Using Citizen Science to Understand Human Disturbances on Philippine Coral Reefs

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ABSTRACT

The Philippine region of the Coral Triangle houses the third-largest reef system in the world and largely relies on these marine ecosystems for the livelihoods of its inhabitants. Climate change is driving the severe degradation of these vital reef systems which are further impacted by the lack of long-term studies monitoring and analyzing the long-term impacts of human activities on reef health. Citizen science, like Reef Check and CoralWatch, is a collaborative approach that attempts to mitigate this knowledge gap by engaging volunteer scientists in large-scale data collection. To understand the capacity of citizen science to convey the relationship between anthropogenic disturbances and reef health, I identified the top three most prominent disturbances documented in Reef Check over a twenty-year period (2000-2020): tourism, overfishing, and industrial pollution. I contextualized these findings by conducting a literature review. Then, I used CoralWatch to visualize the study sites and their color distribution, a proxy for coral bleaching, across space and time. Using a Pearson correlation analysis to understand the relationship between coral reef health and the presence of anthropogenic disturbances, results showed that there is significant negative relationship ($\rho = -0.876$) that illustrates that sites that experience a high amount of human activity are also the most degraded reefs. Investigating the potential for best practices of robust citizen science data will be essential for supplementing traditional monitoring methods and guiding data-driven decision-making aimed at restricting the most prominent human activities impacting reef systems in the Philippines.

KEYWORDS

volunteer monitoring, Marine Protected Areas, The Coral Triangle, coral bleaching, marine ecosystems

INTRODUCTION

Coral reefs contain higher species diversity per unit area than any other aquatic ecosystem in the world and they are composed of potentially more species than tropical rainforests (Roberts et al 2002). These extraordinary reef systems have existed for over 400 million years, surviving multiple mass extinction events. Coral reefs account for 25% of all marine life, despite making up only 1% of the oceanic floor (NOAA 2019). Coral reefs are also highly productive systems that can be characterized by their ability to cycle nutrients, sequester carbon, and protect coastlines from erosion and storm damage (Cohen et al. 2009). However, the rise of climate change driven by anthropogenic disturbances has been severely degrading reef ecosystems. Anthropogenic disturbances are defined as human-caused disruptions or alterations of the natural environment. Examples of these disruptions include the emission of fossil fuels which drive warming sea surface temperatures causing ocean acidification. Ocean acidification, the process of atmospheric carbon dioxide dissolving in seawater and lowering the pH of the ocean, has drastically affected the survival of many reef systems across the globe. Minimal changes in pH have extremely significant impacts on marine organisms, especially coral which have calcium carbonate skeletons that rely on stable pH levels to grow and thrive (NOAA 2021). Scientists predict that 90% of the world's coral reefs may be lost by 2050 as a result of ocean acidification (Dubinsky 1996).

The Coral Triangle is a 130,000 square kilometer hot spot for marine biodiversity spanning over the Philippines, Indonesia, Malaysia, Papua New Guinea, the Solomon Islands and Timor-Leste (Lalas et al. 2023). This area is home to over 500 species of reef-building corals, 1,200 species of fish, and 6 species of marine turtles (Greenpeace 2016). The Coral Triangle is an essential spawning and nursery ground for various commercially significant fish species, like Big-eye tuna and Yellowfin tuna (Cabral et al. 2012). The Philippine region of the Coral Triangle (Figure 1) represents the third largest reef system in the world, with the highest species richness of hard corals globally (Licuanan et al. 2019). Although countless Marine Protected Areas (MPAs) have been established to prohibit human activities, current governmental structures and policies in place have not been sufficient to prevent reef degradation. The survival of these reef systems is crucial for preserving biodiversity, supporting fisheries.

