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Tracing Coral Reefs: A Citizen Science Approach in Mapping Coral Reefs to Enhance Marine Park Management Strategies

Chai Ming Lau[1], Abdul Adzis Kee-Alfian[2], Yang Amri Affendi[3], Julian Hyde[1], Alvin Chelliah[1,4], Yun Sing Leong[1], Yin Lee Low[1], Putri Asma Megat Yusop[5], Ven Thye Leong[1], A. Mohd Halimi[4], Yaman Mohd Shahir[4], R. Mohd Ramdhan[6], Ai Gaik Lim[7] and Noor Ikhwanie Zainal[7]*

[1] Reef Check Malaysia, Kuala Lumpur, Malaysia, [2] SEAlutions Sdn Bhd, Kuala Lumpur, Malaysia, [3] Institute of Ocean and Earth Sciences, University of Malaya, Kuala Lumpur, Malaysia, [4] Tioman Marine Conservation Group (TMCG), Reef Check Malaysia, Kuala Rompin, Malaysia, [5] Institute of Oceanography and Environment, Universiti Malaysia Terengganu, Kuala Terengganu, Malaysia, [6] B&J Diving Centre, Kuala Rompin, Malaysia, [7] Department of Fisheries, Ministry of Agriculture and Agro-based Industry, Putrajaya, Malaysia

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Edited by:
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***Correspondence:**
Chai Ming Lau
edmund@reefcheck.org.my;
e_lcm@yahoo.co.uk

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Effective marine park management and protection of coral reefs can only happen if managers have adequate knowledge of reef health and area. However, obtaining such information is labor intensive and difficult with limited funding and time. Reef Check Malaysia was engaged by Department of Marine Parks Malaysia to map the coral reefs surrounding Tioman Island Marine Park and document health status and site specific threats. To achieve this, we utilized the Reef Check survey method, a simple, rapid and holistic standardized reef monitoring protocol based on scientific principles. This method is suitable where funds and time are limited. A total of 95 sites surrounding Tioman Island were surveyed with the assistance of certified Reef Check EcoDiver volunteers and representatives from local stakeholders. This citizen science approach proved successful and generated a baseline map revealing a difference in the health of coral reefs between the west and east sides of Tioman Island, where the West had $<25\%$ live coral cover as compared to $>50\%$ on the East. Combined with data on indicator fish and invertebrates, as well as human and natural impacts, the results suggest that Tioman Island should be separated into three distinctive conservation priority zones to enhance management strategies of this marine park. This is an example of an innovative way to engage and involve local stakeholders in planning conservation and management strategies.

Keywords: citizen science, marine protected area management, reef check, coral reef mapping, geographic information system

INTRODUCTION

Coral reefs around the world are facing growing threats from changes to the environment through climate change (Praveena et al., 2012; Rinkevich, 2015). Mass coral bleaching events have become more frequent, affecting reefs worldwide (Tun et al., 2010). Many scientists have called for more frequent monitoring of coral reefs in order to better manage this crisis (Tun et al., 2010). There is also a need to improve mapping of coral reefs which will contribute to a better understanding of connectivity among networks of MPAs. Knowing the extent of reefs in an area can also help to focus management activities, especially in managing the limited resources available.

Around the world, many researchers and scientists have engaged non-scientist volunteers who are able to assist in data collection and compilation for scientific projects (Bonney et al., 2014). Such citizen science programs are very much underutilized (Cigliano et al., 2015) although information from such programs can be of great contribution to projects that have limited resources available. Reef Check is a citizen science tool created to include the participation of non-scientists in a scientific monitoring exercise (Hodgson, 1997, 1999, 2001; Hodgson and Stepath, 1998; Hodgson and Wilkinson, 2001). There are many monitoring and scientific survey exercises that use Reef Check data for management and better understanding the changes that are rapidly occurring in many reefs, especially in this region (Hodgson and Wilkinson, 2001; Hill and Wilkinson, 2004; Wilkinson, 2008; Wood and Dipper, 2008; Hughes et al., 2010; Wetzelhuetter et al., 2014). This paper elaborates on baseline data collected for coral reef status in Tioman utilizing the Reef Check method. Surveys were conducted with the assistance of local community stakeholders and volunteers, who represent the "citizen science" part of the program.

