., 2006a; Raymundo et al., 2008	Gilutungan MPA outside	Cordova, Cebu	VR	3	20 m	LIT	NA	2006-2007
138	FISH, 2010	Balisungan,Coron Bay	Coron, Palawan	WPS	10	50 m	PIT	NA	2006-2010
139	FISH, 2010	Bugor,Coron Bay	Coron, Palawan	WPS	10	50 m	PIT	NA	2004-2010
140	FISH, 2010	Cuaming,Coron Bay	Coron, Palawan	WPS	10	50 m	PIT	NA	2008-2010
141	FISH, 2010	Decaive-Apo Is.-Bintuan,Coron Bay	Coron, Palawan	WPS	10	50 m	PIT	NA	2004-2010
142	FISH, 2010	Lajala-Uson Is.	Coron, Palawan	WPS	10	50 m	PIT	NA	2004-2010
143	FISH, 2010	Tangtangen (Royucan_sagrada)	Coron, Palawan	WPS	10	50 m	PIT	NA	2006-2010
144	Garcia et al., 2003	Fringing reef, Mararison Is.	Culasi, Antique	SS	6	50 m	LIT	10	1994-1998
145	Garcia et al., 2003	Gui-ob reserve,Mararison Is.,	Culasi, Antique	SS	6	50 m	LIT	20	1994-1998
146	CCEF	Balud-Consolacion Marine Sanctuary - inside	Dalaguete, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
147	CCEF	Balud-Consolacion Marine Sanctuary - outside	Dalaguete, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
148	CCEF	Casay Marine Park and Sanctuary - inside	Dalaguete, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
149	CCEF	Casay Marine Park and Sanctuary - outside	Dalaguete, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008

150	CCEF	Cawayan Marine Sanctuary - inside	Dalaguete, Cebu	VR	3	50 m	PIT	6 - 8	2007-2008
151	CCEF	Cawayan Marine Sanctuary - outside	Dalaguete, Cebu	VR	3	50 m	PIT	6 - 8	2007-2008
152	White et al., 2002	Apo Island Fish Sanctuary	Dauin, Negros Oriental	VR	10	50 m	PIT	6 - 8	1981-2002
153	White et al., 2002	Apo Island Fish Sanctuary	Dauin, Negros Oriental	VR	154	1 m^2	snorkel	2 - 4	1983-2002
154	Reboton & Calumpong, 2000	Apo Island Marine Sanctuary	Dauin, Negros Oriental	VR	4	20 m	LIT	NA	1999-2000
155	Raymundo et al., 2006a	Apo Island MPA	Dauin, Negros Oriental	VR	3	20 m	LIT	NA	2006-2007
156	White et al., 2002	Apo Island Non-sanctuary	Dauin, Negros Oriental	VR	6	50 m	PIT	6 - 8	1981-2002
157	White et al., 2002	Apo Island Non-sanctuary	Dauin, Negros Oriental	VR	119	1 m^2	snorkel	2 - 4	1992-2002
158	Alcaria & Bagalihog, 2003, 2005	Apo Marine Sanctuary	Dauin, Negros Oriental	VR	2	50 m	LIT	NA	1996-2003
159	Raymundo et al., 2006a	Can-uran reef (fishing ground)	Dauin, Negros Oriental	VR	3	20 m	LIT	NA	2006-2007
160	White et al., 2007	San Isidro-Dau Marine Sanctuary,	Dauis, Bohol	VR	11	50 m	PIT	7 - 8	2003-2007

161	White et al., 2007	San Isidro-Dau Marine Sanctuary,	Dauis, Bohol	VR	15	1 m^2	snorkel	2 - 4	2003-2007
162	EcoGov 2, 2007	Mapalad-Dibaraybay Marine Sanctuary inside	Dinalungan, aurora	NPS	4	50 m	VT	5 - 8	2003-2006
163	EcoGov 2, 2007	Mapalad-Dibaraybay Marine Sanctuary outside	Dinalungan, aurora	NPS	3	50 m	VT	5 - 8	2003-2006
164	Raymundo et al., 2006b	Banilad MPA	Dumaguete City, Negros Oriental	VR	6	25 m^2	ND	NA	2004-2005
165	White, 1984	Bantayan Beach	Dumaguete City, Negros Oriental	VR	2	100 m	Scuba/ Snorkel	2	1981-1982
166	White, 1984	Bantayan Beach	Dumaguete City, Negros Oriental	VR	2	100 m	Scuba/ Snorkel	2	1982-1983
167	White, 1984	Bantayan Beach	Dumaguete City, Negros Oriental	VR	2	100 m	Scuba/ Snorkel	2	1981-1983
168	Alcaria & Bacalihog, 2003	Lomangcapan	Enrique Villanueva, Siquijor	VR	2	50 m	LIT	NA	1997-2001
169	Alcaria & Bacalihog, 2003	Poblacion	Enrique Villanueva, Siquijor	VR	2	50 m	LIT	NA	1994-2001
170	Alcaria & Bagalihog, 2003, 2005	Tulapos Marine Sanctuary	Enrique Villanueva, Siquijor	VR	2	50 m	LIT	NA	1996-2003
171	CCEF	Tulapos Marine Sanctuary - inside	Enrique Villanueva, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2009

172	CCEF	Tulapos Marine Sanctuary - outside	Enrique Villanueva, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2009
173	Alcaria & Bacalihog, 2003	Alumar	Getafe, Bohol	VR	2	50 m	LIT	NA	1994-2001
174	Alcaria & Bacalihog, 2003	Canlauron Marine Sanctuary	Getafe, Bohol	VR	2	50 m	LIT	NA	1995-2001
175	CCEF	Poblacion Marine Sanctuary - inside	Ginatilan, Cebu	VR	6	50 m	PIT	6 - 8	2008-2009
176	CCEF	Poblacion Marine Sanctuary - outside	Ginatilan, Cebu	VR	3	50 m	PIT	6 - 8	2008-2009
177	Alcaria & Bacalihog, 2003	Malusay Marine Sanctuary	Guilhungan, Negros Oriental	VR	2	50 m	LIT	NA	1999-2001
178	White, 1984	Maloong Canal Shoal MPA-inside	Lamitan City, basilan	CS	4	50 m	Snorkel	3 - 5	2005-2007
179	FISH, 2010	Adlay,Lanuza Bay	Lanuza, Surigao del Sur	SPS	10	50 m	PIT	NA	2006-2010
180	FISH, 2010	Auqui	Lanuza, Surigao del Sur	SPS	10	50 m	PIT	NA	2004-2010
181	FISH, 2010	Capandan, Lanuza Bay	Lanuza, Surigao del Sur	SPS	10	50 m	PIT	NA	2006-2010
182	FISH, 2010	Carrascal,Lanuza Bay	Lanuza, Surigao del Sur	SPS	10	50 m	PIT	NA	2004-2010

183	FISH, 2010	General Is.,Lanuza Bay	Lanuza, Surigao del Sur	SPS	10	50 m	PIT	NA	2004-2010
184	FISH, 2010	Uba	Lanuza, Surigao del Sur	SPS	10	50 m	PIT	NA	2006-2010
185	CCEF	Nonoc Marine Sanctuary - INSIDE	Larena, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2009
186	CCEF	Nonoc Marine Sanctuary - OUTSIDE	Larena, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2008
187	CCEF	Sandugan Marine Sanctuary - OUTSIDE	Larena, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2009
188	CCEF	Sandugan Marine Sanctuary -INSIDE	Larena, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2009
189	CCEF	Taculing-Cangmalalag Marine Sanctuary - INSIDE	Larena, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2009
190	CCEF	Taculing-Cangmalalag Marine Sanctuary - OUTSIDE	Larena, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2009
191	CCEF	Lower Cabancalan Marine Sanctuary - inside	Lazi, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2008
192	CCEF	Lower Cabancalan Marine Sanctuary - outside	Lazi, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2008
193	CCEF	Talayong Marine Sanctuary -inside	Lazi, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2008

194	CCEF	Talayong Marine Sanctuary -outside	Lazi, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2008
195	White et al., 2005	Arthurs Rock Fishing Sanctuary	Mabini, Batangas	WPS	15	50 m	PIT	7 - 8	1993-2005
196	White et al., 2005	Arthurs Rock Fishing Sanctuary	Mabini, Batangas	WPS	232	1 m^2	snorkel	2 - 4	1993-2005
197	White et al., 2005	Cathedral Reef Sanctuary	Mabini, Batangas	WPS	410	1 m^2	snorkel	2 - 4	2001-2005
198	White et al., 2005	Cathedral Reef Sanctuary	Mabini, Batangas	WPS	11	50 m	PIT	6-7	2001-2005
199	White et al., 2001	Selo point reef	Mabini, Batangas	WPS	3	50 m	PIT	5 - 8	1993-1995
200	White et al., 2001	Selo point reef	Mabini, Batangas	WPS	49	1 m^2	snorkel	2- 3	1993-1995
201	White et al., 2005	Twin Rocks Fishing Sanctuary	Mabini, Batangas	WPS	10	50 m	PIT	6-9	1993-2005
202	White et al., 2005	Twin Rocks Fishing Sanctuary	Mabini, Batangas	WPS	287	1 m^2	snorkel	2 - 4	1993-2005
203	Philreefs, 2003	Twin Rocks Fishing Sanctuary (MPA-in)	Mabini, Batangas	WPS	4	50 m	Video transect	6-7	2000-2001
204	Philreefs, 2003	Twin Rocks Fishing Sanctuary (MPA-out)	Mabini, Batangas	WPS	4	50 m	Video transect	6-7	2000-2001
205	White et al., 2005	white house reef	Mabini, Batangas	WPS	4	50 m	PIT	4 - 5	1994-2005
206	White et al., 2005	white sand reef	Mabini, Batangas	WPS	6	50 m	PIT	4 - 6	1993-2005
207	White et al., 2005	white sand reef	Mabini, Batangas	WPS	183	1 m^2	snorkel	2 - 4	1995-2005
208	Alcaria & Bacalihog,	Marcelo	Mabini, Bohol	VR	2	50 m	LIT	NA	1994-2001

	2003								
209	CCEF	Gawahon Conservation Area - inside	Malabuyoc, Cebu	VR	3	50 m	PIT	6 - 8	2005-2006
210	CCEF	Montaneza Marine Sanctuary -inside	Malabuyoc, Cebu	VR	3	50 m	PIT	6 - 8	2006-2009
211	CCEF	Montaneza Marine Sanctuary -outside	Malabuyoc, Cebu	VR	3	50 m	PIT	6 - 8	2006-2009
212	CCEF	Sto.Nino-Looc Marine Sanctuary - inside	Malabuyoc, Cebu	VR	3	50 m	PIT	6 - 8	2005-2009
213	CCEF	Sto.Nino-Looc Marine Sanctuary - outside	Malabuyoc, Cebu	VR	3	50 m	PIT	6 - 8	2005-2009
214	CCEF	Bogo Baseline Survey - INSIDE	Maria, Siquijor	VR	3	50 m	PIT	6 - 8	2007-2009
215	CCEF	Bogo Baseline Survey - OUTSIDE	Maria, Siquijor	VR	3	50 m	PIT	6 - 8	2007-2009
216	CCEF	Candaping B Marine Sanctuary - outside	Maria, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2009
217	CCEF	Candaping B Marine Sanctuary -inside	Maria, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2009
218	CCEF	Minalulan Marine Sanctuary - inside	Maria, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2008
219	CCEF	Olang Marine Sanctuary -	Maria, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2009

		inside							
220	CCEF	Olang Marine Sanctuary - outside	Maria, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2009
221	CCEF	Pescador Island Marine Sanctuary - inside	Moalboal, Cebu	VR	3	50 m	PIT	6 - 8	2006-2007
222	CCEF	Pescador Island Marine Sanctuary - outside	Moalboal, Cebu	VR	3	50 m	PIT	6 - 8	2006-2007
223	CCEF	Saavedra Fish Sanctuary - inside	Moalboal, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
224	CCEF	Saavedra Fish Sanctuary - outside	Moalboal, Cebu	VR	3	50 m	PIT	6 - 8	2005-2007
225	Raymundo et al., 2006a; Raymundo et al., 2008	Saavedra MPA inside	Moalboal, Cebu	VR	3	20 m	LIT	NA	2006-2008
226	Raymundo et al., 2006a; Raymundo et al., 2008	Saavedra MPA outside	Moalboal, Cebu	VR	3	20 m	LIT	NA	2006-2008
227	CCEF	Bangcogon Baseline Survey -MPA inside	Oslob, Cebu	VR	4	50 m	PIT	6 - 8	2005-2009
228	CCEF; White et al., 2010	Gawi Marine Sanctuary - outside	Oslob, Cebu	VR	4	50 m	PIT	6 - 8	2005-2010
229	CCEF; White et al., 2010	Gawi Marine Sanctuary -inside	Oslob, Cebu	VR	4	50 m	PIT	6 - 8	2005-2010
230	White et al., 2002	Sumilon Island Fish Sanctuary	Oslob, Cebu	VR	13	50 m	PIT	6 - 8	1981-2002

