ARTICLE

Resilience to thermal stress of coral communities in Talim Bay, Lian, Batangas

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Abstract—Climate change driven disturbances such as increases in sea surface temperature (SST) pose a critical threat to coral reefs. Increased understanding of the mechanisms that maintain coral community structure (i.e., coral cover and species diversity) now allows for the assessment of resilience of coral communities to thermal stress. Such an assessment was conducted in Talim Bay, Lian, Batangas and sought to quantify factors that relate to resistance (i.e., coral community structure) and recovery potential (i.e., coral recruitment, topography of the reef and historical data on mortality and recovery). The Bay was found to be dominated by bleaching-resistant coral species, suggesting high resistance to thermal stress. Recovery potential was also assessed to be high and was associated with the physical characteristics of the reef, the coral size structure, and the presence of adjacent reefs for reseeding. Sedimentation and nutrient loading were found to have a significant role in determining the status of the coral communities of Talim Bay. Insights from this resilience assessment may inform coastal communities of management measures which are necessary to alleviate stress on coral reefs to minimize coral reef degradation and phase shifts.

Keywords—Coral community structure, Resilience, Climate Change

INTRODUCTION

The growth, abundance, and distribution of corals in a coral reef are influenced by natural disturbances that may be physical (e.g., storms, change in sea level and temperature) or biological (e.g., predation and grazing, coral disease and bleaching, crown-of-thorns outbreaks; Hughes & Connell, 1999; Nyström et al., 2000). Coral communities naturally have the capacity to recover from such disturbances and retain their structure and function (Nyström & Folke, 2001). However, such capacity is undermined by anthropogenic impacts and climate change. For example, increased frequency and severity of anomalous sea surface temperatures driven by climate change (IPCC, 2007) are expected to lead to more coral bleaching events (Hoegh-Guldberg, 1999; Obura & Grimsditch, 2008; Burke et al., 2012; McClanahan et al., 2012). The same disturbances may also impede resilience, and result in further degradation and changes in community structure of the reef (Berumen & Pratchett, 2006).

The suite of ecological and environmental factors that determine the potential to recover from, or resist disturbances are quantified in various resilience assessment protocols (e.g., Obura & Grimsditch, 2009; Maynard et al., 2010; McClanahan, 2012). Most branching coral genera such as *Acropora*, *Montipora*, *Pocillopora*, *Seriatopora*, and *Stylophora* are prone to bleach; while most massive *Porites* and lagoon-resident *Pavona* do not readily bleach (Marshall & Schuttenberg, 2006). One can thus project a reef community's tendency to bleach by examining its coral community structure. Recovery potential, on the other hand, can be assessed by looking at levels of coral recruitment and connectivity, and the physical condition of the reef habitat (Obura & Grimsditch, 2009; McClanahan et al., 2012).

We assessed the levels of resilience in 20 reef stations at Talim Bay, Lian, Batangas that have been exposed to anomalous warming of up to 12 degree heating weeks in 1998 and 2010 (http://coralreefwatch.noaa.gov/satellite/baa.php). A degree heating week (DHW) is defined as the prolonged warming of the sea surface and accumulation of thermal stress experienced by coral communities resulting to bleaching and mortality (Wilkinson & Souter, 2008). The assessment in Talim Bay was meant to provide the basis of efforts at managing human impacts on reefs in the face of changes driven by climate change.

MATERIALS AND METHODS

Study area and biophysical profile

Talim Bay, Lian, Batangas is located at the southwestern part of Luzon, Philippines (13°58' N; 120°37' E; Fig. 1). Talim Bay has a total coastline length of about 16 km. The inner bay is 850 hectares in area and bay mouth is approximately 3 km wide. Water currents flow southward during flood tide and northwards during ebb tide. These currents are normally weak due to the Bay's shallow depth and bottom topography (David et al., 2010). Based on the National

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Mapping and Resource Information Authority (NAMRIA, 1979) topographic maps and Google Earth ® satellite images, there is an estimated 183 ha of coral reefs, 225 ha of seagrass, and 30 ha of mangroves in the area. Coral reefs of Talim Bay are of the fringing type and occur at depths of up to 20 m. Talim Bay is home to at least 200 species of corals, which represent about 40% of the 484 species found in the Philippines (http://coenomap.philreefs.org).

