Analysis of coral reef benthic cover changes around Kapoposang Island, Pangkep Regency, South Sulawesi using multi-temporal remote sensing imagery

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Abstract. Coral degradation has become an important issue in the Kapoposang Marine Tourism Park, Kapoposang Island, Pangkep Regency, South Sulawesi. This study aimed to monitor changes in live coral cover over the period of 2006-2017. The study integrated two methods: the interpretation of multitemporal satellite images and Rapid Reef Assessment (RRA) surveys. The results revealed changes in each benthic category on Kapoposang Island (i.e. live coral; dead coral; rubble; seagrass/algae and sand). During the period from 2006 to 2017, live coral cover decreased by 13.18% while dead coral and rubble (coral fragments) increase by dead 9.63% and 0.15%, respectively.

1. Introduction

Indonesia is one of the six countries in the Coral Triangle, also known as the Amazon of the Ocean, a marine biodiversity hotpot containing approximately 30% of the world's coral reefs [1]. Specifically Indonesian coral reefs cover an area of approximately 25,000 km^2 [2], about 10% of the global coral reef area of 284,300 km^2 [1,3], with the highest coral taxonomic richness of 569 species from 82 genera and 15 families [1,2].

Kapoposang Island is in the Spermonde Archipelago, Makassar Strait, adminsitratively within Pangkep Regency, South Sulawesi Province, Indonesia. According to [4,5] , the overall condition of coral reefs in the Spermonde Islands in 2008-2009 was: 2% in very good condition, 19.24% in good condition, 63.38% in moderate condition and 15.38% in poor condition. Over the period from 1996 2012, there has been degradation of the coral reefs around Kapoposang Island [5–7]. For example, 44.25% of hard coral and dead coral cover 39.12% were reported in 2009, while in 2012 the recorded coral cover had decreased 24.9% of live coral while dead coral had increased to 65.95%. The degradation of coral reefs around Kapoposang Island has mostly been caused by human activities, such as the use of bombs and cyanide in fishing [8], and an increase in the amount of anthropogenic waste and sedimentation [6,7].

Spatial information on changes in the condition of coral reefs around Kapoposang Island is needed for future management. Remote sensing methods are one of the most suitable alternatives for surveying, modeling and multi-temporal assessments of coral reef condition. These methods have several advantages for monitoring multi-temporal changes, as they can be relatively inexpensive, easily updated and provide rapid mapping methods [9–12]. This study aimed to evaluate changes in the cover and condition of coral reefs in Kapaposang Island over the period of 2006-2017, integrating

two methods: the interpretation of multitemporal satellite images and Rapid Reef Assessment (RRA) surveys.

2. Methodology

This study comprised two main stages: preliminary data processing in March-April 2017 and data collection in Kapoposang Island, Pangkep Regency, South Sulawesi Province from June to October 2017 (Figure 1). The data processing stage was conducted in the Laboratory of Marine Geo-spatial and Fisheries Information Systems, Faculty of Marine Science and Fisheries, Hasanuddin University. Raw data was obtained from a SPOT 5 Image recorded on December 11th, 2006 and a Sentinel-2 Image recording on May 20th, 2017.