231	White et al., 2002	Sumilon Island Fish Sanctuary	Oslob, Cebu	VR	235	1 m^2	snorkel	2 - 4	1986-2002
232	CCEF	Sumilon Marine Sanctuary - inside	Oslob, Cebu	VR	3	50 m	PIT	6 - 8	1981-2010
233	CCEF; White et al., 2010	Sumilon Marine Sanctuary - inside	Oslob, Cebu	VR	161	1 m	snorkel	2 - 4	1986-2010
234	CCEF	Sumilon Marine Sanctuary - outside	Oslob, Cebu	VR	3	50 m	PIT	6 - 8	1981-2010
235	CCEF	Sumilon Marine Sanctuary - outside	Oslob, Cebu	VR	3	50 m	snorkel	2 - 4	2005-2008
236	Raymundo et al., 2006a; Raymundo et al., 2008	Balicasag Is. MPA inside	Panglao, Bohol	VR	3	20 m	LIT	NA	2006-2007
237	Raymundo et al., 2006a	Balicasag Is. MPA outside	Panglao, Bohol	VR	3	20 m	LIT	NA	2006-2007
238	White et al., 2007	Balicasag Marine Sanctuary	Panglao, Bohol	VR	8	50 m	PIT	7 - 8	1983-2007
239	White et al., 2007	Balicasag Marine Sanctuary	Panglao, Bohol	VR	15	1 m^2	snorkel	2 - 4	1992-2007
240	Stockwell et al. (unpublished)	Balicasag Marine Sanctuary-reef flat	Panglao, Bohol	VR	3	20 m	LIT	3 - 4	2005-2006
241	Stockwell et al. (unpublished)	Balicasag Marine sancturay reef slope	Panglao, Bohol	VR	3	20 m	LIT	10 - 12	2005-2006
242	Christie et al., 2002	Balicasag non-sanctuary	Panglao, Bohol	VR	10	50 m	LIT	5 - 7	1984-1999
243	White et al., 2007	Balicasag Non-sanctuary	Panglao, Bohol	VR	7	50 m	PIT	7 - 8	1983-2007
244	White et al., 2007	Balicasag Non-sanctuary	Panglao, Bohol	VR	14	1 m^2	snorkel	2 - 4	1992-2003

245	Christie et al., 2002	Balicasag sanctuary	Panglao, Bohol	VR	10	50 m	LIT	5 - 7	1984-1999
246	White et al., 2007	Bilisan Marine Sanctuary	Panglao, Bohol	VR	9	50 m	PIT	7 - 8	1999-2007
247	White et al., 2007	Bilisan Marine Sanctuary	Panglao, Bohol	VR	12	1 m^2	snorkel	2 - 4	1999-2007
248	White et al., 2007	Bilisan Non-sanctuary	Panglao, Bohol	VR	8	50 m	PIT	7 - 8	2003-2007
249	Stockwell et al. (unpublished)	Black Forest reef slope	Panglao, Bohol	VR	3	20 m	LIT	10 - 12	2005-2006
250	White et al., 2007	Bolod Marine Sanctuary-in	Panglao, Bohol	VR	7	50 m	PIT	7 - 8	1996-2007
251	White et al., 2007	Bolod Marine Sanctuary-in	Panglao, Bohol	VR	13	1 m^2	snorkel	2 - 4	1999-2007
252	White et al., 2007	Bolod Non-sanctuary	Panglao, Bohol	VR	4	50 m	PIT	7 - 8	2003-2007
253	Stockwell et al. (unpublished)	Diver's Haven reef flat	Panglao, Bohol	VR	3	20 m	LIT	3 - 4	2005-2006
254	Stockwell et al. (unpublished)	Diver's Haven reef slope	Panglao, Bohol	VR	3	20 m	LIT	10 - 12	2005-2006
255	White et al., 2007	Doljo Marine Sanctuary-in	Panglao, Bohol	VR	7	50 m	PIT	7 - 8	1996-2007
256	White et al., 2007	Doljo Marine Sanctuary-in	Panglao, Bohol	VR	11	1 m^2	snorkel	2 - 4	1999-2007
257	White et al., 2007	Doljo Non-sanctuary	Panglao, Bohol	VR	8	50 m	PIT	7 - 8	2003-2007
258	White et al., 2007	Tawala Marine Sanctuary	Panglao, Bohol	VR	10	50 m	PIT	7 - 8	1999-2007
259	White et al., 2007	Tawala Marine Sanctuary	Panglao, Bohol	VR	13	1 m^2	snorkel	2 - 4	1999-2007
260	Alcaria & Bacalihog, 2005	Campalabo Marine Sanctuary	Pinamungajan, Cebu	VR	2	50 m	LIT	NA	2002-2003
261	UPVFI	Mantalinga	roxascity, Capiz	VR	3	50 m	LIT	NA	1998-2006

262	UPVFI	Olutayan	roxascity, Capiz	VR	4	50 m	LIT	NA	1998-2006
263	UPVFI	Tuad_01	roxascity, Capiz	VR	4	50 m	LIT	NA	1998-2006
264	Soliman et al., 2003	Atulayan MFR,Lagonoy Gulf,Bicol	Sagñay, Camarines Sur	NPS	4	25 m	ND	NA	1995-1996
265	CCEF; White et al., 2010	Colase Marine Sanctuary - inside	Samboan, Cebu	VR	4	50 m	PIT	6 - 8	2004-2010
266	CCEF	Colase Marine Sanctuary - outside	Samboan, Cebu	VR	3	50 m	PIT	6 - 8	2004-2009
267	The Local Governance for Coastal Management Project, 2005	Colase Marine Sanctuary-inside	Samboan, Cebu	VR	4	50 m	PIT	NA	2002-2003
268	The Local Governance for Coastal Management Project, 2005	Colase Marine Sanctuary-inside	Samboan, Cebu	VR	4	50 m	PIT	NA	2002-2003
269	The Local Governance for Coastal Management Project, 2005	Colase non-sanctuary	Samboan, Cebu	VR	2	50 m	PIT	NA	2002-2003
270	The Local Governance for Coastal Management Project, 2005	Colase non-sanctuary	Samboan, Cebu	VR	2	50 m	PIT	NA	2002-2003
271	Soliman et al., 2003	Agoho San Andres,Lagonoy Gulf	SanAndres, Catanduanes	NPS	5	25 m	ND	NA	2000-2001

272	CCEF	Maite Proposed Marine Sanctuary - inside	SanJuan, Siquijor	VR	3	50 m	PIT	6 - 8	2008-2009
273	CCEF	Maite Proposed Marine Sanctuary - outside	SanJuan, Siquijor	VR	3	50 m	PIT	6 - 8	2008-2009
274	CCEF	Paliton Marine Sanctuary -inside	SanJuan, Siquijor	VR	3	50 m	PIT	6 - 8	2006-2008
275	CCEF	Paliton Marine Sanctuary -outside	SanJuan, Siquijor	VR	3	50 m	PIT	6 - 8	2006-2008
276	CCEF	Tubod Marine Sanctuary -inside	SanJuan, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2008
277	CCEF	Tubod Marine Sanctuary -outside	SanJuan, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2008
278	CCEF; White et al., 2010	Pasil Marine Sanctuary - inside	Santander, Cebu	VR	4	50 m	PIT	6 - 8	2004-2010
279	CCEF; White et al., 2010	Pasil Marine Sanctuary - outside	Santander, Cebu	VR	4	50 m	PIT	6 - 8	2004-2010
280	CCEF;Raymundo, 2008	Bagacay Marine Sanctuary - inside	Sibonga, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
281	CCEF;Raymundo, 2008	Bagacay Marine Sanctuary - outside	Sibonga, Cebu	VR	3	50 m	PIT	6 - 8	2005-2008
282	White et al., 2002	Cangmating,non-sanctury	Sibulan, Negros Oriental	VR	4	50 m	PIT	6 - 8	1997-2001

283	White et al., 2002	Cangmating,Sibulan inside sanctuary	Sibulan, Negros Oriental	VR	4	50 m	PIT	6 - 8	1997-2002
284	UPVFI 2007; FISH 2010	Doh-Tong,Simunul	Simunul, Tawi-tawi	SS	10	50 m	PIT	NA	2004-2010
285	UPVFI 2007; FISH 2010	Tonggosong-Maruwa,Simunul Ubol	Simunul, Tawi-tawi	SS	10	50 m	PIT	4 - 6	2006-2010
286	UPVFI 2007; FISH 2010	Tundon,Simunul	Simunul, Tawi-tawi	SS	10	50 m	PIT	4 - 6	2006-2010
287	CCEF	Banban LUYANG MPA -INSIDE	Siquijor, Siquijor	VR	3	50 m	PIT	6 - 8	2006-2009
288	CCEF	Banban LUYANG MPA -OUTSIDE	Siquijor, Siquijor	VR	3	50 m	PIT	6 - 8	2007-2009
289	CCEF	Caticugan Marine Sanctuary -INSIDE	Siquijor, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2008
290	CCEF	Caticugan Marine Sanctuary -OUTSIDE	Siquijor, Siquijor	VR	3	50 m	PIT	6 - 8	2005-2008
291	UPVFI 2007; FISH 2010	Batu-batu Kalape,Panglima Sugala	Sugala, Tawi-tawi	SS	10	50 m	PIT	3 - 5	2004-2010
292	Soliman et al., 2003	San Miguel Is MFR.,Lagonoy Gulf,Bicol	Tabaco, Albay	NPS	10	25 m	ND	NA	1997-2001
293	Marine Sanctuary UN-FSTDI, 2006	Talisay MPA inside	Tabina, Zamboanga del Sur	CS	2	50 m	LIT	6 - 9	2003-2006
294	Marine Sanctuary UN-FSTDI, 2006	Talisay MPA outside	Tabina, Zamboanga del Sur	CS	2	50 m	LIT	6 - 9	2003-2006

295	Marine Sanctuary UN-FSTDI, 2006	Tambunan inside Marine Sanctuary	Tabina, Zamboanga del Sur	CS	3	50 m	LIT	8	2003-2006
296	Marine Sanctuary UN-FSTDI, 2006	Tambunan outside Marine Sanctuary	Tabina, Zamboanga del Sur	CS	3	50 m	LIT	8	2003-2006
297	FISH, 2010	Bantigue,Danajon Bank	Talibon, Bohol	VR	12	50 m	PIT	NA	2004-2010
298	FISH, 2010	Bilang-bilangan,Danajon Bank	Talibon, Bohol	VR	12	50 m	PIT	NA	2004-2010
299	FISH, 2010	Cataban,Danajon Bank	Talibon, Bohol	VR	10	50 m	PIT	NA	2006-2010
300	Marcus et al., 2007	Danajon Bank	Talibon, Bohol	VR	120	20 m	LIT	NA	2000-2002
301	FISH, 2010	Hingutanan,Danajon Bank	Talibon, Bohol	VR	12	50 m	PIT	NA	2004-2010
302	FISH, 2010	Pinamgo,Danajon Bank	Talibon, Bohol	VR	10	50 m	PIT	NA	2006-2010
303	FISH, 2010	Sag,Danajon Bank	Talibon, Bohol	VR	10	50 m	PIT	NA	2006-2010
304	White et al., 2005	layag-layag,caban is	Tingloy, Batangas	WPS	8	50 m	PIT	6 - 9	1993-2005
305	White et al., 2005	layag-layag,caban is	Tingloy, Batangas	WPS	927	1 m^2	snorkel	2 - 4	1993-2005
306	White et al., 2005	Pulang buli reef	Tingloy, Batangas	WPS	8	50 m	PIT	6 - 9	1993-2005
307	White et al., 2005	Pulang buli reef	Tingloy, Batangas	WPS	133	1 m^2	snorkel	2 - 4	1993-2005
308	White et al., 2005	Sepoc pt	Tingloy, Batangas	WPS	7	50 m	PIT	6 - 8	1993-2005
309	White et al., 2005	Sepoc pt	Tingloy, Batangas	WPS	80	1 m^2	snorkel	2 - 4	1993-2005
310	White et al., 2005	Sombrero	Tingloy, Batangas	WPS	11	50 m	PIT	1- 9	1983-2005
311	White et al., 2005	Sombrero	Tingloy, Batangas	WPS	149	1 m^2	snorkel	2 - 5	1993-2005
312	Palma et al., 2003	Baguan 1	Turtle Is.,	SS	4	25 m	VT	5	1997-2002

			Tawi-tawi						
313	Palma et al., 2003	Baguan Is.2	Turtle Is., Tawi-tawi	SS	4	25 m	VT	5	1996-2002
314	Palma et al., 2003	Baguan Is.3	Turtle Is., Tawi-tawi	SS	4	25 m	VT	5	1996-2002
315	Palma et al., 2003	Bakungaan Shoal	Turtle Is., Tawi-tawi	SS	4	25 m	VT	5	1997-2002
316	Palma et al., 2003	Langgan	Turtle Is., Tawi-tawi	SS	4	25 m	VT	5	1997-2002
317	Palma et al., 2003	Taganak	Turtle Is., Tawi-tawi	SS	4	25 m	VT	5	1997-2002

Appendix 2: Data Sources of Chapter III

Alcaria, J.F. & S. Bagalihog, 2003. Central Visayas. In Aliño, P., A. Uychiaoco, M. Deocadez, Ochavillo, D., & 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.

Alcaria, J.F. & S. Bagalihog, 2005. Status and Trends of Coral Reef Areas in Central Visayas. In Aliño, P., R. Miclat, M. Sabater, M.C. Quiblan, G.J. Tiquio, M.V. Baria & H.K. Alonzo (eds), Reefs through time: 2004 biennial report on the status of Philippine coral reefs. Coral Reef Information Network of the Philippines (PHILREEFS) and the Marine Science Institute (MSI), University of the Philippines (UP), Diliman, Quezon City: 73-78.

Aliño, P., 1985. Notes on the coral community structure of a back reef area in Cangaluyan Is., Pangasinan. Natural and Applied Sciences Bulletin 37: 225-234.

Arceo, H., S. Salmo III, E. Aurellado & H. Alano, 2005. Balingasay Marine Protected Areas, Bolinao, Pangasinan. In: Aliño, P., Miclat R.,Sabater M., Quiblan MC, Tiquio GJ, Baria MV, Alonzo HK (eds) Reefs through time: 2004 biennial report on the status of Philippine coral reefs. Coral Reef Information Network of the Philippines (PHILREEFS) and the Marine Science Institute (MSI), University of the Philippines

(UP), Diliman, Quezon City: 30-37.

Christie, P., A. White & E. Deguit, 2002. Starting point or solution? Community-based marine protected areas in the Philippines. Journal of Environmental Management 66: 441-454.

Coastal Conservation and Education Foundation, Inc. (CCEF) (personal communication)

Coral Reef Information Network of the Philippines (Philreefs), 2003. Appendices. 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: 184-185.