Tioman is one of the most popular tourist destinations in Malaysia, receiving some 250,000 visitors per year (Department of Marine Park Malaysia, 2017). With 81 resorts and 36 dive centers, mostly congregated on the western side, Tioman has become one of the top destinations for marine recreational activities. Tioman has been a marine protected area (MPA) with a no-take approach since being gazetted in 1994. After more than 20 years, there was a need to review the MPA approach and designating zones within MPA is one of the new approaches being considered. However, without a clear coral reef map of Tioman, it is difficult to assign zones. Therefore, the objectives of this work are (1) to develop a baseline coral reef map along the Pulau (= island) Tioman coastline, (2) to identify priority areas of coral reefs for effective management and (3) to demonstrate the importance of citizen science involvement in providing valuable management information.

METHOD

Study Sites

This study was conducted at Pulau (= island) Tioman, Malaysia. The island is situated between 02°48′52.1′′ N, 104° 10′29.3′′ E which is approximately 32 km off the east coast of Peninsular Malaysia, in the state of Pahang. The waters surrounding the island extending to 2 nautical miles from the coastal line were gazetted as a Marine Park in 1994 under the Fisheries Act, 1985.

For this study, a total of 95 sites were surveyed along the island's coastline of approximately 55 km with a distance of 500 m between each transect points. The surveys were conducted over 32 days by a team of surveyors comprising marine biologists and volunteers (both local islanders and others).

Reef Check Method With Minor Modification

This survey was conducted using the Reef Check protocol, which utilizes the concept of indicator species and is an eco-holistic approach in which three components of the reefs are recorded, namely fish, invertebrates and substrate (Hodgson, 1999). At each site, a 100 m transect is laid perpendicular to the shore. The transect is separated into four segments of 20 m with a 5 m gap in between segments. For both fish and invertebrates, assessments are conducted as a 5 m wide belt transect along each segment. For substrate, a Point Intercept Transect (PIT) is conducted at 0.5 m intervals along each of the segments with the assistance of a plumb line to remove observer bias. The benthic category touched by the plumb at each data point is recorded. The depth of the reef along the 100 m transect is recorded at the start and end points of every segment.

For the purpose of this survey, an additional category was added for a better representation of the study objectives. Dead coral (DC) is listed as an additional category instead of being categorized as rock (RC) under the standard 10 substrate categories in Reef Check.

Quality Control

All volunteers have been trained and certified following the standard training procedure of Reef Check Eco-Diver to ensure a minimum 80% correct identification of indicator species and substrate categories. All Eco-Divers were also required to have good diving skills, particularly buoyancy.

Data Analysis and Mapping

The data for substrate, fish and invertebrates were used to plot the baseline map, each group of indicators being classified into different categories. The Coral Reef Health Criteria (Chou et al., 1994) were used for the classification of substrate. The percentage of live coral cover (LCC), which is the sum of percentage of hard coral (HC) and soft coral (SC) were separated into four classes, each with a different rating, as follows:

(a) 0–25%: Poor;
(b) 26–50%: Fair;
(c) 51–75%: Good;
(d) 75–100%: Excellent.

The dead coral cover (DCC) was also subjected to the same class, however, with an inversed rating from LCC. The data of LCC and DCC formed the basis of the geographic information system (GIS) mapping using QGIS software for visual interpretation. As for fish and invertebrate indicators, only Parrotfish and Long-spined Sea Urchins (Diadema) were selected and plotted onto the map, respectively. The abundance of these two organisms were classified into classes based on other studies as a metric of healthy population (Carreiro-Silva and Mcclanahan, 2001; Bonaldo et al., 2017). For Parrotfish, abundance that is <5 ind.500 m^3 is considered unhealthy population while abundance with >15 ind.500 m^3 is considered healthy. For LSU, abundance with <6 ind.100 m^2 is healthy, abundance of 6 to 60 is moderate while abundance that is >60

