Occurrence and Prediction of Coral Bleaching Based on Ocean Surface Temperature Anomalies and Global Warming in Indonesian Waters

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Abstract. This study investigates the locations of coral bleaching events in Indonesia based on the Sea Surface Temperature Anomaly (SSTA) from the 2015-2019 period. SST was downloaded from the satellite with a resolution of 4 km. The method used was the Hotspot Index and Degree Heating Week issued by the National Ocean Atmospheric Administrations (NOAA) through the Coral Reef Watch (CRW) program. Results obtained from the Hotspots index shows that almost all Indonesian waters have the potential to experience coral bleaching and the area that has a high potential is West Sumatra with the Death Index Degree Heating Week reaching 8-12 °C-weeks with Alert Level 2 status. an increase in temperature by 1.5°C as a result of global warming, then the area with the most massive death impact was West Sumatra with an increase of 3.82 - 6.32°C-weeks. The relationship between SST anomaly and coral reef mortality is 55 - 56%, so it is a strong relationship category.

1. Introduction

The coral reef ecosystem is one of the biological resources that are high in biodiversity in Indonesia, with 590 hard coral species [1]. The dynamic of SST could affect the sustainability of coral reef ecosystem [2], as well as other marine biotas [3]. The optimum temperature for coral reef growth in Indonesia is between 23 – 30 °C with a minimum temperature of 18°C. Beyond these temperatures, coral reefs will experience a decrease in growth, reproduction, metabolism and productivity of calcium carbonate [4]. SST anomaly by only an increase or decrease of 1 – 2 °C can cause bleaching and death in corals [5]. Coral bleaching occurs when corals (hard and soft) and other marine animals in symbiosis with zooxanthellae leave the coral due to stress [6].

The incidence of coral bleaching in 1997-1998 [7] reached about 50% or more of the recorded coral cover in West Bali National Park (up to 100%), Karimunjawa National Park (50-60%), Thousand Islands National Park, Gili Islands, Lombok (up to 90%) and East Kalimantan. Regional
and global climatic conditions strongly influence SST conditions. Several studies have stated that bleaching and coral mortality in Indonesia is caused by ENSO (El Nino Southern Oscillation) [8] and IOD (Indian Ocean Dipole), especially in a negative phase that impacts Indonesian waters, mainly Western Indonesian waters [9], [10]. Also, bleaching is greatly influenced by the phenomenon of global warming, which can cause mass damage to the world's coral reefs [11]. According to the Intergovernmental Panel on Climate Change in a special report titled "Global Warming of 1.5 °C Special Report" [12], the earth has experienced an increase in temperature of 0.5 °C. It is expected that the threshold for the increase in the earth's temperature will reach the limit of 1.5 °C. By this speculated increase, it is expected to impact coral reefs with the possibility of degradation in quality up to 70-90%.

This research emphasizes on indications of changes in SST at coral reef locations. The unique characteristics of the Indonesian region gave different responses to temperature changes. Eastern Indonesia is influenced by monsoons and currents from the Pacific and in the Western Region is more influenced by rivers and monsoons [13]. For this reason, this study uses the Hotspot coral bleaching status index (HS) and Degree Heating Week (DHW) which have been widely used in previous studies [8], [11], [14] to determine the potential location for coral bleaching events.

2. Methodology

2.1. Geographic Area

The research study area is in Indonesian waters, where there are coral reef spots (Figure 1). The coral reefs' location spread along the coast of Indonesia, especially in shallow areas (0 – 50 meters).

![Figure 1: Distribution of spot coral reefs in Indonesia (blue dots) overlaid with eco-regions (EL)](image)

The total coral reef distribution on the island of Sumatra reaches 478,587 hectares. The area of coral reefs in Java is around 67,869 hectares and in Kalimantan around 119,304 hectares. Furthermore, Sulawesi Island is the island with the most extensive coral reefs in Indonesia, reaching 862,627 hectares.
hectares. The area of coral reefs on the island of Bali reaches 8,837 hectares, the total area of East Nusa reaches 272,123 hectares and Maluku and Papua, namely 439,110 hectares and 269,402 hectares. Therefore, based on this information, the potential of coral reefs in Indonesia reaches a total of 2,517,858 hectares in these islands, not including the other 17,000 islands in Indonesia [15].

