CORAL REEFS DEGRADATION PATTERN AND ITS EXPOSURE TOWARDS CLIMATE CHANGE IN BUNAKEN NATIONAL PARK

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ABSTRACT: Coral reef is one of many shallow-water ecosystems that are found in Bunaken National park. The coral reefs ecosystem in Bunaken National Park are threatened by the impact of climate change, such as rising seawater temperature, Change in Salinity, and increase extreme meteorological events. This study will address the coral reefs condition and its pattern in Bunaken National Park, how are the water condition in Bunaken National Park changes in the timespan of 2002-2017, and what are the relations between the degradation pattern of the coral reefs and the seawater condition as an exposure towards the ecosystem Climate change in the context of this study is based on oceanographic variables such as sea surface temperature and seawater salinity. The methods that are used in this study is through meta-descriptive analysis to determine the exposure of the coral reefs, spatial-descriptive analysis to relate between climate change and coral reef conditions. The results showed that the degradation conditions of coral reefs from 2002 to 2013 have decreased, but the condition of the degraded coral reefs has increased by 2017. Based on the analysis of the conditions of the exposure and coral reefs show that there is a correlation between the two.

Keywords: Coral Reefs, Climate Change, Exposure, and Shallow-water

1. INTRODUCTION

1.1 Coral Reefs and its Exposure

The existence of coral reefs has an important function for maintaining the morphological structure of a coastal body where coral reefs serve as destructive wave barriers that can lead to coastal abrasion [1]. In addition, coral reefs also have a variety of functions and use that can be utilized directly by human life economically, such as when humans can utilize flora and fauna on coral reef ecosystems [2]. Another usage on where coral reefs can be utilized by people is through preserving them and using them as a means for tourism [2].

Although coral reefs provide benefits for people and play an important role to support marine habitat, the coral reefs are one of an ecosystem that is very sensitive towards environmental change. This is because coral reefs are one of an ecosystem that needs a specific environmental condition for it to live and to develop properly. A slight condition change in the sea could impact the ecosystem severely. A coral reefs ecosystem must have a specific amount of sea surface temperature, salinity, acidity, ocean current, as well as the amount of sunlight received [2].

The ecosystem of coral reefs can experience different kind of challenges that could threaten its existence. Challenges faced by coral reefs such as challenges to coral reef ecosystem damage, pollution from human waste, extreme weather events that can damage corals or climate challenge experienced locally or globally that can disrupt growth and can be deadly for the coral reef ecosystem [3]. Climate change is one of the main disruptions faced by coral reef ecosystems. Basically, climate change can have an impact on the condition of the sea, which could affect atmospheric and marine conditions. Changes in the environmental condition could hinder the growth and productivity of the coral reefs, as well as threatened its existence [3].

Many previous studies have revealed that climate change greatly affects oceanic marine conditions, whether the conditions of ocean currents movement, physical, chemical, or biological conditions. Climate change globally can affect sea surface temperatures, ocean currents, salinity, seawater acidity, sea levels, and other variables [4]. Sea changes will have an impact on coral reef ecosystems, as coral reefs need to have very specific conditions to live to grow [5]. With climate change, the development and life of the coral reef ecosystem will be disrupted because there is a variable component of the sea undergoing slowly experienced changes [6].

Climatological factors and meteorological factors that can affect the condition of coral reefs among others are sea surface temperatures [7], the salinity of seawater [7], and other extreme meteorological events [8]. The climate change exposure variables that will be used in this research are sea surface temperature and salinity of seawater.

1.2 Coral Reefs Degradation

The degradation of coral reefs means that the condition of the reefs is damaged on which could not function properly as an ecosystem for marine habitats [9]. Degraded coral reefs could be considered that the reefs are bleached, deceased (dead), infected by a disease, as well as physically destroyed from human activity. In this research, the coral reefs that are being classified as degraded coral reefs are deceased coral reefs and bleached coral reefs, since those are the conditions that are mostly being affected by the environment in Bunaken National Park [10].

1.3 Coral Reefs in Bunaken National Park

Bunaken National Park is a national park located in the Celebes Sea that contains five islands (Bunaken Island, Manado Tua Island, Siladen Island, Mantehage Island, and Nain Island). Bunaken National Park is located in the northern part from Manado City, North Sulawesi Province, Indonesia

Bunaken National Park consists of various marine ecosystems and coastal morphology. The ecosystems of Bunaken National Park are dominated by coral reef ecosystems, where there are various biotic, abiotic, flora, and fauna components in the area. In addition to the coral reef ecosystem, Bunaken national park also has other types of ecosystems such as seagrass beds, and mangroves [11]. Bunaken National Park has an area of 79 thousand hectares which consists of five islands (Bunaken Island, Manado Tua Island, Siladen Island, Mantehage Island, and Nain Island).