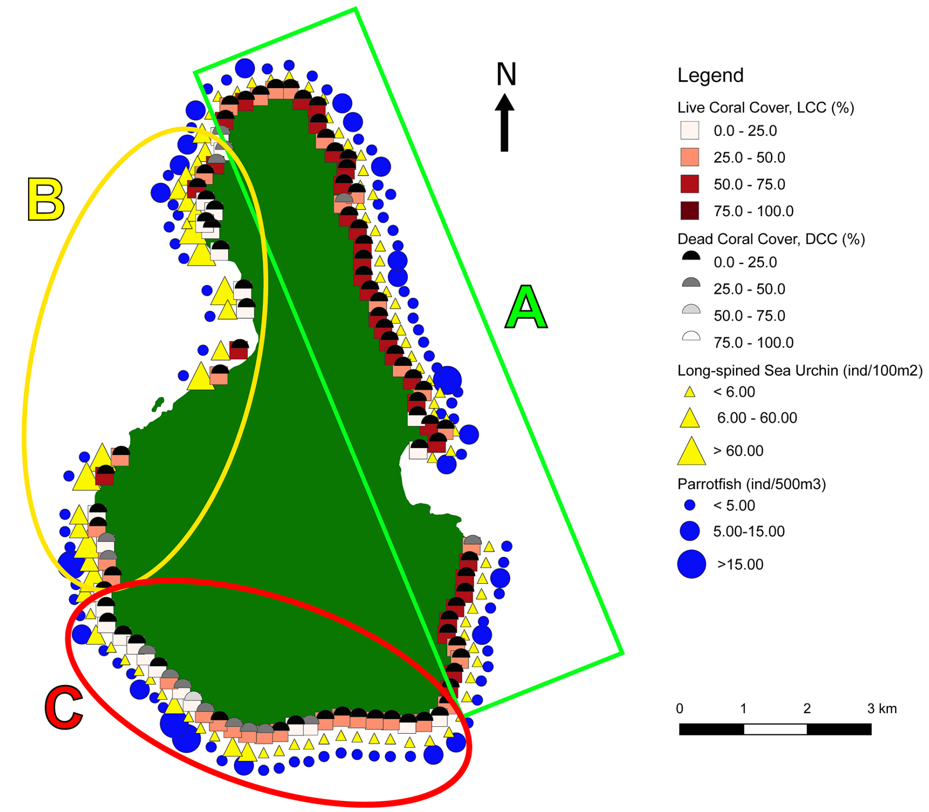

FIGURE 1 | Map showing four Reef Check indicators (Live Coral Cover, Dead Coral Cover, Long-spined Sea Urchin and Parrotfish) at each of the 95 survey sites, with three distinctive zones of **A** (green), **B** (yellow) and **C** (red) determined via visual analysis.

ind.100 m^2 is deemed unhealthy. All classifications and their respective values are presented on the map in **Figure 1**.

The percent cover of LCC and DCC as well as abundance of Parrotfish and Diadema were compared with a non-parametric Kruskal–Wallis test in which the fixed factor were the zones established from the visual interpretation of the GIS plotted map. When differences were significant, a *post hoc* Dunn test with Bonferroni adjustment method were used. All statistical analysis was conducted using R (R Core Team, 2019).

RESULTS

Substrates

Our survey estimated that Tioman is surrounded by an area of 5.46 km^2 of fringing reef. The biotic substrate composition of this area of coral reef is comprised of 32.3 ± 1.7% (mean ± SE) of HC, 6.4 ± 0.7% of SC, 2.2 ± 0.3% of nutrient indicator algae (NIA) followed by 1.0 ± 0.2% of sponge (SP) and 0.6 ± 0.1% of others (OT). Meanwhile, the abiotic substrate composition of the coral reef is 0.4 ± 0.1% of recently killed coral (RKC), 15.5 ± 1.0% of DC, 8.2 ± 0.8% of rock (RC), 7.0 ± 0.9% of rubble (RB), 20.8 ± 2.0% of sand (SD) and 5.7 ± 1.5% of silt (SI) (**Figure 2**). The average percentage of LCC for Tioman determined from this study is 38.8 ± 2.0% which falls into the rating of "Fair" under the Coral Reef Health Criteria.

