Coral Bleaching Detection Using PRISMA Hyperspectral Satellite Imagery in Calatagan, Batangas

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Abstract

Coral bleaching arises due to stress from warming seas and pollution. Several studies on bleaching detection utilize multispectral imagery, due to data availability. In this study, the usage of PRISMA hyperspectral data imagery was assessed for coral bleaching detection in Calatagan, Batangas, and sea surface temperature (SST) for confirming bleaching occurrence. In-situ measurements were gathered for spectral data of live and bleached corals, and a collaborative qualitative data interview with a coral bleach patroller and municipal office was conducted to gain further information about bleaching details in the area. Sentinel-2 L2A was also used for comparison during classification. Spectral Angle Mapper (SAM) was utilized for image classification, while using field data and data from related studies for spectral library. A total of 27.12% relative to the coral reef area was classified as bleached corals. T-test statistics were done to analyze the live and bleached corals, which exhibited that only two (2) bands in the green region were found to be not separable. Using box plots, bleached corals showed to have generally lower reflectance values than live corals for RGB region, as compared to Sentinel, with bleached having higher values, which implies that spatial resolution can affect the spectral response of different features. Using ground truth data, 60.6% user's accuracy for bleached corals, and 63.4% overall accuracy is achieved. Hence, hyperspectral satellite imagery can be utilized in coral bleaching detection, despite its limitations. Depth variables and diverse sample points are recommended for the betterment of coral bleaching detection.

1. Introduction

1.1 Background of the study

The Philippines, an archipelago enriched with almost 600 diverse coral species, plays a pivotal role in the marine ecosystem. However, 200 of these species face the threat of extinction, primarily due to escalating ocean temperatures and pollution arising from coastal development (Licuanan et al., 2017). Batangas is an urbanized province with an average hard coral cover of 40%. Recent news from various coral reef watch efforts in the Philippines have reported that parts of Batangas are experiencing coral bleaching events (Philippine Coral Watch PH, 2022).

Sea surface temperature is one of the factors of coral bleaching events. The continuous increase in temperature due to global warming has caused coral bleaching to become a danger to the future, because food, livelihoods, and coastal protection (Hoegh-Guldberg et al., 2017) are the top essentials that depend on coral reefs. Although there have been continuous and wide efforts in taking care of our coral reefs, this demands more datasets and observations to successfully implement it, such as detection, using technologies that may help in the development of the presently available data. While these corals have immense ecological and economic significance for the country, monitoring their health poses challenges. Traditional in-situ surveys are limited in their reach, especially in deeper regions (Darling, 2016). Consequently, there's an urgent need to embrace alternative detection methods, with hyperspectral imagery emerging as a promising solution for monitoring changes in coral reef statuses due to the narrow spectral bands it provides (Bajjouk et al., 2019).

Through capacity building and citizen science, this study was able to determine the concurrent issue of coral bleaching in the municipality. The Municipal Environment & Natural Resources of Batangas was able to contribute and share its knowledge regarding the coastal resources present in the marine waters of Calatagan, Batangas. Moreover, experts and citizen science reports aided in gathering, processing, and validating data on coral bleaching detection in Calatagan, Batangas.

2. Methodology

2.1. Study Area

The study was conducted in the municipality of Calatagan, which is located at coordinates 13°49′56″N 120°37′56″E. Calatagan is a 2nd class municipality in the province of Batangas, Philippines. Due to the municipality's expansive area, the fieldwork was specifically carried out within the boundaries of Brgy. Gulod, Calatagan, Batangas. This area was selected due to the presence of coral reefs and reported cases of coral bleaching.

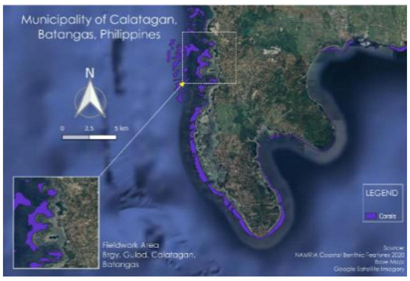

Figure 1. Municipality of Calatagan, Batangas

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2.1. Coral Bleaching Reports & Coral Bleach Patroller Interview

The Philippine Coral Bleaching Watch (PCBW) is a program jointly conducted by the University of the Philippines Marine Science Institute and the Department of Environmental and Natural Resources – Biodiversity Management Bureau – Coastal and Marine Division. The program aims to map bleaching events and monitor the health of coral reefs in the country through the reports of bleach patrollers (PCBW, 2020). Based on these reports, the researchers were able to narrow down potential study areas and decided to focus on the Batangas area, specifically Calatagan. This decision was driven by the most recent report from PCBW and the occurrence of a massive coral bleaching event in 2020 (Cinco, 2020).