2.2. Data and Method
Data used in this study are SST data, the distribution of coral reef locations in Indonesia, and coral bleaching in Indonesia in 2015 - 2019. SST data was taken from 2009 to 2019 to obtain the Maximum Monthly Mean (MMM) value with a monthly range of time. MMM is obtained to determine the maximum limit conditions for SST in Indonesia [16]. This data was downloaded from the Aqua MODIS Level 3 satellite (https://oceancolor.gsfc.nasa.gov/) [11] with a resolution of 4 km. Another software used in this study was SEADAS to create the spatial distribution of SST anomalies in Indonesia and then produce output in maps as Hotspots index and Degree Heating Week. Data on the distribution of coral reefs in Indonesia is obtained from the Indonesian Coral Reef Foundation (TERANGI) in the form of .shp format. Data on coral bleaching cases in Indonesia were obtained from the Reef Check Indonesia Foundation, reliable news sources from rapid assessment by the diver who looked at coral reef diseases. The total data summarized were as many as 141 data from 304 incidents in monthly coral bleaching reports in 2015-2019.

2.3. Data Analysis
In this study, the study area was analyzed into 11 regions based on ecoregions in Indonesia (Figure 1). However, the southern region of Java or EL. 2 is not included in this research area due to the lack of coral reef presence in the area. Therefore, only 11 out of 18 ecoregions in Indonesia can be studied. Each area will be compared based on SST anomalies and data of coral bleaching events from previous reports/studies.

The requirement for determining the MMM Value is data collection for a minimum of 7 years that is used to determine the SST or HS anomaly value [16] by combining monthly SST data and monthly climate data to obtain a Hotspots index in the form of a map to determine coral reef spots. HS values ≥ 1°C in water indicate coral bleaching. HS 1°C is used in disclosing the occurrence and distribution of coral bleaching. When water gets HS ≥ 1°C, then DHW is calculated. DHW is the length of time that HS inhabits water in a week with units of degrees °C - Weeks. If the DHW value is <4 - Weeks, it indicates that the corals are experiencing stress accumulation because the SST increases by 1°C for four weeks. DHW ranged from 4-8°C - Weeks, indicating that the corals experienced significant coral bleaching, while DHW > 8°C - weeks, the corals experienced extensive bleaching that was deadly to the corals [8]. Here is the equation of HS and DHW values according to Eladawy et.al [16].

$$\text{HS} = \text{Monthly SST} - \text{MMM}$$

Where:
- HS = Hotspot,
- MMM = Maximum Monthly Mean,
- Monthly SST = Monthly value of sea surface temperature

$$\text{DHW} = \sum_{i=1}^{n} (\text{HS}_i \geq 1 \, ^\circ C)$$

Where:
- DHW = Degree Heating Week,
- HS = Hotspot,
- n = Amount of weeks
When water obtained a value of HS ≥ 1°C, then the DHW value can be calculated with the equations and criteria in determining the coral bleaching status [16]. Furthermore, the results were analyzed using a comparative descriptive method with output in HS and DHW distribution maps which will be compared each month during 2015 - 2019 bleaching events. HS and DHW categories to determine the criteria of coral conditions can be seen in Table 1.

Table 1. Criteria in determining coral bleaching status

| Hot Spot (°C) | Degree of Heating Weeks/ DHW (°C-weeks) | Alert Status |
|---------------|------------------------------------------|--------------|
| HS: ≤ 0       | -                                        | No Stress & No thermal stress on corals |
| HS: 0-1       | -                                        | Watch & Low thermal stress on corals |
|               | DHW < 4                                  | Warning & Thermal stress are accumulated |
| HS: > 1       | DHW 4 - 8                                | Alert Level-1 & Strong thermal stress on corals, which may result in partial Bleaching |
|               | DHW > 8                                  | Alert Level-2 & Severe thermal stress on corals, which may result in widespread bleaching with likely corals mortality |

In the IPCC report (2018) [12], it has been stated that the threshold for the increase in the earth's temperature is at 1.5 °C. Therefore, further predictions of the mortality rate are carried out with an increase in temperature of 1.5 °C and also measure the relationship of SST anomaly to the mortality rate.

