Sensitivities of coral reefs in the Verde Island passage to climate change

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Abstract The Verde Island Passage (VIP) is located at the center of marine shorefish biodiversity in the Philippines. It is under tremendous amount of stress from natural and anthropogenic impacts. A vulnerability assessment of the VIP's coral reef areas to climate change, particularly elevated sea-surface temperatures (SST), increased storminess and sea-level rise (SLR) is presented. Potential impacts on live hard coral cover due to increasing SST ranged from 3% to 22% loss. These projections were based on the high percentage covers of thermally sensitive coral families such as acroporids and pocilloporids. Potential impacts on diversity attributed to high SST ranged from 0.8% to 1.6% based on species-area curves and 10% to 49% based on sensitivities of coral genera from available literature. Estimated live hard coral cover and diversity loss due to the impact of storms ranged from 12.5% to 37.5% and 7% to 22%, respectively. Sea-level rise had the lowest impact on reef cover and diversity, resulting to an estimated loss of 4% to 7% in coral cover and 0.60% to 0.80% in coral diversity. Impact on reef fishes was measured based on their dependence and association with corals. Percentage loss of reef fish species richness and abundance ranged from 9% to 16% and 12% to 54%. These projected impacts on the health and biodiversity of the coral reefs of the VIP are conservative but still significant. The towns and communities surrounding the passage should not be complacent and should increase their

efforts to protect and manage their coral reef areas.

Keywords coral reefs, vulnerability assessment, sea-surface temperature, storminess, sea-level rise

Introduction

The Philippines is considered as the center of marine shorefish biodiversity (Carpenter and Springer 2005) and has one of the most diverse coral reefs in the world, thereby making it part of the Coral Triangle. However, the Philippines are also named as a biodiversity hotspot due to both anthropogenic and natural stressors which are impacting species diversity and abundance (Burke et al. 2002; Wilkinson 2004). It is currently under tremendous amount of threats due to climate change impacts (IPCC AR4 2007). The country's coastal areas are highly vulnerable to changing sea-levels (Perez et al. 1999, Nicholls and Cazenave 2010), temperatures (Peñaflor et al. 2009) and storms (Emanuel 2005).

Increasing sea-surface temperatures (SST), sea-levels, and storm frequency and strength are detrimental to coral reefs. Elevated SSTs cause bleaching in scleractinian corals (Hoegh-Guldberg 1999). Accelerated sea-level rise (SLR) can drown coral reef communities by pushing them

into deeper and low-lit areas and thereby reduce photosynthesis due to increased light attenuation (Hoegh-Guldberg et al. 2007). Increased strength and frequencies of storms can destroy corals by seriously damaging reef areas and reducing their recovery (Dollar and Tribble 1993).

There is growing interest in the Verde Island Passage (VIP) since its establishment as a conservation priority area. Various species of marine mammals and turtles were found in this area. The reefs of the VIP are also notable for their high coral and reef fish species diversity. Various agencies, organizations and institutions have implemented monitoring projects since the establishment of marine protected areas (MPAs) in the VIP (CI-Philippines 2009). However, there are no known studies on the impacts of climate change in the VIP. A vulnerability assessment of the human well-being and marine biodiversity of the VIP to climate change was conducted from June to August 2009. The marine biodiversity component aimed to project the possible impacts of selected climate change stressors on coral reefs, mangroves, seagrass beds and fisheries. This paper presents the projected impacts of increasing

SSTs, storm strength and frequencies and SLR on coral communities and associated reef fishes.

Material and methods

The VIP (13.621751°N, 120.666570°E) is surrounded by 5 major provinces of the Southern Tagalog region (Fig. 1). It has a total reef area of ~8,128 hectares, of which 2,125 hectares are covered by live corals. The reefs of the VIP are fringing and generally narrow, occurring at shallow waters on inshore areas near the bay heads. Some reefs still occur in deep areas particularly in the bay mouths. The western side of the VIP has more developed reef areas compared to the eastern side.

Data from a total of 41 sites belonging to 8 municipalities (Figure 1) were collected from Conservation International – Philippines' MPA monitoring and evaluation program. State variables (e.g. coral cover, fish abundance) from the monitoring data were pooled to determine potential impacts of selected climate change stressors on coral and

Fig. 1 Map of the Verde Island Passage (map not drawn to scale). Data and other relevant information were taken from the CI-Philippines funded MPA monitoring assessments and reconnaissance surveys. A total of 41 survey sites belonging to eight (8) municipalities around the VIP were used in this study.

reef fish communities.