An interview was conducted with the Municipal Environment & Natural Resources of Batangas to further assess the coral reef status and presence of other benthic features in the area. Insights and potential collaborations were presented. Furthermore, an interview was also conducted on February 27, 2023, with an expert coral bleaching patroller in the municipality, Mr. Jessie Delos Reyes, as shown in Figure 2. The coral bleach patroller identified specific coral bleaching sites in Calatagan and discussed their causes. Mr. Delos Reyes emphasized that coral bleaching predominantly occurs during the summer season, from March to May, with a peak in July. However, he also highlighted the significance of considering the thermocline factor during this month. Consequently, trends in sea surface temperature data were examined accordingly.

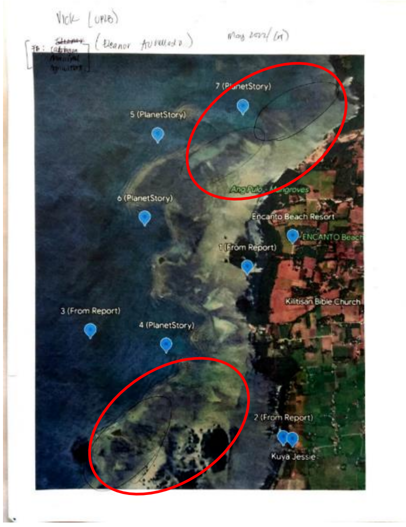


Figure 2. Coral bleaching sites (encircled in red) near the field survey area as determined by a coral bleaching patroller, Mr. Delos Reyes.

2.2. Data and Methods

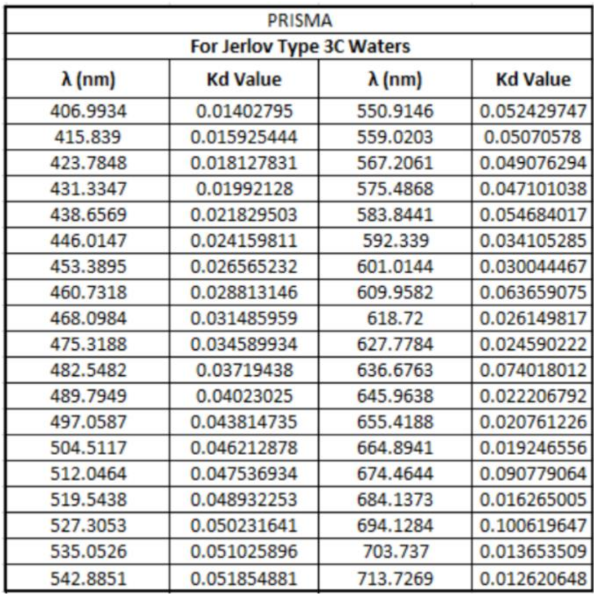
This study utilized PRISMA hyperspectral imagery from the Italian Space Agency to detect coral bleaching occurrence in Calatagan, Batangas. The PRISMA hyperspectral imagery contains prism spectrometer for Visible/Near Infrared (VIS/NIR) (400-1010 nm range) and Near Infrared/Shortwave Infrared (NIR/SWIR) (920- 2505 nm range) bands, having a total of 234 channels for both bands. For this study, the researchers have retained the visible and near-infrared (VNIR) data cube (ESA, 2019). Sentinel L2A is a multispectral remote sensing dataset which was used for the comparison with the PRISMA's image classification.

In-situ data was collected using USB4000 Fiber Optic Spectrometer for spectral signature collection. The in-situ data for the spectral signature of bleached corals was used as the endmember spectra in the Spectral Angle Mapper (SAM) classification with threshold value of 0.05. Other benthic features such as sand, live corals, sand with algae, non-coral were also added to avoid overclassification of data.

Before classification, the satellite images underwent pre-processing. Since PRISMA product is already atmospherically corrected and geocoded, noise reduction using Minimum Noise Fraction Transform, georeferencing, and non-water masking were executed. On the other hand, Sentinel-2A products underwent deglinting, land, cloud, and non-coral features masking. Water column correction was applied to both hyperspectral and multispectral images using Simple Radiative Transfer Model (SRTM). A study by Tamondong et al., has proved that SRTM produced highest overall accuracy in benthic mapping compared to Lyzenga's Optical Model (LOM) and Stumpf's Ratio Model (SRM) (2013). Using Eq. 1, the variables were applied to each band of the PRISMA and Sentinel-2 L2A images.