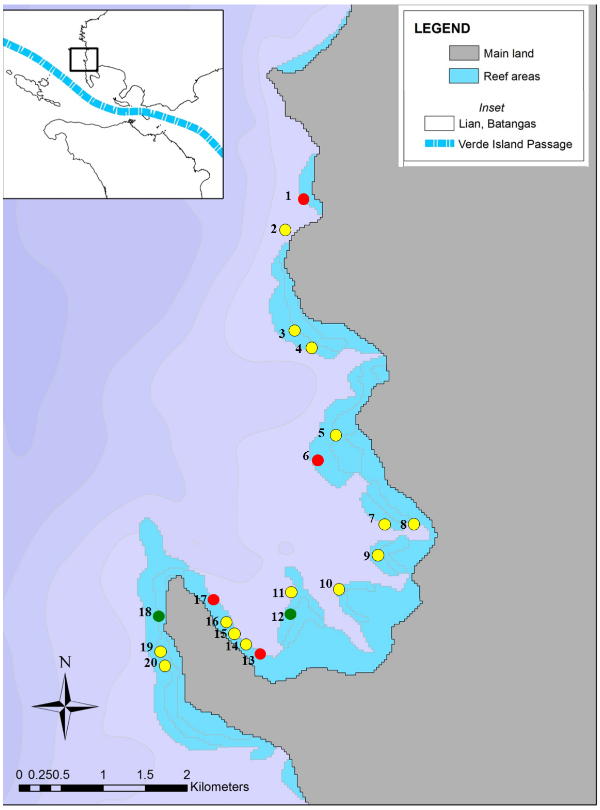

Figure 1. Map of Talim Bay with inset map showing location of Talim Bay, Lian, Batangas in the Verde Island Passage, Philippines. Shown here are the location of sampling stations and corresponding resilience indices (i.e., green: high, yellow: moderate, and red: low resilience).

Information on coral community structure

Data collection was conducted in April 2010. During the conduct of this study, there was an observed increase in sea surface temperature from 28°C to 31°C. There were 20 stations, 100 m to 250 m apart, which were sampled for this study (see Fig. 1). At each station, 20 m transect lines were laid at 2 m depth intervals starting from the shallowest portion of the reef (~1m) down to the reef base (17 m maximum) where hard corals can still be found. Benthic data were gathered using the phototransect method (van Woesik et al., 2009). Coral Point Count with Microsoft Excel extensions (CPCe; Kohler & Gill, 2006) was used to overlay 10 randomly positioned points on each transect photograph to help in estimating percent cover of hard coral, soft coral, fleshy algae, turf algae, crustose-coralline algae, rubble, sand, and silt. Hard corals that were scored were assigned to one of 75 taxonomic amalgamated units (TAUs). These globally standardized TAUS are typically coral genus-growth form combinations for coral taxa recognizable from transect images (van Woesik et al., 2009).

Resistance of coral communities and resilience assessment and ranking

The resistance level of the coral communities in the 20 reef sampling stations was initially computed by assigning the TAUs found to one of three bleaching resistance categories ("low" "moderate" and "high"). An example for resistance is the response of coral taxa to increase in sea surface temperature (SST) which causes coral bleaching. Branching coral species that grow rapidly are more prone to bleaching compared to the slower-growing genera with dome-shaped or encrusting forms. The top ten hard corals that have low resistance to bleaching during an increase in sea surface temperature are: *Millepora* spp., *Isopora* spp., tabular *Acropora* spp., *Pocillopora damicornis*, *Stylophora pistillata*, arborescent *Acropora* spp., *Seriatopora hystrix*, *Pachyseris* spp., *Montipora* – plates, *Merulina* spp. (Marshall & Baird, 2000; Marshall & Schuttenberg, 2006). The coral cover of each of these TAUs were then added to compute an aggregate resistance score per station.