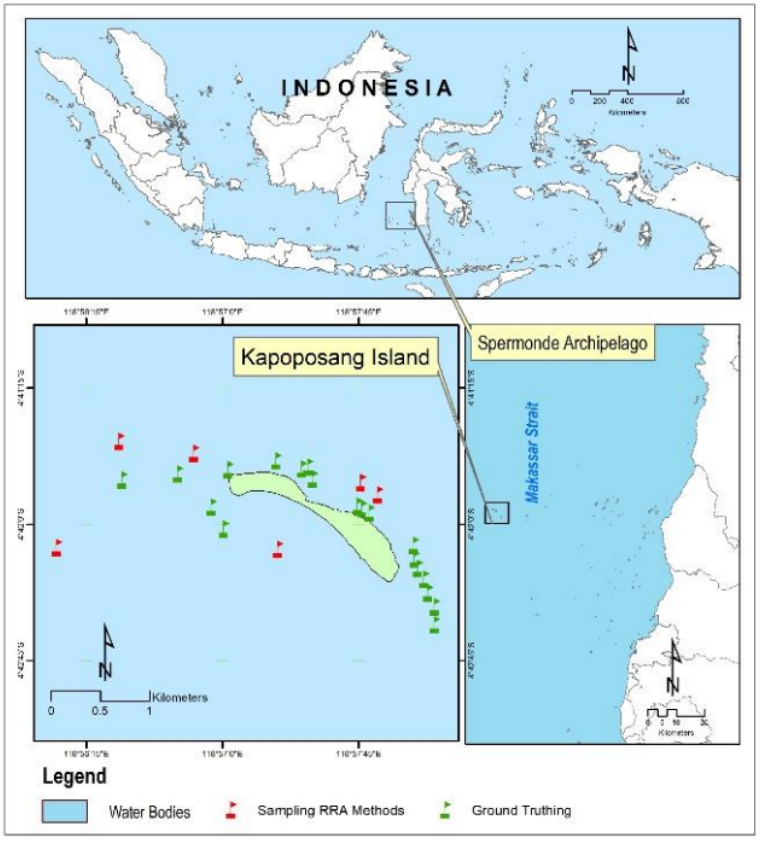

Figure 1. The study location in Kapoposang Island, Pangkep Regency, South Sulawesi Province.

2.1. Data Analysis Procedures

The data analysis procedures were divided into two major steps: firstly, the remote sensing data processing that consists of early stages of processing satellite imagery and secondly, the verification of processed satellite imagery or ground truthing. During the verification step, a Rapid Reef Assessment (RRA) was conducted to obtain an estimation of coral cover. A flow chart of the research procedure is displayed in Figure 2.

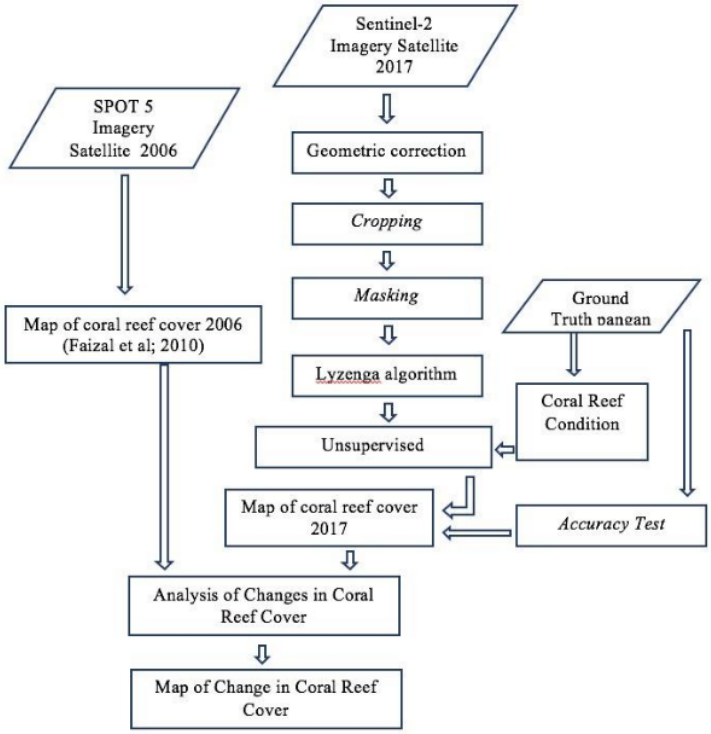

Figure. 2. Flow chart of data processing.

2.2. Image pre-processing

Satellite image pre-processing stages were: (1) satellite image restoration, (2) geometric correction, (3) cropping of satellite imagery. The cropping of satellite imagery was based on the condition of the shallow waters of the study area.

