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Research Article

Study of Sea Surface Temperature (SST), Does It Affect Coral Reefs?

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Abstract

This research aims to identify the influence of Sea Surface Temperature (SST) to coral disease and bleaching using MODIS-Aqua data from 2003-2009 and NOAA Coral Reef Watch data. Field-data collection on coral disease and bleaching was carried out in Bunaken National Park, Wakatobi National Park, and Raja Ampat, in August, October, and November 2009, respectively. The presence of coral disease and bleaching was observed by using time-swim method. A prevalence formula was used to calculate the percentage of coral disease and bleaching colonies. The range of mean SST value from each location: Bunaken from 26.84-31.45°C, Wakatobi from 26.09-31.95°C and Raja Ampat from 27.72-31.36°C. There is an influence of SST anomaly on the presence of dis- ease and coral bleaching. During 2003-2019, the highest SST anomaly that could increase the risk of the coral bleaching phenomenon was found in 2010. Coral disease and bleaching were found at locations with high SST anomaly, low nitrate and available phosphate. However, high SST anomalies were not a main cause of coral disease and bleaching. In many locations in Indonesia, mass-bleaching has occurred and the ability of coral adaptation is the main key in dealing with this phenomenon.

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1. Introduction

Indonesia has extensive waters 6,400,000 km² with coastline length of 108.000 km and ±17.504 islands (BIG *et al*., 2018). Based on the characteristics, coastal ecosystem is divided into natural and man-made. Natural coastal ecosystem is located in the coastal zone, such as coral reefs, mangrove, seagrass beds, sandy beach, Barrington formation, estuary, lagoon, delta, and small island (Dahuri, 2003)

Coral reefs are composed mainly of reef-building corals: colonial animals (polyps) that live symbiotically with the single-celled microalgae (zooxanthellae) in their body tissue and secrete a calcium carbonate skeleton. Coral reefs are formed by hundreds of thousands of these polyps and are found in warm, shallow, clear, low-nutrient tropical and sub-tropical waters, with optimum temperatures of 25-29ºC although they exist in wide ranges from 18ºC (Florida) to 33ºC (Persian Gulf) (Wilkinson and Buddemeier, 1994).

Coral reefs are vulnerable to predict climate change because they bleach rapidly and dramatically in response to increase sea surface temperatures (SSTs). Corals live in environments that are close to their thermal threshold (the upper temperature limit for life), and even temperature increases by 1 or 2ºC above average over a sustained period of time (i.e. a month) can cause mass bleaching (Hoegh-Guldberg, 1999). The potential severity of the predicted increases was by 1 to 3ºC in SSTs by 2050 and 1.4 to 5.8ºC in earth surface temperatures by 2100. (Hoegh-Guldberg, 1999)

Coral diseases and syndromes generally occur in response to biotic stresses such as bacteria, fungi, and viruses, and/or abiotic stresses such as increased sea water temperatures, ultraviolet radiation, sedimentation, and pollutants. One type of stress may exacerbate each other (Porter, 2010; Ampou *et al*., 2020). Through Aqua-Modis satellite, we can access sea surface temperature data and its temporal variability which can be used to determine the high-risk coral bleaching area. The optimum temperature coral is able to with stand is 24-29ºC and each species of coral have a specific "bleaching threshold" (Krupa, 2006). Corals can be with stand certain temperature; however, a positive anomaly of temperature 1-2ºC to 5-10 weeks in dry season can cause corals to be bleached (Buchheim, 2013)

Southeast monsoon in Indonesia is known as a dry season generally influenced by the wind direction from eastern (Australia continent) to western region (Asian continent). Meanwhile, northwest Monsoon is influenced by the wind direction from the Asian continent to Australia continent. The shift season from March to May, and from September to November. The phenomenon of coral bleaching related to the application (increasing) of sea surface temperature in Indonesia globally was reported by Wouthuyzen *et al.* (2015) who found an increase of hotspot by 1-2ºC compared with maximum monthly mean of SST 29.1ºC. Study on SST in relation to coral bleaching and disease in the Indonesian coral reef ecosystem is less understood. This study present SST anomaly over Indonesian waters in relation to prevalence of coral bleaching and disease in the Bunaken National Park, the Wakatobi National Park, and the Raja Ampat Marine Protected Area.

2. Materials and Methods

2.1 Study Area

The coral reef areas in eastern Indonesia are part of the Coral Triangle Region. These areas have high biodiversity because they are a suitable environment to grow coral reef organism (Veron *et al*., 2009). Research locations are shown in Figure 1 and consists of three sites: the Bunaken National Park, North Sulawesi (BNP) (1°N,124°E); Runduma Island of Northeast Wakatobi district, Southeast Sulawesi (WNP) (-5°S,124°E), and Raja Ampat (Waisai) Bird's Head Seascape of Papua (00⁰S,130⁰E). Field observation and measurement were undertaken on August 2009 in the BNP, October 2009 in the WNP, and November 2009 in the Raja Ampat.

2.2 Time Swims

Time swim with given time was performed for coral disease and bleaching visual census and under-water photos. It can be applied in a 30 minute dive using *self-contained underwater breathing apparatus* (SCU-BA) equipment to observe the occurrence of coral disease and bleaching in the depth of 5 and 10 meters (English *et al*., 1997; Bianchi *et al*., 2004).

2.3 Disease and Bleaching Prevalence

Disease prevalence is the proportion of disease colonies to the total measured population of colonies. It can be calculated for individual populations, species or genera, or for the coral community as a whole, as well as for each particular disease or syndrome, similar group of diseases or for all diseases lumped together. What is calculated depends on the question asked.

$$\text{Prevalence (P)} = \left(\frac{D-B}{T}\right) \times 100 \qquad \ldots\ldots\ldots\ldots (1)$$

$$\text{Total Prevalence (TP)} = \frac{P}{\sum \text{Location}} \qquad \ldots\ldots\ldots\ldots (2)$$
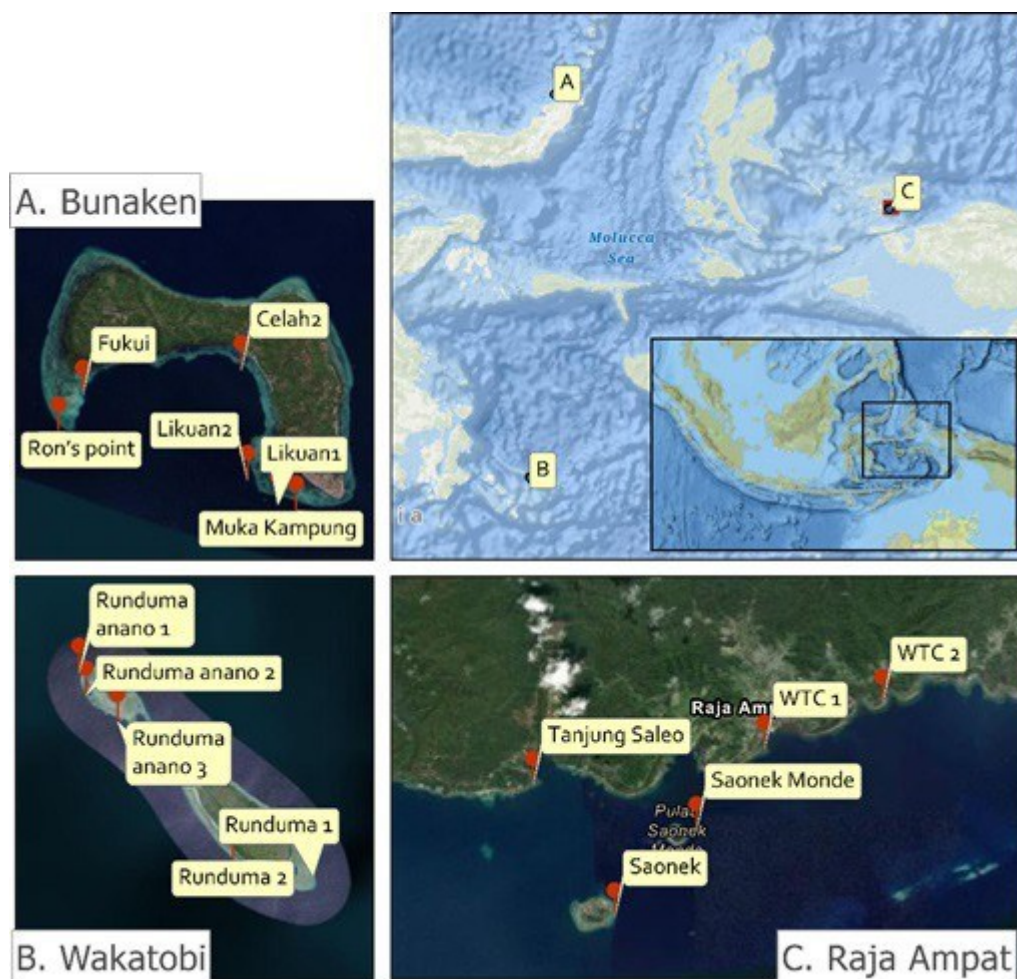
Figure 1. Map of three study sites and sampling stations: A. Bunaken Island, Bunaken National Park (BNP), North Sulawesi; B. Runduma Island, Wakatobi National Park (WNP), Southeast Sulawesi; C. Waisai, Raja Ampat Marine Protected Area (MPA), Papua Bird's Head Seascape.