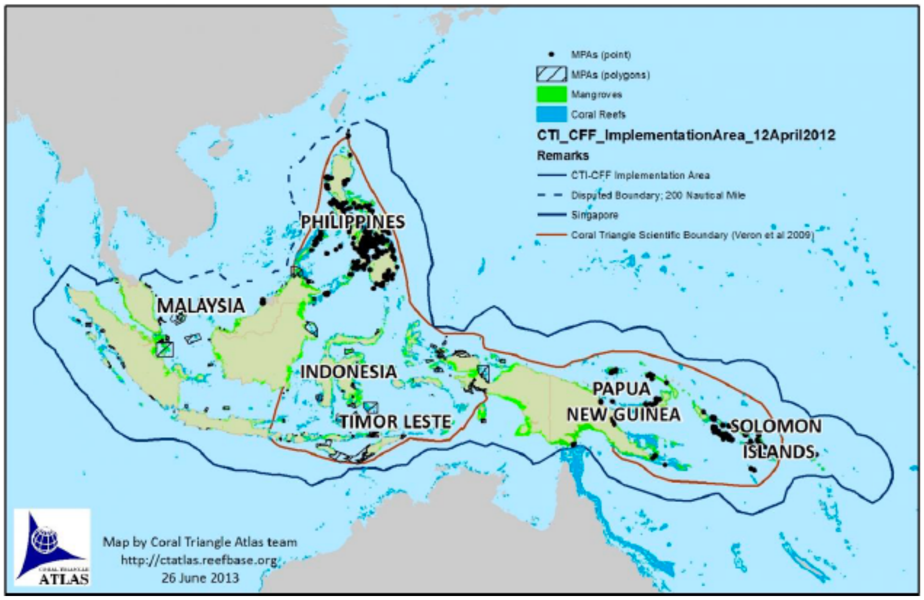

Figure 1. The Coral Triangle. This region encompasses the countries of the Philippines, Indonesia, Timor Leste, Malaysia, Papua New Guinea, and the Solomon Islands (Coral Triangle Atlas 2024).

Currently, traditional coral reef monitoring methods can be rather limited in scope and unable to capture the dynamic ecological processes that occur within reef systems. Even though there is a considerable amount of research on the impacts of human-caused disturbances, there are few studies on their long-term effects on coral reefs and on reef resilience. The prevalence of destructive fishing methods, such as cyanide and dynamite fishing, are driven by weak governance in MPAs and severely disrupts reef dynamics (Matorres et al. 2023). Additionally, the rapid growth of tourism coupled with the increasing development of urban infrastructure along the Philippine coast are understudied disturbances raising concerns. This is because regions of the world, like the Philippines, have received less monitoring attention. At the same time, newer citizen science efforts like Reef Check and Coral Watch can provide us with real-time data on numerous reef systems around the world (Gouraguine et al. 2019). Citizen science is a collaborative approach to scientific research that recruits the public to participate in the scientific process (e.g. by contributing to data collection and analysis) (Vercelloni et al. 2021). Reef Check and Coral Watch place volunteers under rigorous training programs to conduct high quality reef transect surveys along the coast of the Philippines. This method of data collection can help to fill the gap that exists between traditional coral reef monitoring and anthropogenic disturbances on coral reefs in the Philippines.

The central aim of this research is to investigate how citizen science can improve our understanding of anthropogenic disturbances on reefs. I achieved this through the investigation of the following subquestions: (1) How are the most prominent anthropogenic disturbances, according to Reef Check, affecting reef systems in the Philippines? (2) According to Coral Watch, how has the color distribution of reefs, a proxy for coral bleaching, changed across space and time? (3) To what extent does there exist a significant relationship between the color distribution of reefs and the presence of anthropogenic disturbances? I predicted for my findings to illustrate the prominence of tourism activities with the growth of urban infrastructure along the coast of the Philippines (Yan et al. 2024). I also expected for there to be a significant, negative relationship between the presence of anthropogenic disturbance and coral reef health across both space and time. To conduct this research, I used a twenty-year coral reef monitoring dataset collected by citizen scientists in the Philippine portion of the Coral Triangle.

