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## Development of a benthic spatial ratio index as an indicator of small island deformation

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**Abstract.** The ability of coral reefs and seagrass beds to reduce wave energy positions these ecosystems as the most reliable natural protection for many small islands, especially for coral islands and atolls. With coral damage reaching 174 hectares per year, there must be changes in the spatial composition of coral reefs and seagrass beds around many small islands in the Spermonde Archipelago, changing the shape of the islands and reducing the quality of life of their inhabitants. This study aimed to map the spatial composition of benthic substrates (coral reefs, seagrass beds, and macroalgae) around small islands over time, and to relate changes in substrate composition to island shape change. The initial study was conducted at Barrangcaddi island from July to December 2018. Three field surveys collected spatial data on benthic substrates (coral, seagrass, macroalgae), bathymetry, waves, tides, and beach profiles. The satellite data used were Sentinel 2 images from 2015 to 2018. Satellite image processing included atmospheric correction using the DOS method, land masking, geomorphic segmentation, and classification using the maximum likelihood, Self Organizing Map and Segmentation methods. Thirteen benthic substrate classes were validated with thematic accuracy ranging from 86% to 95%. The land area of Barrangcaddi Island changed around 6 percent from 2015 to 2018. The benthic spatial ratio index for Barrangcaddi Island shows that the north side of the island was the most vulnerable to coastal abrasion, and the existing benthic substrate is no longer effective in reducing the wave energy that hits the island from this side.

### 1. Introduction

The detection of small islands change is rarely doing at Spermonde Archipelago. With coral damage reaching 174 hectares per year [1] there must be changes in the spatial composition of coral reefs, seagrass beds and benthic habitat around small islands in this region, changing the shape of the islands and reducing the quality of life of their inhabitants. The use of sensing technology that routinely and consistently observes this remote area could be an alternative solution for this task.

Satellite remote sensing is an alternative solution to this problem. The use of multispectral imagery can easily distinguish the land of an island and its waters so that changes in land area can be map over a period of time. However, this information is insufficient because the change recorded by satellite images is still affected by tides. Additional information such as spatial composition of the benthic substrate is needed to prove the changes. The benthic substrates (coral, seagrass) known as natural fortress to protect the island from sea waves and ocean currents. The change of this composition may indicate a change of shoreline and the shape of the island.



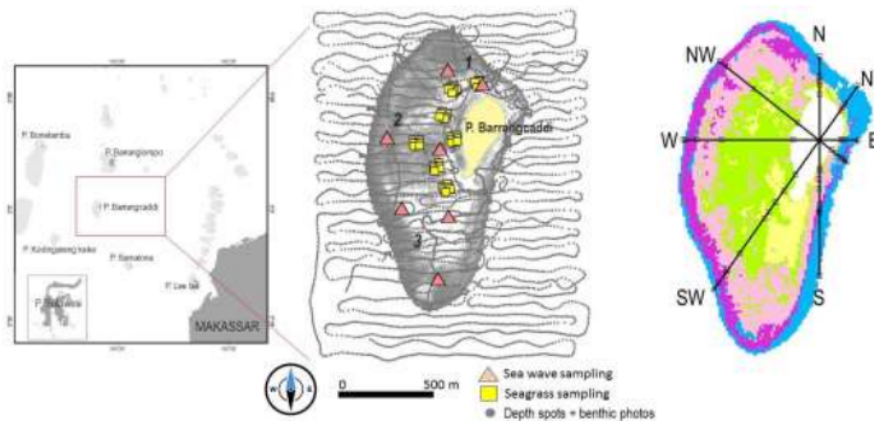
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This study aims to map the benthic spatial changes of Barrangcaddi Island between 2015 to 2018 and calculate the spatial ratio of benthic substrates as an indication of changes in shoreline and shape of the island. This information may support the stakeholders to formulate appropriate steps in overcoming the impacts that occur due to shoreline changes on small islands.

## 2. Material and methods

This study took place on July to November 2017 and January to November 2018. The study location was at Barrangcaddi Island within the administrative area of Makassar City, Indonesia (Figure 1). The field survey was conducted 4 (four) times, once in 2017, twice in August and once in November 2018.



**Figure 1.** Study location (left) and the windrose line to extract spatial benthic ratio

### 2.1. Data collection

This study uses field data and satellite images. The satellite imagery of sentinel 2A downloaded from the website <https://earthexplorer.usgs.gov/>. Tidal prediction generated at <http://tides.big.go.id/> maintain by Geospatial Information Agency (BIG). Field data collected were seagrass cover, bathymetry, waves, tides, currents and large amount of benthic substrate photos.

The benthic substrate survey carried out using photo lapse time techniques using an underwater camera. This camera installed next to the boat so that it can take continuous photos as long as the GPSmapsounder record water depth and position [2]. Seagrass surveys were carried out at 30m x 30m area similar to McKenzie method [3]. Seagrass cover in a quadrat 0.5 x 0.5 meters recorded every 5 meters of transect line. Total 7 seagrass station observed where each station had 18 points so that the total data points were 126.