Dacles, T., G. Ledesma, V. Lumbab, K. Pacifico, H. Arceo, H. Alano, R. Abesamis, A. Harborne, A. Gill, P. Raines, J. Ridley, J. Solandt, J. Slater, A. Page, M. Beger & D. Fenner, 2003. Danjugan Island Marine Reserve and Sanctuaries, Negros Occidental. 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: 139-143.

Delizo, D., D. Apistar, R. Diaz, E. Lucas, D. Raymundo, A. Sabonsolin & A. Tesch, 2007. Summary Field Report, Municipality of Badian, Cebu, Philippines, 2007. The Coastal Conservation and Education Foundation, Inc. and the Local Governance for Coastal Management Project (LGCMP), Cebu City.

Garcia,L.M., Y. Primavera-Tirol, E. Amar, C. Marte, R. Agbayani, S. Siar & D. Baticados, 2003. 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: 128-132.

Geronimo, R., S. Salmo III, M. Deocadez, F. Castrence, K. Pacifico, C. Junsan & Sagip Lingayen Proj and Partners, 2008. Status of Coral Reefs in Lingayen Gulf. In Alino 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: 15–25.

Marcus, J.,M. Samoilys, J. Meeuwig, Z. Villongco & A. Vincent, 2007. Benthic status of near-shore fishing grounds in the central Philippines and associated seahorse densities. Marine Pollution Bulletin 54: 1483–1494.

MSU Naawan Foundation for Science and Technology Development, Incorporated (MSUN-FSTDI), 2006. Marine Sanctuary Monitoring and Evaluation and Training in Selected MPAs of IBRA9 Final Report. The Philippine Environmental Governance Project 2 (EcoGov 2) Technical Report.

Palma, J., W. Licuanan, J. Dumaup, R. Cruz, Capili, E., R. Apostol & R. Biyo, 2003. In Aliño, P., A. Uychiaoco, M. Deocadez, Ochavillo, D., & 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: 152-159.

Philippine Environmental Governance 2 Project (EcoGov 2), 2007. Strengthening MPA Management in Baler Bay Training on Marine Sanctuary Monitoring and Evaluation (M&E) Technical Report.

Raymundo, D.J., 2008. Summary Field Report: 2006 Reef Monitoring Surveys in Sibonga, Cebu, Philippines. Coastal Conservation Education Foundation.

Raymundo, L., A. Maypa, K. Rosell, P. Cadiz & P. Rojas, 2006a. A Survey of Coral Disease Prevalence in Marine Protected Areas and Fished Reefs of the Central Visayas, Philippines. Coastal Conservation Education and Education Foundation, Inc. (CCEF) Tech. Report.

Raymundo, L., A. Maypa & P. Cadiz, 2006b. Reef Rehabilitation Project of the Central Philippines Final Report. Coastal Conservation Education and Education Foundation, Inc. (CCEF) Tech. Report.

Raymundo, L., A. Maypa, P. Rojas, R. Myers, P. Cadiz, K. Rosell, 2008. Marine Protected Area Surveys of the Central Visayas – 2007 Summary Report. University of Guam Technical Report No. 122.

Reboton, C. & H.P. Calumpong, 2000. How much damage do divers and snorkelers do to corals? In Moosa, M.K., S. Soemodihardjo, A. Soegiarto, K. Romimohtarto, A. Nontji, Soekarno & Suharsono (eds). Proceedings of the Ninth International Coral Reef Symposium 2:787-790.

Soliman, V., A. Mendoza, Jr. & D. David, 2003. Lagonoy Gulf, Bicol. 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: 101-105.

Stockwell, B., J. Maypa, C.R. Jadlock & M. Inocencio. Balicasag Island Risk Assessment: Estimating the carrying capacity of coral reefs for SCUBA diving at Balicasag Island, Panglao, Bohol. Silliman University - Angelo King Center for Research and Environmental Management.(unpublished report).

The Local Governance for Coastal Management Project, 2005a. Arbor Marine Sanctuary and North Granada Marine Sanctuary, Boljoon, Cebu. In Aliño, P., R. Miclat, M. Sabater, M.C. Quiblan, G.J. Tiquio, M.V. Baria & H.K. Alonzo (eds), Reefs through time: 2004 biennial report on the status of Philippine coral reefs. Coral Reef Information Network of the Philippines (PHILREEFS) and the Marine Science Institute (MSI), University of the Philippines (UP), Diliman, Quezon City: 95-99.

The Local Governance for Coastal Management Project, 2005b. Colase Marine Sanctuary, Samboan, Cebu. In Aliño, P., R. Miclat, M. Sabater, M.C. Quiblan, G.J. Tiquio, M.V. Baria & H.K. Alonzo (eds), Reefs through time: 2004 biennial report on the status of Philippine coral reefs. Coral Reef Information Network of the Philippines (PHILREEFS) and the Marine Science Institute (MSI), University of the Philippines (UP), Diliman, Quezon City: 90-94.

The Local Governance for Coastal Management Project, 2005c. Daan Lungsod-Guiwang Marine Sanctuary and Poblacion Marine Sanctuary, Alcoy, Cebu. In Aliño, P., R. Miclat, M. Sabater, M.C. Quiblan, G.J. Tiquio, M.V. Baria & H.K. Alonzo (eds), Reefs through time: 2004 biennial report on the status of Philippine coral reefs. Coral Reef Information Network of the Philippines (PHILREEFS) and the Marine Science Institute (MSI), University of the Philippines (UP), Diliman, Quezon City: 85-89.

UNEP, 2004. Monitoring Coral Reefs for Better Management Schemes: UNEP EAS/RCU Small Grants Fund Programme 2002-2003.

University of the Philippines in the Visayas Foundation Inc., University of the Philippines-Visayas, Miag-ao, Iloilo (author's data)

UPVFI, 2007. Monitoring and baseline assessment of marine protected areas in the Fish Project focal areas: Tawi-tawi. Technical Report, University of the Philippines-Visayas, Miag-ao,Iloilo.

USAID/DA-BFAR FISH Project, 2010. Consolidated Report: Monitoring of the capture fisheries and marine protected areas (reef habitats) in the FISH Project's focal areas: Coron Bay, Danajon Bank, Lanuza Bay and Tawi-tawi. FISH Project Final Report,Tetra Tech EM Inc., Ortigas Center, Pasig City.

Vergara, M.W., 2009. Coral community structure of the Bolinao reef system, Northwestern Philippines. Master's Thesis. Unversity of the Philippines.

White, A., 1984.Marine parks and reserves: management for Philippine, Indonesian and Malaysian coastal reef environments. Ph.D. University of Hawaii.

White, A.T., A. Meneses, S. Tesch, A. Maypa, B. Stockwell, E. White & R. Martinez,2007. Summary Field Report: Coral Reef Monitoring in Bohol, Philippines,March 26-April 3, 2007. The Coastal Conservation and Education Foundation, Inc. and Fisheries Improved for Sustainable Harvest Project, Cebu City.

White, A.T., A. Maypa, S. Tesch, B. Stockwell, A. Meneses, E. White & T.J. Mueller, 2005. Summary Field Report: Coral Reef Monitoring Expedition to Mabini and Tingloy, Batangas, Philippines, March 19–27, 2005. The Coastal Conservation and Education Foundation, Inc. and the Fisheries Improved for Sustainable Harvest (FISH) Project, Cebu City.

White, A.T., A. Maypa, S. Tesch, R. Diaz, R. Martinez & E. White, 2008. Summary Field Report: Coral Reef Monitoring Expedition to Tubbataha Reefs Natural Park, Sulu Sea, Philippines, March 26 – April 1, 2008. The Coastal Conservation and Education Foundation, Inc., Cebu City.

White, A.T., D. Apistar, S. Tesch, R. Martinez & White, E., 2010. Summary Field Report: Coral Reef Monitoring Expedition to Southern Cebu, Philippines, March 22 – 29, 2010. The Coastal Conservation and Education Foundation, Inc., Cebu City.

White, A.T., P. Christie, J. Apurado, A. Meneses, E. White & S. Tesch, 2001. Summary Field Report: Coral Reef Monitoring in Mabini and Tingloy, Batangas, Philippines, April 6-25, 2001.Coastal Resource Management Project and the Sulu Fund for Marine Conservation Foundation,Inc., Cebu City.

White, A.T., P. Christie, J. Apurado, A. Meneses, M. Ovenden, S. Tesch & E. White, 2002. Summary Field Report: Coral Reef Monitoring in Cebu, Negros and Siquijor,Philippines, March 23-31, 2002. The Coastal Conservation and Education Foundation,Inc. and Coastal Resource Management Project, Cebu City.

CHAPTER IV

A meta-analysis on spatiotemporal variability of coral cover change in the Philippines

4.1 Introduction

Assessing the long-term trends of coral cover change in the Philippines gave an overview of the condition of the reefs in one of the most important regions in the Coral Triangle. However, it remains unclear whether coral cover is equally changing spatially particularly on MPAs or if there are regional differences in the timing and magnitude of cover change because the type and extent of stressors vary geographically as shown here. Examining the spatiotemporal trends may provide a link to drivers of coral cover change in the Philippines. Previous studies have shown the variable temperature regimes (Botin et al., 2009; Peñaflor et al., 2009) and exploitation levels in the Philippine basins (Green et al., 2003). With rising atmospheric carbon dioxide (CO_2), coral reef ecosystems are not only threatened by local anthropogenic impacts but also by global warming and ocean acidification (e.g. Hoegh-Guldberg et al., 2007; Carpenter et al., 2008; Pandolfi et al., 2011; Darling & Côté, 2013). MPA is perceived a solution to increase the resilience of coral reefs to climate change (e.g. Hoegh-Guldberg et al., 2007; Bellwood et al., 2004; Darling et al., 2013). Therefore, to devise effective conservation strategies, it is important to understand the spatial pattern of coral cover change to prevailing disturbances through time. Examining the spatiotemporal variability of coral cover change could determine under which conditions and where coral reefs are most critical or at risk.

4.2 Methodology

Additional sites were included in the data set in Chapter III to cover more sites for regional comparison. Similarly, studies that reported percentage living hard coral cover, had at least two surveys on the same reef, with information on the number and length of transects covered were selected. Studies were included regardless of the purpose, survey method used, and the location of the survey (e.g., protected reefs). A site defined by each study was considered as a separate site but pooled same depth/zone as a single coral cover mean (Gardner et al., 2013). Patterns of coral cover change were examined through annual rate of change (ARC) estimated similarly as Equations 3.2.1 and 3.2.2.

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 4,999 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). 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.

To examine the robustness of the results and potential influence of exceptionally large effect sizes, sensitivity test was performed (Bancroft et al., 2007; Kroker et al., 2010). In each analysis, sites were ranked according to the magnitude of effect size (regardless of the direction of ARC) then systematically excluded the largest effect size in a step-wise manner and ran the analysis again. The number of sites needed to change the significance of the results was determined. If the largest effect size changed the significance of the result indicating influence on the overall effect, this was eliminated in the analysis.

Annual rate of coral cover change was examined spatially according to biogeographic subregions (Fig. 4.1; see also Chapter 2.2.3). Categorical meta-analyses were conducted to assess the differences on rates of coral cover change among biogeographic regions in relation to time, trend in absolute coral cover and effect of protection. Comparisons between groups were done given adequate data (≥4) to compare (Bancroft et al., 2007). Temporal heterogeneity across regions was examined for the entire duration of the study (overall) and 5-year intervals by including the replicate surveys that fell within the period. Some years had longer (6 years instead of 5 years) intervals, to compensate for the low sample size and missing data in 1987–1988 and 1990–1991.

The percent hard coral cover at the start and end of time series data on each site was classified based on quartile category classification used in Chapter 2.2.3. Based on this classification, each site was evaluated if it remained stable, increased or decreased over time and grouped accordingly. In each categorical group, rates of coral cover change among regions were compared to determine if there is a region that increased or decreased faster than the others.

Effect of protection from fishing was determined by comparing the rates of change in coral cover between MPAs and non-MPAs across biogeographic regions for the entire duration of the study. Only MPAs with a known year of establishment with surveys after the year of designation were considered. Site selection bias was tested by comparing the initial coral cover between MPAs and non-MPAs simultaneously monitored within the first 5 years of protection following Selig & Bruno (2010). If there was a site selection bias, sites were ranked according to the magnitude of coral cover differences between in and out of MPAs and then omitted systematically in a step-wise fashion until the difference in coral cover between inside and outside MPAs was no longer significant.

4.3 Results and Discussion

A total of 1,175 monitoring surveys were collated from six biogeographic regions from 325 sites surveyed on 162 MPA and 163 non-MPA sites between 1981 and 2010. This is 27 MPA sites more than the previous data set (Chapter III) that has surveys after establishment. About 215 sites (66%) were monitored in the Visayas region, 45 (14%) in West Philippine Sea, 44 (14%) in Sulu Sea, 12 sites (4%) in South Philippine Sea (SPS), 6 (2%) in Celebes Sea (CS) and 3 (1%) in North Philippine Sea (NPS). In spite of the addition of data and sensitivity tests performed, the overall result remains the same. There is still an overall coral cover increase between 1981 and 2010 (ARC = 1.27%; CI = 0.30 to 2.28%) and significant differences in rates of change in coral cover between MPA and non-MPA sites (QM = 1.97, P = 0.02; Fig. 4.2). Methodological tests also showed no single study had significant influence on the overall result (Fig. 4.3).

Annual rates of coral cover change were also significantly positive in spite of the omission of the two largest monitoring studies from CCEF (ARC = 1.62%; CI = 0.58 to 2.73%) and Fisheries Improved for Sustainable Harvest (FISH) Project of University of the Philippines in the Visayas Foundation Incorporated (UPVFI; ARC = 1.51%; CI = 0.42 to 2.68%). There was also no bias in the overall annual rates of coral cover change if sites from Visayan Seas region were removed (ARC = 1.46%; CI = 0.25 to 2.92%); thus no single study had influence on the overall trend in coral cover in the present inventory.