where D-B is disease-bleaching colonies and T is total colonies. A prevalence value was estimated for each area sample unit. An average prevalence value with standard deviation can then be calculated for habitats, zones or reefs (depending on the stratification and the question) by using the sample unit prevalence value (Rayundo *et al*., 2008).

2.4 Sea Surface Temperature (SST) Data

SST Product from NOAA Satellite

The Coral Reef Watch data from the NOAA satellite were performed in this study. NOAA Coral Reef Watch 5 km Satellite Virtual Station Time Series was used and applied for North Sulawesi (Bunaken), Southeast Sulawesi (Wakatobi), and West Papua (Raja Ampat) station. Briefly, the 5 km resolution data were calculated by averaging multiple temperature observations (weighted by distance from pixel center, conditionally out to a maximum of 150-km), which are based on 4-km AVHRR global area coverage (GAC) SST acquired daily (NOAA Coral Reef Watch, 2018).

SST Product from MODIS-Aqua Satellite

The Modis SST data were obtained from Earth Engine platform (Gorelick, 2017). Based on the Ocean Color SMI: Standard Mapped Image MODIS Aqua Data have 500 m spatial resolution (NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group). The data are available from July 2002. Therefore, this study only shows the bleaching threshold from January 2003-December 2019.

There are four steps in identifying the coral stress level (NOAA Coral Reef Watch, 2018) as shown in Figure 2. First is calculating the weekly and monthly average from the daily SST data. Second is to estimate the maximum of monthly mean climatology based on the highest of the monthly mean SST over 2003-2019. Third, HotSpot value is calculated by subtracting the weekly SST with the MMM SST. Only positive values were derived, since the HotSpot was designed to show the occurrence and distribution of heat stress conducive
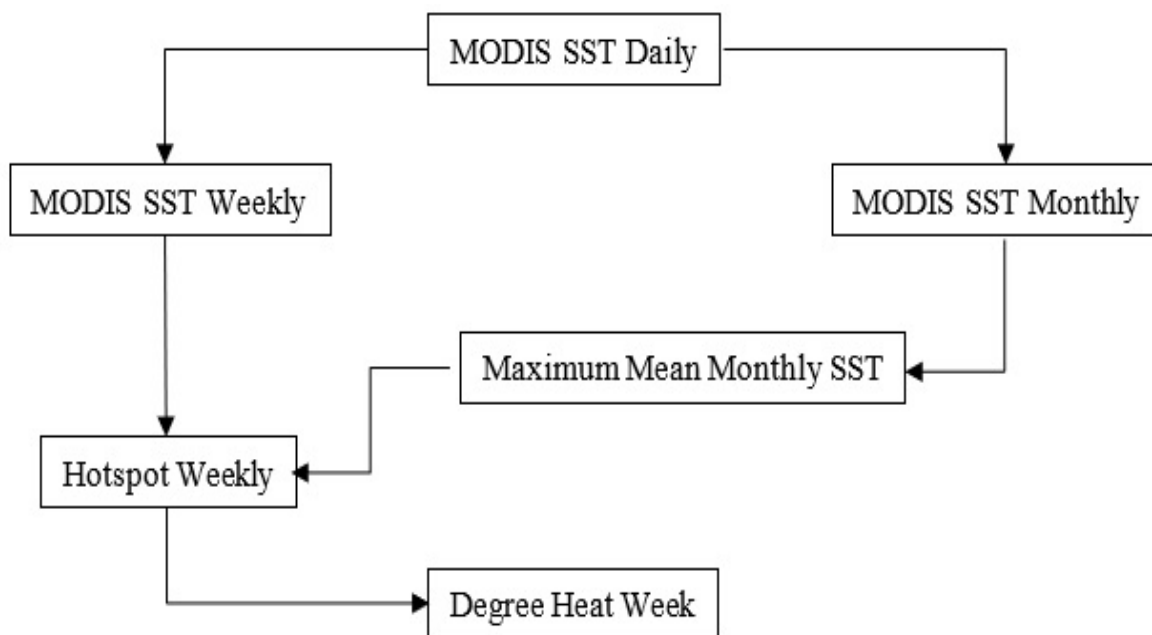
Figure 2. Processing flow chart of MODIS-Aqua SST Product

to coral bleaching. Last the calculation of Degree Heating Week (DHW), as a 12-week accumulated HotSpot value upper 1°C.

Then the stress levels defined in the Table 2 were based on current values (at that time) of the Coral Bleaching HotSpot and DHW products (NOAA Coral Reef Watch, 2018). These levels were defined in terms of the HotSpot and DHW values. When low heat stress was present at a reef site (0°C < HotSpot < 1°C) a Bleaching Watch was posted for the site. A bleaching warning was posted when the HotSpot => 1°C. A DHW accumulation of 4°C-weeks triggered a Bleaching Alert Level 1. At Bleaching Alert Level 1, significant bleaching was expected at the site within a few weeks of the alert. An accumulation of 8°C weeks triggered a Bleaching Alert Level 2, at which point severe, widespread bleaching and significant coral mortality were likely.

Table 1. Prevalence category of coral disease and bleaching

No	Prevalence (%)/Location/Genus-Species	Category
1	0 – 50	good
2	51 – 75	fair
3	76 – 100	poor
4	>100	bad/serious condition

Table 2. The stress levels based on HotSpot and DHW product.