3. Result and Discussion
3.1. Conditions of Indonesian SST in 2015 – 2019
SST in Indonesia seas has a different range in each region and year [17]. Based on the research results [18], SST in Indonesia is generally at 26 – 31 °C. However, to further review the conditions in several regions, based on the graph, it is generally known that every year Indonesia experiences changes in SST conditions. Evaluating from 2015-2019 SST, the maximum value in each year on the graph has exceeded the maximum SST limit in Indonesia (maximum monthly mean) with different values.

In 2015, the highest value of SST was at 31 °C in the South Sulawesi area where the conditions had exceeded the maximum limit and the area with SST was in the South Java area of 21 °C. The following year in 2016, the highest SST score was at 31.83 °C in the Nusa Tenggara area, and the minimum SST in Indonesia in 2016 was in the Papua area with an SST value of 23.31 °C. In 2016 there was a very high increase in SST compared to other years. This happens because of the ENSO (El Nino Southern Oscillation) phenomenon [19]. A strong El Nino only occurred in May 2015 and ended until October 2015 [20]. The La Nina phenomenon occurred in July - December 2016, which resulted in an increase, but it did not look significant because indications of La Nina were weak [21].
Figure 2. Conditions of SST for 2015 - 2019 based on maximum and minimum values in several regions in Indonesia. The orange line is the maximum SST value in Indonesia (Maximum Monthly Mean) 29.06 °C

In 2017, the highest SST value was in South Sulawesi with a value reaching 30.97 °C. The Mean SST value in Indonesia is in West Sumatra with the SST value at 28.76 °C, and the lowest value is in the Southern Java area with a value reaching 21.3 °C. In 2018 the highest SST value was in West Sumatra with a value of 30.78 °C and the average value of SST in Bali waters with a value of 28.4 °C. The lowest value is still in South Java with an SPL value of 21.78 °C. For 2019 the highest value is in the West Papua area with an SST value reaching 31.31 °C and normal conditions at a value of 28.41 °C. The lowest value in 2019 is in the area of 20.35 °C South Java.

3.2. Hotspots Index and Degree Heating Week

After knowing the average annual SST conditions in various regions in Indonesia, then to determine the impact of SST anomaly on coral reefs, the HS and DHW indexes are displayed to determine potential indications of coral bleaching and the mortality rate (Figure 3).

Figure 3. (Left) HS Index and (right) DHW 2015 with Dark Circle = Monitoring for coral bleaching events (Source: Reef Check Indonesia Foundation and Hadi et al., 2020)
January was in the category of coral damage in the medium category Level 1 with DHW values at 4 – 8 °C - Weeks in the Central Maluku (1) region with an HS index of 1.5 °C. In February, the Thousand Islands (2) were at a warning state, while East Java (3) and West Nusa Tenggara (4) were at alert Level 1. In March the West Kalimantan (5) region experienced a level of damage at level 1. In April, coral reef conditions were in the warning stage for the Karimunjawa Islands (7) and Riau Islands (6) areas. Bunaken (8) and West Papua (14) suffered damage, indicating that it was at DHW 4 – 8 °C. In May, with three reported incidents, it suffered damage to the medium category with level 1 status in the West Sumatra and West Kalimantan (5) regions until it was indicated in the level 2 category. In June the Thousand Islands (2) region was in warning status, but it was different in Central Maluku (1), which entered the Level 1 stage. In July there were no reports of coral bleaching events in Indonesia. Then in August West Sumatra (5) is at Level 2 and while Aceh is in Level 1.

In September, the level of damage was still at level 1 in the Aceh (12) Natuna Sea region (13). In October, the level of damage was level 1 with the location in the Riau Islands. In November the areas that experienced severe damage were in the regions of East Java, Bali (3), East Nusa Tenggara (16), West Nusa Tenggara, Makassar (17), and West Papua (14) with the damage status reaching Alert Level 2 and other areas of the Thousand Islands were in the Alert Level 1 category. The impact of bleaching on corals is Level 1 for the affected areas such as Banten, West Kalimantan (5), North Sulawesi (19), and Central Maluku (1).