4.3.1 Temporal trend

Overall coral cover improved in Celebes Sea (ARC = 11.40%; CI = 7.99 to 16.6%) and West Philippine Sea (ARC = 3.20%; CI = 1.51 to 5.37%) although no significant variation in annual rates of cover change found among biogeographic regions ($Q_M = 3.10$, $P = 0.15$; Table 4.1). Coral cover increased in West Philippine Sea is mainly attributed to reefs in Batangas and Palawan, particularly MPAs. More reefs still need to be surveyed to understand the spatiotemporal patterns in Celebes Sea, North and South Philippine Sea regions.

Temporal comparison in 5-year intervals showed regional similarity in rates of coral cover change across periods suggesting a system-wide trend except in 1996-2000 (Table 4.1). In 1981-1986, overall cover showed a statistical negative change (ARC = -9.09%; CI = -15.8 to -2.14%). Coral cover decline in Visayas region (ARC = -8.86%; CI = -15.4 to -1.24%) corroborates early reef assessments that reefs had already been degraded due to prevalent destructive fishing activities, overfishing, coral harvesting and sedimentation through deforestation across the country (Gomez & Alcala, 1979;

Gomez et al., 1981; Yap et al., 1985).

Overall cover increased significantly in 1989-1995 (ARC = 11.66%; CI = 6.39 to 18.09%). Favorable condition allowed the coral cover to increase in all sites surveyed in Batangas in West Philippine Sea (ARC = 11.87%; CI = 5.75 to 19.7%), as conservation efforts lead to abatement of illegal fishing activities in the early 1990s and establishment of its first MPA in 1991 (WWF, 2007). This was also the timing of short-term global cooling period following the Mt. Pinatubo eruption in 1991 (IPCC, 2007).

Coral cover loss was significantly different from zero (ARC = -4.74%; CI = -7.44 to -1.78%) in 1996-2000, which coincided with mass coral bleaching driven by anomalously high sea surface temperatures (SST) in the 1997–1998 strong ENSO event. Annual rates of change in coral cover was found to be statistically different across biogeographic regions ($Q_M = 8.92$, $P < 0.001$), with significant cover reduction in Sulu Sea (ARC = -10.9%; CI = -14.2 to -8.06%) compared to the other regions particularly in Visayas which did not change (ARC = 0.11%; CI = -2.90 to 3.71%). Only few sites were included in the West Philippine Sea, but coral cover did not significantly change because these were surveyed after the bleaching event (ARC = -10.9%; CI = -14.2 to -8.06%). Likewise in Celebes Sea that increased (ARC = -10.9%; CI = -14.2 to -8.06%) although this is inconclusive because of the limited number of sites. Of the 13 sites in Sulu Sea region that declined, 11 were surveyed on the isolated (150 km from the nearest population center) largest protected atoll reefs of Tubbataha Reefs National Park (TRNP). The high mortality rates in TRNP in 1998 were due to the dominance of bleaching-sensitive coral species, *Acropora* (Arceo et al., 2001). Coral assemblages that commonly grow within MPAs are vulnerable to disturbance and the high abundance of bleaching-susceptible taxa like *Acropora* and *Montipora* lead to high coral mortality during anomalous sea warming (McClanahan et al., 2007; Darling et al., 2013).

Overall cover statistically increased in 2001-2005 (ARC = 4.88%; CI = 1.62 to 8.44%). The period 2001-2005 was a good condition for recovery as indicated by significant cover improvement in all Celebes Sea sites (ARC = 8.19%; CI = 5.27 to 11.2%) and all MPAs (ARC = 10.4%; n = 23; CI = 4.91 to 15.82%) particularly newly established MPAs (ARC = 13.8%; n = 10; CI = 2.90 to 24.7%) in Visayas region (overall: ARC = 9.40%; CI = 1.37 to 15.1%). COTS outbreak were observed in Cebu in 2004 however there was no indication that reefs declined in 2004 in Visayas. The increasing pattern on new MPAs is also consistent in Sulu Sea (new MPAs: ARC = 4.16%; n = 4; CI = 0.16 to 8.97%; overall: ARC = 3.99%; CI = -0.14 to 7.92%) and West Philippine Sea (new MPAs: ARC = 4.16%; n = 4; CI = 2.05 to 6.56%; overall: ARC = 0.23%; CI = -2.73 to 3.68%) although the number of new MPAs is few compared to Visayas region. Moreover, the impact of fishing in Batangas in West Philippine Sea was apparent from coral breakage due to boat anchorage and low density of fish density (White et al., 2005) although coral cover did not significantly reduce (ARC = -2.61%; n = 11; CI = -6.27 to 2.52%).

Between 2006 and 2010, multiple disturbances of coral predation and bleaching had affected many reefs but there was no overall net change in coral cover found (ARC = -1.28%; CI = -3.26 to 0.74%). In Visayas, reefs were significantly affected by siltation, infestation of Crown-of-thorns seastar (COTS), *Acanthaster planci;* corallivorous gastropod, *Drupella* spp.; sponge *Terpios* spp. in 2006-2007 (Raymundo et al., 2006, 2008) and 2008 (COTS collection in south Cebu, *Dean Apistar, pers. comm.*). Aside from predation, among the observed impact outside MPAs were coral breakage from boat anchor, fish traps, blast fishing and tourism-related activities like snorkeling and diving (Raymundo et al., 2006, 2008; White et al., 2007). Thermal stress recurred in 2010 coinciding the strong La Niña which lead to coral bleaching in many parts of the country although not as extensive in 1998 (Fig. 4.5). The compounding impacts of multiple disturbances consequently resulted to no significant change in coral cover despite the presence of numerous MPAs in Visayas (overall: ARC = -1.19%; CI = -4.19 to 1.55%; MPAs: ARC = 1.41%; CI = -2.02 to 5.46%), and new MPAs in Surigao del Sur in South Philippine Sea (ARC = 1.34%; CI = -1.33 to 4.74%). While, cover significantly increased in West Philippine Sea (ARC = 3.06%; CI = 0.35 to 5.61%) but declined in Sulu Sea (ARC = -5.88%; CI = -9.20 to -2.77%). The rates of cover change however, did not statically vary among biogeographic regions ($Q_M = 3.62$, $P = 0.13$). COTS outbreak was also observed in West Philippine Sea and Celebes Sea (WWF, 2007) concomitant with thermal stress in 2007 (Fig. 4.4). Coral cover decline is reflected in 2008 survey in all sites (Coron, Palawan) in West Philippine Sea. But it quickly recovered in 2010 prior to the bleaching in June to November. While, coral cover both in and out of MPAs in Tawi-tawi in Sulu Sea was in constant decline since 2008 although neither bleaching, COTS nor siltation was observed during monitoring. Reefs are actively managed and regulations are strictly enforced within MPAs (*Wilfredo Campos, pers. comm.*). The cause of decline is still not clear, but the annual mean SST in 2007 had increased more than the average temperature in 2000s and had been warmer than average in 2006-2010 than 2001-2005 (Fig. 4.6). Corals have different responses to sea warming depending on taxa and morphologies. Some taxa die without effective bleaching and branching corals have limited ability to acclimatize to sudden changes in environmental conditions than massive taxa (McClanahan, 2004). Thus, frequent and abrupt temperature increase in 2008 may have reduced growth and recruitment, adaptability and morbidity of corals in Tawi-tawi although further investigation is still needed to determine the underlying cause of the decline.

4.3.2 Coral cover trend

There were no significant regional differences found in annual rates of coral cover change for sites that increased (Q_M = 1.48, P = 0.28) and remained stable (Q_M = 0.91, P = 0.49; Table 4.2). However, rates of coral cover change varied significantly across the reefs that declined (Q_M = 3.22, P = 0.004). High coral cover loss was noted in Sulu Sea (ARC = -8.34%; CI = -12.6 to -5.20%) but Visayas region was declining faster than the others (ARC = -13.14%; CI = -15.4 to -10.9%). Of 9 sites in Sulu Sea, 5 of these were from Tawi-tawi which had a comparable coral loss with Visayas region (ARC = -12.20%; CI = -16.8 to -7.38%). Coral loss was notably higher (13% yr^{-1}) than the rate of increase (11% yr^{-1}) in Visayas region. Furthermore, coral cover loss in Visayas was significantly different (Q_M = 0.99, P = 0.01) between MPAs (ARC = -9.53%; CI = -13.2 to -6.0%) and non-MPAs (ARC = -15.50%; CI = -17.9 to -13.2%; Fig. 7a).

Out of 20 non-MPA sites, 14 changed from initially Fair to Poor condition and of the 17 surveyed in 2000s, 11 were monitored in 2005-2010. To examine further the cause of decline because the recent period is when predation and bleaching were observed, rates of cover change on these fishing grounds were compared with adjacent MPAs. High coral mortality was due to fishing because cover did not change within MPAs (ARC = -1.33%; CI = -4.76 to 1.70%) compared to significant coral loss outside (ARC = -15.22%; CI = -18.15 to -12.64%; figure not shown). This may imply that fishing is the main driver of coral cover decline in Visayas region and its combination with acute disturbances results to rapid coral cover loss. Fishing through boat anchor and fishing gears such as heavy weighted nets, fish traps result to physical damage of corals (Mangi & Roberts, 2006; Cinner et al., 2009). Habitat degradation can also change the fish community and function of species that depend on the reef. Moreover, overfishing of herbivores could have consequential impact on the survival of corals after disturbances (Mumby, 2006; Mumby et al., 2006).

On the contrary, no significant cover decline was noted on non-MPAs in 2006-2010 (ARC = -3.19%; CI = -7.68 to 1.08%), 2001-2005 (ARC = 2.83%; CI = -11.1 to 15.0%) and 1996-2000 (ARC = -1.12%; CI = -4.68 to 2.26%; Fig. 7b). Only in 1981-1986, that coral cover loss was evident in non-MPAs in Visayas region. However, if reefs are exploited continuously at this rate the small losses annually could be substantial over time. Furthermore, 43% (26/61) of non-MPAs in Visayas are now in Poor condition which could have consequent effect on fisheries as it is estimated that degraded reefs yield only 4-5 mt•km^{-2}•yr^{-1} compared to 15-20 mt•km^{-2}•yr^{-1} from good condition reefs (Alcala & Russ, 2002).

4.3.3 Effect of protection

Removing site selection bias, the rates of coral cover change between MPAs and non-MPAs were only significantly different in Visayas ($Q_M = 3.94$, $P = 0.003$; Fig. 4.8). The gap in coral cover has become substantial for over three decades between MPAs (ARC = 3.32%; CI = 1.55 to 5.20%) and outside (ARC = -1.42%; CI = -3.71 to 0.74%) reflecting the impact of fishing in Visayas. This finding supports the study on recent losses of fish species diversity in Visayas region due to intense fishing pressure

(Nañola et al., 2010). Aside from the accessibility of Visayas being the central region surrounded by population centers, it also has a high density of municipal fishers (Alcala & Russ, 2002; Green et al., 2003, Nañola et al., 2010).

Compared to Visayas region, coral cover on MPAs also increased (ARC = 3.63%; CI = 2.49 to 4.74%) in West Philippine Sea but not statistically different (Q_M = 0.25, P = 0.17) from fishing grounds (ARC = 1.46%; CI = -0.62 to 4.02%) after 13 years. Most of the surveys in the West Philippine Sea were conducted in the 1990s when destructive fishing was relatively less frequent than early decades. Coral cover did not increase on MPAs in Sulu Sea (ARC = 0.79%; CI = -1.26 to 2.80%), omitting Tawi-tawi sites however, cover on MPA is also statistically positive (ARC = 1.86%; df = 20; CI = 0.25 to 3.99%). Although MPAs in Surigao del Sur in Sulu Sea was only established in 2006, coral cover remained stable (ARC = 1.98%; CI = -1.92 to 7.40%). This is contrary to coral decline (ARC = -7.50%; CI = -14.1 to -2.20%) on MPAs established in the same year in Tawi-tawi. Although the reason for the disparity is still not clear, the sudden and frequent warming in Tawi-tawi since 2008 may have not allowed the corals to acclimatize or adapt to warmer temperatures (Fig. 4.6).

Although the rates of coral cover change did not vary statistically between in and out of MPAs, coral cover increased within MPAs. In general, coral cover is either enhanced over time or maintained following protection. However, the present design of MPAs must be reconsidered in areas prone to frequent and sudden warming and close to large sources of nutrients as COTS outbreak is enhanced by eutrophication (Brodie et al., 2005; Fabricius et al., 2010).

4.3.4 Philippine reefs and other regions

Similar to the study of Bruno & Selig (2007), the timing of coral cover decline was earlier than assumed, as coral cover was degrading even before the initial assessment in late 1970s in the Philippines. There was also a high percentage of reefs in "good' to "excellent" category in the early decades, however, based on coral cover change of individual reef sites (Table 4.1) coral cover increased in 2001-2005 contrary to the declining absolute coral cover (1997-2004) in the Philippines as reported in Bruno & Selig (2007). Similar to the result of quartile category classification shown in 2.4.2, the overall trend was potentially biased by well-surveyed biogeographic region because reefs surveyed at different times were pooled into a single mean estimate (Cote et al., 2006). Moreover, this study also demonstrated that some biogeographic regions improved since 2005 as the number of "good" reefs have increased compared to that of "poor" reefs.

Unlike the Philippines, the Great Barrier Reef (GBR) is regarded as the least threatened reef system in the world due to its low impact from local human induced pressures and the entire system is managed as multi-use marine park (Sweatman et al., 2011; De'ath et al., 2012). It is also distant from sparse population centers, and the impacts of overfishing (Osborne et al., 2011), destructive fishing, pollution and tourism are relatively minimal (De'ath et al., 2012). However, recent long-term study showed this largest coral reef in the world declined at 0.52% yr^{-1} (28% to 13.8%) between 1985 and 2012 and has drastically declined since 2006 at 1.45 yr^{-1} (De'ath et al., 2012). This has been attributed to large-scale acute disturbances mainly of tropical cyclones, COTS outbreaks (Sweatman et al., 2011; De'ath et al., 2012) and least by bleaching (Osborne et al., 2011; De'ath et al., 2012). The trend of cover decline in GBR is comparable to Caribbean reefs (Gardner et al., 2003; Cote et al., 2005; De'ath et al., 2012). There were substantial region-wide cover losses in the 1980s and had constantly declined from 50% in 1970s to 10% in 2001 in the Caribbean reefs (Gardner et al., 2003; Cote et al., 2005). Rapid cover declines were due to a combination of hurricane, region-wide mass die-off of *Acropora* due to white band disease and regional collapse of herbivorous sea urchin, *Diadema antillarium* populations leading to a phase shift from coral to algae-dominated community (Gardner et al., 2003; Schutte et al., 2010). While, according to Shutte et al., 2010 coral disease was the leading cause of region-wide decline in Caribbean reefs for over 35 yrs.