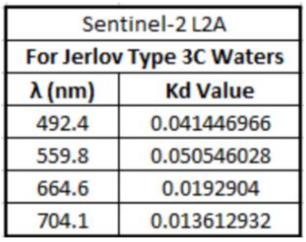
$$R_{o-}(\lambda_i) = R_{\infty}(\lambda_i) * (1 - e^{-2K_d z}) + R_b(\lambda_i) * (e^{-2K_d z}) \qquad (1)$$

Where $R_{o+}(\lambda_i)$ is the spectral reflectance below the surface, $R_{o-}(\lambda_i)$ is the spectral reflectance just below the water surface and can be obtained by multiplying $R_{o+}(\lambda_i)$ and 0.545, $R_{\infty}(\lambda_i)$ is the spectral reflectance of an infinitely deep homogenous water column, R_b is the bottom reflectance and z is water depth. For the water depth value, satellite derived bathymetry of Calatagan, Batangas were downloaded from Google Earth Engine. A spectral parameter, Kd or the diffuse attenuation coefficient is used for determining the point at which a water column reaches optical infinity, and is usually acquired from field surveys; however, a field for bathymetry data wasn't performed. Nonetheless, an article by Williamson and Hollins entitled "Measured IOPs of Jerlov water types" includes the diffuse attenuation coefficient of different coastal and open water types. For Calatagan coastal waters, Jerlov Type 3C water inherent optical properties were used, given that Type 1C is the clearest type of water. Performing linear interpolation for the PRISMA and Sentinel bands, the tables below show the Kd value used for the water column correction of PRISMA and Sentinel, see Table 1 and Table 2.



PRISMA			
For Jerlov Type 3C Waters			
λ (nm)	Kd Value	λ (nm)	Kd Value
406.9934	0.01402795	550.9146	0.052429747
415.839	0.015925444	559.0203	0.05070578
423.7848	0.018127831	567.2061	0.049076294
431.3347	0.01992128	575.4868	0.047101038
438.6569	0.021829503	583.8441	0.054684017
446.0147	0.024159811	592.339	0.034105285
453.3895	0.026565232	601.0144	0.030044467
460.7318	0.028813146	609.9582	0.063659075
468.0984	0.031485959	618.72	0.026149817
475.3188	0.034589934	627.7784	0.024590222
482.5482	0.03719438	636.6763	0.074018012
489.7949	0.04023025	645.9638	0.022206792
497.0587	0.043814735	655.4188	0.020761226
504.5117	0.046212878	664.8941	0.019246556
512.0464	0.047536934	674.4644	0.090779064
519.5438	0.048932253	684.1373	0.016265005
527.3053	0.050231641	694.1284	0.100619647
535.0526	0.051025896	703.737	0.013653509
542.8851	0.051854881	713.7269	0.012620648

Table 1. Diffuse attenuation coefficients for 38 bands of PRISMA



Sentinel-2 L2A	
For Jerlov Type 3C Waters	
λ (nm)	Kd Value
492.4	0.041446966
559.8	0.050546028
664.6	0.0192904
704.1	0.013612932

Table 2. Diffuse attenuation coefficients for 4 bands of Sentinel-2 L2A.

2.2.1. Classification

Two levels of classification were executed, firstly, the images underwent K-means Unsupervised Classification in QGIS having the parameters of classifying ten (10) different classes in a total of twenty (20) iterations. The output layer was vectorized and the unwanted classes including the features not needed were removed such as deep water, sand, seagrass from near shore. Hence, this was used to mask out the aforementioned features. To be able to classify bleached corals in the satellite images, spectral matching approach was utilized to match spectrum of a bleached coral from the satellite image into a reference spectrum from the in-situ measurement of bleached coral for it to be confirmed as a bleached coral.

Furthermore, the researchers then utilized the Spectral Angle Mapper (SAM) which is not only a spectral similarity measure, but also used as a technique for target detection. Kutser (2006) proves that SAM can be used to create spectral classification maps by separating materials into groups having similar spectrum, since it uses n-dimensional angles to match pixels into their respective reference spectra, and this method has found to be helpful for spectral libraries acquired under variable field and illumination settings, such as those found in coral reefs.

