Philippine Journal of Science
150 (1): 139-143, February 2021
ISSN 0031 - 7683
Date Received: 30 Jun 2020

RESEARCH NOTE

Changes in Benthic Cover in the South Atoll of Tubbataha Reefs due to Possible Eutrophication

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The Tubbataha Reefs Natural Park is of global and local importance and is a benchmark and aspirational model for the condition of reefs within an MPA. Recently, small but significant overall declines in hard coral cover (HCC) and increases in algae were detected in Tubbataha. Changes were most consistent in Site 4 at the South Atoll, where lagoon waters drain through during ebb tide. Space available to corals here was covered by cyanobacteria in 2018, and then by sponges in 2019. These sponges have begun to overgrow coral. These changes in Site 4 are likely due to an increase in guano-derived nutrients in the lagoon waters of the South Atoll. They may initiate a continuing decline in corals and, thus, require enhanced monitoring.

Keywords: benthic cover, coral reefs, eutrophication, monitoring, seabirds

The Tubbataha Reefs Natural Park, a UNESCO World Heritage Site, is the largest and best-managed no-take marine protected area in the Philippines (Dygico *et al.* 2013). The 970.3-km^2 park consists of 100 km^2 of reefs and is situated in the Sulu Sea, which itself is globally known for its high diversity of corals (de Vantier and Turak 2017). The coral reefs in the marine park appeared to be resilient to thermal stress since no significant changes in HCC and diversity were detected despite ocean warming (Licuanan *et al*. 2017). HCC and diversity in Tubbataha were so high and stable from 2012–2015 that the park was declared a benchmark and aspirational model for the condition of reefs within an MPA (Licuanan *et al.* 2017). Average HCC and diversity there were, thus, used as bases to define assessment scales for reef status [*i.e.* an HCC Category B reef has more than the then average HCC of Tubbataha, which was 33% (Licuanan *et al.* 2017, 2019)].

However, there was an annual 1.1% decrease in HCC from 2012–2019 in four monitoring sites of the North and South Atolls in Tubbataha (Figure 1; two-level repeated measures ANOVA year: $F_7 = 2.54$, $p < 0.05$; site x year: $F_{21} = 2.09$, $p < 0.05$). Each monitoring site is made up of two 75 m x 25 m monitoring stations, and each station is sampled using five randomly deployed 50 m x 1 m photo-transects [methods are described in Licuanan *et al.* (2017)]. In contrast, the cover of algal assemblages (mainly turf algae) in the same four sites increased 1.9% over the same period (year: $F_7 = 52.461$, $p < 0.0001$; site x year: $F_{21} = 3.064$, $p < 0.01$). The significant interaction term indicates the patterns in HCC and algal assemblages varied per site per year (Figure 2a). Much of these patterns were driven by changes in Site 3 (South Atoll), where there was a 23% decline in HCC between 2015 and 2017 due to damage from drifting logs and metal buoys. Of concern in this report are the smaller changes since 2017, particularly in monitoring Site 4 (South Atoll), where consistent losses in HCC of 1.1% per year were measured since 2012 ($F_{79} = 6.64$, $p < 0.05$) and where the cover of algal assemblages is highest (Figure 2a). These shifts in the transect data of Site 4 are mirrored in the changes in cover within a fixed 4 m x 4 m plot (geographic coordinates 8.80656 N, 119.82169 E) in Site 4, Station B that is used to monitor minute changes with high statistical power [at least 80% power