Stress Level	Definition	Effect
No Stress	HotSpot <= 0	--
Bleaching Watch	0 < HotSpot < 1	--
Bleaching Warning	1 <= HotSpot and 0 < DHW < 4	Possible Bleaching
Bleaching Alert Level 1	1 <= HotSpot and 4 <= DHW < 8	Significant Bleaching Likely
Bleaching Alert Level 2	1 <= HotSpot and 8 <= DHW	Severe Bleaching and Significant Mortality Likely

Table 3. SST comparison in each study site

No	Area	Location*	Date	Time	Longitude	Latitude	Temperature in Celsius		
							Measurement	Modis Weekly	Modis Daily
1		Runduma 1	21-10-09	13.02	124.359	-5.352	30.00	30.25	Cloudy
2		Runduma 2	21-10-09	15.49	124.334	-5.347	29.00	30.25	Cloudy
3		Runduma anano 1	22-10-09	7.59	124.286	-5.289	30.00	28.80	28.51
4	Wakatobi	Runduma anano 2	22-10-09	8.40	124.288	-5.296	29.00	28.80	29.091
5		Runduma anano 3	22-10-09	11.15	124.298	-5.304	30.00	29.96	28.421
6		Saonek Monde	18-11-09	12.57	130.806	-0.451	28.00	29.78	Cloudy
7		Tanjung Saleo	18-11-09	14.25	130.770	-0.441	29.00	29.51	Cloudy
8	RajaAmpat	WTC 1	19-11-09	9.40	130.821	-0.433	28.00	29.78	Cloudy
9		WTC 2	19-11-09	11.20	130.847	-0.423	28.00	30.290	Cloudy
10		Saonek	19-11-09	15.32	130.788	-0.470	29.00	30.72	Cloudy
11		Celah2	18-8-09	14.50	124.765	1.616	29.00	30.33	31.08
12		Fukui	19-8-09	10.15	124.739	1.612	28.00	30.33	28.85
13		Likuan1	18-8-09	12.44	124.771	1.594	29.00	30.26	31.08
14		Likuan2	18-8-09	16.25	124.766	1.598	29.00	30.26	28.96
15	Bunaken	Muka Kampung	18-8-09	11.16	124.774	1.593	29.00	30.26	28.96
16		Ron's point	19-8-09	9.40	124.735	1.606	28.00	30.26	28.85

*The name of dive site

3. Results and Discussion

3.1 Validation of MODIS-Aqua SST Product

The MODIS-Aqua SST product has been validating for several area that have oceanic instruments such as buoys. Unfortunately, most such instrument are deployed in the open ocean and small areas in this study site, Bunaken, Wakatobi, and Raja Ampat are not available. This research tried to validate SST product from MODIS-Aqua Satellite with the SST data from field measurement. The SST comparisons of each site observation are shown in Table 3. The difference between measurement and MODIS satellite product reached $\pm 1^0$C in each site. A bias in the result is assumed because of the inaccurate measurement instrument and atmospheric correction problem for the satellite (Feldman, 2009).

3.2 Comparison of SST Product from MODIS and NOAA

NOAA Coral Reef Watch Bleaching Alert is built based on 50 km spatial resolution imagery. This low spatial resolution creates a huge average value that generalizes the SST information. Several coral reef ecosystems are gathered in small colonies and not in a wide area. For this kind of ecosystem, smaller spatial resolution imagery is needed. Ocean Color SMI: Standard Mapped Image MODIS-Aqua Data product with 500m spatial resolution provides better information for small coral reef ecosystem. This research compares the SST information and bleaching threshold from NOAA and MODIS data in three observation sites.

Figure 3 shows the SST variation based on Coral Reef Watch data and MODIS-Aqua in three study sites. Overall, the SST pattern is equal, but there is a difference between DHW produce from NOAA and MODIS data. Since the NOAA DHW product is not build based on the specific observation site shown in Figure 1, the result is slightly different. The proposed MODIS DHW product which showed a site specific result was one of the advantages.

In the Bunaken site, the variability of SST value showed a not significant value over a year. An average of high weekly temperature reached a maximum of April-June, and September-October with a higher value

of 31.45 ℃. The higher temperature during 2003-2019 was recorded during the shift season in May 2010 of 31.29ºC. The average of high temperature in the dry monthly season for the period 2003-2019 was 31.25ºC in May.

The Wakatobi site was in the normal condition and did not reach bleaching threshold (Figure 3e), whereas results of the Modis Aqua data (Figure 3b) show the WNP average of high weekly temperature maximum from May-April and November-December-with a higher value 30.71ºC. The higher temperature during 2003-2009 occurred in the shift season 2009 precisely in May of 31.53ºC. The average of high temperature in the dry monthly season for the period 2003-2019 was 30.72ºC in May. The bleaching warning event are shown to have appeared starting from November to June every year.

The Raja Ampat site showed that the SST variation was in the normal condition and did not reach to bleaching threshold limit, however it was over to the bleaching threshold based on the results of the MODIS-Aqua data (Figure 3a). The highest weekly temperature was shown in April-May, and October-November that reached to be 30.55ºC (MODIS-Aqua, Figure 3b). The highest temperature ~31.57ºC during the period 2003-2019 was found in the shift season April 2008. However, the average of higher temperatures in the dry month season for the period 2003-2009 was 30.52ºC and found in April.

In general SST from NOAA and MODIS-Aqua data showed a similar pattern in each site (Figure 3). In more detailed analysis, the result showed a different result between large scale analysis which is 50 km spatial resolution (NOAA data) and small-scale analysis of 4 km spatial resolution (MODIS-Aqua data). In the MODIS-Aqua data analysis, an SST condition that reached the bleaching threshold was found several times while in the NOAA Coral Reef Watch showed a different result. For the case of the BNP, the WNP, and Raja Ampat coral reef ecosystems, low spatial resolution imagery was not suitable to describe the condition because of the scale of the site.

3.3 MODIS-Aqua SST Product Analysis for Coral Bleaching Alert

NOAA Coral Reef Watch provided data to observe coral bleaching on a global; however, for observing a small scale more detailed information is needed. With a 50 km spatial resolution area such as the Bunaken, the Wakatobi, and Raja Ampat will produce great generalized information. By using the MODIS-Aqua SST product, a small-scale area will be analyzed more accurately. Based on MODIS-Aqua SST weekly (seven days) product, several pieces of information were calculated such as maximum weekly, minimum weekly, weekly mean, monthly mean climatology, and

number of weeks of Coral Reef Bleaching Alert to evaluate the contribution of SST. Table 4 showed the summary of the Coral reef Bleaching Alert analysis results in each site from 2003 to 2019. Each site shows different number and pattern in regard to the coral bleaching phenomena.

The Bunaken site list as the highest number of coral bleaching alert. Since 2003, 63 weeks have been recorded to be categorized as coral Bleaching Alert Level 1, inevitably affecting the condition of coral reef around the Bunaken Island. In fact, Ampou (2010) identified that the condition of coral reef health in the Bunaken Island is in poor condition. Years with strong bleaching alerts are shown from April until December in 2010, 2013, and 2014.

The Wakatobi site depicted a different bleaching alert pattern, as the alert tends to start from November until June with two peaks of January-February and May-June. Compared with the other two sites, the Wakatobi site specifically Runduma Island is the coral area with the lowest possibility of coral bleaching, according to the observed SST value. The highest number of weeks in a year that shows a coral bleaching alert are in 2016-2017, but the number is small, as it is only 11 weeks overs the last 16 years.

The coral reef on Raja Ampat has also been affected by the increase of SST, as shown by a 20 weeks bleaching alert during 2003-2019. The Raja Ampat site showed two peaks of bleaching alert October-January, and March-August. In relation to the Bunaken site, the highest number of weeks in a year showing a coral bleaching alert was found in 2010.