Using the data acquired from the field, the spectral signatures were resampled to the wavelengths of both PRISMA and Sentinel-2 L2A. Threshold values (in radians) were also applied as the maximum value of angle accepted between the reference spectra and pixel vector. To prevent an overestimation of bleached corals, a series of trial and error was conducted to determine the appropriate threshold value. When using a threshold value of 0.05, the classification yielded favorable results, with detected coral bleaching aligning with the ground truth data and interview information. However, increasing the threshold value led to an overestimation of bleached corals, where the entire coral reef cover was detected as bleached. Table 3 shows the threshold values applied for both PRISMA and Sentinel images.

	PRISMA L2D (March 10, 2023)	**Sentinel-2 L2A** (March 2023)
Class	**Threshold Value**	
Bleached Corals	0.050	0.050
Live Corals	0.100	0.100
Sand	0.100	0.100
Water	0.100	0.100
Sand with Algae	0.100	0.100
Non-coral	0.100	0.100

Table 3. Maximum angle in radians threshold

The pixel values of the output raster for the classification represent the difference in spectral angle of the reference spectrum and target spectrum (in radians), which means that the lower value indicates a better match. The threshold values were deemed optimal by assessing the resulting images in conjunction with field data results and knowledge of the study site.

The variables and methodological processes used and done to both PRISMA and Sentinel-2 satellite images were made sure to be same or at least similar, to ensure that these variables will have the same treatment, thus, not having an effect on the results.

After classifying the satellite images, the results from classification were checked using the location of data derived from the in-situ survey to ensure if such measurements were derived accurately. Moreover, a confusion matrix for bleached corals and other classes was done to assess the accuracy of the classification map produced (Xu et al., 2021) using ArcGIS Pro.

2.2.2 Sea Surface Temperature Data for bleaching analysis

In addition, the sea surface temperature (SST) information from NOAA and MODIS was examined to validate the classification map. This variable demonstrates a notable correlation with the incidence of coral bleaching in the area. Values from each dataset were correlated to examine whether their values can be related or not, the result shows positive strong correlation; hence, SST values from MODIS and NOAA were combined. To check for sea surface temperature anomalies, let us first define the definition of SST anomaly. SST anomaly is defined as the difference between the current

SST and the climatological SST (Liu, 2021). For coral bleaching detection, the maximum monthly mean (MMM) sea temperature is calculated since the upper limit of SST for determining heat bleaching needs to be based on the mean SST during the hottest period.

This MMM was then used for the hotspot and degree heating week (DHW) which are the parameters in detecting coral bleaching thermal stress, where the “hotspot is the positive anomaly relative to MMM climatological data” having a unit of °C, and the DHW is the “cumulative sea temperature thermal anomalies (hotspots) in the last 12 weeks”. Equation 3.1 and Equation 3.2 are obtained from a similar study regarding 2020 Coral Bleaching Event by Liu et al (2021). According to NOAA, Table 2 below shows the parameters needed for analysis.

Stress Values	Definition	Effect
Bleaching Warning	DHW < 4	Warning: Thermal stress accumulated on corals
Bleaching Alert Level 1	DHW 4-8	Level 1: Strong thermal stress on corals, may result in partial bleaching
Bleaching Alert Level 2	DHW > 8	Level 2: Severe thermal stress on corals, widespread

Table 4. Bleaching parameters using DHW

The accuracy of the classification map was validated through the utilization of ground truth data, coral bleaching reports, and qualitative interview with coral bleach patroller in Calatagan, Batangas. Using statistical methods, the effective bands in detecting coral bleaching were found by measuring the bands’ separability between live and bleached corals. Moreover, a comparison was conducted using Sentinel L2A satellite imagery to further evaluate the performance of PRISMA.

3. Results and Discussion

3.1 Coral bleaching detection using PRISMA

Through the use of Spectral Angle Mapper (SAM) algorithm, with threshold value of 0.05, the classification yielded favorable results. A total of 27.12% of the coral reef cover were classified as bleached corals using PRISMA, having most of it in the northern west part of the area.