![Figure 4.](image)

2016 is the year that allows for mass coral bleaching (Figure 4), due to occurrence of ENSO in that year where La Nina and El Nino create high anomalous temperatures will increase the possibility of coral bleaching [21]. In January, the level of damage to coral reefs due to coral bleaching was at the warning stage, and Central Sulawesi (19) reached a level 1 alert with anomalies per week of 4 – 8 °C - weeks. In February, Central Sulawesi had achieved level 2 damage and West Sumatra (5) Level 1. Other regions, East Java (15), Bali (3), East Nusa (16), were in the warning category. In March, West Kalimantan (5) and Central Sulawesi achieved the most severe damage. West Sumatra (5) and East Java (15) are at level 1 while the surrounding regions are still in the warning category with the DHW index score at 1 – 4 °C - weeks. April is the month with the most reports of coral bleaching events, and Kalimantan is still experiencing severe damage because it has entered level 2. Other areas are indicated to be at level 1 for Central Sulawesi, and West Sumatra and other areas are still in a warning status. In May, West Sumatra and Riau Islands (13) were in the DHW index value of 4 – 8 °C - weeks
Level 1, and West Kalimantan was still spotted with severe damage, while in other areas it was indicated in the warning category. Aceh (12) was in the level 1 category in June, and South Kalimantan (22) was only in the warning category.

The water area in Banten Province is at a warning level, namely in July and August, areas indicated by coral bleaching are in a warning status. West Sumatra in September experienced Level 2 damage, and Banten (23) is still in the warning category. In November and December, there were no reports of coral bleaching events.

In 2017 (Figure 5) January for the North Maluku (25) and East Nusa (18) regions were at alert level 1. In February in the Flores Sea area, there were deaths up to Level 2 for locations in the waters of the Karimunjawa Islands (15), Bali Island (3) and Takabonarate National Park (17). In March, North Bali's waters indicated damage to coral reefs up to Level 2 and waters of Central Sulawesi (19) at Level 1. In April, East Java (15) were in the Level 1 category of damage to coral reefs and Central Maluku (1) was at Level 2. In May in the West Nusa (16) Region indicated in the warning status and East Nusa. East Java in June was in a warning status until the following month the level of damage increased to Level 2. In the same month, Bangka Belitung (26) waters were in warning status, Bengkulu (20) was at level 1 with anomaly value of 4 – 8 °C - weeks and West Papua (14) reaches Level 2. In August and September, there are no data on coral bleaching events. In October, Aceh (12) was at Level 2, and Bali was still at a warning status. In November, the waters of Bali and South Sulawesi reached Level 1, and West Kalimantan (5) indicated a Level 2 status. In December there is only one coral bleaching case in East Java that was in a warning status.

Figure 5. (Left) HS Index and (right) 2017 DHW with Dark Circle = Monitoring for coral bleaching events (Source: Reef Check Foundation Indonesia and Giyanto et al., 2017)
In 2018 (Figure 6) based on the DHW Index, it is known that in January West Sumatra (10) suffered damage to high mortality with a DHW index of 8 - 12 °C - weeks, the same as Central Maluku (1) but in contrast to Southeast Sulawesi (21), the damage reached Level 1 or anomalies per week are at 4 - 8 °C - weeks. In February, the Riau Islands (13) reached high levels of damage and other areas, namely East Java (15) and Central Sulawesi (19), were in moderate damage with a DHW index of 4 - 8 °C - weeks. In March, East Kalimantan (29) was the highest in terms of damage, namely the DHW index value of 4 - 8 °C - weeks, while other areas, namely DKI Jakarta (2), Riau Islands (13) and Aceh (12) were at Level 1. In April, several regions are in the high category DHW, which is level 2. Those regions are Bangka Belitung (26), Central Maluku and West Papua (14) while in the region of Sulawesi, namely Southeast Sulawesi and Makassar are in the level 1 category.

In May, West Sumatra (10) was in the warning category, Riau Islands was in the DHW 4 - 8 °C - weeks index, and Central Sulawesi showed severe damage. Aceh region in June has reached index level 1, and East Nusa is indicated in a warning status. However, in the following month in July, East Nusa (18) was still in a warning condition, and Aceh was at alert level 1. In August, no data was reported, but the DHW index results may be relatively high, namely in West Sumatra and the waters in the region, Eastern Indonesia, such as the Halmahera Sea and North Maluku (25). In September Aceh has increased to level 1 status compared to July and the Riau archipelago, North Sulawesi Region is at an indication of Level 1.