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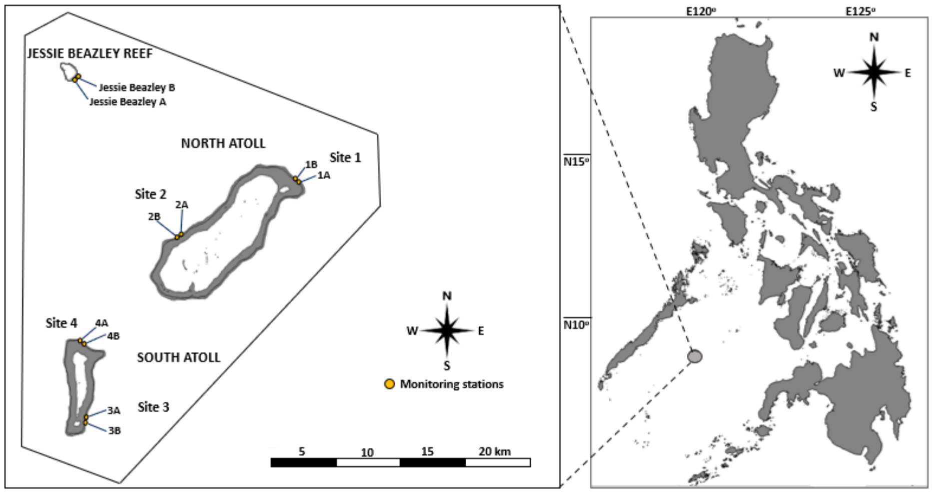

Figure 1. Map of the Tubbataha Marine Natural Park, the four monitoring sites, and the two monitoring stations within each site.

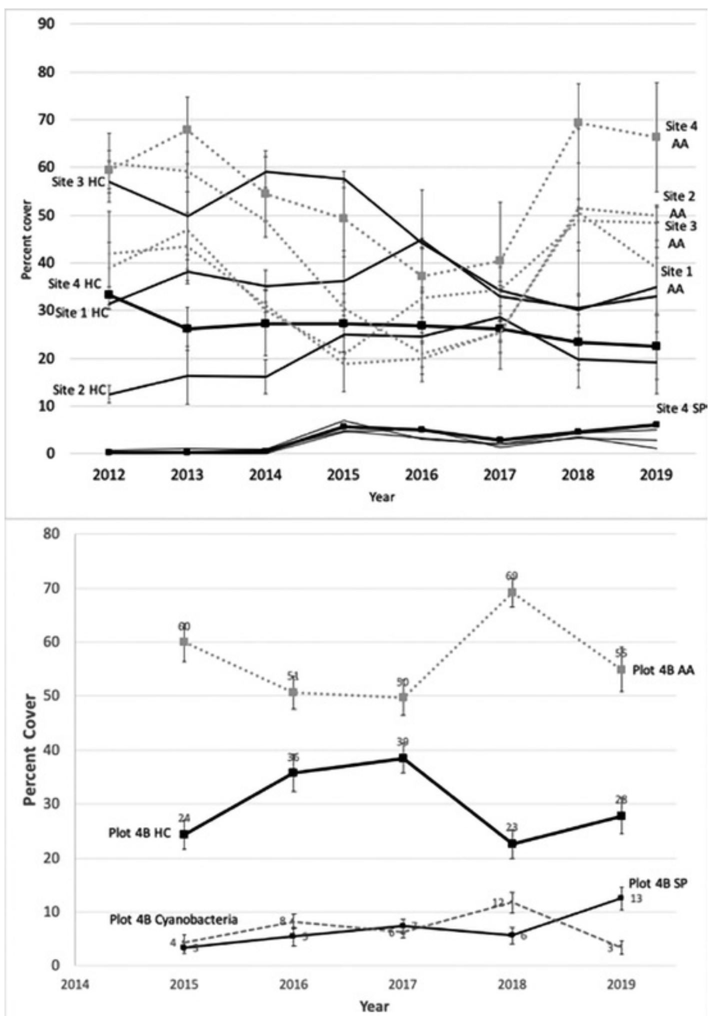

Figure 2. Cover of hard coral (HC), algal assemblages (AA; includes turf algae and cyanobacteria), and sponges (SP) in the monitoring sites (Figure 2a; upper panel) and in a fixed 4 m x 4 m plot in Station B of Site 4 (Figure 2b; lower panel). Cyanobacteria is plotted separately in Figure 2B. Error bars (where shown) represent ± 1 standard error and were computed from the two stations per site in Figure 2a, and the 30 frames scored per year in Figure 2b. Square markers denote Site 4 data.