Impacts of SST, SLR and storms were estimated by calculating potential losses in live hard coral cover and diversity and reef fish abundance and diversity. The potential effects of SST, SLR and storms were categorized as low and severe impacts. Estimated impacts were based on actual field observations during the coral bleaching event in 1998 and 2007 for SST and Typhoon Caloy (International name: Chanchu) in 2006 for storms. For SST, a 2°C rise above normal caused low impact while 2–3°C rise above normal caused severe impact (Licuanan, unpublished). Potential impact of storms was estimated based on the study by Licuanan (unpublished report) on the loss of coral cover in Pagbilao, Quezon (located east of the VIP). Low impact of storms was based on the coral cover lost in reef areas located in sheltered sites, whereas severe impact was based on the coral cover lost in exposed reef areas. Low and severe impact scenarios for SLR are based on IPCC estimates of 5 cm SLR for low impact and 88 cm SLR for severe impact (IPCC 2007).

SST sensitivity for coral cover was estimated by calculating percentage coral cover loss of highly susceptible taxa from the observed accounts during the 1998 and 2007 coral bleaching events and available literature. Estimates for low impact were calculated by analyzing percentage cover of *Acropora* sp. Estimates for high impact were calculated by analyzing percentage cover of acroporids, pocilloporids and other thermally sensitive coral genera.

Impacts of increasing SST on coral diversity were computed using species-area curves and coral sensitivities from available literature. A flat species-area curve (Fig. 2) based on the coral data from Veron and Fenner (2000) in Calamianes, Palawan was used to compute for potential diversity loss for low impact. Inputs for severe impact were calculated by looking at coral species richness and removing highly sensitive coral genera specified in Pratchett et al. (2008).

For the impact of SLR, percentage loss of the reef area was computed using the following formula:

$$\% \text{ Area Loss} = \frac{(a'/\sin A) - (a/\sin A)}{a/\sin A} \times 100$$

Wherein, (a) - is the maximum depth of the reef community before sea level rise; (a') - is the maximum depth

Fig. 2 Inverted species-area curve based on the data of Veron and Fenner (2000) in Calamianes, Palawan, Philippines.

of the reef community after sea level rise; and, (A) - is the angle of the reef slope. The angle of the reef slope was measured as the elevation from the horizontal. This formula, however, only applies to deep coral communities along the reef slope. It is assumed that in the event of sea level rise, the coral communities located at the bottom of the reef slope will drown. Another assumption is that the more detailed information regarding the distributions of coral cover and diversity across the reef is not available. Potential coral diversity loss was measured by using the species-area curve based on the coral data of Veron and Fenner (2000).

There is little study on coral and reef fish correlation in the Philippines. Impacts of coral loss on reef fish abundance and diversity were determined by calculating the percentage loss of specialized reef fish species indicated in Pratchett et al. (2008). Potential losses of reef fish abundance (individuals 1000 m⁻²) were calculated by taking into account the abundances of specialized fish species from the total reef fish abundance. Similarly, reef fish species richness (species 1000 m⁻²) loss was computed by subtracting the number of specialized species from the total number of species present.

Results

The status of the coral communities in the VIP fell under poor category of Gomez et al. (1994), with 23.8%

mean cover of live hard corals. A total of 61 coral genera were observed in the belt transects during the 2007 and 2008 surveys. The reefs in the passage were mostly dominated by the coral *Porites* sp., followed by *Acropora* sp., *Diploastrea heliopora*, *Montipora* sp., *Goniastrea* sp., *Echinopora* sp., *Pocillopora* sp. and *Seriatopora* sp. Reef fish status fell under poor category with an average abundance of 270.9 individuals 1000 m⁻² (based on the index by Hilomen et al. 2000) (Table 1).

Potential effect of SST increase in the VIP showed that the estimated loss during low impact ranged from 3% to 14% (Table 2). These estimates were based from the 1998 bleaching event in Palawan. Composition of the bleached corals belonged to Acroporidae and Pocilloporidae, the two most thermally sensitive families based on literature. Estimated losses during severe impact ranged from 6% to 22%. These estimates were based on the observations made during the 2007 bleaching event in the municipality of Lian, Batangas, of the VIP. Other families of corals such as faviids, fungiids and poritids were also found to be bleached apart from acroporids and pocilloporids. These families are also known to bleach in prolonged high temperatures.

Impact of temperature increase based on the flat species-area curve resulted in loss of less than 1% to 1.6% during low impact (Table 2). A flat species-area curve was made by sorting the sites according to increasing number of species, which was also used to compute the curve. Severe impact resulted in 10% to 75% loss, (based from Pratchett et al. (2008).

Sea level rise does not pose a major challenge to coral reefs. Studies have concluded that changes in sea level rise are relatively slow compared to the rate of coral growth, for example branching corals can grow up to 20 cm per year (Done 1999). It is assumed that the corals located at the edge of the reef slope will drown due to increased light attenuation. For example it is expected that if sea level rises to 5 cm 1% of corals will be lost, and if sea level rises to 1 m coral loss will be of 4 to 7%. The edge of the reef slope also has the lowest coral diversity (Huston 1985), resulting in an estimated loss of less than 1%.