In October the West Kalimantan area was at Level 1 status, and in November the Bali (3) waters were in a warning condition. In December, Karimunjawa Islands (15) and Central Sulawesi indicated Level 2 deaths. Its areas in South Sulawesi (17) and West Papua indicated level 1 alert status. In 2019 (Figure 7) In January, the condition of coral reefs in Bali (3) waters was in warning status and South Sulawesi especially in Takabonerate National Park (17) it reached 4 - 8 °C which was already at Level 1. In February, the North Maluku region (28) experienced deaths were at 4 - 8 °C - weeks DHW, and so was the West Papua region (14). In March there was only one incident, namely in East Nusa with a range of 4 - 8 °C - weeks or included in the level 1 category. April can be seen in the Riau Islands (13), there is no indication of death, but if we pay attention, there are colours in a warning condition. Banten region (23) shows a range of 1 - 4 °C - weeks. The East Java region (15) shows very extreme mortality, namely 8 – 12 °C - weeks and the West Nusa and East Nusa regions are each in the warning category or the DHW index value <4 °C - weeks.
In May, the indication of death coral in the Aceh area (12) is at Level 1. West Sumatra with a small index value of $1 - 4^\circ C$ - weeks, and so is the same as the Riau Islands (13). In the Eastern Region of Bali, the highest mortality rate is $8 - 12^\circ C$ - weeks compared to the West Nusa to East Nusa regions (16) which are only at the index of $4 - 8^\circ C$ - weeks. In June, in Aceh and East Java (15), there were only a low index value in the Aceh region, namely $1 - 4^\circ C$ - weeks and East Java was already in the Alert Level 1 condition.

In July, the Bengkulu (10) region suffered damage with a warning status. The region along Nusa Tenggara was in a condition of the highest mortality, namely in the range of $4 - 8^\circ C$ - weeks. Southeast Sulawesi and South Sulawesi both have mortality rates of $4 - 8^\circ C$ - weeks or status level 1. In August, there were no reports of coral bleaching events. In September, Bengkulu region experienced another death with a rate of $8 - 12^\circ C$ - weeks or the highest number of deaths. In this month, the Aceh region experience no cases of coral bleaching based on the results of the HS index map. Then for East Nusa, it is in the range of $4 - 8^\circ C$ - weeks with relatively high mortality and the West Papua region (14).

In October West Sumatra (10) experienced a very high mortality rate that reached the Level 2 category with a DHW index range of $8 - 12^\circ C$ - weeks. Southeast Sulawesi (29) and Bali (3) are in a warning condition. Then in West Kalimantan (5), according to the index map, there is no indication of coral mortality. In November, the conditions were the same as in October, namely West Sumatra, there was a high mortality rate, and at the same time, Bali and Nusa Tenggara were still in warning status. In December, the coral reefs of the Riau Islands (13) were in a mortality status with a DHW index of $8 - 12^\circ C$ - weeks and also in the northern part of Bali with the same conditions. Meanwhile, in West Sumatra, coral reefs' condition is in the range of $4 - 8^\circ C$ - weeks or at alert level 1.

During the last five years from 2015 - 2019, there were 134 locations for coral bleaching events summarized in this study. Table 2 below present a summary of all coral bleaching events in Indonesia based on the Marine Ecoregion (EL) as in Figure 1:
Table 2. Bleaching Incidence and Mortality from HS and DHW Index Based on Marine Ecoregion (EL)

| Ocean Ecoregion | Bleaching Cases (HS Index) | Coral Mortality Rates (DHW Index) |
|-----------------|----------------------------|----------------------------------|
| West Sumatera (EL.1) | 21 | 8-2 °C-weeks (Status Alert Level 2) |
| North Natuna Sea (EL.3, EL.4, EL.5) | 19 | 4-8 °C-weeks (Status Alert Level 1) |
| Java Sea (EL.6) | 21 | 4-8 °C-weeks (Status Alert Level 1) |
| Makassar Strait (EL.8) | 7 | 4-8 °C-weeks (Status Alert Level 1) |
| Flores Sea (EL.9) | 40 | 8-2 °C-weeks (Status Alert Level 2) |
| Savu Sea (EL.13) | - | - |
| Banda Sea (EL.12, EL.15) | 8 | 4-8 °C-weeks (Status Alert Level 1) |
| Molluca Sea (EL.10, EL.11) | 7 | 1-4 °C-weeks (Warning) |
| Halmahera Sea (EL.14, EL.16, EL.17) | 8 | 4-8 °C-weeks (Status Alert Level 1) |
| North Sulawesi (EL.7) | 3 | 1-4 °C-weeks (Warning) |
| Arafuru Sea (EL.18) | - | - |