METHODS

Surveying methods

CoralWatch data collection

CoralWatch employs a "Do-it-Yourself" method of data collection that was developed by scientists from the University of Queensland using the coral color chart (see Appendix A). The color chart uses color as a proxy indicator for coral bleaching where each color square corresponds to the concentration of symbiotic algae living in the coral tissue. Volunteers are instructed to employ one of the following methods to conduct a reef survey: (1) random survey by swimming in an imaginary line and choosing the closest coral after every second fin kick, (2) a transect survey by selecting corals by following a transect and recording any findings after every few meters, and (3) permanent transect by selecting corals that are easily recognizable and easily returnable to monitor over time.

Reef Check data collection

Reef Check employs more stringent criteria for collecting reef data to ensure robust monitoring (Reef Check 2024). Survey instructions vary depending on the geographic region volunteers are located in. For surveys to be considered, all data collectors must be certified Reef Check EcoDivers. To become an EcoDiver, volunteers must enroll in a three-day certification course that trains citizens how to conduct full-scale surveys and high-quality data. To qualify for the program, volunteers must have an open water diver license, have 25 logged dives, and be at least 15-years old. Once volunteers have submitted their data, the surveys enter a large database that is publicly accessible.

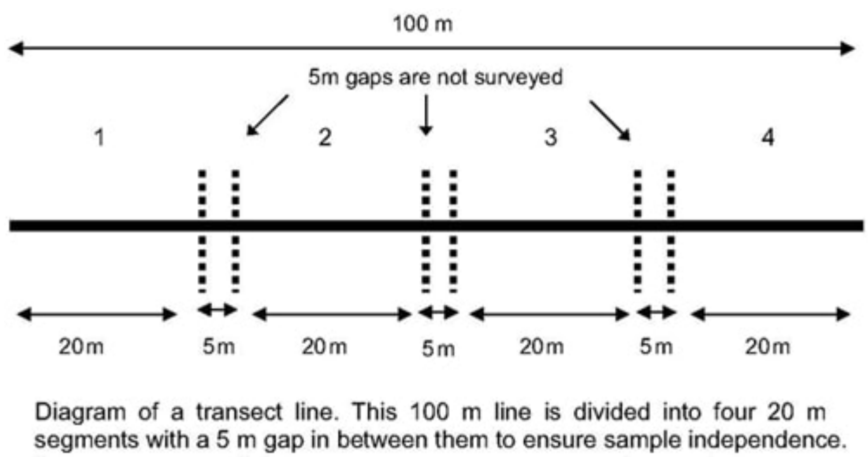

Figure 2. Reef Check survey transect line visual. Volunteers are instructed to collect data in four different 20 meter transects with a gap of 5 meters in between (Reef Check 2024).

Data contents

To explore the potential of citizen science to supplement traditional data collection methods, I compile data retrieved from both Reef Check and Coral Watch to perform data analysis procedures in my desired study site. From Reef Check, I have access to 923 surveys spanning the years 2000 to 2020. The data is represented in three csv (comma separated values) files with one dataset called *belt* containing information about coral bleaching data percentage per segment, a second dataset called *site* with descriptions of specific transect segments including human disturbances, and a final dataset called *substrate* containing information about the types of substrates found within each segment. From Coral Watch, I have access to 7,407 surveys spanning the years 2000 to 2020 all compiled within one Excel file. The Excel spreadsheet is formatted to have one tab per survey type, one tab listing all Records, one tab listing all Projects and one tab listing all Sites. The Coral Watch data is also stored in shapefiles to enable geographic mapping of the study sites.