2.3. Image Processing

Satellite images were processed using in the he Depth Variant Index Algorithm in the identification of sea floor substrate [13]. This algorithm utilizes the visible wavelength blue and green bands. The purpose of using this method is to eliminate the influence of the water column on the identification of shallow water benthic substrates. The Depth Variant Index algorithm uses the following equation:

$$Y = a\log(i) + \frac{ki}{kj}\log(j) \quad (1)$$

Where;

Y = image of the transformation of shallow waters
i = digital value on Chanel 1 on the Sentinel-2
j = digital value on Chanel 2 on the Sentinel-2
ki/kj = coefficient of attenuation

The next stage was the process of satellite image classification. SPOT 5 satellite images in 2006 were classified using an unsupervised method while the Sentinel-2 satellite image from 2017 was classified using a supervised method.

2.4. Ground Truthing

Ground truthing was used for the verification of processed satellite imagery. At the same time as the verification step, an evaluation of data collection procedures included a Rapid Reef Assessment (RRA). The stations were selected based on the results of satellite image analysis, so as to be representative of each shallow water category or habitat. Each observation station consisted of a 10 x 10 meter transect.

2.5. Data Analysis

Analysis of the data used in the study comprised (1) determination of coral reef categories, (2) test of accuracy, and (3) calculation of coral reef area by cover category. Coral reef condition categories was determined based on [14] as follows:

Table 1.Criteria for determining the coral conditions.

coverage (%)	Category
00 – 25	Poor
26 – 50	Moderate
50 – 75	Good
76 – 100	Very Good

The accuracy of the satellite image processing output was assessed using the kappa test accuracy-testing method [15,16]. This accuracy test calculates the accuracy of the user, the accuracy of the procedure, and the Kappa coefficient (K) using the following equations:

$$\text{User accuracy } j = \frac{Sjj}{S.J} \quad (2)$$

$$\text{Procedure accuracy } i = \frac{Sii}{Si.} \quad (3)$$

$$\text{Overall accuracy } OA = \sum_{i=1}^{k} Sij \quad (4)$$

$$K = \frac{N\sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k}(x_{i+} Xx_{+i})}{N^2 - \sum_{i=1}^{k}(x_{i+} Xx_{+i})} \quad (5)$$

Where;

K = Kappa coefficient
K = Number of rows in the matrix
Xii = Number of observationin the coloumn i and row j
xi+ = Marginal amount of the row - j
x+I = Marginal amount of the column - i
N = Total number of observations

Based on [16], the kappa (K) test accuracy result falls into one of 3 classes: if K> 80% the accuracy (agreement) is very high, if K = 40 - 80% the accuracy/agreement is moderate and if K < 40%, the accuracy/agreement is poor. Changes in coral cover area were calculated using the following equation:

$$L = nP \; x \; Rs \; x \; 0.0001 \quad (6)$$

Where;

L =Area of coral coverage (hectares)
nP = Number of Pixels
Rs = Spatial Resolution
0.0001 = Conversion factor from m^2 to hectares

3. Results

3.1. Benthic shallow water cover

The estimation of benthic shallow water cover in Kapoposang Island was obtained from the image classification of Sentinel-2 Depth Variant Index in 2017. The estimated area of benthic shallow water cover in 2006 was obtained from the classification of the SPOT 5 Depth Variant Index in 2006 modified from [17]. The results are shown in Figure 3.