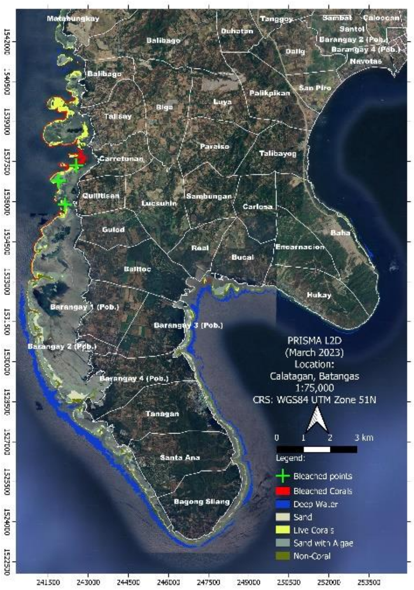
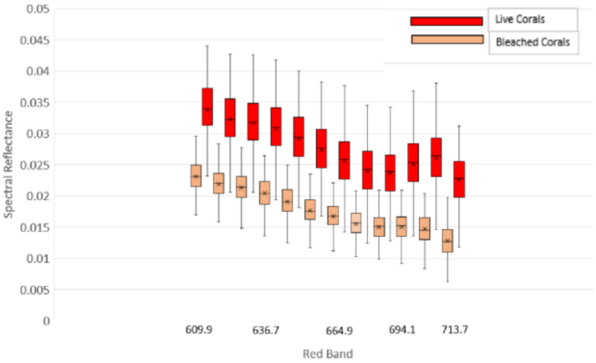


Figure 3. Bleached coral map using PRISMA HSI

To measure the differences between the values of in-situ and classified spectral signatures, RMSE calculations were executed, the classified pixels have achieved low RMSE values relative to the field data ranging from 0-0.03 for the visible bands, hence an indication of matched spectral signature from the library. Moreover, high RMSE can be detected in the red region, specifically bands 25 (592.339 nm) to 38 (713.7269 nm), this can be attributed to the varying depth of the classified pixels since field test spectral signature were depth limited meaning that classified bleached corals in deeper regions are difficult to be verified/matched from the in-situ data. In addition, as depth increased, the measured reflectance in red and Near Infrared (NIR) regions decreased due to the strong absorption by water (Shah et al, 2020.). Low reflectance values in the green and red bands were observed which can be attributed to the reduced pigmentation and loss of zooxanthellae algae (Myers, 1999).



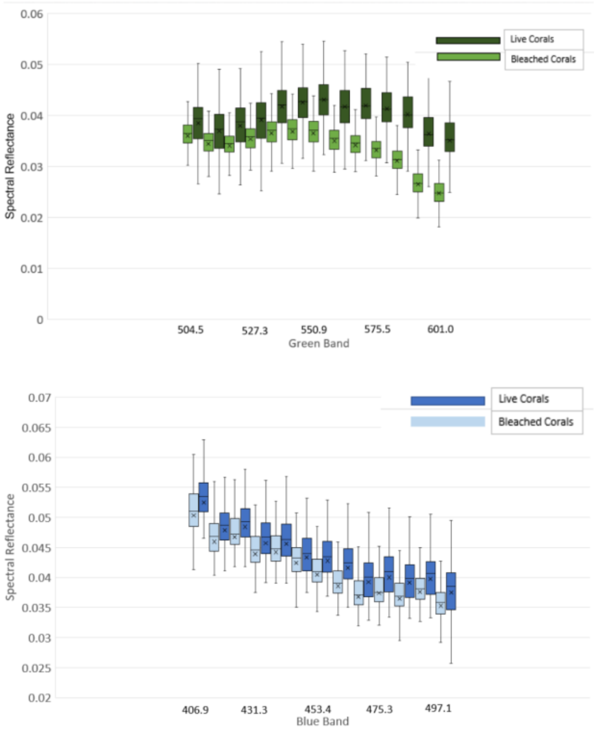


Figure 4. Box plots of RGB bands of Live Corals and Bleached Corals

Subsequently, the separability of bands of live corals and bleached corals were checked. Upon observing, the spectral reflectance is overlapping in the blue region (406.9934 nm to 489.7949nm); hence, there are minimal significant differences between bleached and live corals in these bands but are still separable using t-test statistics with p-value having less than 0.05. Using T-test with 95% confidence level, only the 519.5438 nm & 527.3053 nm wavelengths were found to be not separable in the green region. Moreover, from the figure, the "effective bands" in distinguishing separation and/or differences in the two features are the longer wavelength of green bands and the red bands regions. Hence, observing wavelengths 535.0526 nm to 713.7269 nm would be better in analyzing corals' health. Low reflectance values are observed in the green and red bands of bleached corals. The reduced pigmentation and loss of zooxanthellae lead to lower reflectance values in those bands. High reflectance values and peaks from live corals were attributed to the presence of chlorophyll a-flouresence of the zooxhantellae; hence a lower value for visibly bleached corals (Myers, 1999), results are also anchored on the similarities in Cruz's spectral signature of bleached and live corals. Additionally, live corals have larger variations of values while bleached corals have narrow range values for all wavelengths. Note that this inference was estimated to depths ranging from 2m to 8m for bleached corals.