Overall, in each of the observed sites, the coral bleaching stress shows a different pattern and intensity. This variation is might because of different sensors. However, during the El Niño event in 2009-2010, which indicates as the strongest warming signal in the last four decades, a bleaching alert is appeared for all the sites. The result of coral reef bleaching alert based on SST Modis is lightly different from the NOAA Coral Reef Watch report. In this study, we did not generalize the coral bleaching stress in the entire area of North Sulawesi, Southeast Sulawesi, and West Papua, but only in the specific area, as shown in Figure 2.
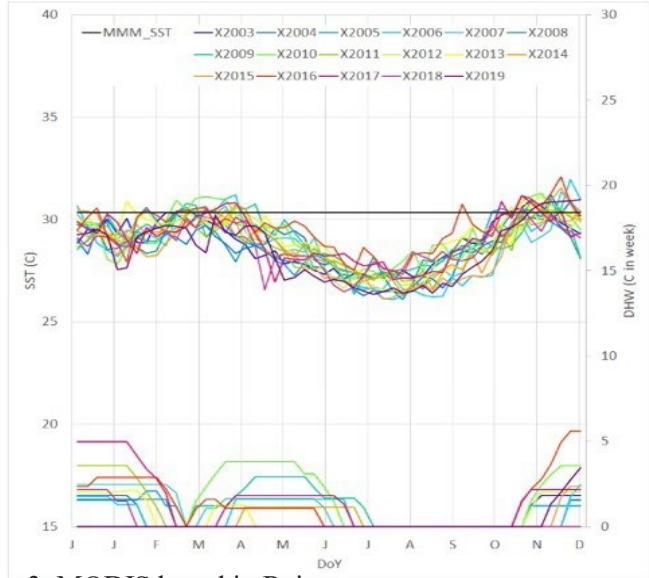
3.4 Is SST a Major Effect on Coral Reefs?

Based on data from previous research results by Ampou (2010) related to the total prevalence value of bleaching and disease at each study site, the average high prevalence is shown at Bunaken National Park especially at 10m depth (83.73, poor) and a low prevalence in Raja Ampat at 10m depth (23.50, good) (Table 5). The coral genus dominant bleaching and disease were *Porites* and *Acropora*, otherwise *Pocillopora* and *Montipora* were less dominant.
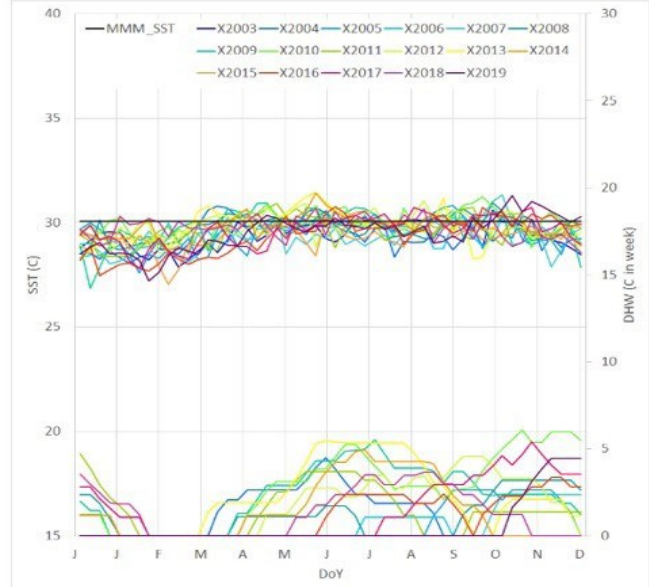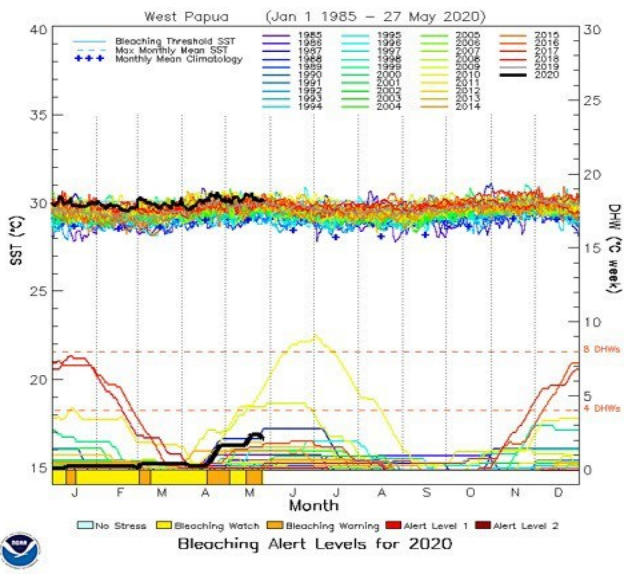
1. MODIS based in Bunaken

4. NOAA based in North Sulawesi
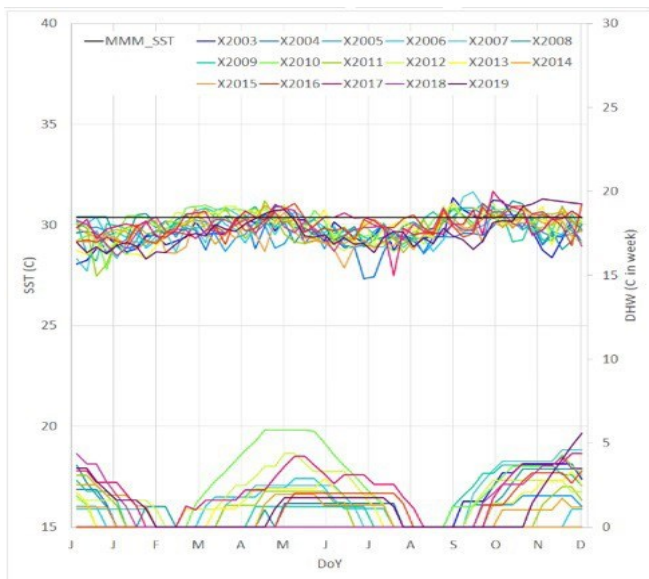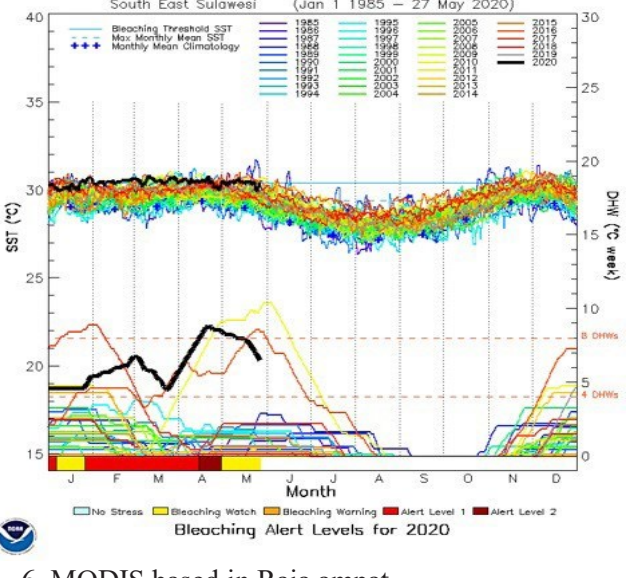
2. MODIS based in Wakatobi

5. NOAA based in Wakatobi

3. MODIS based in Rajaampat

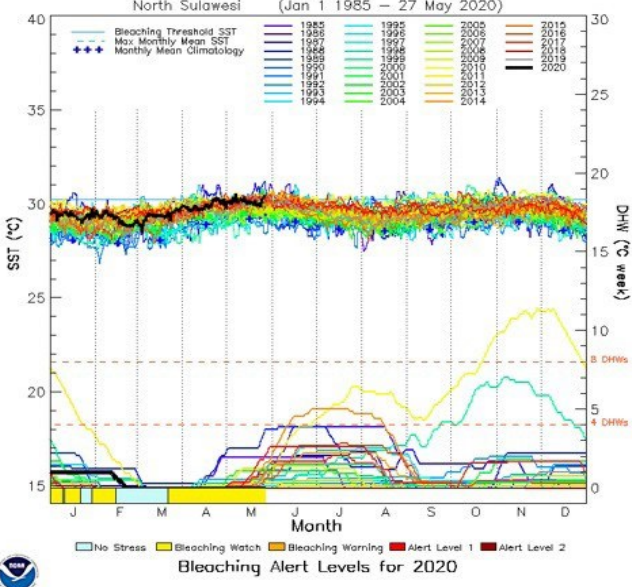6. MODIS based in Raja ampat

Figure 3. SST variation and Degree Heat Week (DHW) based on NOAA Coral reef watch and Modis Aqua