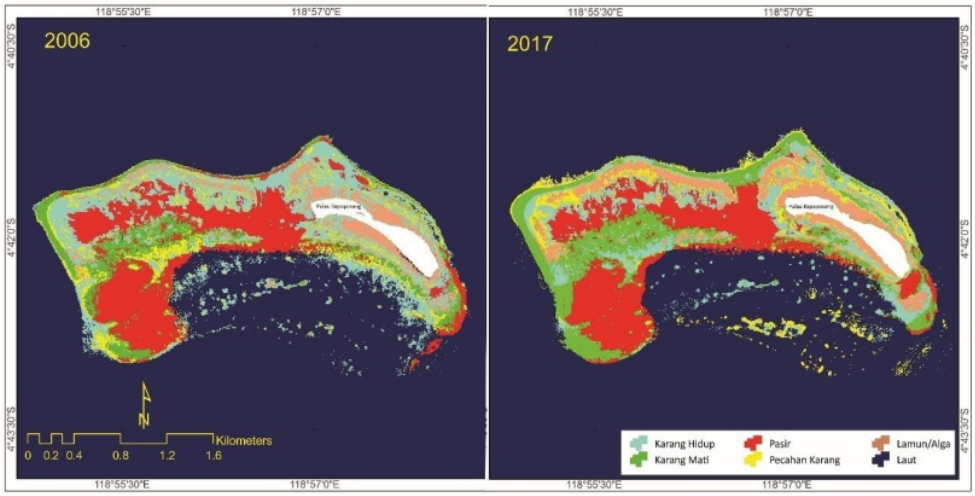

Figure 3. Benthic shallow water cover around Kapoposang Island in 2006 [17] and 2017. Legend: Pale blue = live coral; green = dead coral; red = sand; yellow = rubble; brown = seagrass/seaweed; dark blue = sea; white = land.

The benthic shallow water cover in Kapoposang Island based on the results of the transformation and the multispectral classification of satellite images in 2006 and 2017 consisted of 5 classes of benthic habitats; live coral, dead coral, rubble, sand and seagrass/macroalgae. The results showed that the percentage of live coral cover declined by around 13% from 2006 to 2017 while dead coral increased by around 10% (Table. 2)

Table 2. Substrate composition in the shallow waters around Kapoposang Island in 2006 and 2017.

Substrate	Area of Substrate (Ha)		Percentage (%)		Area of change (Ha)
	2006	2017	2006	2017	2006-2017
Live Coral	335.59	205.39	-130.19	20.91	-130.19
Dead Coral	135.25	230.33	95.08	23.45	95.08
Rubble	110.38	111.93	1.55	11.39	1.55
Seagrass/Algae	93.50	138.32	44.82	14.08	44.82
Sand	312.89	296.37	-16.52	30.17	-16.52
Total	987.61	982.35	-5.26	100	-5.26

The Sentinel 2 -2017 image had an Overall Accuracy (OA) of 65.38% with an error value of 34.62% and a Kappa coefficient of 0.657 which means that this satellite imagery has a confidence

level of 65.7% in detecting benthic shallow water substrate type. The results indicated that the image was a moderate agreement. The confusion matrix is summarized in Table 3 and Table 4.

Table 3. Confusion matrix of the five class substrate classification.

		Ground Truthing					
	Class	Live Coral	Dead Coral	Rubble	Seagrass/Algae	Sand	Total row
Image Interpretation	Live coral	4	4	1	0	0	9
	Dead Coral	1	24	0	0	2	27
	Rubble	5	3	6	0	4	18
	Seagrass/Algae	1	1	0	5	0	7
	Sand	0	1	1	0	7	9
	Total Column	11	33	8	5	13	70

Table 4. The Producer's and user's map accuracy.

Producer Accuracy (%)		Commission Error (%)	User Accuracy (%)		Commission Error (%)
Class	Accuracy		Class	Accuracy	
Live coral	44.44	55.56	Live coral	36.36	63.64
Dead Coral	88.89	11.11	Dead Coral	72.73	27.27
Rubble	33.33	66.67	Rubble	75.00	25.00
Seagrass/Algae	71.43	28.57	Seagrass/Algae	100.00	0.00
Sand	77.78	22.22	Sand	53.85	46.15

3.2. Changes in Coral Reef Cover

Changes in coral reef cover around Kapoposang Island were obtained from the compilation of coral cover in 2006 and 2017. The compilation results (Figure 4 and Table 2) show a decrease in live coral cover over the period of 2006-2007 amounting to 130.19 ha and increases in dead coral cover (95.08 ha) and in rubble (1.55 ha).