The bathymetric survey carried out following crossline transects (Figure 1). GPS drifter used to record sea currents trajectory using lagrangian method. Sea waves measured at three stations, at the north, west and southwest of the island. Each station divided into reef crest substation where the substrates dominated by corals and reef flat substation where the substrate is seagrass or algae. Instantaneous wave height was measured using a pile. The peaks and troughs of the waves passing the measuring mark were recorded continuously for 51 times, and replicate two times for each observation. The stopwatch used to record observation time. Wave height and its period recorded on the form that has been prepare. The tide observed for 31 hours and recorded every one hour. Tide pole stationed at the jetty located on the East side of Barrangcaddi Island.

### 2.2. Data processing and analysis

Data processing and analysis was using Idrisi Terrset 18.1, QGIS Madeira 3.4, Mapsource, Picasa and MS-Excell. Four scenes of Sentinel 2A satellite imagery had download to represent the island at 28

October 2015, 14 July 2016, 8 August 2017 and 8 August 2018. The initial handling was atmospheric correction using the Dark Object Subtraction method [4] so that the pixel values converted from digital number into reflectance. The next step was to crop the image within latitude 5.09161 to 5.7529 South and 119.31187 to 119.32548 East. Land area separated to water based on their reflectance in the infrared band (band 8th). Deepwater outside the reef masked out by delineating it at natural colour composite image. Considering the study area is flat a very shallow intertidal water and exposed at low tide, the water column correction was not implemented. The next processing was segmentation. This process carried out in three stages, the creation of a composite image, the automatic delineation of pixels within the image and third merging similar object to form thematic class segments [5]. Those objects coordinate then used as a reference to extract its reflectance of band 1 to 9 and validated using geotagged photos. This process produces four benthic substrates macro classes and 13 sub-classes, the detail descriptions are shown in Table 1.

**Table 1.** The description of assign thematic class used on image classification

No.	Macro Classes	Sub Classes	Descriptions
1.	Deepwater	deep1 and deep2	this is a class with a water depth of more than 10 meters and geomorphically categorise as a reef slope
2.	Sand	sand1 and sand2	a thematic class represent object dominated by sand
3.	Submerged aquatic vegetation (SAV)	sav1, sav2, sav3, sav4, and sav5	This class represents the thematic objects of seagrass beds with rare, medium, dense cover or seagrass mix algae, and sand. The class take many pixels located at reef flat area.
4.	Coral reef (core)	core1, core2, core3, and core4	The core4 is a thematic class that represents coral objects within reef slope, and reef crest. The core1 to core3 may represent coral mix rubble, sand, and algae on the reef flat or the rubble mix algae, and sand as well.

Image classification also carried out using a pixel-based approach, maximum likelihood method and SOM (Self Organizing Map). The maximum likelihood calculates the probability of each pixel object and then classify it as a class using its probability and spectral similarity [6]. The SOM combines pixel classification methods based on supervised and unsupervised approaches using the artificial neural network algorithm [7]. The accuracy test of thematic classes carried out for each scheme of classification [8].

The actual shoreline coincidence to the date of the satellite imagery is estimated using band 8. Visible light will be absorbed by water in this band so that it will appear dark. Otherwise, the land will look bright. This shoreline can then be compared over time to see what changes have occurred. The bathymetry data were processed to obtain a geomorphic profile of the reef area. Water depth data corrected by tides and then interpolated using the nearest neighbour method. This method relatively restricts the interpolated data to the limit of the range of available data [9]. In this case, depths exceeding 35 meters are negligible. The role of benthic substrates in reducing waves as seen from the percentage of reduction in wave height at measurement points 1 and 2, calculated using the formula:  $\Delta H = ((H1 - H2)/H1) * 100\%$ , where H1 is the wave height at the reef crest (coral substrate), and H2 is the wave height at the reef flat (seagrass substrate).

### 2.3. Benthic spatial ratio index

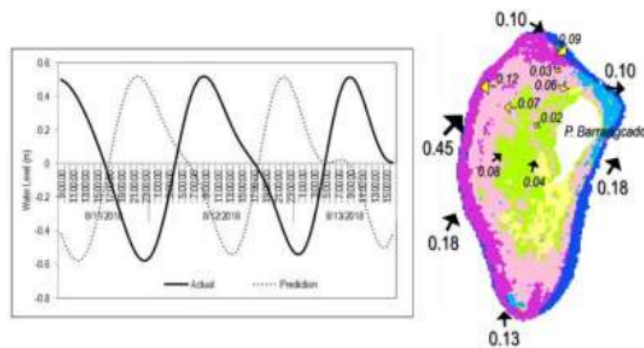
The benthic spatial ratio index (BSI) defined as a measure of the relative width of a particular benthic substrate class in the image composing a landscape along the wind direction vector from the sea to the shore. These values are accumulated and proxied to become an index value as an indication of the role of the local benthic substrates in protecting the shoreline. Thus, it can be said that:  $BSI = f(\text{core fraction, sav fraction, sand fraction, rubble fraction})$ . Each benthic fraction then multiplies to a

coefficient [10]. In this case we use 0.6, 0.24, 0.12 and 0.06 for coral reef, submerged vegetation, rubble, and sand respectively.