Based on Table 2, the most considerable incidence of coral bleaching from the HS index is in the marine ecoregion EL.19, EL.13 or in the Flores Sea area with a DHW mortality index reaching 8 – 2 °C -weeks until it reaches Alert Status Level 2. In comparison, two other areas such as the Savu Sea and Arafuru Sea, the mortality rate of the corals cannot be determined because there are no reports of bleaching events in the area.

3.3. Indication of Bleaching and Death with the SST Anomaly of 1.5 °C

A prediction is made for the mortality rate of coral reefs when the temperature increases by 1.5 °C. According to the Intergovernmental Panel on Climate Change [12], the threshold for the increase in earth's temperature due to global warming is 1.5 °C. A simulation of an increase in temperature of 1.5 °C in the Indonesian Territory was then carried out to 11 Ecoregions (Fig. 8).

During the last five years, every region in Indonesia has experienced significant changes and differences in SST conditions. This condition occurs because of Indonesia's geographic location between the Pacific Ocean and Indian Ocean that creates the possibility of anomaly resulting from ENSO, IOD and Monsoon winds influence the dynamics of SST in each region in Indonesia [22]. West Sumatra is an area with a very high increase in SST, in 2016 where the highest conditions occur, the average value has reached 29.7 °C, and when the SST is increased by 1.5 °C, the result shows that the value reached 31.1°C. It turns out that in the other four years the SST conditions have reached a very high value of 29.06 °C. The SST increase in the last five years had exceeded the maximum SST limit in Indonesia for coral life. Besides the occurrence of ENSO in 2015 and 2016, in 2016, there was also a negative IOD [9]. The IOD peak point was in July with the SST anomaly at -1 °C through the DMI Index (Dipole Mode Index).
Figure 8. Simulated increase in SST of 1.5°C in 11 regions in 2015 - 2019

Note: Blue colour = annual average SST, orange colour = average SPL increased by 1.5°C, Yellow line = maximum temperature limit in Indonesia 29.06°C
4. **Conclusion**

Based on the results of the research conducted, it can be concluded that the suspected coral bleaching events have the potential to occur throughout Indonesian waters. However, from 141 reports of coral bleaching through the Hotspots index for five years, the most number of cases were in the Nusa Tenggara region (EL.9) with 40 cases reported from the HS index with deaths from the DHW index reaching 8 – 12 °C -weeks with level 2 status. By predicting the impact of an increase in SST of 1.5 °C to the coral, it can be determined that it will increase the mortality rate substantially. Among the nine areas where coral bleaching was reported, the most significant impact was in West Sumatra, with an increase of 3.82 - 6.32 °C - weeks. Temperature anomalies can affect the level of damage to coral reefs quite strongly, namely by 55 - 56% while other factors are only 44 - 44.5%.

**Acknowledgement**

We would like to thank those who have helped in completing this paper. This paper will not entirely if it has no supported by great people. Thank you to all the divers who helped a lot in data on coral bleaching event for the last five years. Thanks also to Yayasan Terangi that already mapped the coral reef distribution.

**References**

[1] Tetty Magdalena.M, 2016 Kepentingan Indonesia Aktif Dalam CTI (Coral Triangle Initiative) JOM FISIP 3, 2 p. 1–5.

[2] Peñaflor E L Skirving W J Strong A E Heron S F and David L T, 2009 Sea-surface temperature and thermal stress in the Coral Triangle over the past two decades Coral Reefs 28, 4 p. 841–850.

[3] Harahap S A Syamsuddin M L and Purba N P, 2020 Range of sea surface temperature and chlorophyll- α values based on mackerel catches in the northern waters of West Java, Indonesia AACL Bioflux 13, 4 p. 2265–2272.

[4] Nybakken L Hörkkä R and Julkunen-Tiitto R, 2012 Combined enhancements of temperature and UVB influence growth and phenolics in clones of the sexually dimorphic Salix myrsinifolia Physiol. Plant. 145, 4 p. 551–564.