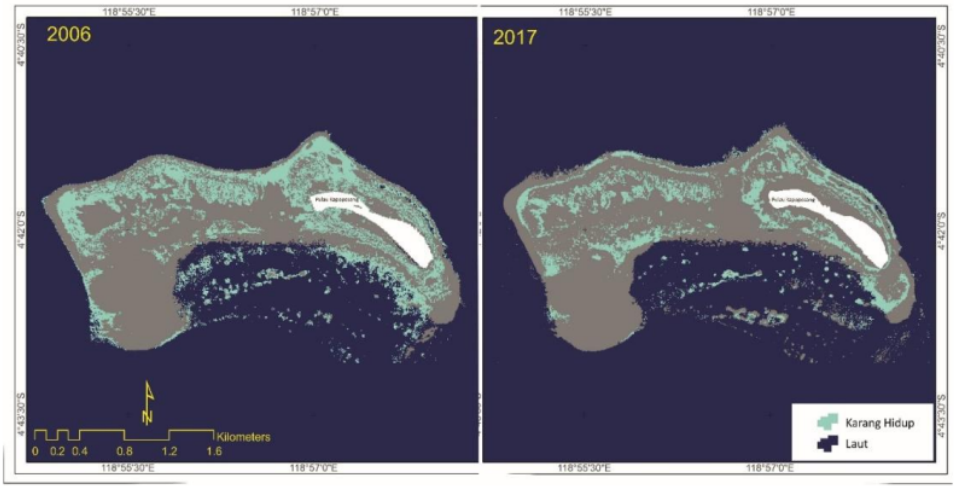

Figure. 4. Comparison of the live coral cover of Kapoposang Island in 2006 and 2017. Legend: pale blue = live coral; dark blue = sea; grey = other shallow-water classes; white = land.

4. Discussion

4.1. Benthic shallow water cover

The new image resulting from an algorithmic depth variance index for Sentinel-2 images in 2017, has a diverse spectral characteristic. The difference in the characteristics was used to divide the shallow water benthic cover into five classes i.e. live coral, dead coral, rubble, seagrass/algae and sand (Figure. 3). The selection of benthic cover classes was based on benthic shallow water cover criteria for Rapid Reef Assessment surveys [12,18,19]. This is supported by the spread of the brightness level of the distorted image which was relatively even in the range of 1.282 - 1.638 as indicated in Figure 5. This graph also shows that based on the Variant Depth Index, image pixels are grouped based on the shape, size, and orientation of the samples in the feature space.

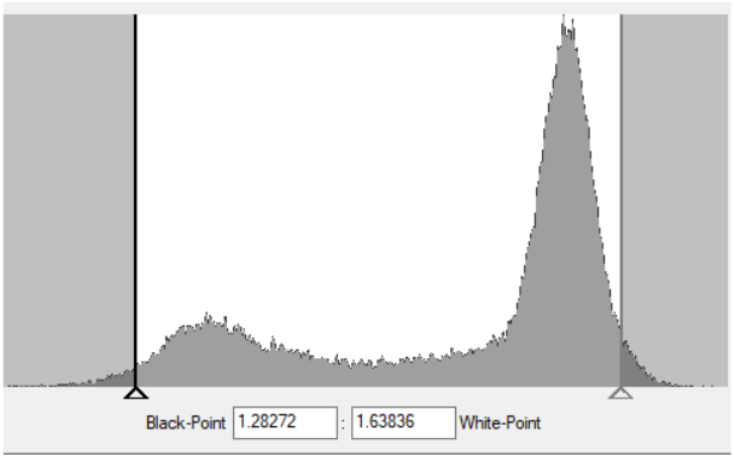

Figure 5. Spectral reflectance curve of the Sentinel-2 image from 2017.

Over the period of 2006-2017 the composition of shallow water benthic cover has changed from dominance by live coral to dominance by dead coral. This change was likely caused by a combination of natural and anthropogenic factors. Based on data from the Agency of National Marine Conservation Areas in Kupang [20], in 1997-2005 the coral reefs of Kapoposang Island were in very good condition, with live coral cover around 90%. Furthermore, [21] reported that between 2005 and 2006 live coral cover around Kapoposang Island decreased by up to 60% due to predation by *Acanthaster plancii*. Coral bleaching in 2009-2010 accelerated the decline in live coral cover [5,22]. By 2015 the condition of the coral reefs of Kapoposang Island had declined further with a percentage of live coral cover around 22% [23]. Based on the results of a 2017 survey, the coral reefs around Kapoposang Island were in moderate condition with a percentage coral cover of 25-30% (Figure 6).