The resilience assessment protocol of Obura and Grimsditch (2009) was also used in this work. The protocol is based on 61 factors grouped into nine (9) indicators of resilience of coral reefs to increase in sea surface temperature. The nine indicator categories are benthic factors (e.g., coral cover, algal cover, other benthos), physical factors (e.g., substrate morphology), coral condition (e.g., current and historic records on mortality, recovery), coral population factors (e.g., size classes, recruitment rates), coral associates (e.g., urchins, other non-fish predators), fish groups (e.g., herbivores), connectivity factors (e.g., dispersal patterns, presence of adjacent reef), anthropogenic factors (e.g., fishing pressure, nutrient loading, sedimentation), and management intervention.

Data for the benthic factors were gathered using the photo-transect method described earlier. A detailed coral community structure study will be presented in a separate paper (España et al., in prep.), only relevant data and information to elucidate bleaching resistance such as coral cover and diversity was used here. Quibilan, M.C. (coral settlement rates), Hilomen, V.V. (reef fish abundance and diversity), David, L.T. (physical setting), Villanoy, C.L. (hydrography and currents), Siringan, F.P. (geo-morphology and sediment dynamics) provided unpublished data and information that supplemented the authors' observations and anecdotal information gathered from interviews of local residents.

Resilience was assessed by assigning scores for each indicator using the 5-point Likert scale wherein a score of 1 designates low/poor/negative condition and a score of 5 designates a high/good/positive condition. For indicators which can be quantified, scores were based on the range and distribution of measurement values (e.g., of coral cover and coral size-distribution). The average scores for all the resilience indicators was used to produce a ranking of the stations from highest to lowest overall resilience. The average scores for each indicator across all the 20 stations were also computed in order to identify which indicators had more influence on the resilience ranking. Detrended correspondence analysis (DCA; using PC-Ord ® ordinations) was also used to better visualize the patterns in the assessed resilience. The difference between the minimum and maximum average scores was divided by three in order to get a range and further classify resilience as low, moderate, or high.

RESULTS AND DISCUSSION

Overall, Talim Bay coral reef stations were characterized by 67% algae (mostly algal turfs), 20% hard coral, and 13% abiotics (i.e., silt, rock) including soft corals and other organisms. Of the 20% hard coral cover, 9% were categorized to have high bleaching-resistance, 6% moderate and 5% were low (Fig. 2).

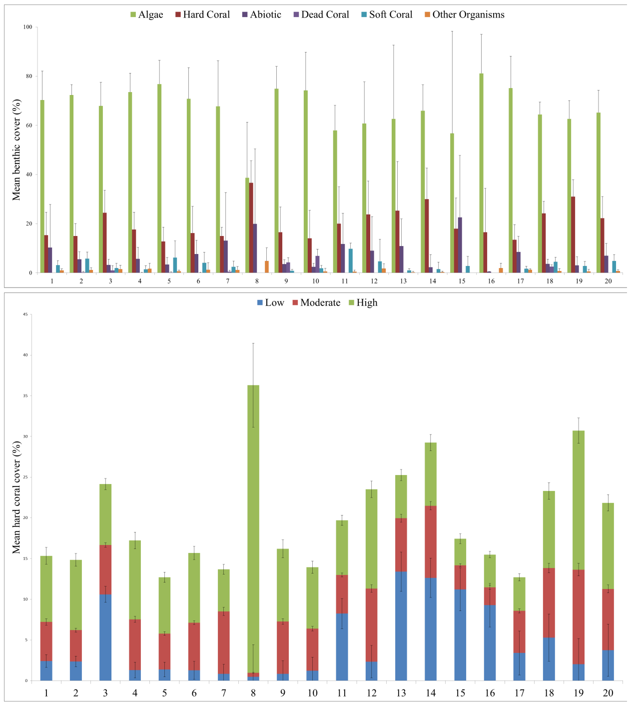

Figure 2. Top panel: Mean benthic cover across stations; Lower panel: Abundance of high-, moderate- and low-resistant coral species across stations. Error bars indicate standard deviation. Refer to study area map for the location of each station in the Bay.

Most of the stations located outside the bay (northeastern: Station 1, 2, 4 to 9 and southern: 18, 19 and 20) were dominated by high bleaching-resistant corals such as *Diploastrea heliopora*, *Heliopora coerulea*, *Favites* spp., and massive *Porites*; except for station 3 which had high abundance of bleaching-prone corals such as tabulate and corymbose *Acropora* spp. The stations at the central part of the bay (stations 10 to 17) were dominated by moderate bleaching-resistant corals such *Goniastrea* spp., *Favia* spp., *Favites* spp., and *Platygyra* spp.; and bleaching-prone corals such as *Acropora* and *Montipora*. High coral cover (36%) of lagoon species massive *Porites*, *Pavona frondifera*, and *P. decussata*) made Station 8 unique (Fig. 2, Table 1).