Compared to GBR, local anthropogenic pressures have been a pervasive threat to reefs in the Philippines due to high reef dependence of large population living on the coast (Burke et al., 2011). Similar to Carribean reefs which is also overfished (Hughes et al., 1994; Jackson et al., 2001), coral cover decline in 1980s was predominantly due to overfishing and destructive fishing. However, there is no evidence of benthic phase shift in the Philippines despite overfishing as it showed cycles of coral cover disturbance and recovery across regions. Even in Visayas with intense fishing, coral cover has remained stable on fishing grounds since the early 1990s (Fig. 4.7b) and has higher coral cover than macroalgae levels (Stockwell et al., 2009). Coral disease is not well-documented in Indo-Pacific and is an emergent disturbance, although it was measured at low prevalence in some Visayan reefs (Raymundo et al., 2003; Coral Diseases Working Group of the Global Environmental Facility Coral reef Targeted Research program, 2007). Frequency of COTS outbreaks has increased only in 2000s, although the severity of this has been not quantified. Further, there has been no report of large-scale COTS infestation on the Philippine reefs. In spite of the occurence of multiple stressors such as thermal stress and predation, there is no overall net coral cover decline estimated in this study. The average coral cover is notably higher in the Philippines with the lowest mean coral cover of 20% (1985) compared to GBR (14%) or Caribbean (10%), and an increasing trajectory is at 1.3% yr^{-1} for almost three decades.

Roff & Mumby (2012) reviewed the geographical disparity in resilience between Indo-Pacific and Caribbean reefs that lie remarkably in the species composition and diversity of coral and key functional redundancy of herbivores. Indo-Pacific reefs have high diversity of fast growing branching coral species of families Acroporidae and Pocilloporidae that grow >100 mm yr^{-1} (*Acropora* spp. grows 165 mm yr^{-1}; Dullo, 2005) which also recover faster following disturbance. While, Caribbean reefs had only 2 species of *Acropora* and its mass mortality due to white band disease led to its low reef resilience. Indo-Pacific reefs also showed faster recovery (Graham et al., 2011) and a high percentage of reefs recovering following disturbance compared to other regions. High species richness of herbivores in Indo-Pacific such as families Acanthuridae and Scaridae have greater functional redundancy in limiting algal growth thus preventing abundance of macroalgae and resist coral-macroalgae phase shift (Bellwood et al., 2004; Roff & Mumby, 2012).

4.4 Conclusion

This study has demonstrated the spatial variability of coral cover change in different biogeographic regions over time. Coral cover increased in both Celebes Sea and West Philippine Sea regions, however, most of the sites had no monitoring in the recent years when numerous disturbances had occurred. The overall rates of change in coral cover are comparable among biogeographic regions suggesting synchronous occurrence of impacts although temporal trends showed that coral reefs in Sulu Sea were most significantly affected by thermal stress than other regions. Significant coral loss in Tawi-tawi in Sulu Sea is consistent in all the findings that warrant detailed investigation for its reduction in spite of protection. On the other hand, reefs in the Visayas region are more influenced by overexploitation as demonstrated by significant differences on rates of coral cover change between in and out of MPAs. In recent years, frequent occurrence of coral predation and thermal stress had impacted the reefs, the coupling of these stressors with intensive fishing result to rapid cover decline. However, despite the multiple disturbances that occurred in 2006-2010 none of the regions significantly declined except in the Sulu Sea as influenced by Tawi-tawi. All MPAs have shown to enhance coral cover on a long-term or mitigate coral loss on short term regionally. However, there is a need to optimize the conservation and management strategies of reefs vulnerable to temperature anomalies and close to large sources of nutrients as COTS outbreak are becoming frequent and sea surface temperatures is expected to increase. Although no net coral cover decline on fishing grounds in Visayas, this could eventually lead to significant coral declines if current losses continue at pace.

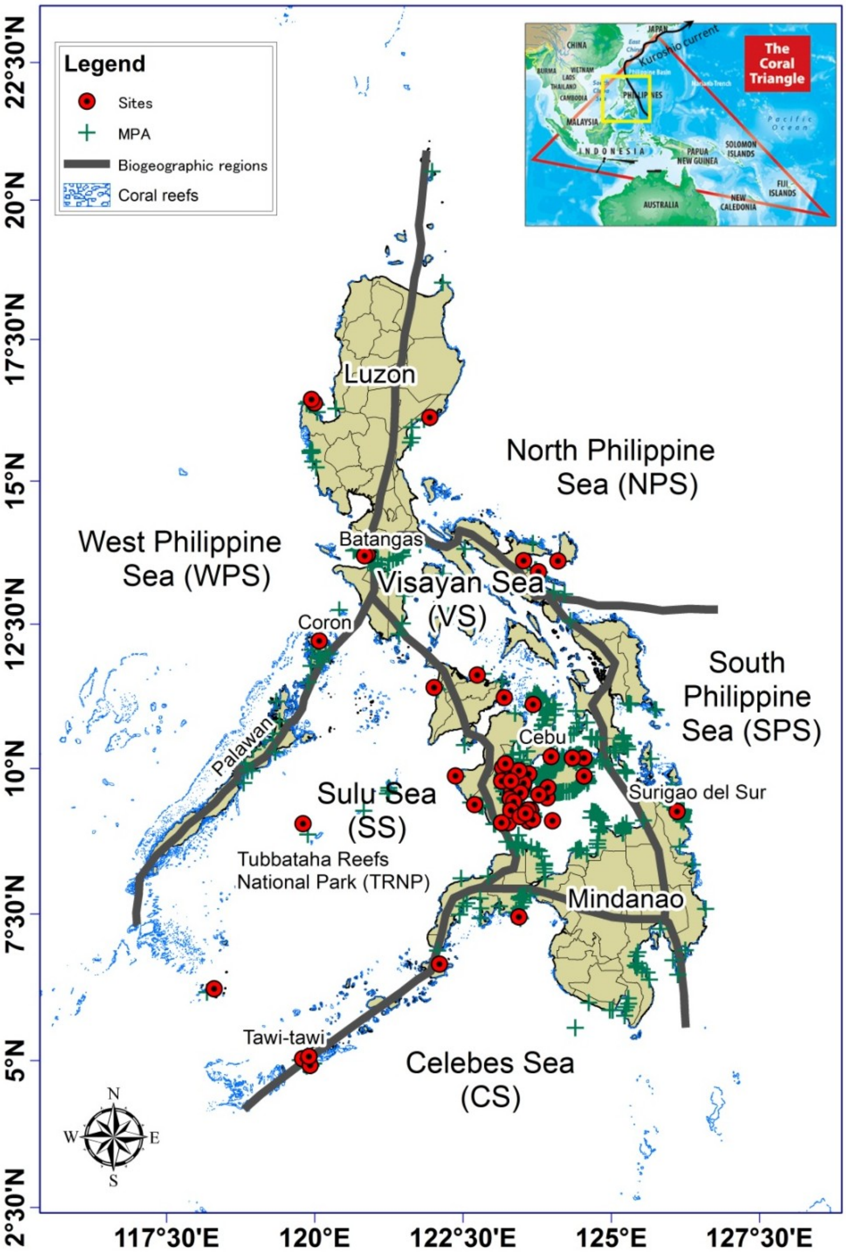


Figure 4.1 Locations of study sites, MPA and the six biogeographic regions: West Philippine Sea (WPS), North Philippine Sea (NPS), South Philippine Sea (SPS), Sulu Sea (SS) and Celebes Sea (CS).

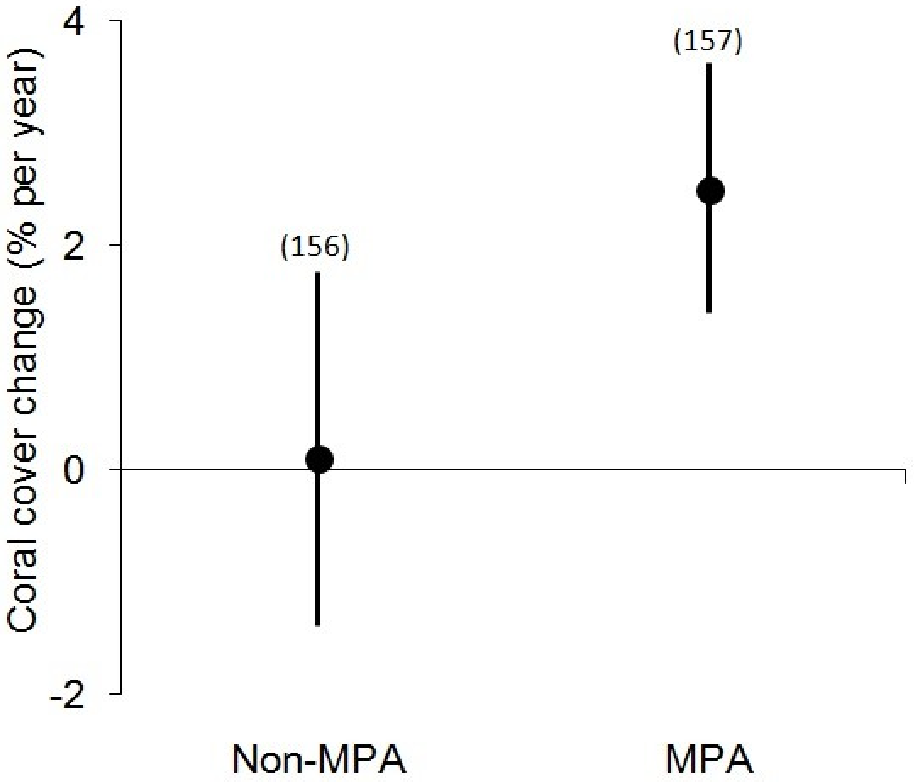


Figure 4.2 Annual rates of change in hard coral cover on MPA and non-MPA sites. Bars are 95% bias-corrected bootstrapped confidence intervals. Sample sizes are given in parentheses.

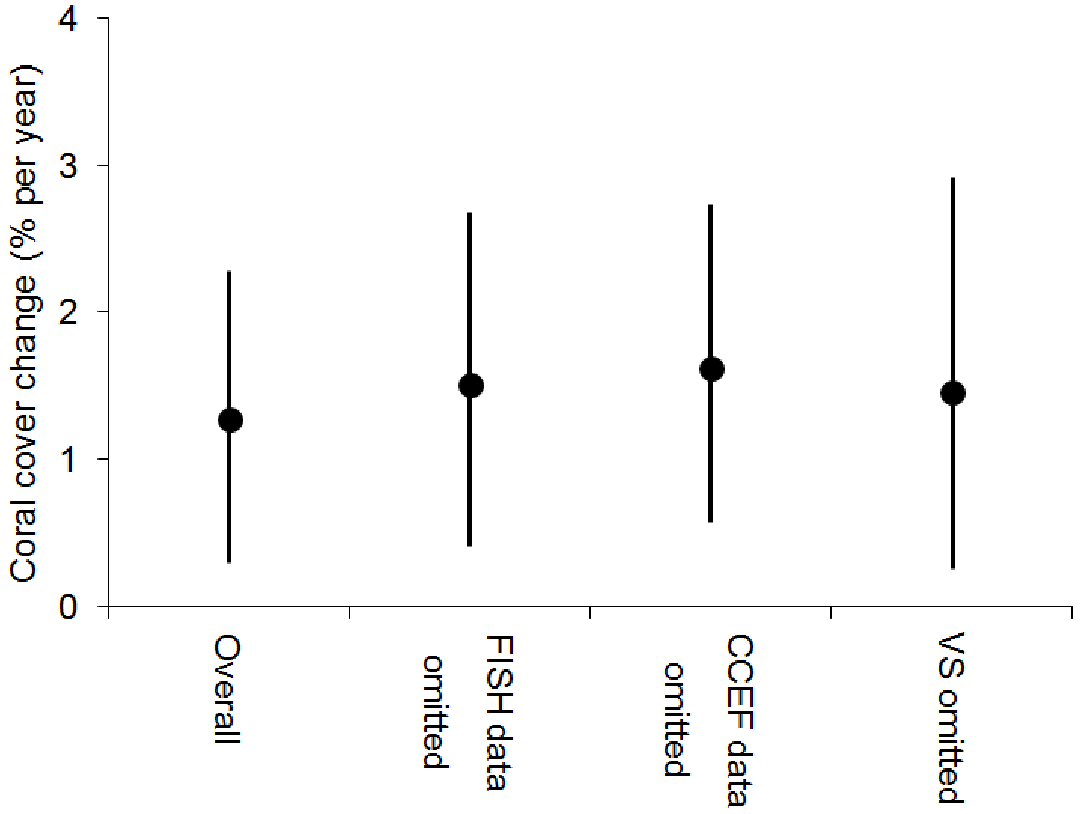


Figure 4.3 Annual rates of change in hard coral cover obtained from monitoring programs of CCEF and FISH Project of UPVFI and well represented region in Visayan Sea. Bars are 95% bias-corrected bootstrapped confidence intervals. Sample sizes are given in parentheses.