Fish Indicators

There are nine indicator fishes listed under the Reef Check method and in this study, Butterflyfish (Chaetodontidae) topped the list in terms of abundance at a mean of 6.65 ± 0.53 ind.500 m^{-3} (mean ± SE). The second highest abundance is Parrotfish (Scaridae) observed at a mean of 4.33 ± 0.67 ind.500 m^{-3} followed by Snapper (Lutjanidae), Grouper (Serranidae) and Bumphead Parrotfish (*Bolbometopon muricatum*) at 0.92 ± 0.20, 0.71 ± 0.11 and 0.07 ± 0.04 ind.500 m^{-3}, respectively. The lowest abundance of fishes recorded are Moray eels (Muraenidae) and Sweetlips (Haemulidae) at only 0.05 ± 0.01 and 0.03 ± 0.01 ind.500 m^{-3} while Humphead Wrasse (*Cheilinus undulatus*) and Barramundi Cod (*Cromileptes altivelis*) were not found at all during the entire survey (**Figure 2**).

Invertebrate Indicators

Out of the nine Reef Check indicator invertebrates, only five were observed during this study. The highest abundance observed is the Long-spined Sea Urchins (LSU; comprised of the genus Diadema and Echinotrix) with an average of 15.02 ± 3.61 ind.100 m^{-2} (mean ± SE) followed by Sea Cucumbers (only three