Bunaken National Park has more than 8 thousand hectares of coral reefs, spread around of the five islands of Bunaken National Park. The depth and distribution of coral reefs in the Bunaken National Park area varied greatly, where the range of depth of coral reefs in the Bunaken national park ranges from 5 to 200 meters below sea level [11].

This research is done because climate change is a phenomenon that gives impact to the coral reef ecosystem. The reason for this research was conducted in Bunaken National Park because coral reef ecosystem located in Bunaken National Park has a very high economic function, such as used for tourism and as food availability for human [11]. The study is conducted to analyze how the degradation of the coral reefs ecosystem in Bunaken National Park, relates to its exposure towards climate change.

The condition of the coral reefs within the national park is varied, on which there are coral reefs conditions that are healthy, bleached, and deceased [12]. One of the main reasons why there are still plenty of healthy coral reefs in this national park is that this national park is still continually being conserved since its main purpose the national park was built is to conserve the ecosystem. Nevertheless, there are still coral reefs that are deceased, and bleached. The degradation that happens to the coral reefs could be traced based on a lot of environmental factors. One of the factors that contribute the increasing susceptibility of the condition of the coral reefs is climate change, where the increase of the sea surface temperature, acidity, and the frequency of extreme weather is a strong contributing factor why the coral reefs are degraded in the national park [13]. Other factors that may increase the degraded and damaged coral reefs in the national park is because of human activity. Since the local people are dependent on the livelihood of the marine habitat in the national park it could provide a serious threat to the coral reefs' ecosystem without a proper management program [11].

2. METHODS

2.1 Shallow-water Analysis

The first process is to analyze the shallow-water ecosystem in Bunaken National Park to identify the distribution and the pattern of the benthic habitats in the shallow-water ecosystem in Bunaken National Park from a satellite image. The satellite image that is used in this study is a satellite image from Landsat 7 ETM+ and Landsat 8 OLI. It will analyze the shallow-water ecosystem in Bunaken National Park in the year 2002, 2007, 2013, and 2017.

The shallow-water analysis is a remote sensing method that uses reflectance radiance value in a satellite image to get an algorithm that will help to detect the shallow-water column. In a more generic term, the shallow-water analysis is a supervised classifying method through an algorithm that can detect the ecosystem beneath the shallow-water [14]. This method for this study will be done by using satellite image processing software. The value of the reflectance values is based on band number 1, 2, and 3 from the Landsat satellite imagery. The calculation of the algorithm eq. (1, 2 and 3) is used three different times to retrieve red, blue, and green spectrum. The red spectrum is based on B1 and B2, the green spectrum is based on B1 and B3, and the blue spectrum is based on B2 and B3. The band of each equation is based on the first, second, and third Landsat image layer on each band.

$$Y = (ln \text{ 1st B} + (ki/kj) \; ln \text{ 2nd B}) \tag{1}$$
$$Ki/kj = a + (a2+1)1/2 \tag{2}$$
$$a = (Var(\text{1st B}) - Var(\text{2nd B})/ \\ (2*Covar(\text{1st B} *\text{2nd B})) \tag{3}$$

Y is the equation for the algorithm to be written in the band math, 1st B, and 2nd B is the 1st and the 2nd band equation based on the value of its reflectance radiance, ki/kj is a variant and covariant

constant which is gotten from a. a is a value gotten from variant value of the 1st B and 2nd B divided by its covariant. 1st B and 2nd B means the band number (B1, B2, or B3) depending on the color spectrum.

The calculation is done to identify the benthic ecosystem in the shallow-water in Bunaken National Park. After the calculation through band math is finished, three different algorithms will be produced on which will display three different color spectrums. The three algorithms are inputted in the band math which will be selected based on the color spectrum in the order of red, green, and blue.

After calculating through band math for analyzing the shallow-water ecosystem, a classification for each type of morphology is needed to distinguish between types of coral reefs. The types of classification that will be done is by distinguishing the healthy coral reefs, the degraded coral reefs (deceased coral reefs, and bleached coral reefs), and seagrass. To distinguish the habitats, collecting sample directly from the study region is necessary. 300 samples have been collected directly in the study region specifically from Bunaken Island, figure 1 shows the map of the distribution where the sample was collected in Bunaken Island.