3.2 Comparison of PRISMA and Sentinel

Moreover, Sentinel-2 L2A satellite images were used for comparison, as several studies have already investigated coral bleaching detection using multispectral imagery, such as those conducted by Yamano et al. (2003) and Liu et al. (2021). Therefore, Sentinel-2 L2A image classification was compared to PRISMA image classification, considering the in-situ measurements obtained during field data gathering and the utilization of the same spectral library for both images. Both images were acquired in March 2023.

In comparison to the 27.12% of bleached corals classified using PRISMA, 15.22% were classified using Sentinel-2 L2A. Both satellites were capable of detecting bleaching in the same areas, with most detected bleached corals located on the western part of Calatagan, encompassing Barangays Gulod, Quilitisan, Carretunan, and Talisay. Speckled bleached corals were observed in Barangays Poblacion, Tanagan, Sta. Ana, and Balitoc in the southwest of Calatagan, with minimal bleaching observed around Barangay Real in the southeast of Calatagan.

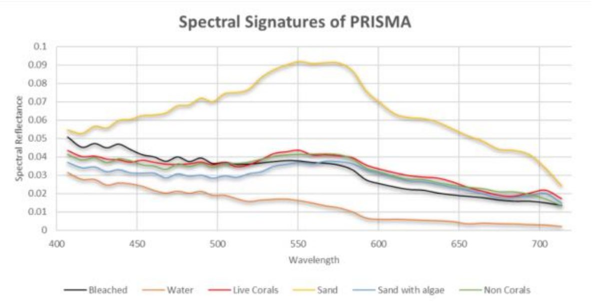


Figure 5. Spectral signatures of PRISMA HSI

The spectral separability of bands of live and bleached corals was also assessed for Sentinel. Using a T-test with a 95% confidence level, it was found that the blue band was not separable, while the green and red bands were separable. The spectral reflectance values of bleached coral were higher in RGB compared to live corals, except in the red region (665.6 to 704.0 nm), consistent with the findings of Cruz [unpublished] and Xu et al. (2021), where the spectral signature of bleached coral decreased in the red region. This can be attributed to the strong water absorption in the red band. Additionally, the possibility of algae overgrowth on the bleached corals may have caused this absorption, especially since the mass coral bleaching that occurred in 2020 have resulted in non-recovery of affected corals. This inference was estimated for depths ranging from 2m to 10m for bleached corals.

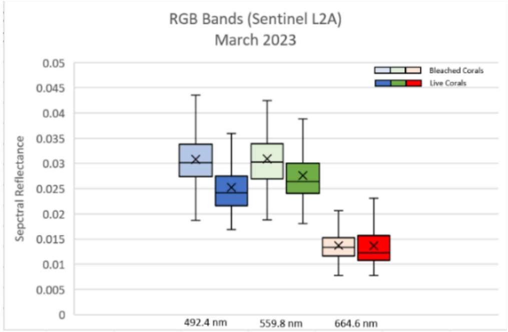


Figure 6. Boxplot for bleached vs live corals of Sentinel-2 (RGB bands)

From these observations on the results of PRISMA and Sentinel-2, PRISMA demonstrated the ability to discriminate between live and bleached corals considering its spectral resolution. Using t-test statistics, it was determined that the fractions of blue, red, and the majority of green bands in PRISMA were separable with a p-value of less than 0.05, rejecting the null hypothesis; hence, there exists a significant difference between the two features which acknowledges that the spatial resolution of PRISMA has the potential to be able to detect bleached corals despite its 30m resolution. Additionally, given this resolution, spectral responses for bleached corals are highly sensitive due to finer details of wavelengths. Overall, given the statistical approach used, wavelengths ranging from 535.0526 nm to 713.7269 nm are efficient bands in coral bleaching detection using PRISMA as it produced the highest spectral separability of bleached corals to live corals.

Moreover, zooming in on the classifications for both Sentinel-2 and PRISMA, as illustrated in Figure 7, both satellites were able to detect bleaching in the same areas, with most detected bleached corals concentrated on the western part of Calatagan, including Barangays Gulod, Quilitisan, Carretunan, and Talisay. Speckled bleached corals were observed in Barangays Poblacion, Tanagan, Sta. Ana, and Balitoc in the southwest of Calatagan.