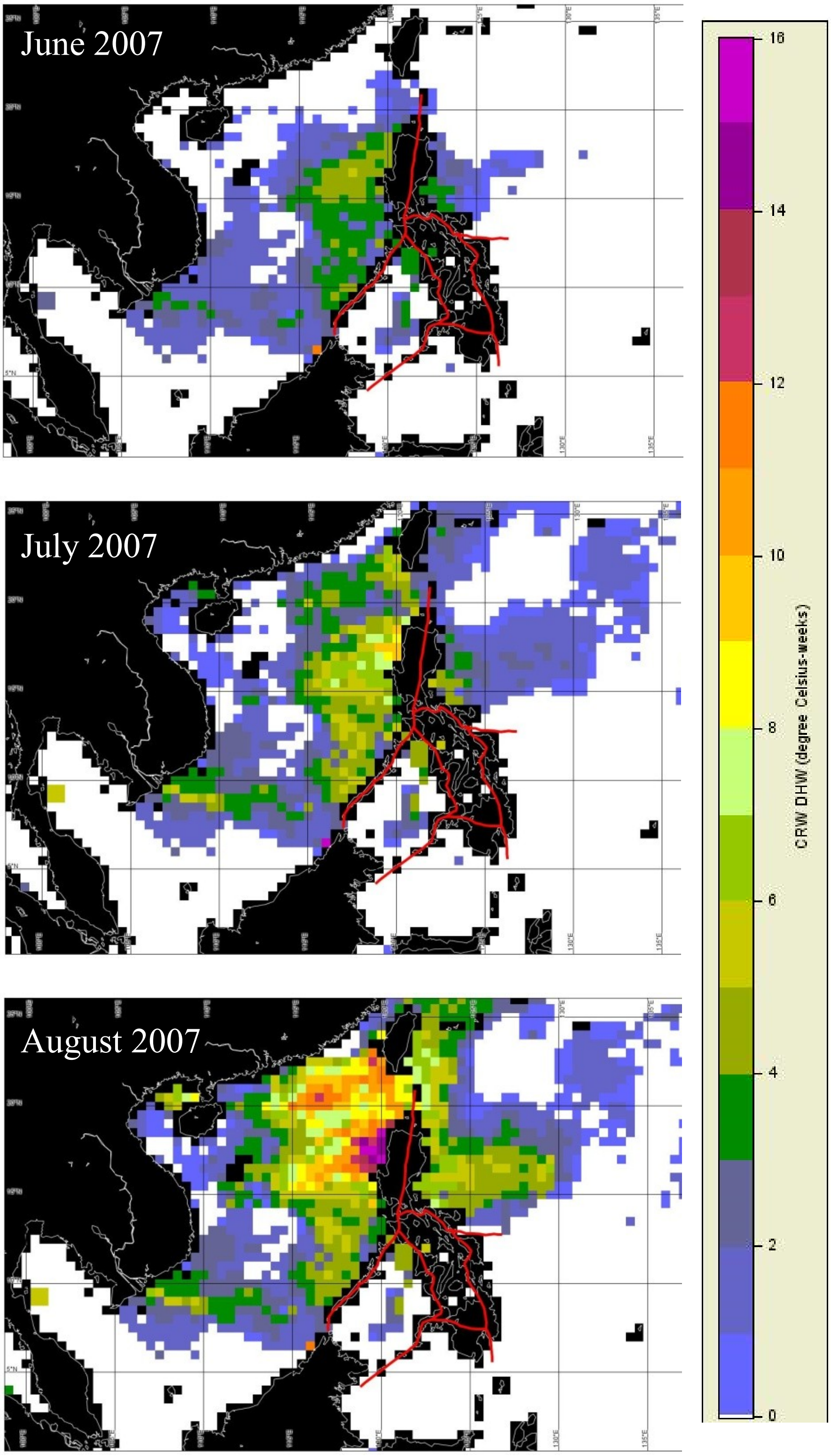


Figure 4.4 Degree Heating Weeks in June-August 2007 in the Philippines (Source: NOAA Coral Reef Watch, 2000; http://coralreefwatch.noaa.gov/satellite/hdf/index.php).

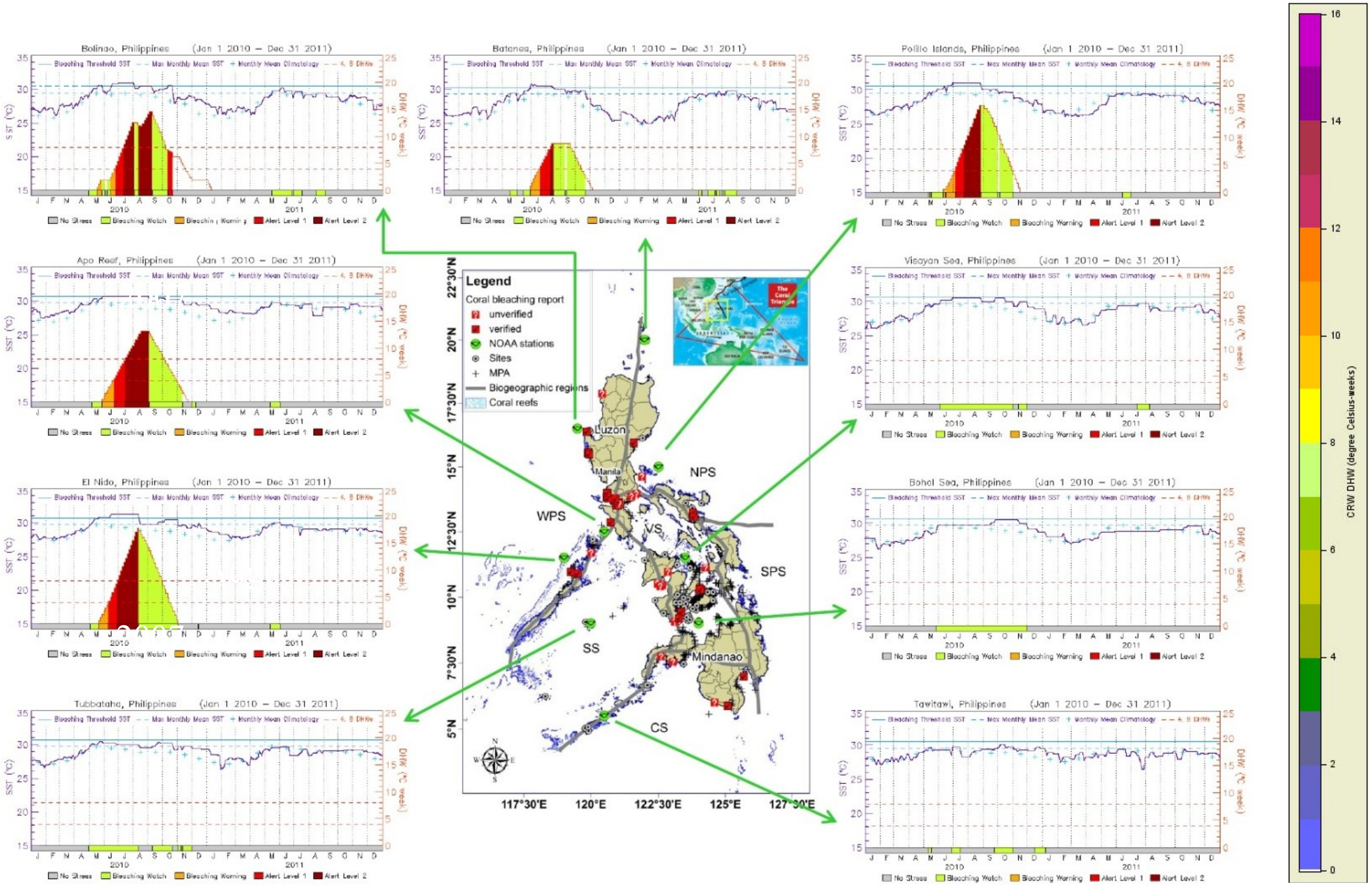
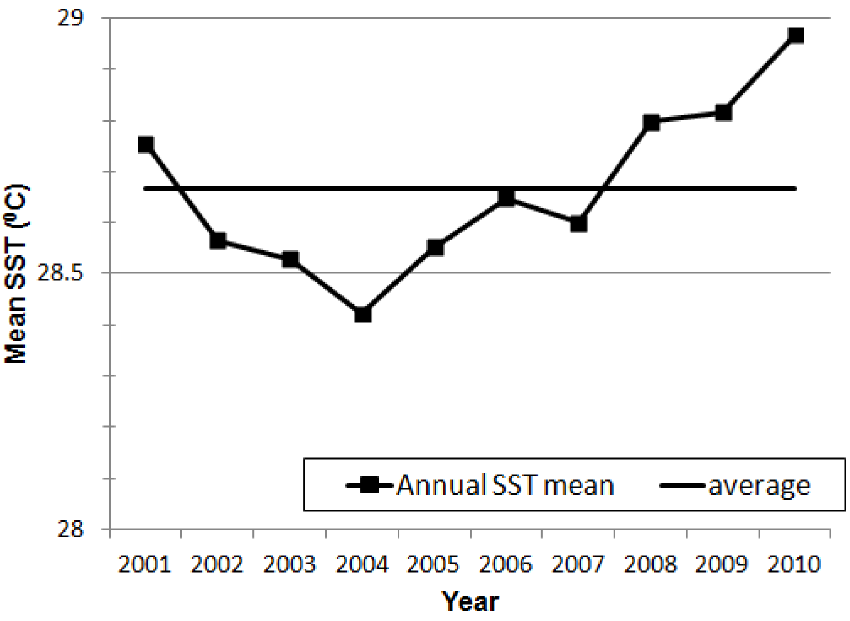


Figure 4.5 Time series SST and DHW (graph) on NOAA virtual stations in 2010-2011 and bleaching observations in 2010 denoted by red marks (Source: Philippine Coral Bleaching Watch, https://phcoralbleaching.crowdmap.com/).



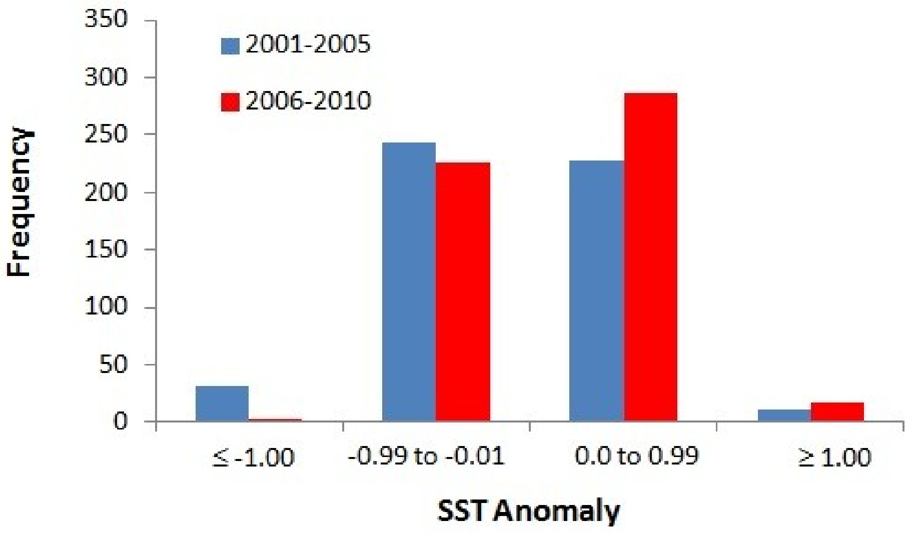


Figure 4.6. Top: Annual mean SST in Tawi-tawi in Sulu Sea and the overall average SST from 2001 to 2010. Bottom: SST anomaly in Tawi-tawi obtained from NOAA Coral Reef Watch (http://coralreefwatch.noaa.gov/satellite/vs/index.html).Positive numbers mean the temperat ure is warmer than average and negative means cooler than average.

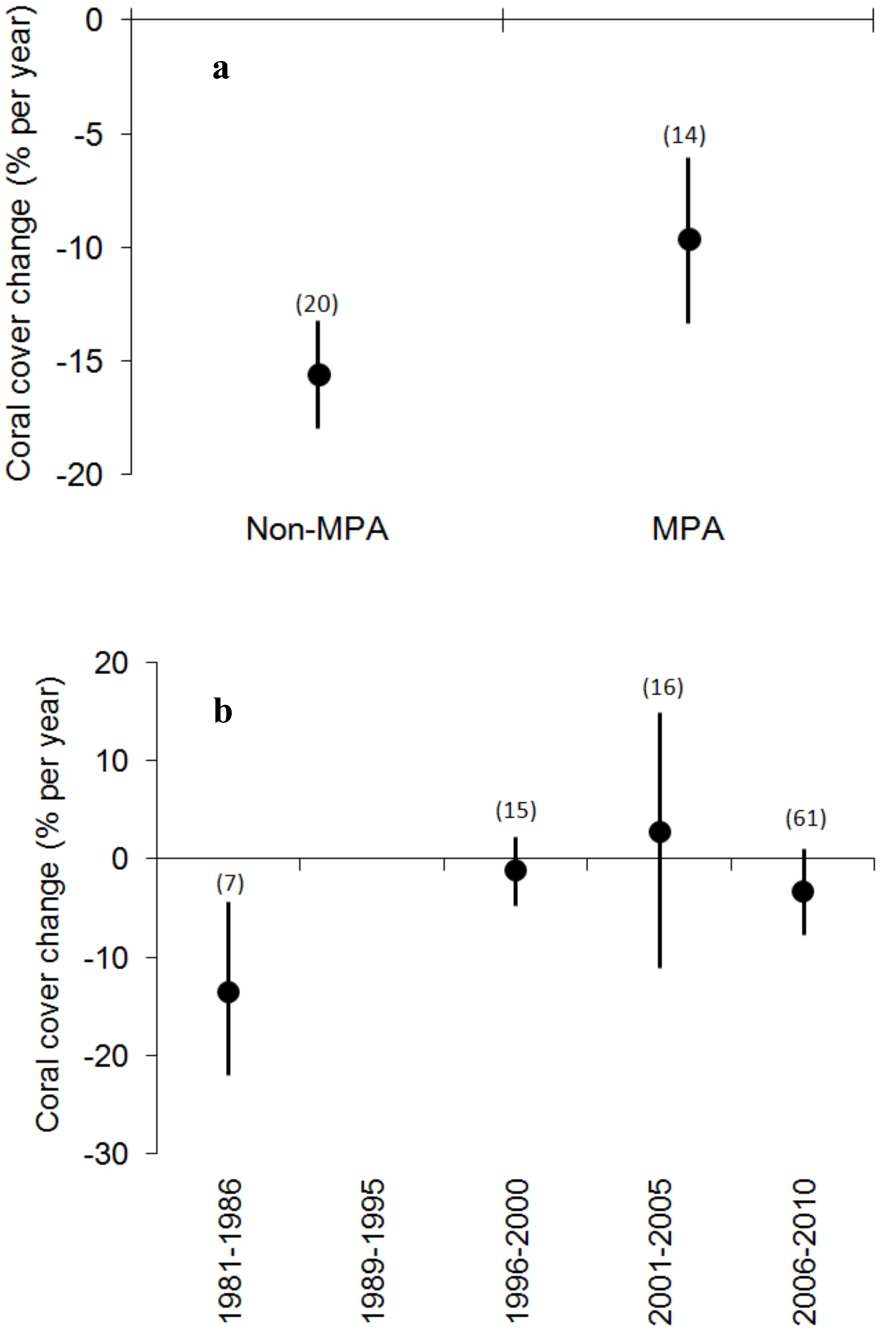


Figure 4.7 a.Comparison of faster rates of decline between MPA and non-MPA sites in Visayas region. b. Annual rates of coral cover change on non-MPAs across periods in Visayas region. Bars are 95% bias-corrected bootstrapped confidence intervals. Sample sizes are given in parentheses.