Table 4. Coral Bleaching Alert over Bunaken, Wakatobi, and Raja Ampat in 2003-2019. Red marks show the highest number of bleaching stress alert

Bunaken																	
Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Weekly Max	30.6	30.77	30.81	30.42	31.32	30.93	30.93	31.21	30.92	31.04	31.45	31.41	30.32	30.76	30.73	30.68	31.29
Weekly Mean	29.41	29.41	29.46	29.46	29.31	29.7	29.72	29.95	29.67	29.78	29.8	29.83	29.33	29.33	29.61	29.75	29.51
Weekly Min	27.87	28.07	27.6	28.29	27.87	28.68	26.84	28.8	28.38	28.52	28.18	28.58	27.06	27.46	27.8	28.57	27.21
Monthly Max	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05	30.05
No Stress	21	25	20	21	26	15	12	8	14	11	13	11	23	21	16	13	20
B. Watch	30	19	27	29	22	29	26	26	30	30	26	32	28	21	25	30	25
B. Warning	0	22	15	9	10	30	31	23	34	28	24	18	0	26	21	31	4
B. Alert Lv.1	0	1	0	0	0	0	8	15	1	4	12	11	0	0	7	0	4
B. Alert Lv.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wakatobi																	
Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Weekly Max	30.94	31.23	30.9	31.95	31.35	30.59	31	31.31	30.89	31.24	30.91	30.74	31.55	32.1	31.17	30.61	30.97
Weekly Mean	28.87	28.6	28.94	28.59	28.87	28.63	29.03	29.19	28.76	28.9	29.16	28.78	28.59	29.57	29.04	28.74	28.47
Weekly Min	27.05	26.27	26.61	26.09	26.58	26.09	26.33	27.07	26.62	26.5	26.6	26.33	26.11	27.33	26.95	26.49	26.35
Monthly Max	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35
No Stress	32	41	31	37	34	37	33	30	39	28	27	36	34	22	32	38	36
B. Watch	17	9	18	9	13	14	13	12	12	20	22	13	15	20	14	12	11
B. Warning	6	9	17	21	26	10	18	21	9	6	12	12	3	28	23	6	4
B. Alert Lv. 1	0	0	0	0	0	0	0	1	0	0	0	0	0	3	7	0	0
B. Alert Lv.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Raja Ampat																	
Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Weekly Max	31.35	30.93	30.92	30.85	31.64	31.2	31.08	30.99	31.2	31.11	31.1	30.97	30.63	31.06	31.68	31.06	31.29
Weekly Mean	29.67	29.48	29.67	29.82	29.8	29.97	29.88	30.07	29.83	29.93	29.92	29.83	29.58	29.93	30.12	29.9	29.66
Weekly Min	28.07	27.33	28.53	28.69	27.72	28.8	28.23	27.81	27.46	28.73	28.33	28.79	27.86	28.99	27.49	28.49	28.32
Monthly Max	30.36	30.36	30.36	30.36	30.36	30.36	30.36	30.36	30.36	30.36	30.36	30.36	30.36	30.36	30.36	30.36	30.36
No Stress	24	25	21	13	17	15	14	12	18	14	15	16	22	14	5	9	28
B. Watch	22	25	28	32	25	30	30	23	27	27	27	30	29	29	33	35	14
B. Warning	13	16	10	24	31	20	31	25	23	40	29	30	4	24	37	15	24
B. Alert Lv.1	0	0	0	0	3	0	0	11	0	2	0	0	0	0	4	2	3
B. Alert Lv.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5. Total prevalence value in coral

No	Location	Depth (m)	∑ Prevalence (%)/location/Genus-Species	Categories
1	Bunaken National Park	5	55.47	fair
		10	83.73	poor
2	Raja Ampat MPA	5	30.67	good
		10	23.50	good
3	Wakatobi National Park (Runduma Island)	5	23.55	good
		10	50.94	fair

Runduma Island (WNP) has highest positive anomaly for all years compared with other sites, while in the Raja Ampat the lowest positive anomaly was observed. The BNP also showed a high positive anomaly for all years. By comparing anomaly information with prevalence information, a pattern was shown. In the sites with high positive anomaly this is correlated with a poor or fair coral condition. This condition indicates that coral bleaching and disease occurred (Figure 4). Increasing SST is not the main contribution of coral bleaching and disease because we found a higher positive anomaly and better condition of coral prevalence in the Wakatobi compared with the condition in the BNP. There are some other factors besides temperature that contribute to coral bleaching and disease incidence, such as water quality, competition, predator, and human activities (Hoegh-Guldberg, 1999; Grimsditch and Salm, 2006). The El-Niño sea level fall in the long-term period can also trigger bleaching, disease or even death in coral reefs (Ampou et al., 2017).
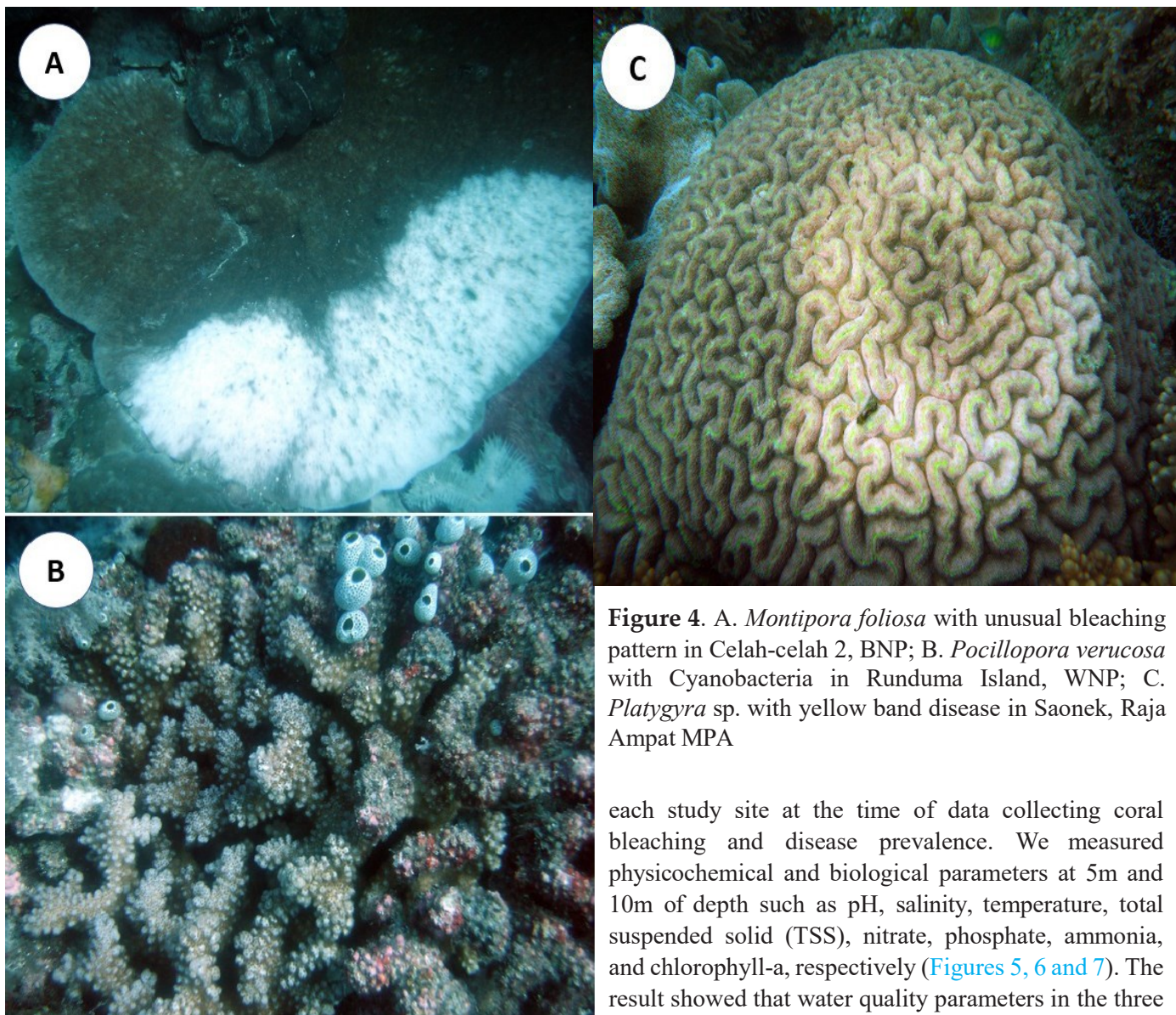
Figure 4. A. *Montipora foliosa* with unusual bleaching pattern in Celah-celah 2, BNP; B. *Pocillopora verucosa* with Cyanobacteria in Runduma Island, WNP; C. *Platygyra* sp. with yellow band disease in Saonek, Raja Ampat MPA