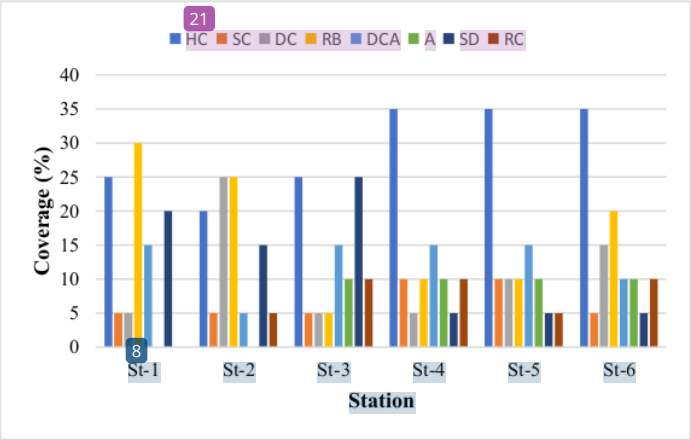

Figure 6. Percentage of coral reef habitat cover around Kapoposang Island.
HC = hard coral
SC = soft coral
DC = dead coral
DCA = dead coral algae
A = algae
RC = rubble

4.2. Changes in Coral Reef Cover

The compiled classifications of shallow water benthic cover in 2006 and 2017 show a decrease in the area of live coral cover from 335.59 hectares to 205.39 hectares, with a reduction of the live coral area by 130,190 hectares. This condition was accompanied by an increase in dead coral cover from 135.25 hectares to 230.33 hectares with a difference of 95.08 hectares. In addition, rubble also increased slightly from 110.38 hectares to 111.93 hectares with a difference of 1.55 hectares. The phenomenon of decreasing extent of live coral cover has also occurred in several regions in Indonesia [1–3,24]. In addition, sand cover decreased by 16.52 hectares while seagrass/algae cover increased by 44.8 hectares, changes which were most likely caused by increased nutrients that can spur algal growth (top-down) [25,26] or the availability of space for algal growth due to dead coral (bottom-up) [27].

There is a difference in the total area of shallow water benthic cover between the imagery map in 2006 and the 2017 imagery map. The total area of shallow water benthic cover in 2006 was 987.61 hectare and in 2017 was 982.35 hectare. This difference is caused by the recording conditions of different satellite images; in 2016 the mean sea level at the time of recording was 0.5 meters above chart datum, while in 2017 the mean sea level was 0.9 meters above the datum (Figure 7).

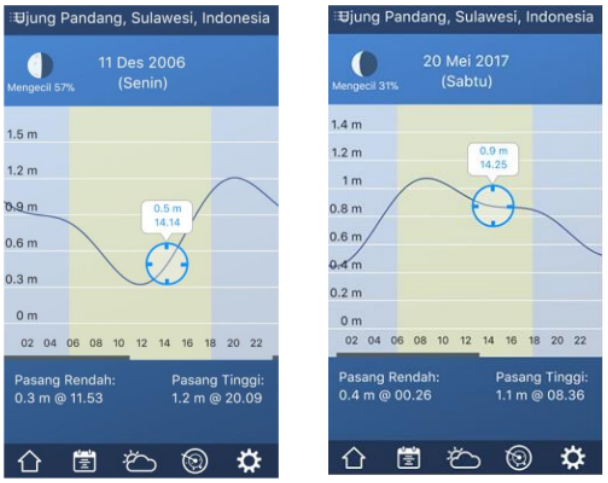

Figure 7. Tidal range conditions at the time of image recording acquisition

5. Conclusion

The study revealed changes in each benthic category in the shallow waters around Kapoposang Island. These changes included a decrease in live coral cover (13.18%) and an increase in dead coral cover (9.63%) and coral rubble (0.15%).

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