[5] Hoegh-Guldberg O, 1999 Climate change, Coral Bleaching And The Future Of The World's Coral Reefs Mar. Freshw. Res. 50 p. 839–836.

[6] Yvonne et al., 2016 Panduan Pemantauan Pemutihan Karang Jakarta: DIRJEN Pengelolaan Laut, KKP.

[7] Wilkinson C, 1998 The 1997-1998 mass bleaching event around the world Status coral reefs world 1998 p. 15–38.

[8] Wouthuyzen S Muhammad A and Lorwens J, 2015 Coral Bleaching Incidents of 2010 in Indonesian Waters Revealed Through Analysis of Sea Surface Temperature Oceanologi dan Limnol. di Indonesia. 1, 3 p. 305–327.

[9] Martono M and Wardoyo T, 2017 Impacts of El Niño 2015 and the Indian Ocean Dipole 2016 on Rainfall in the Pameungpeuk and Cilacap Regions Forum Geogr. 31, 2 p. 184–195.

[10] Adiwira H Purba N P Harahap S A and Syamsuddin M L, 2018 Variabilitas suhu laut pada kejadian IOD (Indian Ocean Dipole) di perairan barat Sumatera menggunakan data Argo Float Depik J. 7, 1 p. 28–41.

[11] Nuryana J Hendrawan I G and Karim W, 2017 Pendugaan Kejadian Pemutihan Karang Berdasarkan Analisis Suhu Permukaan Laut (SPL) Tahun 2015-2016 di Perairan Bali J. Mar. Aquat. Sci. 4, 2 p. 286.

[12] IPCC, 2018, IPCC 2018 Report: Global Warming of 1.5 °C, in Global Warming of 1.5 C Chapter I, p. 49–91.

[13] Purba N P and Pranowo W S, 2015 Deskripsi Karakteristik Massa Air dan Sirkulasi Laut Unpad Press 1, 1.

[14] Pangestu D Ramadhanti R S and Fadlan A, 2018 Pemetaan Potensi Pemutihan Karang Di...
Perairan Indonesia Menggunakan Analisis Data Suhu Permukaan Laut  

Pros. Semin. Nas. Fis. dan Apl. p. 65–73.

[15] Giyanto et al., 2017, Status Terumbu Karang Di Indonesia 2017. Pusat Oseanografi Oseanografi - LIPI, Jakarta, p. 1–41.

[16] Eladawy A Nadaoka K Negm A Saavedra O C and Hanafy M, 2015 Assessment of Long Term Thermal Stress on Egyptian Coral Reefs Based on Remotely Sensed Sea Surface Temperature Data  

Int. J. Environ. Sci. Dev. 6, 12 p. 938–946.

[17] Purba N P Pranowo W S Faizal I and Adiwira H, 2018 Temperature-Salinity stratification in the Eastern Indian Ocean using argo float  

IOP Conf. Ser. Earth Environ. Sci. 162, 1.

[18] Gaol J L Arhatin R E and Ling M M, 2014 Pemetaan Suhu Permukaan Laut Dari Satelit Di Perairan Indonesia Untuk Mendukung “ One Map Policy ”  

Proceeding Semin. Nas. Penginderaan Jauh 2014 2014 p. 433–442.

[19] Ahmad A L Syamsuddin M L Purba N P and Sunarto, 2019 Thermal front condition through El Niño and Indonesian throughflow phase in southern sea of East Java and Bali on the east monsoon  

IOP Conf. Ser. Earth Environ. Sci. 303, 1 p. 0–8.

[20] Purba N P Pranowo W S Heryati H Rizal A and Yuliani L, 2018 Java Sea Surface Temperature Variability during ENSO 1997 - 1998 and 2014 - 2015  

Omni Akuatika 14, 1 p. 96–107.

[21] Athoillah I et al., 2017 Analysis of the 2015 Strong El Nino and the 2016 Weak La Nina (Their Influence on Humidity, Wind and Rainfall Conditions in Indonesia)  

J. Sains Teknol. Modif. Cuaca 18, 1 p. 33–41.

[22] Susanto R D Gordon A L and Zheng Q, 2001 Upwelling along the coasts of Java and Sumatra and its relation to ENSO  

Geophys. Res. Lett. 28, 8 p. 1599–1602.