The station with the highest resilience score was station 18 and the lowest score was at station 16 (Table 2). DCA analysis superimposing the average scores for each of the resilience variables showed that resilience varied across stations because of differences in coral cover, the abundance of bleaching-resistant species,

TABLE 1. Summary of bleaching resistance levels of corals species, and coral cover (abundance) across the sampling stations.

Resistance level	TAUs | Stations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
High	*Diploastrea heliopora Galaxea fascicularis Heliopora coerulea Fungia* spp. *Pavona* spp. *Porites* massive *Turbinaria* spp.	8	9	7	10	7	9	5	35	9	8	7	12	5	8	3	4	4	9	17	11
Moderate	*Goniastrea* spp. *Favia* spp. *Platygyra* spp. *Favites* spp.	5	4	6	6	4	6	8	0	6	5	5	9	7	9	3	2	5	9	12	8
Low	*Acropora* branching *Acropora* corymbose *Acropora* tabulate *Montipora* encrusting *Pocillopora* spp.	2	2	11	1	1	1	1	0	1	1	8	2	13	13	11	9	3	5	2	4
	Total coral cover	**15**	**15**	**24**	**17**	**13**	**16**	**14**	**36**	**16**	**14**	**20**	**23**	**25**	**29**	**17**	**15**	**13**	**23**	**31**	**22**

TABLE 2. Summary of ranking and resilience scores for all stations and the indicators that influence resilience.

Stations	Rank	Total score	Resilience indicators								
			Benthic	Physical	Coral Condition	Coral Population	Coral associates	Fish groups	Connectivity	Anthropogenic	Management
18	1	27.0	4.2	3.4	4.2	2.2	3.3	2.0	2.8	3.3	1.7
12	2	26.2	3.2	3.1	2.4	3.7	3.3	2.0	3.6	3.3	1.7
11	3	25.7	3.2	3.1	2.6	3.0	3.3	2.0	3.6	3.3	1.7
10	4	25.6	2.4	3.0	4.2	2.2	3.3	2.0	3.6	3.3	1.7
14	5	25.5	3.2	3.1	2.6	2.8	3.3	2.0	3.6	3.3	1.7
8	6	25.4	2.6	2.6	4.2	2.2	3.3	2.0	3.6	3.3	1.7
7	7	25.4	2.4	2.8	4.2	2.2	3.3	2.0	3.6	3.3	1.7
19	8	25.2	3.8	3.4	1.8	3.2	3.3	2.0	2.8	3.3	1.7
3	9	25.1	3.0	3.4	2.8	2.8	3.3	2.0	2.8	3.3	1.7
20	10	25.1	3.6	3.4	2.2	2.8	3.3	2.0	2.8	3.3	1.7
6	11	25.0	2.8	2.7	2.8	2.8	3.3	2.0	3.6	3.3	1.7
4	12	24.7	2.8	3.4	2.6	2.8	3.3	2.0	2.8	3.3	1.7
15	13	24.6	1.8	2.9	4.2	1.8	3.3	2.0	3.6	3.3	1.7
5	14	24.6	2.8	2.7	2.4	2.8	3.3	2.0	3.6	3.3	1.7
9	15	24.6	2.6	2.7	4.2	2.0	3.3	2.0	2.8	3.3	1.7
2	16	24.5	2.8	3.3	2.6	2.8	3.3	2.0	2.8	3.3	1.7
13	17	24.1	2.0	2.9	2.6	2.7	3.3	2.0	3.6	3.3	1.7
17	18	23.9	2.2	2.8	2.2	2.8	3.3	2.0	3.6	3.3	1.7
1	19	23.6	2.2	3.3	2.4	2.7	3.3	2.0	2.8	3.3	1.7
16	20	23.3	2.2	2.9	2.4	2.7	3.3	2.0	2.8	3.3	1.7
Average score			2.8	3.0	3.0	2.7	3.3	2.0	3.2	3.3	1.7

coral recruitment rate, transport, and presence of adjacent coral reefs thereby improving connectivity, and cooling and flushing promoted by the topography of the reef (Fig. 3).