According to Burt *et al.* (2020) even with future global climate change, coral reefs will be able to adapt to disturbances. Other factors that greatly affect the resilience process are the acclimatization process, intragenerational effects and the evolutionary pressure of the coral reefs itself (Drury, 2020).

The ability of coral resilience in Indonesia is relatively high as occurred in the Pieh Island, West Sumatra. This has been shown in previous studies by Wouthuyzen *et al.*, (2020). However, the key factor of coral dealing with disturbances is their ability to adapt, known as being resistant, and resilient (Odum, 1989; Carpenter *et al.*, 2001; Grimsditch and Salm, 2006).
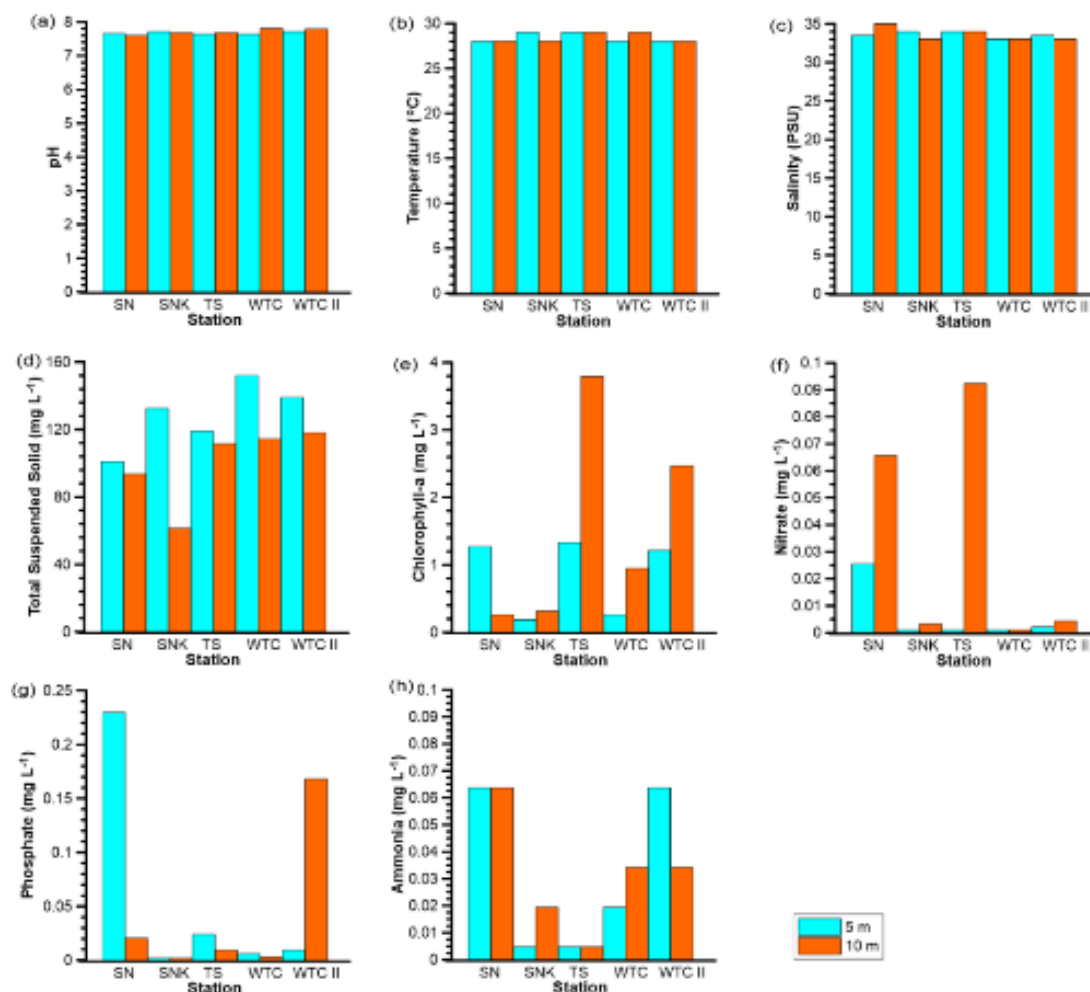
3.5 Water quality

This study, undertook water quality field measurement to provides environmental condition of each study site at the time of data collecting coral bleaching and disease prevalence. We measured physicochemical and biological parameters at 5m and 10m of depth such as pH, salinity, temperature, total suspended solid (TSS), nitrate, phosphate, ammonia, and chlorophyll-a, respectively (Figures 5, 6 and 7). The result showed that water quality parameters in the three study sites had no significant difference in terms of pH, salinity, and temperature (Figures 5a-c, 6a-c, & 7a-c).

In general, the average of pH at three study sites is in the ideal condition for supporting coral growth. The threshold according to the Ministry of Environment of the Republic of Indonesia (2004) is 7-8.5. The average pH in the Raja Ampat, the WNP, and the BNP were respectively 7.7, 7.68, and 8.12 at depth of 5m and 7.71, 7.71, and 8.08 at a depth of 10m. Degree of acidity or pH describes the concentration of hydrogen ions in a certain area of waters (Rogers *et al.*, 2001). It is closely related to carbon dioxide concentration and alkalinity. Acidic water in a certain period can lead to bleaching in coral.