Manipulating citizen science data

Identifying and contextualizing prominent anthropogenic disturbances

Reef Check demonstrates high potential in conveying information about the most impactful human disruptions that are imperative for designing mitigation strategies in the Philippines, containing over fifteen disturbance fields in the data. Examples of disturbances included by Reef Check include the presence of snorkeling, diving, various types of fishes, storm occurrences, and kayaking activities. The bulk of the work in trying to identify the most prominent anthropogenic disturbance involves cleaning the data to get rid of null values and any archived disturbance fields. The disturbance fields are ranked on a low-high scale for each reef survey. To identify the most prevalent disturbances, I filtered the data to display the disturbances that show the most counts for ‘high’, which indicates that a specific site experiences a large amount of this anthropogenic activity and narrow it down to the top three fields. After identifying the most prominent disturbances, I conducted a literature review to gain context for how these disturbances are specifically affecting Philippine reefs.

Visualizing reef health across space and time

To understand the shape of the data from Coral Watch, I visually observed the study sites relative to their geographical location in the Philippine portion of the Coral Triangle and analyzed trends in color distribution, a proxy for reef health. To do so, I used the interactive map tool provided on the CoralWatch website. Then, I proceeded to visualize the average color distribution and the number of surveys conducted for a given year using the csv files from CoralWatch over a ten-year period. The color code corresponds to a color from Coral Watch’s color chart (shown below) which indicates the severity of bleaching that the reef is experiencing where a score of 3 or above indicates a healthy reef.

Correlation between bleached colonies and anthropogenic disturbances

To examine the correlation between the percentage of coral colonies bleached and anthropogenic disturbances, I merged the *site* dataset, which contains information about anthropogenic disturbances present for a reef site, and the *belt* dataset which contains information about the percentage bleached. To analyze the relationship between these variables, I created a heatmap and examined the correlation between variables using Pearson correlation analysis. This method relies on the following assumptions of the data: (1) the two variables being compared are normally distributed and (2) the relationship between the variables is linear (BCU 2016). The first assumption holds true by the Central Limit Theorem since our sample size is large and the second assumption also holds true because scatter plots of these variables conveyed a linear trend.

RESULTS

The top three human disturbances and their impacts

Aggregation of the Reef Check survey sites data revealed the three most prominent anthropogenic disturbances affecting reefs: tourism, overfishing, and industrial pollution. Table 1 provides an overview of these disturbances as well as key characteristic attributes. Examples of tourism activities include snorkeling, scuba diving, tours/cruises, recreational activities and wildlife viewing. The overfishing category encompasses a range of fishing methods like cyanide fishing, blast fishing, and drift net fishing. Industrial pollution refers to any pollution stemming from coastal urban infrastructure like factories, power plants, and landfills. From these three disturbances, I conducted a literature review to gain context for how these activities are impacting reef systems in the Philippines. This review analyzed ten relevant scientific articles on the three prominent disturbances and how they are affecting the Philippines. The overarching points of this literature review illustrates a large consensus in the lack of effective regulation for Philippine reef sites, despite the establishment of Marine Protected Areas. The large dependence of coastal communities on fisheries resulted in an abundance of destructive fishing activities that persist, proving these MPAs as controlled on paper and not on actual grounds (Vercelloni et al.

2021). Despite the establishment of over 1,500 MPAs, there remain very few examples of best case MPA sites. These processes allow us to understand how citizen science can be paired with existing studies to understand how significant human disturbances are affecting Philippine reef systems. The results of this sub question align with my initial hypothesis that overfishing would be a key disturbance impacting reefs.

Analysis of color distribution trends across space and time

The visualizations of color distribution, a proxy for reef health, represented a consistent decrease in overall reef health over time (2000-2020) but trends are inconsistent across space. From the resulting maps, we can see that a majority of the surveys are concentrated in the Cebu and Manila region (Figure 3). These regions also correspond to the most popular tourist destinations which results in higher rates of human activities (Licuanan et al. 2019). In terms of color distribution, we can see a shift over time where sites are transitioning to lighter colors, indicating a high persistence of coral bleaching. I compared the site maps and color trends plot with the color distribution chart from Coral Watch to understand the trends of color shifts and how it corresponds to reef health. Across time, the colors of survey sites appear to get lighter (assigned with color code A/B/C/D-5 on the CW color chart) which indicates a majority bleached reef. I also compared the different survey sites' proximity to the coast to distinguish shallow reef systems from deep reef systems in order to understand how this affects reef health. Table 2 reveals that the majority of reefs surveyed correspond to shallow reef systems, likely due to the higher feasibility and accessibility of these reefs compared to deep water systems (Yan et al. 2024). The results of this sub question slightly differ from my hypothesis that there would be more inconclusive trends in color distribution over time.