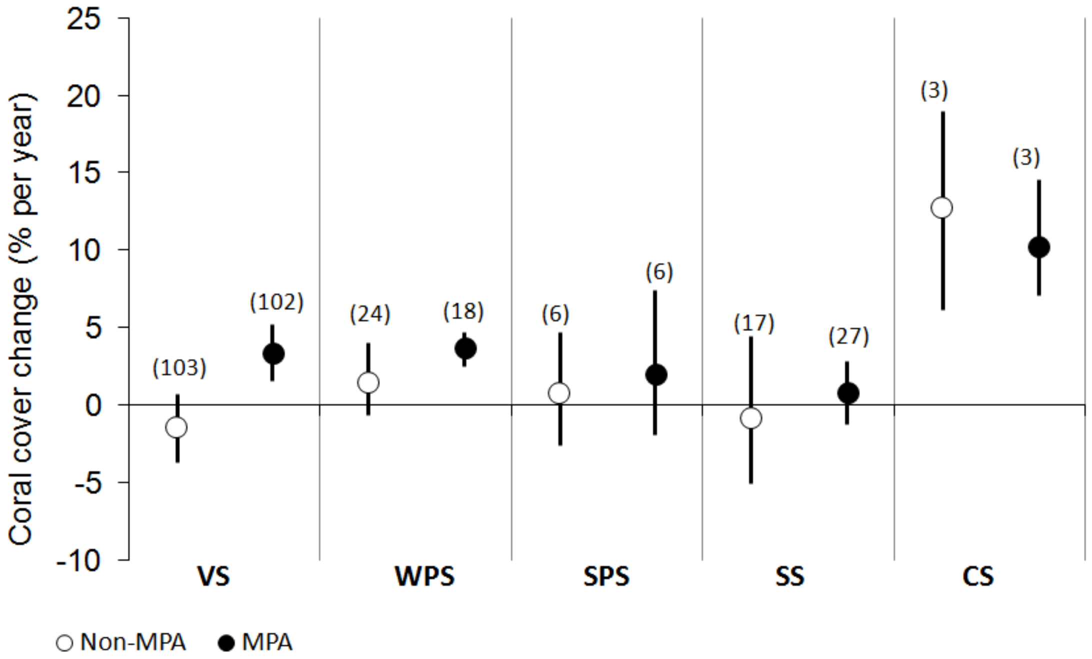


Figure 4.8 Overall annual rates of coral cover change between MPAs and non-MPAs in different biogeographic regions. Bars are 95% bias-corrected bootstrapped confidence intervals. Sample sizes are given in parentheses.

Table 4.1 Temporal trend of annual rates of coral cover change in six biogeographic regions. “-“ means no data. Statistically significant values are in bold: regional values denote significant confidence intervals while P values represent significant regional differences in ARC. Number of sites are in parentheses.

Time	Biogeographic Regions							Categorical Results	
	Overall	VS	WPS	SS	SPS	CS	NPS	Q_M	P
	%ARC	%ARC	%ARC	%ARC	%ARC	%ARC	%ARC		
Overall (1981-2010)	**1.27** **(325)**	0.83 (215)	**3.20** **(45)**	0.16 (45)	1.34 (12)	**11.40** **(6)**	2.68 (3)	3.10	0.15
1981-1986	**-9.09** **(13)**	**-8.86** **(11)**	**-27.22** **(2)**	–	–	–	–	0.38	0.55
1989-1995	**11.66** **(20)**	–	**11.87** **(15)**	7.67	–	–	–	0.32	0.57
1996-2000	**-4.74** **(51)**	0.11 (32)	2.07 (4)	**-10.9**	–	**4.95** **(2)**	–	**8.92**	**<0.001**
2001-2005	**4.88** **(85)**	**9.40** **(39)**	0.23 (27)	4.50 (14)	–	**8.19** **(5)**	–	6.35	0.19
2006-2010	-1.28 (163)	-1.19 (124)	**3.06** **(13)**	**-5.88** **(14)**	1.34 (12)	–	–	3.62	0.13

Table 4.2 Annual rates of change in coral cover in six biogeographic regions that Increased, Decreased and remained Stable from 1981 to 2010. “-“ means no data. Significant values are in bold: regional values denote significant confidence intervals while P values represent significant regional differences in ARC.

Coral condition Trend	Biogeographic Regions												Categorical Results	
	VS		WPS		SS		SPS		CS		NPS		Q_M	P
	Sites	%ARC	Sites	%ARC	Sites	%ARC	Sites	%ARC	Sites	%ARC	Sites	%ARC		
Stable	123	-0.21	24	0.93	31	1.41	7	0.39	2	**7.87**	2	0.07	0.91	0.49
Decreased	34	**-13.14**	4	**-3.48**	9	**-7.42**	2	**-2.23**	_	_	_	_	3.22	**0.004**
Increased	58	**10.84**	17	**8.32**	4	**3.22**	3	**6.12**	4	**13.14**	2	**5.95**	1.48	0.28

CHAPTER V

Conclusion

5.1 Summary

This study presents the first comprehensive analysis on long-term trends of coral cover in the Philippines. It revealed facets of coral cover trend on spatiotemporal pattern, trajectory and magnitude of coral cover change and the effectiveness of MPAs in enhancing the coral cover over time.

This study found an overall increase in the rate of change in coral cover for almost three decades in the Philippines. This increase may be attributed to four decades of conservation efforts that contributed to the overall positive change in coral cover as the rate of change increased within MPAs than outside. Reef protection helps in the recovery of key functional groups such as fish herbivores that reduce the abundance of macroalgae after acute disturbances (Mumby et al., 2006; Stockwell et al., 2009; Mumby & Harborne, 2010). This consequently permits recovery of coral through survival of coral recruits and growth in the absence of fishing (eliminating destructive fishing, damage from anchor and fishing gear) that affect the substrate condition (Russ, 1999; Walmsley & White, 2003). Coral recovery is nonlinear, slower for extreme and small coral losses but immediate recovery at medium to high levels of coral decline (Graham et al., 2011). Although no relationship was found between the rate of coral cover change with the level of protection, age and size of MPA, coral cover relatively increases with at least 6 yrs of protection and MPA size of >10 ha (Fig. 3.7). This indicates that MPA can yield positive results even with a manageable size of MPAs and manage them as part of networks.

Historical timeline of reef disturbances and the temporal trend in coral cover change demonstrated that local human induced disturbances and thermal stress are major threats to Philippine reefs. There was an increased recurrence of COTS infestation in 2000s, although previous studies have showed indirect evidences that it could be due to local human activities (Dulvy et al., 2004; Fabricius et al., 2010). Temporal trend shows cycles of disturbances and increases in 5-year intervals showing comparable rates of coral cover change across the regions except in 1996-2000. In recent years (2006-2010), compounding impacts of reemergence of COTS outbreaks and coral bleaching in 2010 have affected the reefs across the region. A brief decline in cover due to COTS and immediate recovery in West Philippines prior to bleaching in 2010 showed an overall increase in West Philippine Sea. This also reflects in the improvement of "good" cover and reduction of "poor" reefs in the recent years.

Coral cover loss in Sulu Sea was due to a constant decline of coral cover in all Tawi-tawi reefs since its first survey in 2006. This concurs with the increased trend of "poor" reefs and decline of "good" reefs recently. Although the underlying cause of the decline is still unclear, however; sea temperatures were warmer than average in 2006-2010 than the previous period. The declining trend in Tawi-tawi is opposite to the observed response of coral cover after initial protection (≤5 yrs. of protection), which either rapidly increases or maintain its coral cover similar to the new established MPAs in South Philippine Sea in 2006. More detailed surveys should be conducted to understand the underlying cause of coral cover change in Tawi-tawi. Although coral reefs in Visayas showed no net change in coral cover in 2006-2010, many of these reefs are currently in a degraded state ("poor" category). There were also differential rates of coral cover found in 1996-2000 among the reefs regionally with significant coral losses estimated in Sulu Sea than other regions like Visayan Sea. The high dominance of bleaching-sensitive *Acropora* spp. on Tubbataha Reefs Natural Park lead to substantial coral losses during the 1998 bleaching. The data in Tubbataha during 2010 bleaching event is limited to determine whether corals developed an adaptive capacity from thermal stress or it remained vulnerable to temperature anomalies, but like Tawi-tawi, it still needs further studies. Chronic human impact is unlikely in Tubbataha due to its distance from population centers; thus thermal anomaly is the most prevalent driver of coral cover change on these reefs.

5.2 Integrating Quartile category and Meta-analysis

Similar to previous studies that used secondary studies in assessing the coral cover trends (e.g., Cote et al., 2005; Bruno & Selig, 2007; Shutte et al., 2007), many of the collated data were snapshot surveys. In estimating annual rates of change in coral cover, this requires a number of information such as repeated measurements over time, number of transects and transect lengths used which some of the surveys have not reported. While, time series data are limited in many areas thus cannot give reliable measure of trends, the use of quartile category can provide some insights on the condition of the reefs. Like for instance in Celebes Sea and South Philippine Sea where time-series data are limited thus insufficient to give reliable representation of the region. It is also worthy to know the state of coral cover because “poor” reefs also indicate a decline in fiheries yield (Alcala & Russ, 2002).

There is a little information about spatiotemporal trends in Celebes Sea, South Philippine Sea and North Philippine Sea. Overall rate of coral cover showed a positive change in Celebes Sea, which also showed an increase of reefs on “fair”category and a reduction in “poor” reefs. Coral cover in South Philippine Sea has been weakly positive in recent years, but many of the reefs are in “good” condition, and none was in “poor” category. There is sparse data in North Philippine Sea although most of the reefs are in “fair” category; a slight increase was noted on “poor” reefs than “good” reefs in this region. Utilizing the percentage absolute coral cover with rates of coral cover change could provide holistic information of coral cover trends. The use of quartile category can be used for rapid reef assessment since not many reefs are well surveyed particularly in developing countries and have long-term monitoring program in place. Although examination of subregional trends is highly recommended to see the trajectory of change to reduce potential bias of a well surveyed region. As the information of time-series increases, this can be coupled by robust and quantitative measure of coral cover change like meta-analysis.

5.3 Implication for Management

This study shows the significance and effectiveness of MPAs as a reef conservation tool to arrest coral decline in the region with high dependence on the reef and highly threatened reef ecosystem. MPAs are found to help either mitigate coral loss or enhance coral cover in both short and long-term regardless of the size or duration of protection. Presently, only 7% of 22,484 km^2 of the Philippine reefs is protected (Burke et al., 2011) and the Philippine Marine Sanctuary Strategy aims to protect 10% of the reefs in 2020 (Weeks et al., 2010). At least 526 MPAs must be established with 20 ha MPA size annually in 6 years to achieve this target. This is relatively lesser and smaller in size than the recommended yearly establishment of 545 MPAs of ≥31 ha until 2020

(Weeks et al., 2010).

Among the regions, Visayas is at high risk that warrants conservation priority. Local anthropogenic impact mainly intense fishing is the predominant driver of coral cover degradation in Visayas. The small losses over time have become substantial as revealed by significant gap of coral cover change inside and outside of MPAs over three decades. Rapid coral loss was also detected in recent years on reefs with compounding impacts of multiple stressors concomitant with fishing compared to its adjacent MPA. Visayas reefs seem resistant to disturbances however coral cover on fishing grounds is weakly declining at a rate of 1.42% yr^{-1} (CI = -3.71 to 0.74%) which has rapidly declined in 2006-2010 at 3.19% yr^{-1} (CI = -7.68 to 1.08%), equivalent to 3.32% yr^{-1} coral cover increase on MPAs. Significant decline is imminent if fishing continues at pace because severity and frequency of disturbance is likely to increase due to impacts of climate change.

Aside from the establishment of MPAs, there is a need to mitigate fishing impact by restricting fishing gears particularly heavy weighted nets or traps that damage the benthic habitat, because the area of fishing ground is still larger than areas that can be protected from exploitation. While MPAs seem to enhance the coral cover, MPA design must be reconsidered in areas vulnerable to sudden increases in temperature, as the sea surface temperature is likely to increase. Regular reef monitoring in Sulu Sea, North Philippine Sea, South Philippine Sea and Celebes Sea is recommended to understand the pattern of coral cover change in these regions.