Fig. 1. Distribution of Sample-collection in Bunaken Island

The plotted sample will then be converted to a polygon, so it can be used as the region of interest by using geographic information system (GIS) application. The region of interest that have been converted are inputted to the shallow-water algorithm. The sample data will be used further to classify each shallow-water ecosystem in the study area by using supervised classification. Supervised classification will classify the whole shallow-water in the study region, based on the 300-sample data that have been collected. After conducting supervised classification, the results show healthy coral reefs, deceased coral reefs, bleached coral reefs, and seagrass beds within the shallow-water. This analysis can be further done by converting file types into vector files and performing geometric calculations to determine the area of healthy coral reefs, deceased coral reefs, bleached coral reefs, and seagrass beds in 2017. Which will result in a map that shows the whole study region based on the classification that has been inputted inside the shallow-water algorithm.

2.2 Sea Surface Temperature (SST) Analysis

The Surface temperature of seawater can be obtained by using the processed Landsat image [15] To obtain sea surface temperature data from Landsat image, it is necessary to pre-process the image where the image will be corrected based on the radiance value. The first thing to look for to identify sea surface temperatures is to identify the value of spectral radiance from an image that was previously still a digital number [16]. Digital number is a maximum radiance of band 10 on Landsat 8 or band 6 in Landsat 7. Radiance spectral obtained by using the equation:

$$Lx \text{ (Landsat 7)} = 0.0370588 \text{ B6} * \text{digital number} + 32 \tag{4}$$

$$Lx \text{ (Landsat 8)} = 0.0003342 * b10 + 0.1 \tag{5}$$

Where Lx is the Radiance Spectral value

The radiance spectral equation will be inserted into the band math where the satellite image will calculate the value of the spectral radiance to obtain the sea surface temperature value. After obtaining the radiance spectral value, then the processed image can be used directly to determine its temperature using the equation:

$$T = K2 / \ln (K1 / L\lambda + 1) \tag{6}$$

$$T \text{ (Landsat 8)} = 1321.0789 / (\text{Ln} ((774.8853 / L\lambda) + 1)) \tag{7}$$

$$T \text{ (Landsat 7)} = 1282.71 / a\log (666.09 / L\lambda) + 1 \tag{8}$$

Where T is temperature, and K1 / K2 is the value of calibration constant at band 10 on Landsat 8 or band 6 on Landsat 7.

The T equation will be entered into the math band. After getting an image that has a temperature value, then the value needs to be changed in order to be the value of sea surface temperature, using the equation:

$$SST = (0.0684 * (\text{float (B1) 3})) - (5.3082 * (B12)) + (137.59 * B1) - 1161.2 \tag{9}$$

Where B1 is the layer of T and SST is Sea Surface Temperature or Sea surface temperature (SST) [17].

The equation of the SST will be inserted into the math band to get the image layer showing the SST data. After getting the value of sea surface temperature, the map of sea surface temperature in Bunaken National Park area can be done by classifying seawater to indicate which area which are optimal, less suitable, and not suitable according to the classification that is shown in table 1 [11].

Table 1: SST Suitability for Coral Reefs

Parameter	Optimal	Less Suitable	Not Suitable
SST	27-30 $^{\circ}$C	<27 $^{\circ}$C	>30 $^{\circ}$C

Seawater Salinity Analysis

To identify the salinity of seawater, the type of image pre-processing performed in this analysis is by correction of radiometric and calibration of the reflectance type by performing calibration of the digital number reflectance. After image pre-processing, math band calculations will be performed using an algorithm. The algorithm used to identify marine salinity distribution is Cimandiri algorithm [18], where the algorithm has the equation:

$$\text{Salinity} = 29{,}983 + 165{,}047 \, (B2) - 260{,}227 \, (B3) + 2{,}609 \, (B4) \qquad (10)$$

Where:

B2: Blue Band
B3: Green Band
B4: Red Band

The image processing to obtain the value of seawater salinity is by inputting the equation input to the band math, on which the bands that are used in this analysis are band 2,3 and band 4 that shows true color. After obtaining the value of seawater salinity, the map of it can be obtained from the satellite image within the Bunaken National Park can be done by classifying seawater to indicate which region is are optimal, less suitable, and not suitable for coral reefs based on the classification as set out in Table 2 [8].