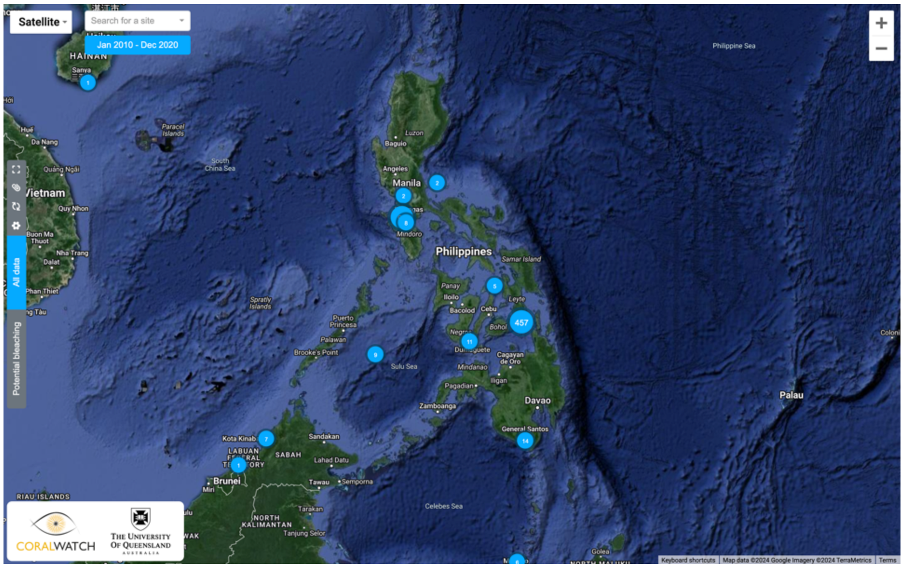

Figure 3. Site map using the interactive map from CoralWatch.

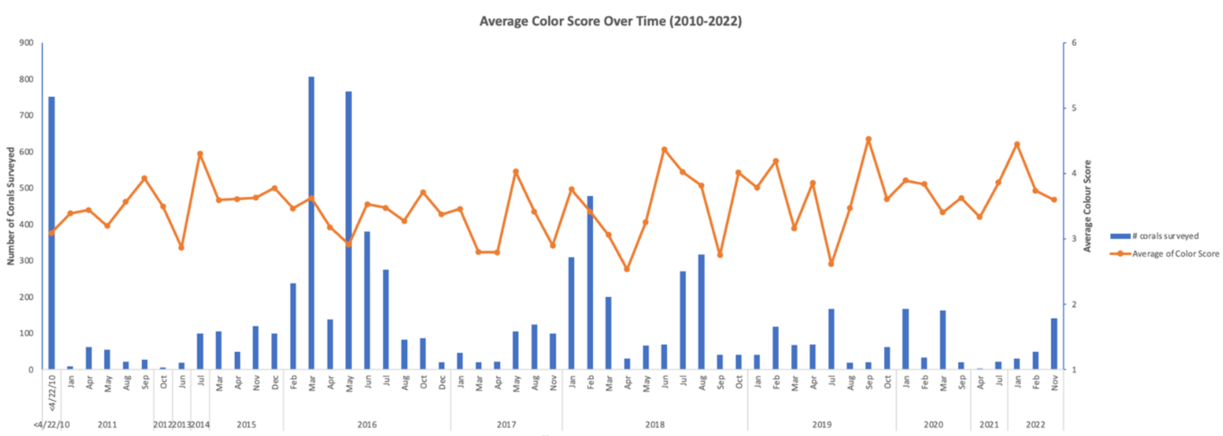

Figure 4. Average color score over time using CoralWatch data. (CoralWatch 2024).