for at least 6% absolute change in cover; see Raymundo *et al*. (2018) for the methods used for the fixed plots]. HCC here declined by 16%, and algal assemblages increased by 19% in 2018 (Figure 2b). Sponge cover then increased by 7% the following year. The nature of the changes in Site 4 is the concern of this report since it may presage a shift in the composition of the benthic community. Water in Site 4 becomes relatively warm and turbid during ebb tide, indicating South Atoll lagoon waters drain out in this vicinity. The rocky bottom there that was not occupied by corals and turf algae became covered by filamentous cyanobacteria, possibly *Lyngbya*, in 2018 (Figure 3). Cover of cyanobacteria in the fixed plot increased from 6% in 2017 to 12% in 2018. These rocky areas then became covered by yet unidentified sponges in the following year (Figure 3). The coral-killing cyanobacteriosponge *Terpios hoshinota* was also identified as overgrowing corals in Site 3 (Figure 4). These small changes may indicate that the water in the lagoon of the South Atoll is slowly becoming eutrophic, with increased nutrient levels and consequent shifts in the plankton and benthic communities (Bell 1992; Albert *et al.* 2005). These changes may initiate a continuing decline in corals. For example, outbreaks of sponges can affect coral larvae's ability to settle and recruit on the reef by pre-empting space and outcompeting them (Brandt *et al.* 2019), aside from impairing photosynthesis

Figure 3. Close-up images of the filamentous cyanobacteria and sponges in Site 4. Notice the sponge overgrowing coral (right). The ruler shown is in cm.

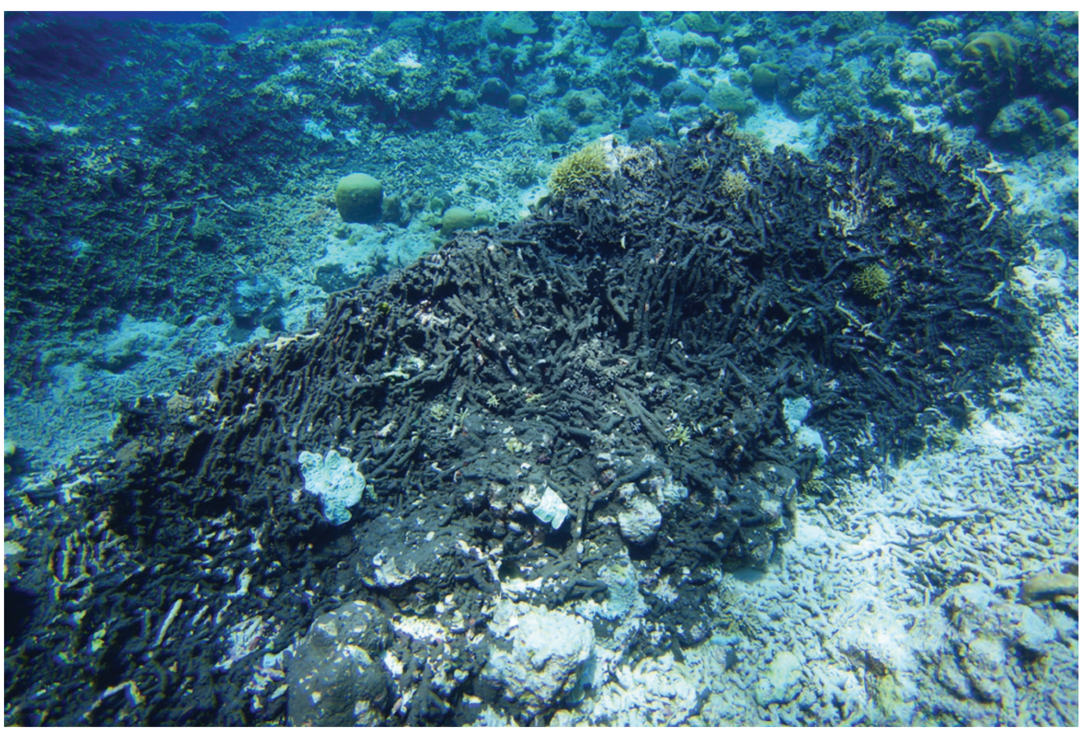

Figure 4. A patch of *Terpios hoshinota* overgrowing coral (mostly *Isopora brueggemanni*) in Site 3. Notice some corals and tunicates growing over the *Terpios*. The *Terpios* patch is about 5 m x 1 m in dimension.

of coral symbionts (Pawlik *et al.* 2007) and overgrowing coral directly (Plucer-Rosario 1987).