The majority of the storms entering the Philippines pass through the northern part of the country. Strong waves brought by strong storms (e.g. typhoons or Category Storm 5) seriously threaten coral reefs as it can decimate

Table 1 Status of coral reefs in the Verde Island Passage. Coral cover is expressed as the mean percentage (%) of live hard corals, whereas fish abundance is expressed as mean of total individuals 1000 m⁻². Coral diversity is expressed as number of coral genera observed in the municipality. Fish diversity is expressed as number of fish species observed in the municipality.

	Municipality	Sites	Coral Cover	Coral Diversity	Fish Abundance	Fish Diversity
1	Batangas City	4	12.9	39	415.0	139
2	Calatagan	8	24.2	44	234.3	113
3	Looc	6	29.4	41	181.0	87
4	Lubang	6	24.8	39	371.2	147
5	Mabini	3	33.8	45	303.8	151
6	Nasugbu	2	29.3	28	85.5	44
7	San Juan	8	19.6	42	176.3	100
8	Tingloy	3	19.2	41	488.3	142
General Weighted Mean			23.8		271	

Table 2 Summary of potential impacts on scleractinian coral cover and diversity and reef fish species richness and abundance.

	Potential impact on coral cover	
	Low	Severe
Increased SST	3% to 14%	6% to 22%
Sea-level Rise	0.25% to 0.38%	0.4% to 7%
Strong Typhoon	12.50%	37.50%

	Potential impact on coral diversity	
	Low	Severe
Increased SST	0.7% to 1.6%	10% to 75%
Sea-level Rise	0.60%	0.6 to 0.8%
Strong Typhoon	7.00%	22.00%

Potential impact of coral loss on reef fishes	
Species Richness	9% to 16%
Fish Abundance	12% to 54%

larger reef areas in a single event (Dollar and Tribble 1993). Typhoon Caloy was categorized as a Tropical Storm (Category Storm 2) when it passed through the VIP area in 2006. It stayed in the VIP region for more than 2 hours. There were no data available for the VIP before the impact of the typhoon. Data gathered for Pagbilao, Quezon, a municipality adjacent to the eastern side of the VIP, were used as a proxy to estimate coral cover loss. Low impact caused 12.5% reduction of coral cover, whereas, severe impact caused 37.5% reduction in coral cover.

There is still a large gap on the research about the impacts of climate change on the physiology and behavior of coral reef fishes. Majority of the interest and studies done on climate change impacts on reef fishes are habitat associations and community dynamics (Wilson et al. 2010). Unfortunately, studies on habitat (coral) and fish relationship are greatly lacking in the Philippines. Estimates were based from the studies of Pratchett et al. (2008), which identified that reef fish species were highly dependent or

associated with certain species of corals. If coral cover and diversity in the VIP are reduced, 9% to 16% potential impact on fish species would be estimated. This potential impact on reef fish species can be translated to 12% to 54% impact on reef fish abundance.

Discussion

The projections presented here are conservative. Nonetheless, these estimates are not unreasonable as they are based on actual field observations and literature review. The figures calculated are conservative as the interactions between climate change impacts have not been considered. The interaction of increased SSTs, SLR and more frequent and stronger storms are likely to have greater impact compared to their individual impacts. Moreover, these impacts can act together and aggravate the poor status of the reefs which has already been degraded by human

activities. For example, sediment can smother corals and reduce light penetration. Inshore reefs and lagoons are prone to chronic sedimentation (Anthony 2006). The impact of strong storms and heavy rainfall can further increase runoff in inshore reef areas, causing severe degradation (Rogers 1990).

On a positive note, the estimates are also conservative since the impacts of climate change on the reefs of the VIP can be less than what is projected. Furthermore, recovery of reefs and adaptation of coral and fish species were not considered. It was assumed that the climate change impacts were likely to be severe for the reef areas. The lower parts of the reef slope is also often considered to be the least developed ones (Huston 1985). Hence, coral cover loss due to drowning is likely to be insignificant. Diversity in the reef slope however is another concern, as it contains more species compared to shallow reef flat.

Closer examination of the methodologies used show that these values are imprecise. This is primarily due to time constraints and insufficient data. More elaborate analysis could be done provided that there are more detailed data on cover and diversity patterns within reefs, between reefs and across the reef flat and at deeper areas. Nonetheless, the projections shown here capture the likely scenarios that can be seen in the next 10 to 50 years.

On a management point-of-view, the methods used are simple and easy to apply. It can provide estimates that are important for managers and policy-makers to implement coastal resource management projects and legislations. Since estimates on the impacts of climate change are already known, it is important to act on manageable man-made impacts. The VIP's reef areas are already in a poor state due to the rapidly growing coastal population and development. The highly urbanized coastal areas of some municipalities and over-fished waters need urgent and coordinated responses in order to prepare for climate change.

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