Reef health is correlated with the presence of anthropogenic disturbances

Running a Pearson correlation analysis in Python allowed me to obtain a high negative correlation coefficient between coral bleaching (the average percent of colonies bleached over 4 transects as indicated by ‘s1’, ‘s2’, ‘s3’, ‘s4’ in the Reef Check data). These relationships are visualized using scatterplots which display approximately negative, linear trends between variables (Figure 1). The Pearson correlation analysis delivers a value of rho = –0.876 between the variable ‘avg_%_colonies_bleached’ and ‘overall_anthro_impact’, which was transformed into numerical data using One-Hot-Encoding to perform quantitative analysis. The results of this sub question align with my hypothesis that the sites with a high presence of human disturbances are the ones that experience the highest percentage of reef degradation.

Table 2. Relationship between the percent of MPA sites, their overall anthropogenic impact, and proximity to shore. Volunteers from Reef Check were instructed to indicate the overall anthropogenic impact on a low to high scale, if the site is an MPA, and its average distance from shore.

	overall_anthro_impact	%_protected	avg_distance_from_shore (m)
0	High	2.31	251.49
1	Low	27.67	603.15
2	Medium	17.51	628.27
3	None	3.14	404.24

DISCUSSION

Our findings from citizen science data extrapolation and corresponding literature review suggest that reef health is significantly correlated with the top three anthropogenic disturbances identified, despite a majority of the investigated sites being MPAs. Color distribution, a proxy for bleaching, trends over the examined 12-year period also showed consistent negative patterns of reef health across study sites. The results of this study enable us to address the gap that exists between traditional methods of data collection and in the context of studying coral reef degradation. Furthermore, this paper brings attention to the imperative to implement stricter regulations that prohibit certain marine recreational activities that negatively affect reefs to ensure the survival of these essential ecosystems. Properly allocating resources and weighing them more towards impactful, data-driven management practices that not only establish additional marine protected areas, but strictly limit the activities occurring in these areas can have a large impact on preventing extreme coral bleaching in coastal reef systems in the Philippines. The findings from this study strongly suggests that citizen science acts as a blueprint for information-based governance that marine conservation groups and decision-makers should consider in weighing mitigation tactics.

Citizen Science as a tool for redirecting human activities

Manipulation of Reef Check data allowed for the extrapolation of three of the most prominent human activities (overfishing, industrial pollution and tourism) affecting reef health which the corresponding literature review reveals are recreational activities that are not well-mandated or limited by the Philippine government. While citizen science data may not be strong enough to formulate robust claims in favor of reef conservation, supplementing this data with traditional data, and in this case, a literature review analyzing the consequences of the most detrimental human activities to reefs can be powerful and revealing. The literature review demonstrated several studies skeptical of the reliability and utility of citizen science data with one particular study (Done et al. 2017) investigating the accuracy of Reef Check data in Queensland, Australia. This study, along with others, dispel common beliefs in the unreliability of citizen science and show how impactful it can be in promoting environmental stewardship and for providing indicators of ecological conditions at a spatial scale. Current mandates like the Presidential Proclamation No. 57 requires the Bureau of Fisheries and Aquatic Resources of the Department of Agriculture to emphasize the need to conserve and protect the country's coastal and marine resources but do not actually prohibit activities damaging to reefs. It is evident that establishing MPAs is not sufficient to prevent reef degradation; this requires the implementation of statistically robust monitoring methods coupled with local and national government action (Sully and Van Woesik 2020). The capacity of citizen science to be transformed into a supplemental tool to guide serious decision making and aid traditional reef monitoring data should be a high priority for management stakeholders, policy makers, and affected communities.