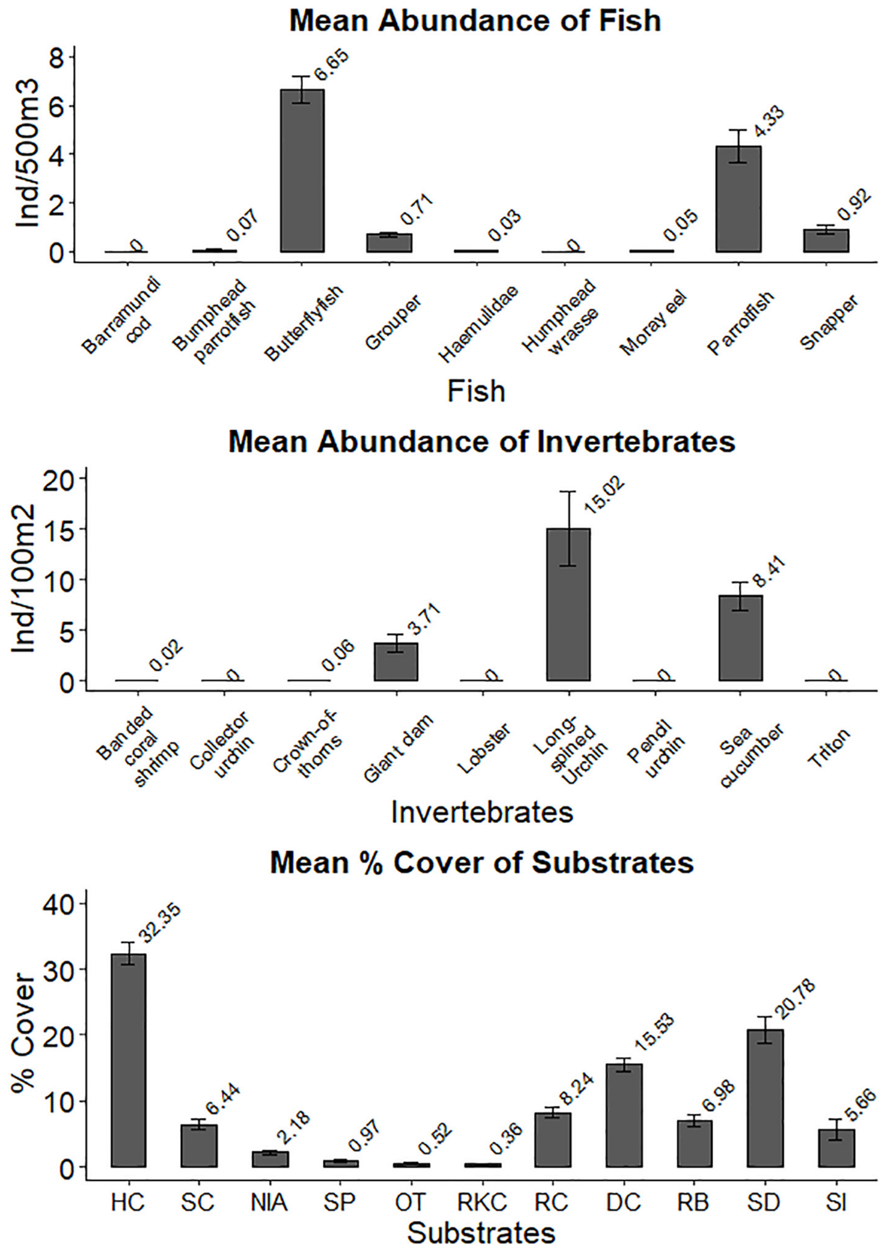

FIGURE 2 | Mean abundance (mean ± SE) of all Reef Check indicators for fish (individual/500 m^3) **(top)**, invertebrates (individual/100 m^2) **(middle)** and percentage coverage (mean ± SE) of Reef Check substrate categories (%) **(bottom)** for Pulau Tioman (*n* = 95).

species taken into account namely *Holothuria edulis*, *Stichopus chloronotus* and *Thelenota ananas*) and Giant Clams (*Tridacna* spp.) with 8.41 ± 1.39 and 3.71 ± 0.87 ind.100 m^{-2}. Only 0.02 ± 0.01 individuals of Banded Coral Shrimp (*Stenopus hispidus*) were observed within 100 m^2 while Crown-of-Thorns Starfish (*Acanthaster planci*) comprised 0.06 ± 0.02 ind.100 m^{-2} (**Figure 2**).

Map

The map shows the different classes for the four main indicators namely LCC, DCC, long-spined urchin (LSU) and Parrotfish at each of the 95 survey sites (**Figure 1**). The different color tones of square and semi-circle symbols indicate the different classes for LCC and DCC, respectively. For LSU and Parrotfish, the different sizes of triangle and circle symbols indicate the respective different abundance classes. For the purpose of this study, the overall reef health is represented by a combination of all four indicators. Sites with higher percentage of LCC and lower percentage of DCC as well as higher abundance of Parrotfish and lower abundance of LSU are considered to be healthy. In contrast, sites with low LCC, high DCC, low abundance of Parrotfish and high abundance of LSU are considered to be less healthy.