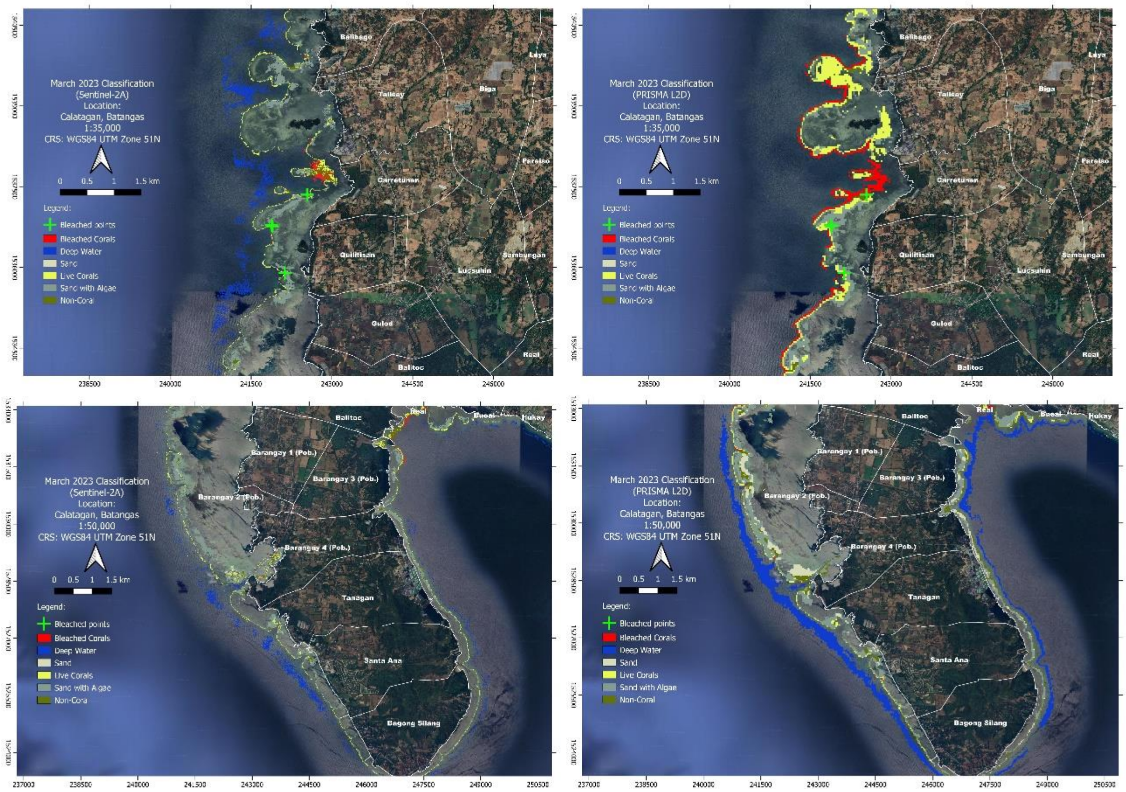


Figure 7. Bleached corals classification of PRISMA and Sentinel 2 L2A

Furthermore, detection limits for PRISMA were also determined. The 30m spatial resolution causes spatial misregistration of features, with the overlapping response in PRISMA's blue band possibly resulting from blending with adjacent features in lower spatial resolution imagery. The reverse registration of the blue band in PRISMA and Sentinel can be attributed to Sentinel's ability to delineate pixels more precisely due to its 10m spatial resolution advantage. In this study, the detection of bleached corals in PRISMA was limited to 8 meters water depth, while Sentinel was able to detect up to a maximum of 10 meters water depth.

3.3 Sea surface temperature (SST)

From the acquired Sea Surface Temperature (SST) and DHW (Degree Heating Weeks) data from NOAA Coral Reef Watch, the following plots were obtained. Following NOAA CRW's parameters, a Degree Heating Week (DHW) value below 4 is considered a warning due to the accumulation of thermal stress on corals. These dates correspond to recorded hotspots with an increase of +1°C. DHW values ranging from 4 to 8 indicate Level 1 Alert Bleaching, which can result in partial to full bleaching. A strong correlation was found between Sea Surface Temperature (SST) and coral bleaching making SST a great variable in defining bleaching occurrence because all temperature-related quantities related to coral bleaching are highly correlated (Podesta et al., 1998). Evidently, we can observe in Figure 8 that bleaching occurred from the latter part of May to October 2020 which coincided with the interview to coral bleaching patrollers which mentioned that massive bleaching started in May 2020.