Eutrophication is not the only possible explanation for these subtle changes in the South Atoll but is the explanation most consistent with the data and observations. Ocean warming and resulting mass coral bleaching may also explain the declines in HCC. Warming, however, is typically seen at larger scales (Peñaflor *et al.* 2009) and, thus, its effects should have also led to declines in HCC in the North Atoll of Tubbataha. However, HCC in Site 1 in the North Atoll did not change, and HCC increased in Site 2 ($F_{79} = 7.80$, $p < 0.01$). The composition of the coral assemblages is similar in Sites 2 and 4. Localized declines in HCC could also be caused by crown-of-thorns starfish (COTS) outbreaks and, indeed, there was a small outbreak near Site 3 in 2018. However, the park rangers have not recorded COTS at Site 4, and no declines of *Acropora* – a preferred prey of COTS (Pratchett *et al.* 2017) – have been detected there either.

Neither bleaching nor COTS could account for the spikes in the abundance of cyanobacteria and sponges. The increase in nutrients that could have fed these spikes (Ward-Paige *et al.* 2005; Schils 2012) may have come from seabird droppings (Albert *et al.* 2005), especially at the nesting site in the South Islet, South Atoll. Nutrient elevation due to bird guano has been reported in other atolls and fringing reefs (McMahon and Santos 2017; Graham *et al.* 2018; Benkwitt *et al.* 2019; Savage 2019). Counts of most seabirds in Tubbataha have increased since 2012 (Jensen *et al.* 2019), and this has led to the death of most trees in the South Islet, likely due to guano's excessive enrichment of the soil (A Songco, pers. comm.). This loss of trees resulted in fewer birds nesting in the islet since 2016 (Jensen *et al.* 2019), but the nutrients from the guano may have already leached into the ground. Like in Heron Island (McMahon and Santos 2017), these nutrients are slowly infiltrating into the groundwater of the South Islet and being released into the sea. At some point, the nutrients might trigger a phase shift of the coral community to an algae-dominated stage. Although the considerable grazer biomass of Tubbataha could potentially hold off this shift [see Savage (2019)], the nutrients could also fuel COTS outbreaks (Pratchett *et al.* 2017), adding to the stresses imposed by ocean warming and acidification (Keesing *et al.* 2019). Monitoring of water quality in and around the lagoons of Tubbataha, the macrophyte communities on the reef flats, and the reef fish and benthos on the reef slope must thus be continued, if not intensified, so that we may detect possible imbalances occurring in this globally-significant reef ecosystem in the Philippines. Recent studies suggest the increases in the abundance of cyanobacteria and sponges in reefs are more widespread and not reversible (Knapp *et al.* 2016; Malakar *et al.* 2020) and potentially reinforce each other (de Bakker *et al.* 2017). Monitoring may reveal that the large size and high larval connectivity levels in Tubbataha, coupled with good park management practices, will buffer the reef from more changes in coral cover and diversity. Unfortunately, the global pandemic precluded the authors from joining the monitoring in 2020.

ACKNOWLEDGMENTS

We thank the present and past members of the SHORE Center team for their assistance in the fieldwork and processing of images, and their comments on the manuscript. We also thank the Tubbataha Protected Area Management Board; Angelique Songco and staff of the Tubbataha Management Office; and the officials and personnel of the World Wide Fund for Nature – Philippines and its research vessel M/Y Navorca, particularly Joel Palma, Marivel Dygico, and Ronald de Roa. WY Licuanan is the holder of the Br. H. Alfred Shields FSC Professorial Chair in Biology and Br. Cresentius Richard Duerr FSC Professorial Chair in Biochemistry. The Commission on Higher Education DARE-TO Collaboration On Resource Management among Academe and Local Communities (CORAL) Project supported SE Bahinting.

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