Table 2: Seawater Salinity Suitability for Coral Reefs

Parameter	Optimal	Less Suitable	Not Suitable
Salinity	30 – 36 PSU	>36 PSU	<30 PSU

3. RESULTS

3.1 Coral Reefs Ecosystem in Bunaken National Park

The results of the shallow-water analysis algorithm, shallow-water ecosystems in Bunaken National Park can be seen on the map in Figure 2. The map shows the condition of coral reefs along with the distribution of shallow-water ecosystems in Bunaken National Park in 2002, 2007, 2013 and 2017. The classification used in the map that is shown in figure 2 shows healthy coral reefs, deceased coral reefs, bleached coral reefs, seagrass, and other built-up areas. These maps are based on the shallow-water analysis algorithm that has been classified based on the samples that are collected in Bunaken Island as shown in figure 1. Table 3 shows the area size of each type of shallow-water ecosystem classification in Bunaken National Park from 2002 to 2017.
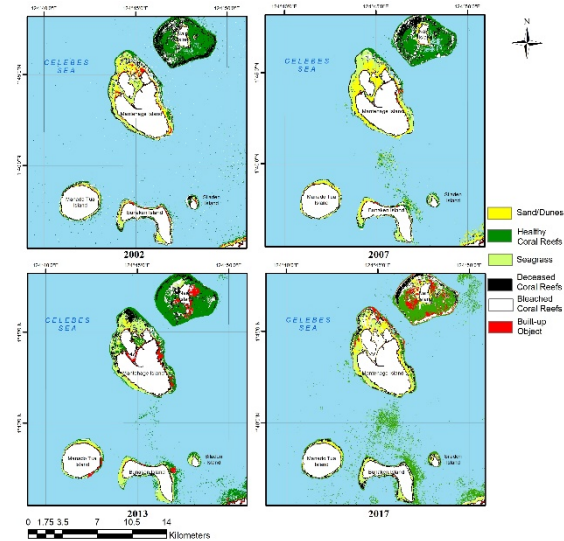

Fig. 2. Spatial Distribution and Its degradation pattern of Coral Reefs in Bunaken National Park (2002, 2007, 2013, and 2017).

Table 3: Area Size of the Shallow-water ecosystem in Bunaken National Park

Area (Ha)	2002	2007	2013	2017
Healthy Reefs	17,461, 330.40	19,419, 023.50	30,565, 753.37	30,684, 798.19
Deceased Reefs	10,405, 567.22	7,180, 707.11	6,237, 082.12	7,015, 449.40
Bleached Reefs	7,204, 242.12	6,699, 643.47	4,373, 714.56	7,845, 673.17
Seagrass	8,757, 983.50	9,993, 298.62	10,834, 288.13	11,616, 532.24

3.2 Sea Surface Temperature in Bunaken National Park

The result of SST analysis in Bunaken National Park can be seen on the map in figure 3. The map shows the condition of the sea surface temperature in Bunaken National park in 2002, 2007, 2013, and

2017. The classifications that are being used in the map from figure 3 is based on what is shown in table 1.

3.3 Seawater Salinity in Bunaken National Park.

The result of Seawater salinity analysis in Bunaken National Park can be seen on the map in figure 4. The map shows the condition of the seawater salinity in Bunaken National park in 2002, 2007, 2013, and 2017. The classifications that are being used in the map from figure 4 is based on what is shown in table 2.
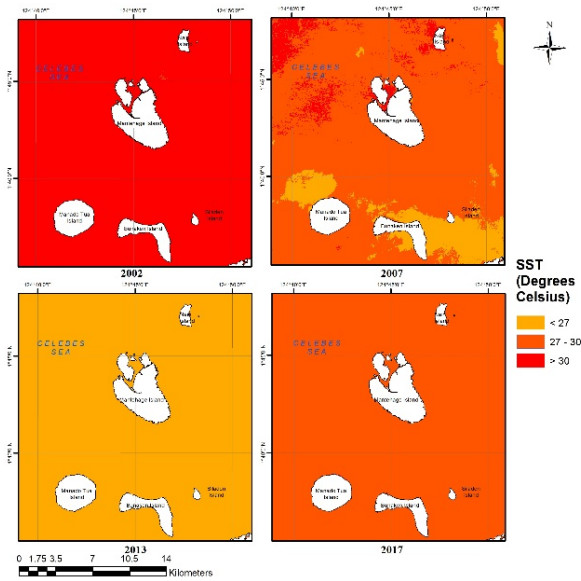