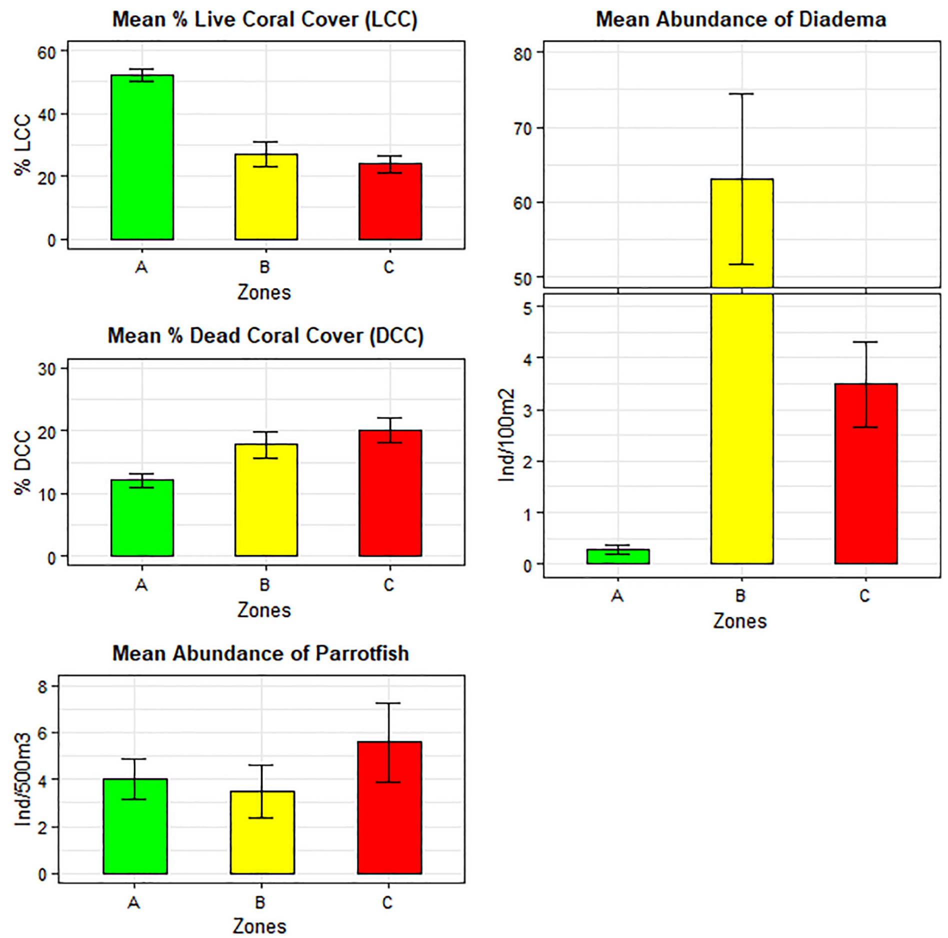

FIGURE 3 | The percentage coverage (mean ± SE) of Live and Dead Coral Cover (% cover), and abundance (mean ± SE) of Parrotfish (individual/500 m^3) and Diadema (Long-spined Sea Urchin) (individual/100 m^2) in the three respective zones (A, B, and C) determined in this study.

Zoning

The zoning on the map is determined using visual analysis on the classification of LCC and DCC, followed by LSU and Parrotfish. A clear pattern can be observed for LCC, DCC and LSU but not so for Parrotfish. Most of the sites with LCC in the 50–75% class or "Good" rating congregated at the north and east of Tioman. Meanwhile a majority of the sites with LCC rated as "Fair" and "Poor" (classified <50%) clearly congregated at the south and slightly scattered on the west. Sites with high DCC (>50%) are congregated on the south. LSU have a different pattern where sites with high abundance (>60.00 ind.100 m^{-2}) are congregated almost exclusively only on the west, whereas all other sites have low abundance (<6.00 ind.100 m^{-2}). There is no clear pattern observed for Parrotfish as sites with the highest abundance are scattered around Tioman. Hence, following the visual analysis of the patterns of LCC, DC, LSU on the map revealed that Tioman can be distinctively grouped into three zones namely A, B, and C (**Figure 1**).

The coral reef in zone A has a mean LCC of 52.2 ± 2.0% (mean ± SE) and low mean DC cover of 12.1 ± 1.0% (**Figure 3**). This zone also comprises sites with low abundance of LSU at 0.28 ± 0.08 ind.100 m^{-2} (mean ± SE). In zone B, the coral reefs have a mean LCC of 26.8 ± 3.8% and a few sites with moderate cover of DC (17.8 ± 2.2%). Zone B also comprised of sites with high abundance of LSU (63.00 ± 11.14 ind.100 m^{-2}). On the south of Tioman island, namely zone C, the mean LCC is in "Poor" condition (23.8 ± 2.5%) with several sites recorded high percentage of DC, 20.1 ± 2.0%. Additionally, the sites in this zone have an average low LSU abundance (3.49 ± 0.81 ind.100 m^{-2}). The abundances of Parrotfish are almost equal in all three zones, with Zone B having the lowest abundance of 3.48 ± 1.09 ind.500 m^{-3} (mean ± SE), followed by Zone A with 4.02 ± 0.84 ind.500 m^{-3} and Zone C with 5.58 ± 1.65 ind.500 m^{-3}.

Statistical analysis showed that all groups of indicator with the exception of Parrotfish have significant difference between zones ($p < 0.05$). *Post hoc* Dunn test reveal that for LCC, there was significant difference between zones A–B and A–C but not between zones B–C. This is followed by DCC, with significant difference only found between zones A–C. Meanwhile the difference of LSU between all zones were significant (**Table 1**).

TABLE 1 | Summary of *post hoc* Dunn test (with Bonferroni adjustment) of three survey components namely live coral cover (LCC), dead coral cover (DCC), parrotfish, long-spined urchins (LSU) comparing between zones A, B, and C.