The temperature from field measurement in the Raja Ampat, the WNP, and the BNP ranged 28-30ºC. Our measurements were in ideal temperature for coral
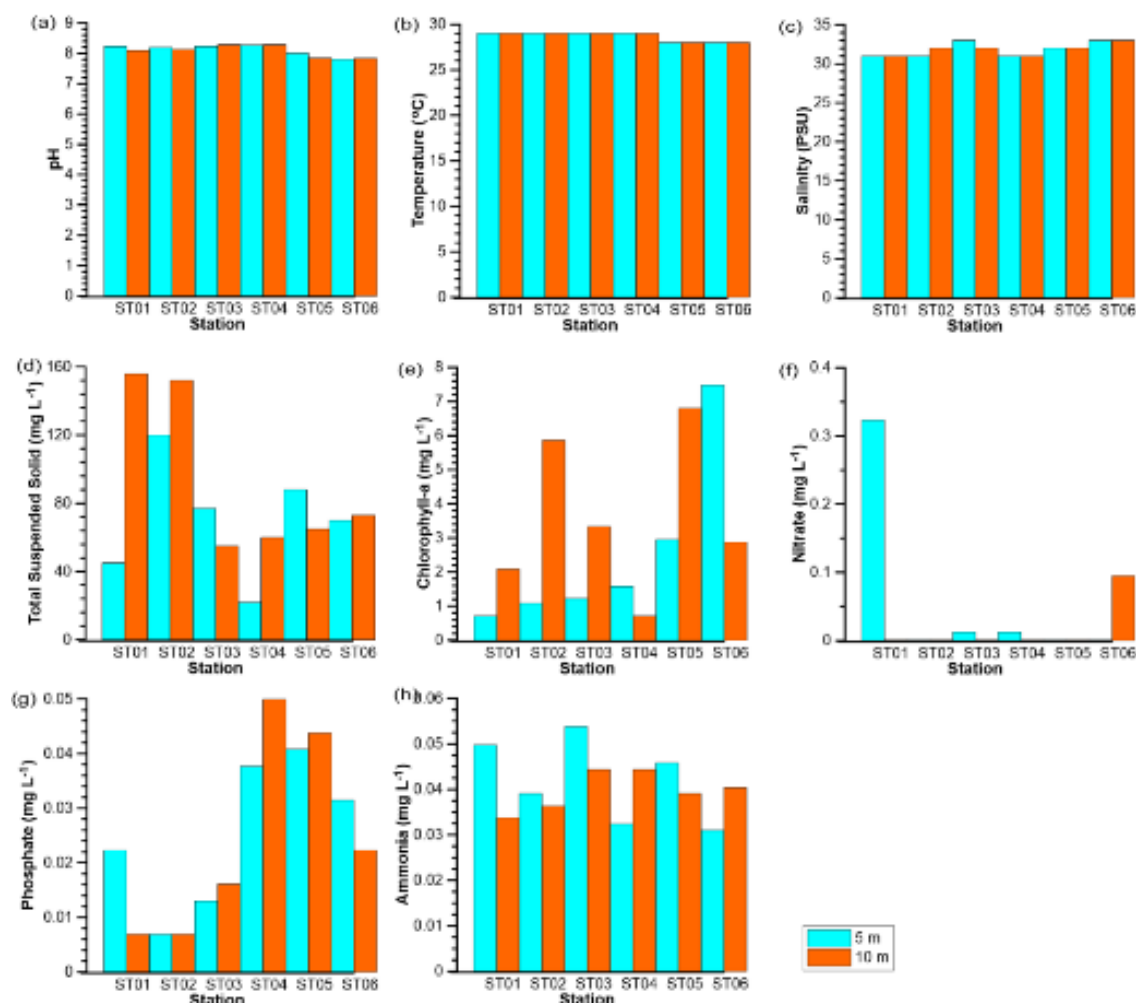
Figure 5. Vertical bar chart water quality of (a) pH, (b) temperature (ºC), (c) salinity (PSU), (d) total suspended solid (mg L-1), (e) chlorophyll-a (mg L-1), (f) Nitrate (mg L-1), (g) phosphate (mg L-1), and (h) ammonia (mg L-1) in Raja Ampat (Waisai) Bird's Head of Papua. Data presented in panels (a) to (h) are taken from different two depths of 5 m and 10 m.

growth (23-30ºC, Wilkinson and Buddemeir, 1994; 28-30ºC, the Ministry of Environment of the Republic of Indonesia, 2004). Each coral species has a certain resistance in adapting to temperature anomaly (Duckworth *et al.*, 2012). The average of water temperature in the Raja Ampat, the WNP, and the BNP at 5m and 10m depth were relatively similar. The values was 28.4ºC; 29.6ºC; and 28.7ºC, respectively, at depth of 5m and 28.4ºC; 29ºC; and 28.7ºC at 10m depth.

Coral reef growth is optimal within water salinity between 33-34‰ (Ministry of Environment of the Republic of Indonesia, 2004). Field measurement indicated that salinity in the WNP was higher than in the other two sites (Raja Ampat and BNP). It reached 35‰, while in the Raja Ampat and BNP the salinity was in ideal con- dition for coral growth (33.6‰ at Raja Ampat; 31.8‰ at BNP). There was no extremely different in salinity at depth of 5m and 10 m.

The total suspended solid (TSS), chlorophyll-a, and nutrients (nitrate, phosphate, and ammonia) have different concentration in three study sites, both at 5m and 10m depth. In general, concentration of TSS in all study sites was above the threshold determined by the Ministry of Environment of the Republic of Indonesia (2004). The averages exceeded 20 mg/l. TSS in the Raja Ampat (128.7 mg/l) which was highest than the WNP (63.7mg/l) and the BNP 70.33mg/l).

Chlorophyll-a (Chl-a) was slightly higher in the BNP compared with the Raja Ampat and WNP. In more detailed, in the BNP, we found this higher Chl-a at 10m depth ranged 0.71-6.68 mg L^{-1}. In addition, a slightly high value of Chl-a of 7.48mg L^{-1} at station 6 at 5m depth was observed. In the Raja Ampat, Chl-a both 5 and 10m depths were fluctuated ranged 0.19-1.33 and 0.26-3.79 mg L^{-1}, respectively. In the WNP, there was a similar Chl-a pattern to the BNP, shown at 10m depth where concentration was 0.63-1.05mg L^{-1} and at 5m was 0.32-0.83 mg L^{-1}.
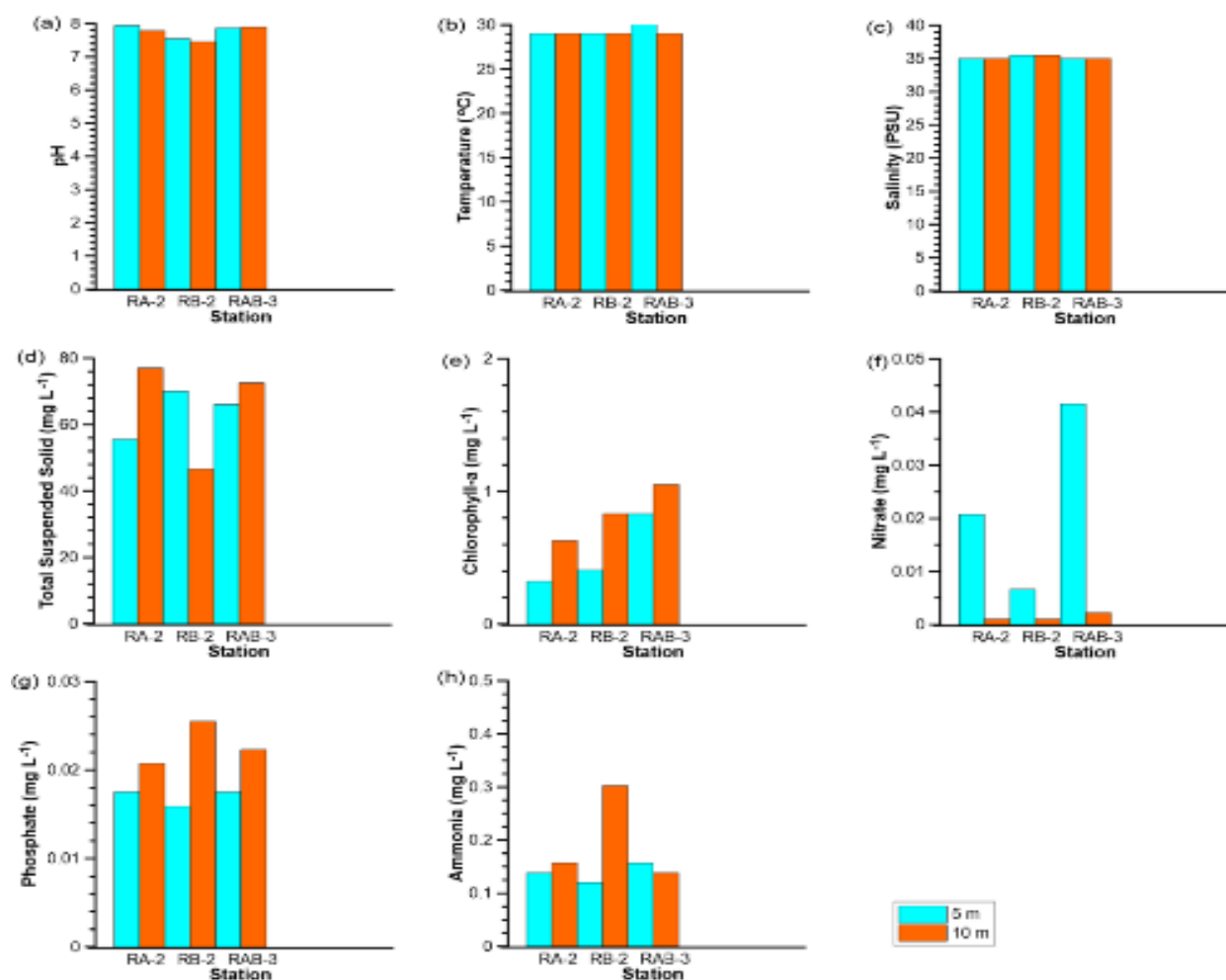
Figure 6. Vertical bar chart water quality of (a) pH, (b) temperature (ºC), (c) salinity (PSU), (d) total suspended solid (mg L-1), (e) chlorophyll-a (mg L-1), (f) Nitrate (mg L-1), (g) phosphate (mg L-1), and (h) ammonia (mg L-1) in Bunaken National Park (North Sulawesi). Data presented in panels (a) to (h) are taken from two different depths of 5 m and 10 m.