Fig. 3. Sea Surface Temperature in Bunaken National Park (2002, 2007, 2013, and 2017).
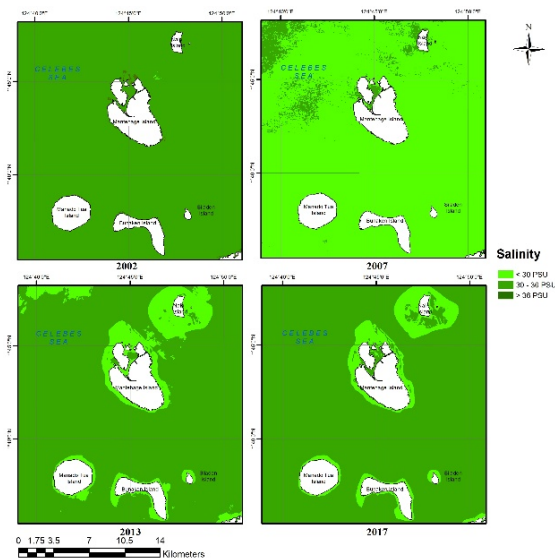

Fig. 4. Seawater Salinity in Bunaken National Park (2002, 2007, 2013, and 2017).

4. DISCUSSION

4.1 Coral Reefs Degradation Pattern

The coral reefs degradation pattern could be shown in figure 2 that shows the map of it. The map shows that the condition of the coral reefs in Bunaken National Park varies in each year. The map shows that Nain Island has the largest shallow-water ecosystem in the National Park. The spatial pattern of the coral reefs in Bunaken National Park is shown that the further away from the coastline, the better the condition of the coral reefs. Almost the outermost layer of the shallow-water ecosystem in Bunaken National Park consists of healthy coral reefs. On the other hand, the spatial pattern of deceased and the bleached coral reefs are located mostly near the coastline of each island in Bunaken National Park.

The map shows that the worst condition of coral reefs degradation happened in 2002, where it has the largest area of deceased and bleached coral reefs combined compared to other years, on which could be seen in table 3. Based on table 3, it is shown that the area of deceased and bleached coral reefs from 2002 to 2013 have decreased in size, whereas the area of healthy coral reefs from 2002 to 2017 have increased. On the other hand, the area of degraded coral reefs from 2013 to 2017 has increased dramatically from the previous years on which have been steadily declined.

4.2 Coral Reefs Exposure towards Climate Change

Based on figure 3 and figure 4 that shows the map of sea surface temperature, and seawater salinity in Bunaken National Park in 2002, 2007, 2013, it shows that the sea surface temperature for the year 2002 are above 30 ºC and the seawater salinity level in 2002 are 30-36 PSU. It shows that the year 2002 has an optimal seawater salinity condition for coral reefs, and not suitable SST condition for coral reefs. The SST condition could possibly the reason why there are large areas of degraded coral reefs in Bunaken National Park since the SST of Bunaken National Park reach up to 36 ºC in 2002 (based on table 3).

In 2007 and 2013 the SST condition in Bunaken National Park are quite varied. The SST condition has relatively been declining compared to 2002. The decline of the sea surface temperature could be a major factor in why the number of degraded coral reefs has been on a declined from 2002 to 2013. The salinity level, on the other hand, was relatively declining in 2007 and goes back incline in 2013.

In 2017 the Sea surface temperature is relatively optimal for coral reefs, where it has a temperature between 27-30 ºC. Even though 2017 was the year

where the degraded coral reefs were at an all-time high from the last 15 years. The reason for that was because the seawater salinity in 2017 around the shallow-water ecosystem for every island in Bunaken National Park has the lowest salinity level (below 30 PSU down to 16PSU).

5. CONCLUSIONS

This study shows that the coral reefs in Bunaken National Park have a pattern on which the furthest away from the island, the better the condition of the coral reefs. Where degraded coral reefs are usually located close from the island. The degrade coral reefs of Bunaken National Park from 2002-2013 were on a decline, where it came to incline once again in the year of 2017. This study shows that there is a correlation between the change of sea surface temperature and seawater salinity level and the area of degraded coral reefs, where the higher the temperature and the lower the salinity level of seawater the bigger the size area of the degraded coral reefs.

6. ACKNOWLEDGMENTS

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