Indicators	Zones	*Z* value	*P* unadjusted	*P* adjusted
LCC	A–B	4.870218	$1.114753e^{-06}$	$\mathbf{3.344260e^{-06}}$
	A–C	5.923989	$3.142246e^{-09}$	$\mathbf{9.426739e^{-09}}$
	B–C	0.573658	$5.661992e^{-01}$	$1.000000e^{+00}$
DCC	A–B	−2.3525603	0.0186446688	0.055934007
	A–C	−3.5511111	0.0003836085	**0.001150825**
	B–C	−0.8493834	0.3956679941	1.000000000
LSU	A–B	−7.855790	$3.972616e^{-15}$	$\mathbf{1.191785e^{-14}}$
	A–C	−3.937606	$8.229843e^{-05}$	$\mathbf{2.468953e^{-04}}$
	B–C	3.737330	$1.859846e^{-04}$	$\mathbf{5.579538e^{-04}}$
Parrotfish	A–B	0.9607672	0.33666924	1.00000000
	A–C	−1.5375523	0.12415811	0.37247434
	B–C	−2.1328647	0.03293583	0.09880749

Zones with significant difference are shown in bold.

DISCUSSION

The citizen science method, Reef Check, was designed to be ecologically holistic with scientific principles (Hodgson, 1997) and has been applied in many research and conservation based projects (Hagan et al., 2007; Wilkinson, 2008; Hughes et al., 2010; Liu et al., 2012; Wetzelhuetter et al., 2014). Hence, the map produced provides reliable baseline information adequate for management to prioritize important zones for protection. Our project findings suggest that the management authority can utilize this baseline map to plan their zoning strategies until more specific and detailed information becomes available.

LCC provides a snap shot of coral reef health as it not only represents the coral dominant reef but also has significant influence on fish species richness and composition where they constitute a positive correlation (Bell and Galzin, 1984). However, LCC cover alone is inadequate as a metric for coral reef health because it does not indicate sufficient information on coral reef resilience (Hughes et al., 2010). The herbivore functional group is becoming increasingly recognized as an important indicator of reef health and resilience. Herbivores play crucial roles in maintaining the natural balance of algae and coral by grazing on macroalgae that competes with corals, preventing a phase shift toward algal dominant reefs and increasing coral reef resilience (Korzen et al., 2011; Bronstein and Loya, 2014). Hence, the keystone algae grazer, Long-spined Sea Urchin and the herbivorous Parrotfish were included as additional components in determining the health of Tioman's coral reefs. On the other hand, DCC suggests the extent of coral reef being damaged due to human and natural disturbances (Hill and Wilkinson, 2004). In this project, DC was an additional substrate category to differentiate natural rocks or rocky shore (RC) from corals that have died due to these disturbances. Natural rock has a smoother surface, has no corallite structure and does not take the typical shapes of corals such as branching, foliose, massive or table. While for DC, the skeletal structure can still be seen albeit slightly eroded compared to RKC. Overall, the combination of all four components of Reef Check indicators (LCC, DCC, LSU, and Parrotfish) were used as proxies to map the coral reefs of Tioman into three distinctive zones with different reef health condition.

Our visual analysis of the zoning map was consistent with and supported by the results from statistical analyses. Our project suggests that Parrotfish was found to be a weak predictor to distinguish different zones and this is likely due to its high mobility. This is expected given that parrotfishes displayed changing home range behavior that is driven by nutritional demand (Welsh et al., 2013). While LSUs are known to be keystone algae grazers, they are also known as bioeroding agents. Hence, too high abundance of LSU can be considered unhealthy to the reefs. Furthermore, higher LSU abundance could also mean that there is proliferation of algae. In this project, the metric of unhealthy LSU abundance is adopted from the study by Carreiro-Silva and Mcclanahan (2001) whereby the abundance of LSU in an unprotected area is approximately 60.00 ind.100 m^{-2} meanwhile the abundance in a protected area is approximately 6 ind.100 $m^{-2.}$

The map produced showed that Tioman can be separated into three distinctive categories of zones and different conservation strategies can be applied to them. Comparatively, based on the visual and statistical analyses, Zone A is considered to be the healthiest, while Zones B and C are less healthy. The different conservation strategies for each zone can be modeled following the Great Barrier Reef Zoning Plan or the categories listed in the IUCN guidelines for protected area management (Great Barrier Reef Marine Park Authority, 2003; Day et al., 2012).