An apparent decrease in reef health over time

According to CoralWatch, patterns in reef health seem to fluctuate across space but experience an overall negative trend over time, indicating a dire need for appropriate resource allocation to ensure robust data collection over time as a powerful indicator of reef resilience. Fluctuations can result from various factors that compound with human disturbances such as natural environmental variability. Understanding temporal patterns in reef health is critical for understanding if there are certain time periods/sites that undergo significantly steeper fluctuations in bleaching and what factors may be accounting for this (Magdaong et al. 2014).

Significant negative correlation between reef health and presence of human activities

A high correlation coefficient obtained after performing [name] statistical analysis illustrates the direct impact of human activities on coral reefs not only crucial for ecological reasons but also for sustaining livelihoods and economic activities dependent on these ecosystems. The results of the statistical analysis suggest that stricter regulations must be enforced in marine protected areas in order to ensure that these segments of coral serve as sanctuaries that prohibit direct human contact. But, it is important to note that there may be confounding variables that affect reef health more strongly than human activities, i.e. rising sea surface temperatures (SST) (Gouraguine et al. 2019). The positive correlation between reef health (measured as % colonies bleached) and human disturbances implies that there are errors surrounding how MPA's are being governed. Therefore, governments and decision makers must produce stricter regulations to prohibit these actions. This can be guided through citizen science initiatives.

Limitations and future directions

The reliance on volunteers for data collection raises concerns about the faithfulness of citizen science data, reflected in the minimal number of publications utilizing citizen science data. As such, this research is limited by the feasibility of measurements that can actually be taken by volunteers. Promoting the implementation of training programs can increase the validity of data measurements, providing more accurate interpretations and measurements.

Additional data collection of quantitative variables like weather conditions can aid in understanding how coral bleaching is also impacted by uncontrollable factors like temperature fluctuations. Currently, the data contained in Reef Check and CoralWatch are largely categorical, likely due to the feasibility of gathering this kind of data. Including more quantitative variables would require extensive citizen science training before volunteers perform transect surveys but would have the added benefit of more robust and usable data. A key component of handling citizen science data is understanding what the best practices of data collection and implementation are for prediction and analysis to be performed. Future studies should utilize citizen science data, like Reef Check and CoralWatch, to produce machine learning models that predict reef health status based on human activities for risk assessment.

This research provides a basis for how citizen science can be analyzed to guide impactful decision-making regarding reef conservation among stakeholders, investors, and governing bodies in the Philippines. Regulations under MPAs have not been proven effective in prohibiting detrimental anthropogenic disturbances that may cause permanent harm to degrading reef systems (Maypa et al. 2012). This pressing dilemma calls for a demand in citizen science data to not only supplement traditional data collection methods, but to spread awareness to the vulnerability of reefs worldwide.

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APPENDIX A: CoralWatch Color Chart

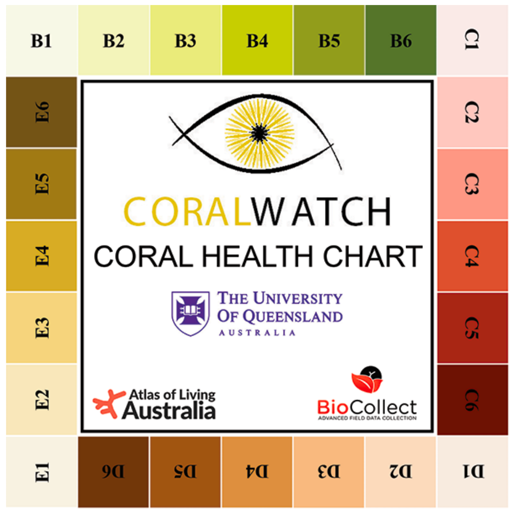

Figure A1. The CoralWatch color chart utilized by citizen scientists to record coral bleaching. Each color square corresponds to the concentration of symbiotic algae living in coral tissue (CoralWatch 2024).