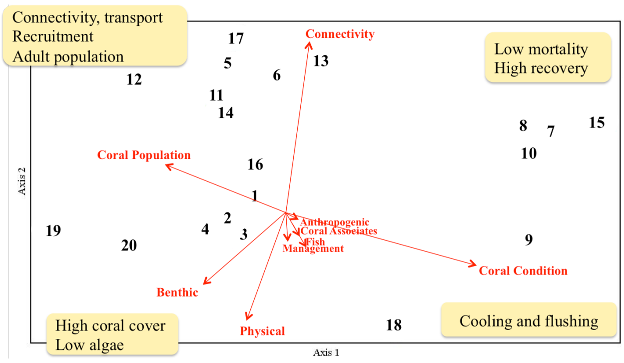

Figure 3. DCA biplots showing the influence of ecological and environmental variables to the resilience of the coral communities in the sampling stations.

Classifying resilience scores showed that two stations (stations 12 and 18) had high resilience, four stations (stations 1, 6, 13 and 17) with low resilience, and the rest of the 14 stations had moderate resilience (see Fig. 1). High resilience is attributed to high coral cover, abundance of bleaching resistant corals such as *Fungia* spp. (e.g., station 12), close proximity to deeper, cooler water (e.g., station 18) where nutrient levels are low and benthic quality is favorable for coral recruits to settle (Graham et al., 2015). Stations with moderate resilience had high species diversity and also abundance of bleaching-resistant corals such as massive *Porites*, *Symphyllia* spp., *Favia* spp., *D. heliopora* and *H. coerulea*. Some of these stations are located outside the bay (e.g., stations 2, 3, 4, 19 and 20) with deep reef bases, unobstructed water movement and continuous flushing. The stations which exhibited low resilience had low coral cover and species diversity (e.g., station 6), low potential for acclimatization of corals to temperature due to a shallower reef base (stations in the inner bay), high sedimentation (e.g., station 13 and 17), occasional exposure during low tide, and a high cover of bleaching-prone coral species (e.g., tabulate, branching *Acropora*).

The average scores of the resilience indicators showed that anthropogenic pressures, such as sedimentation and nutrient loading, had a high impact on the resilience of the reef in Talim Bay (Table 2). High sedimentation in this part of the bay is brought about by coastal run-off from denuded land; farming and sugar cane plantations; and the building of hard structures (e.g., groynes and small docks for tourist boats). The latter structures have altered water movement and the distribution of sediments inside the bay. Areas in Talim Bay that can directly benefit from management interventions are those with high and moderate resilience, especially those situated in the inner bay (e.g., station 10, 11, 14, 15 and 16). Regulation of the construction of hard structures, as well as the protection and rehabilitation of coastal vegetation (e.g., through mangrove planting) should help reduce sedimentation. Another possible mitigation measure is the reduction of fishing pressure, which will allow for the recovery reef fishes stocks, especially those of herbivores which feed on algae and provide more space for coral recruits (Szmant, 2002).

This study shows that overall resilience of Talim Bay is driven by the current state of the coral community (i.e., high abundance of bleaching-resistant corals) and the physical attributes of the reef that contribute to acclimatization of corals, and cooling and flushing of coral habitats. In undertaking a resilience assessment, we were able to characterize the sensitivity of corals to thermal stress and its implications to overall resilience to a combination of exacerbating threats (e.g. siltation, overfishing). Management should consider using the approach taken in this work as a baseline for assessing progress of management interventions. Coastal management efforts should be geared towards addressing anthropogenic stressors and in the long-term, improving overall coral reef resilience through integrated management.

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CONFLICTS OF INTEREST

None

CONTRIBUTION OF INDIVIDUAL AUTHORS

España, N.B. collected and analyzed the data, and led the writing of this manuscript. Licuanan, W.Y. supervised in the collection of data. Both Licuanan, W.Y. and Aliño, P.M. contributed to the conceptualization of the research, sampling design, and revision of the manuscript.

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