Nitrate in the Raja Ampat at 5m and 10m were 0.002-0.03 mg L^{-1} and 0.04-0.09mg L^{-1}, respectively, in the BNP at 5 m it was 0.012-0.32mg L^{-1} and at 10m < 0.09 mg L^{-1}, and in the WNP at 5m was 0.002-0.04mg L^{-1} and at 10m was <0.002. Higher phosphate in the Raja Ampat was only found at 5m at SN station (0.23mg L^{-1}) and at 10m at WTC II (0.17mg L^{-1}), while in the BNP, concentration was varied from 0.01-0.04mg L^{-1} at 5m and from 0.01-0.05mg L^{-1} at 10m. However, in the WNP, phosphate was homogenous at 5 m and ranged 0.02-0.03mg L^{-1} at 10m. Ammonia in the BNP and WNP were observable than in the Raja Ampat. All ammonia concentrations in the study site was more below the threshold determined by the Ministry of Environment of the Republic of Indonesia (2004).

Degradation of water quality in coral reef ecosystem can be directly observed in corals' reduced recruitment, decreased calcification, shallower depth distribution limits, altered competition (more…..

heterotrophic fauna), and loss of biodiversity (ISRS, 2004, Thurber *et al.*, 2014). Understanding the effects of increased turbidity, nitrates, silicates, and temperature on coral cover is crucial given the important roles ecosystem coral reefs play (Hinson, 2016).

Our coral reef ecosystem is located in the pristine area of coral triangle where they are facing high disturbance in particular high SST and nutrient loading induced bleaching and disease, however, the coral may have ability to adapt. We observed based on environmental parameters i.e. pH, salinity, and temperature, coral reefs were living in the normal condition. However, sediment stress as shown by high turbid waters (high TSS) were intruded into nearshore all study site. For an example, in the Raja Ampat, during our present observation, which was conducted coinciding with transitional season somehow rain occurred. If this sediment is continuously entranced to reef, it affects slows coral growth which means that….

Figure 7. Vertical bar chart water quality of (a) pH, (b) temperature (°C), (c) salinity (PSU), (d) total suspended solid (mg L-1), (e) chlorophyll-a (mg L-1), (f) Nitrate (mg L-1), (g) phosphate (mg L-1), and (h) ammonia (mg L-1) in Bunaken National Park (North Sulawesi). Data presented in panels (a) to (h) are taken from two different depths of 5 and 10m.

corals have a very difficult time building reefs and also coral morphology and age distribution. On the other hand, our TSS measurements were higher than 20 mg L^{-1} as required for coral health environment and slightly higher than 10mg L^{-1} which is inimical to Ca- ribbean corals (Rogers, 1983). Since water flow in this study site was strong, we assumed that this turbid water movement to another site is rapid.

In the context of nutrient stress on reefs, previous studies shown increase levels of dissolved inorganic nitrogen (nitrate plus nitrite) have been linked to a reduction of temperature threshold for the coral bleaching and loss of coral cover and diversity (Weidenmann et al., 2013). However, we found high positive anomaly of SST in the WNP and BNP which indicated coral bleaching occurred where most of the dissolved inorganic nitrate was lower and phosphate was more available (see Figures 6g and 7g). We highlighted, when bleaching occurred, phosphate supply was unbalanced with nitrate suggesting results in phosphate starvation of the symbiotic algae (Weidenmann et al., 2013).

In the BNP, we only found a source of nutrient from the mangrove ecosystem. However, it was different in the Raja Ampat site where river run off was the dominant factor on anthropogenic nutrification. When all nutrient-rich river discharge intruded and increased into the ecosystem, they usually modified the ratio of their concentrations and intense and extensive phytoplankton bloomed (Brodie et al., 2011). It is noteworthy that compared with nitrate and ammonia, phosphate limitation plays a major role in control of zooxanthellae in the host tissues (Miller and Yellowlees, 1989). Nonetheless, previous studies have observed an increase algal cell density corresponding to increased dissolved inorganic nitrogen and strong influence in the proliferation rates of zooxanthellae (Fabius, 2005; Miller and Yellowlees, 1989).

Porites and *Acropora* are coral genus dominant bleaching and disease compared with *Pocillopora* and *Montipora*. These genera were more tolerant than *S. siderea* and *Agaricia* spp. (Thurber et al., 2014). Both genera showed two and 3.5-fold increase bleaching…..

due to nutrient loading and bleaching-induced coral de clines. Unfortunately, this study did not determine the level of bleaching and disease due to limited sampling. Further experimental into nutrient loading and identifying the high risk of genus coral and its impact to disease prevalence and coral bleaching is required.

4. Conclusion

The SST anomaly has a significant influence to coral disease and bleaching. However, high SST anomaly is not a main contributor of disease and bleaching. In general, SST data from NOAA and MODIS-Aqua have a same pattern, but specifically have different value. This is due to NOAA and MODIS-Aqua having different satellite sensor, spatial resolution, temporal, spectral and SST algorithm. The ability of coral animals to adapt to disturbance is the main key in dealing with this phenomenon. Nutrient analysis showed phosphate supply unbalanced with nitrate found in the WNP and BNP correlated with high positive anomaly and poor and fair coral condition suggesting coral bleaching and disease. It must be note that the controlling processes of the coral bleaching and disease in this sample may vary temporally and need more high time resolution both over seasonal and inter annual which has not been fully resolved.

Authors' Contributions

EEA collected and analyzed the coral data, drafted the manuscript and designed the figures. MDMM collected and analyzed the SST data and designed the figures. FH and NW collected and analyzed water quality data and designed the figures. All authors discussed the results and contributed to the final manuscript.

Conflict of Interest

The authors declare that they have no competing interests.

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