This study focuses on coral cover, but 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). This study hopefully encourages and sustains 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. May this serve a first step to encourage reef scientists to monitor the reefs regularly, improve the reporting of benthic survey (e.g., observed threats, surveys used, coordinates, date of surveys, number and length of transects, depth) and make the coral cover data publicly available through publication because this information is important for reconstructing long-term ecological studies such as this.

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References

Albaladejo, V. & V. Corpuz, 1982. A market study of the aquarium fish industry of the Philippines: an assessment of the growth and the mechanisms of the trade. In: Gomez, E., Birkeland, C., Buddemeier, R., Johannes, R., Marsh, J. Jr. and Tsuda, R. (eds) Proc. 4th Int. Coral Reef Symposium 1: 75-81.

Alcala, A.C., 1976. Population densities of the Crown-of-Thorns Starfish in two Philippine Reefs. Silliman Journal 23: 279-287.

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., 2000. Blast fishing in the Philippines, with notes on two destructive fishing activities. Silliman Journal 41: 26-47.

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. & E. Gomez, 1985. Fish yields of coral reefs in Central Philippines. Proc. 5th Int. Coral Reef Congr. 5:521-524.

Alcala, A. & E. Gomez, 1987. Dynamiting coral reefs for fish: a resource destructive fishing method. In: Salvat, B. (ed) Human impacts on coral reefs: Facts and recommendations. Antenne Museum E.P.H.E., French Polynesia.

Alcala, L. & E. Gomez, 1990. Recovery of a reef from typhoon damage at Pescador Island, Cebu, Central Visayas, Philippines. In: Proceedings of the First ASEAN Symposium on Southeast Asia Marine Science and Environment Protection. UNEP Reg. Seas Rep. Stud. 116: 105-109.

Alcala, A., E. Gomez, L. Alcala, & T. Luchavez, 1986. Notes on the recovery of the coral reef at Pescador Island off Moalboal, Cebu, Philippines from typhoon damage. Silliman Journal 33: 24-30.

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.

Alcala, A., E. Gomez, & H. Yap, 1987. Philippine coral reefs: status and human responses to changes. Resour. Manag. Optim. 4: 297-340.

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., 1984. The effect of mine tailings on the structure of coral communities at Toledo, Cebu. In: Koh, L. and Hew, C. (eds) Proc. 3rd Symp. Env. National University of Singapore.

Aliño, P., C. Nañola, W. Campos, V. Hilomen, A. Uychiaoco, & S. Mamauag, 2004 Philippine coral reef fisheries: diversity in adversity. In: DA-BFAR (ed) In turbulent seas: The status of Philippine marine fisheries. Coastal Resource Management Project, Cebu City, Philippines.

Aliño, P. & E. Gomez, 1994. Philippine coral reef conservation: Its significance to the South China Sea. In: Yamamoto, K., Ishijima, S., Sakihara, S., Taira, H., Shimabukuro, Z., Teruya, F., Nishihira, F. (eds) Development and Conservation in the Asia-Pacific Region. Proc. Regional Conf. EW Center Assoc.

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.

Barshis, D.J., J.T. Ladner, T. A. Oliver, F.O. Seneca, N. Taylor-Knowles & S.R. Palumbi, 2013. Genomic bias for coral resilience to climate change. Proceedings of the National Academy of Sciences of the United States of America. 110:1387–1392.

Beger, M. & A. Harborn, 2000. Southern Negros Development Programme. Summary report to the Municipality of Sipalay. Coral Conservation Cay LTD. United Kingdom.

Benavente-Villena, A. and Pido, M. (2004) Poaching in Philippine marine waters: Intrusion of Chinese fishing vessels in Palawan waters. In: DA-BFAR (ed) In turbulent seas: The status of Philippine marine fisheries. Coastal Resource Management Project, Cebu City, Philippines.

BFAR, 2009. Philippine Fisheries Profile 2009. Accessed 31 Mar. www.bfar.da.gov.ph

Brodie, J., K. Fabricius, G. De'ath & K. Okaji, 2005. Are increased nutrient inputs responsible for more outbreaks of crown-of-thorns starfish? An appraisal of the evidence . Marine Pollution Bulletin 51: 266-278.

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. & A. Alcala, 1977. Philippine coral reef fisheries resources. Part II. Muro-ami and Kayakas reef fisheries, benefit or bane? Philipp. J. Fish. 15:217-235.

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.

Cinner, J. E., T. R. McClanahan, N. A. J. Graham, M. S. Pratchett, S. K. Wilson & J-B. Raina, 2009. Gear-based fisheries management as a potential adaptive response to climate change and coral mortality. Journal of Applied Ecology 46: 724–732.

Connell, J., T. Hughes, & C. Wallace, 1997. A 30-year study of coral abundance recruitment, and disturbance at several scales in space and time. Ecol. Monogr. 67:461–488.

Coral Disease Working Group of the Global Environmental Facility Coral Reef Targeted Research Program, 2007. Coral Disease, Environmental Drivers, and the Balance Between Coral and Microbial Associates. Oceanography 20:172–195. http://dx.doi.org/10.5670/oceanog.2007.91.

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.

CRC Reef Research Center, 2003. Crown-of thorns on the Great Barrier Reef. Accessed 4 April. http://www.reef.crc.org.au/publications/brochures/COTS_web_Nov2003.pdf

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.

Dullo, W-C., 2005. Coral growth and reef growth: a brief review. Facies 51: 33-48.

Dulvy, N. K., R.P. Freckleton, & N. C. Polunin, 2004. Coral reef cascades and the indirect effects of predator removal by exploitation. Ecology Letters 7: 410-416.

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.

Fabricius, K.E., K. Okaji, & G. De'ath, 2010. Three lines of evidence to link outbreaks of the crown-of-thorns seastar Acanthaster planci to the release of larval food limitation. Coral Reefs 29:593–605.

Fortes, M. & K. Santos, 2004. Seagrass ecosystem of the Philippines: Status, problems and management directions. In: DA-BFAR (ed) In turbulent seas: The status of Philippine marine fisheries. Coastal Resource Management Project, Cebu City, Philippines.

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. Long-term 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.,1991. Coral reef ecosystems and resources of the Philippines. Canopy International 16: 1, 6–7, 10–12.

Gomez, E., 1997. Reef management in developing countries: a case study in the Philippines. Coral Reefs 16:S3-S8.

Gomez, E.D. & A.C. Alcala, 1979. Status of Philippine coral reefs – 1978. Proceedings of the 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., A. Alcala, & H. Yap, 1987. Other fishing methods destructive to corals. In: Salvat, B. (ed) Human Impacts on Coral Reefs: Facts and Recommendations. Antenne Museum, French Polynesia.

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.

Hodgson, G., 1989. The effects of sedimentation on Indo-Pacific reef corals. PhD dissertation, University of Hawaii, Manoa, Hawaii.

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.

Hughes, T., 1994. Catastrophes,Phase Shifts, and Large-Scale Degradation of a Caribbean Coral Reef. Science 265: 1547-1550.

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.

Jontila, J.B.S., Alarcon, R., Bundal M. & J. Parcon, 2010. Benthic Communities of Tubbataha Reef Natural Park: Status and Trends from 1997 to 2010. WWF 2010.

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. & E. Capili, 2004. New records of stony corals from the Philippines previously known from the peripheral areas of Indo-Pacific. Raffles Bull. Zool. 52:285-288.

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.

Licuanan, W., M. Medina, K. Luzon, M. Samson, C. Nañola, R. Rollon, & M. Rolleda, 2011. Priority reef areas in the Pacific coast of the Philippines for marine protected area deployment. Philipp. Agric. Scientist 94:384-400.

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.

Mamauag, S., 2004. The live reef food fish trade in the Philippines. In: DA-BFAR In Turbulent Seas: The status of Philippine marine fisheries. Coastal Resource Management Project of the Department of Environment and Natural Resources, Cebu

City, Philippines.

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, 2007a. Effects of climate and seawater temperature variation on coral bleaching and mortality. Ecological Monographs 77: 503–525.

McClanahan, T.R., N.A.J. Graham, J.M. Calnan & M.A. Macneil, 2007b. Toward pristine biomass: Reef fish recovery in coral reef marine protected areas in Kenya. Ecological Applications 17: 1055-1067.

McManus, J., C. Nañola, R. Reyes, & K. Kesner, 1992. Resource Ecology of the Bolinao Coral Reef System. ICLARM Stud. Rev. 22.

Miller, I., 2002. Crown-of-thorns and other coral predators. In: Best, B., Pomeroy, R. and Balboa, C. (eds) Implications for coral reef management and policy: Relevant findings from the 9th International Coral Reef Symposium. USAID: Washington, D.C.

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.

Mulliken, T. & S. Nash, 1993. The recent trade in Philippine corals. TRAFFIC Bull. 13: 97-105.

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., 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.

Nakao, Y., H. Yamano, M. Fujii, & Y. Yamanaka, 2009. Development and analysis of a coral cover database in seas close to Japan. J. Japan. Coral Reef Soc. 11: 109-209. (In Japanese with English abstract)

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.

Nañola, C., A. Alcala, P. Aliño, H. Arceo, W. Campos, E. Gomez, W. Licuanan, M. Quibilan, A. Uychiaoco & A. White, 2004. Status Report on Coral Reefs in the Philippines. Poster Presented at the 10th ICRS in Okinawa, Japan. 28 June to 2nd July

2004.

Nañola C., P. Aliño & K. Carpenter, 2010. Exploitation-related reef fish species richness depletion in the epicenter of marine biodiversity. Environ. Biol. Fish. 90:405-420.

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.

Ochavillo, D., Hodgson, G., Shuman, C. and Ruz, R. (2004) Status of the Philippine marine aquarium fish trade. In: DA-BFAR In turbulent seas: The status of Philippine marine fisheries. Coastal Resource Management Project, Cebu City, Philippines.

Omori, M., 2010. Comment on "Development and analysis of a coral cover database in seas close to Japan". J. Japan. Coral Reef Soc. 12: 49-51. (in Japanese with English abstract)

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.

Pajaro, M., Aliño, P., Bermas, N. and Atrigenio, M., 1993. The impact of Mt. Pinatubo's eruption on the coral reef benthic communities in Zambales. Proc. 7th Int. Coral Reef Symp.:309.

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.

Pauly, D., Silvestre, G. and Smith, I., 1989. On development fisheries and dynamite: a brief review of tropical fisheries management. Nat. Resour. Model. 3:307-329.

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.

Quibilan, M. and Aliño, P., 2006. Coral community structure of western Philipine reefs I: spatial patterns. Proc. 10th Int. Coral Reef Symp.:341-350.

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 et al., 2003

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.

Reef Check Web Reef Advisory System. “Crown of Thorns”. Accessed 1 March. http://datamanagement.reefcheck.org/factsheet.asp?surveyID=&issuecode=iCT&display=introduction

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.

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.

Roff, G. & P. Mumby, 2012. Global disparity in the resilience of coral reefs. Trends in Ecology & Evolution 27: 404-413. http://dx.doi.org/10.1016/j.tree.2012.04.007

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

Ross, M., 1984. A quantitative study of the stony coral fishery in Cebu, Philippines. Mar. Ecol. 5:75-91.

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

Rubec, P., Cruz, F., Pratt, V., Oellers, R. and Lallo, F., 2000. Cyanide-free, net-caught fish for the Marine Aquarium Trade. Live Reef Fish Inf. Bull. 7: 28-34.

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, 2004. Marine reserves: long-term protection is required for full recovery of predatory fish populations. Oecologia 138: 622–627.

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 protected areas 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.

Spalding, M., M. Kainuma, & L. Collins, 2010. World Atlas of Mangroves. EarthScan Ltd. Washington D.C.

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.

Trono, G., 1999. Diversity of the seaweed flora of the Philippines and its utilization. Hydrobiologia 398/399:1–6.

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.

Uychiaoco, A.J., Arceo, H.O., Gaite, P., Dolumbal, E., Casterence, F. Jr., 2001. Sibulan Marine Reserve. In: Monitoring the Effects of Marine Protected Areas in the Coastal Resource Management Project Learning Areas (1997-2001). University of the Philippines Marine Science Institute and DENR/US-AID Coastal Resource Management Project.

Veron, J. & D. Fenner, 2000. Corals (Zooxanthellate Scleractinia) of the Calamianes Islands, Palawan Province, Philippines. RAP Bull. Biol. Assess. 17:24-26.

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.

Wang, M. C. & B. J. Bushman, 1998. Using the Normal Quantile Plot to Explore Meta-Analytic Data Sets. Physchological Methods 3: 46-54.

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. & A. Cruz-Trinidad, 1998. The values of Philippine coastal resources: Why protection and management are critical. Coastal ResourceManagement Project, Cebu City, Philippines.

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.T., P. Christie, J. Apurado, A. Meneses, M. Ovenden, S. Tesch and E. White, 2002. Summary Field Report: Coral Reef Monitoring in Cebu, Negros and Siquijor, Philippines, March 23-31, 2002. the Coastal Conservation and Education Foundation, Inc. and Coastal Resource Management Project, Cebu City, 126 p.

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, 2005. Sedimentation of silt in the coral reef environment of Palk Bay, India. Journal of Marine Biological Association of India 47: 83-87.

Wood, E. & S. Wells, 1988. The Marine Curio Trade Conservation Issues. A report for the Marine Conservation Society, Herefordshire, UK.

World Meteorological Organization, 2010. 2010 in the top three warmest years, 2001-2010 warmest 10-year period. Accessed 20 April. http://www.wmo.int/pages/mediacentre/press_releases/pr_904_en.htm

World Meteorological Organization, 2010. Climate, Carbon and Coral Reefs. WMO-No. 1063.Accessed 02 November 2013. http://www.wmo.int/pages/prog/wcp/agm/publications/documents/Climate_Carbon_CoralReefs.pdf

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

Yap, H. T., 1997. Assessment of the present health of coral reefs in the Philippines. In: Grigg, R. and Birkeland, C. (eds) Status of coral reefs in the Pacific. UNIHI Sea Grant CP-98-01.

Yap, H. T., 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.