Zone A is proposed to be designated with either Preservation or Scientific Research zone or IUCN Catergory Ia, Ib or even II zone. The objective of this zone should be focused on conserving the ecosystem and associated biodiversity with minimal human impacts. Activities allowed in this zone should be restricted and limited to only research purposes, monitoring, low impact tourism and non-extractive activities. This is to ensure that the many sites of "Good" LCC rating can continue to be preserved without further damage from human activities. There is a local community living within this zone, but it is congregated within a bay. Therefore, some controlled low intensity tourism can be allowed in order to provide some livelihood to the local community. A large part of this zone is mostly rocky formation, uninhabited and exposed to strong wind and waves during monsoon. The mean low abundance of LSU in this zone may suggest low herbivory rate and concomitantly lower bioerosion rate. The low herbivory rate from LSU can be compensated by moderate abundance of Parrotfish to control the proliferation of algae. Bonaldo et al. (2017) found that herbivory rate of parrotfish was 3 to 6 times higher within a MPA and Tioman is already a gazetted MPA with a no-take approach. Excessive growth of algae can inhibit coral settlement, hence lowering coral reef resilience and eventually leading to increased risk of a phase shift toward degraded reef (Bellwood et al., 2004; McManus and Polsenberg, 2004; Hughes et al., 2007). Low LSU abundance also suggest that there is sufficient predation in this area to control LSU's population (Carreiro-Silva and Mcclanahan, 2001) subsequently controlling the bioerosion rate. Therefore, the characteristic of this zone fit to be assigned with the highest conservation priority.

On the other hand, Conservation Park zone or IUCN Category IV zone should be designated for Zone B which comprises several sites mixed with "Good", "Fair," and "Poor" rated LCC, several sites with high DCC (>75%) in addition to numerous sites with high abundance of LSU and moderate abundance of Parrotfish. The primary objectives of this zone should be providing opportunities for sustainable use and recreational activities as well as limited extractive research for academic purposes. The main village of Tioman where all the administration agencies are based is located within this zone. Hence, this zone has reasonable use of resources between stakeholders established for decades for non-extractive recreational activities such as diving and tourism. However, there is a need to control the growing tourism in order to manage the coral reef conditions in a sustainable manner. Our data also highlighted that this zone has high abundance of LSU which may suggest several issues of concern including extraction of their natural predators such as wrasses and triggerfishes, increased level of nutrients and the risk of bioerosion. The high grazing capacity of sea urchins poses a bioerosion threat that can reduce reef stability, growth and resilience (O'Leary and Mcclanahan, 2010). These issues suggest threats of illegal fishing activities and nutrient run-off from tourism operations or land based activities. Hence, Zone B is where most management intervention is recommended.

Zone C is recommended to be designated as General Use zone or IUCN Category VI zone. The objectives of this zone is proposed to be mutually beneficial between conservation and opportunities for sustainable multiple use of the resources. This zone has the poorest coral reef health in terms of LCC and DCC, which also suggest that there is limited livelihood opportunity to the local community residing in this zone. Extractive activities such as traditional, artisanal, recreational fisheries or even research should be allowed. However, there are a few sites with moderate abundance of LSU and Parrotfish to control algal growth. Hence, this zone is highly recommended for habitat rehabilitation or restoration to rebuild the degraded reef and to maintain the balanced population of both herbivorous species.

This project showcases the feasibility of the citizen science approach in mapping baseline information that will be useful for planning of conservation management strategies. The advantage of this approach is that the baseline map can be produced quickly with minimal resources and yet is still sufficiently reliable. Nevertheless, this work was meant to develop a baseline map for management and further studies should be conducted on specific issues carefully when necessary.

AUTHOR'S NOTE

Between the time the work was conducted and the article acceptance, the Department of Marine Park Malaysia, Ministry of Natural Resources and Environment has been restructured and is now parked under the Department of Fisheries, Ministry of Agriculture and Agro-based Industry.

DATA AVAILABILITY

The datasets for this manuscript are not publicly available because this particular work was funded by a governmental agency where access to the data collected from this study must be requested with permission. Requests to access the datasets should be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

CL, AK-A, YA, JH, AL, and NZ contributed the conception and design of the work. AK-A, AC, YSL, YLL, PM, VL, AM, YM, and RM conducted the data collection. CL performed the statistical analysis and GIS. CL and AK-A wrote the manuscript. All authors read and approved the submitted version.

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