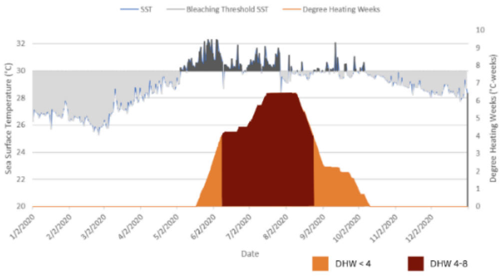


Figure 8. 2020 SST and DHW

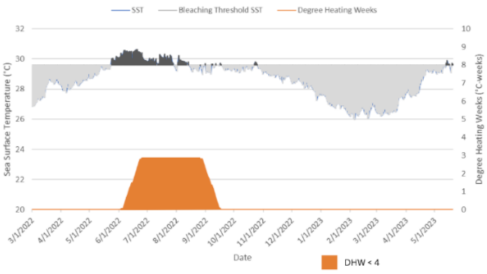


Figure 9. 2022-2023 SST and DHW

Both the PRISMA HSI and Sentinel L2A have sensing date of March 2023, although there are no signs of alert levels in 2023, we can see in year 2022 that thermal stress accumulation was evident, indicating bleaching and the non-recovery of corals for the corresponding years. This observation was confirmed through fieldwork surveys and interviews. Corals bleached in 2020, 2021, and 2022 have still not recovered on the year 2023, or they have been overgrown with algae and likely died out.

The obtained SST results align with the interviews, related literature, and studies on coral bleaching in Calatagan, Batangas.

4. Conclusion

In conclusion, this study aimed to assess the capability of hyperspectral imagery in detecting bleached corals in Calatagan, Batangas. The findings revealed that hyperspectral satellite imagery, such as PRISMA, can effectively discriminate between bleached corals and live corals. The study achieved a 61% accuracy rate in detecting bleached corals. The detected bleached corals in the area align with the field data and interview information, specifically in the barangays of Gulod, Quilitisan, Carretunan, Talisay, Tanagan, Poblacion, Sta. Ana, Balitoc, and Real. The bleaching of corals in these areas is influenced by factors such as the presence of crown of thorns (COT) affecting the coral reefs and the negative impact of human activities, such as urination in the ocean, caused by the growth of public and private resorts. While these factors may be unavoidable, they highlight the need for proper environmental strategies to prevent coral bleaching in the area.

Furthermore, although the 30x30m spatial resolution of hyperspectral imagery may be considered to be a disadvantage, its high spectral resolution may help overcome this limitation when used collaboratively, as compared to incorporating multispectral imagery. Due to the heterogeneous nature of corals and coral bleaching, the fine wavelengths of PRISMA help in detecting significant changes in between the optical bands that might be disregarded in traditional multispectral imagery. In PRISMA, the Visible Near Infrared Region (VNIR) is a crucial data range for detecting coral bleaching, with essential bands in the green and red regions playing a significant role in distinguishing bleached corals. The results demonstrate that wavelengths ranging from 535.0526 nm to 713.7269 nm are the key bands that distinguish bleached corals from healthy ones, which may be overlooked in multispectral imagery due to its lower spectral resolution.

Additionally, sea surface temperature anomalies were included as an additional parameter to assess the occurrence of coral bleaching in the area. In 2020, a year marked by massive coral bleaching in Calatagan, an Alert Level I was achieved using SST. For the current year, thermal accumulation from July 2022 onwards has resulted in coral bleaching that continues to affect the area, as confirmed by coral bleach patrollers.

Moreover, since this study represents the first assessment of bleaching in Calatagan, there was a scarcity of data for validation, which may contribute to future research on coral bleaching in the area. Additionally, bands 25, 26, 27, and 37, with wavelengths of 592nm, 601nm, 609nm, and 703nm respectively, exhibited the highest separation from healthy corals. Further examination of these bands is recommended, as they may contribute to assessing the intensity of coral bleaching. It is important to note that this study relied on a small sample size due to tide conditions and time constraints, which may limit the generalizability of the findings. To strengthen the results, additional research with larger and more diverse sample points is recommended. Furthermore, evaluating the spectral signatures of bleached corals and live corals at varying depths would greatly enhance the study.

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