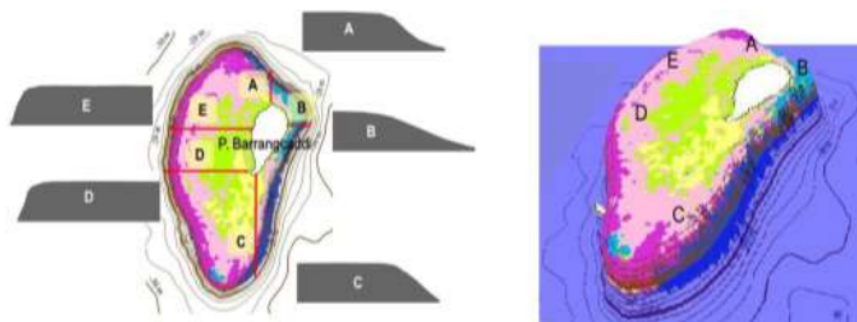
**3. Results**

*3.1. Tides, wave, current and bathymetry*

Tidal observation carried out on 11, 12 and 13 August 2018 to verify the predictions and the result is shown in Figure 2. The tide at Barrangcaddi is mix prevailing semidiurnal, with the actual tidal being 10 hours slower than predicted. The tidal range is about 1.2 m. Current velocity at reef flat was  $0.06 \pm 0.03$  m/s and  $0.21 \pm 0.14$  m/s at reef slope. The current velocity reduction is about 69% when it reaching the reef flat area. The current course mainly north to south and vice versa. The northeast side of the island facing to high pressure of current that coming form west when high tide and from the south when low tide (Figure 2).



**Figure 2.** Tides at Agust 11st to 13rd, 2018 (left) and current velocity during high to low tide (right)



**Figure 3.** Bathymetry profile of Barrangcaddi

Wave height measurements carried out on 12 and 13 August 2018. The wave height at the back of the reef crest on average was  $0.05 \pm 0.01$  m, and in the reef flat area was about  $0.04 \pm 0.01$  m. The results of these measurements indicate that the wave reduction on average is up to 19%. Wave reduction varies on each side of the island. The perpendicular distance from the reef crest to the shoreline is about 500 meters at the west side and about 600 meters at the south side. The highest wave reduction was 40% found at the west side of the island, then 36% at the south. While at the north side, the wave high surprisingly increased by about 32%.

Barrangcaddi Island's bathymetry model generated by interpolation <sup>10</sup> 5,991 depth data using the nearest neighbour method. The depth at reef flat on average is 1.0 m, range from 0.5 m to 1.5 m. A gentle depth profile is found at points A, B and C while at points D and E a steep one is found. The deepest part of reef slope is about 25 m depth (Figure 3). This Barrangcaddi Island is relatively more protected at location C, D and E from ocean currents and waves compared to A and B.

### 3.2. Seagrass

Five seagrass species found at Barrangcaddi Island, <sup>8</sup> namely *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea rotundata*, *Halodule uninervis* and *Halophila ovalis*. Total seagrass cover was  $29.2 \pm 19.4$  % hence the seagrass condition may categorised as moderate [11]. In 2018 survey, the algae such as *Ulva sp.* were also found at the west side. Sparse seagrass distribution found at the Northside while moderate found at West and South sides. The highest composition was *Cymodocea rotundata* (37.8%), *Enhalus acoroides* (29.3%) and *Thalassia hemprichii* (24.3%).

### 3.3. Benthic substrates by satellite images

The spectral signatures of 13 benthic substrate classes of four different image is showed in Figure 4. Reflectance values range between 0.01 and 0.15. Overall, on the visible band, the sand1 class is the highest reflectance, and deep1 is the lowest. Submerged aquatic vegetation (SAV) classes have reflectance between sand and coral classes. Sav1 has the highest reflectance among the sav group. It represents sparse seagrass pixels, thus accentuate the reflectance of the sand. Sav4 is the lowest. This class represent a dense seagrass area. The Sentinel 2 satellite proves as a cost effective to map seagrass [12].

The natural colour composite image of band 432 shows the distribution of benthic substrates on Barrangcaddi Island from 2015 to 2018 (Figure 5). Light brown colour on the reef flats indicates the presence of submerged vegetation, such as seagrass and algae. Very dark brown colour on the outer side of the reef flats indicates coral habitat. Visible light satellite images have limitations in penetrating water depths so that deeper waters will appear very dark. The dark blue colour in the composite image indicates the presence of a sand substrate, which is generally composed of finest to coarse coral fragments. The lighter the blue colour indicates the shallower the water. The image of Barrangcaddi Island shows a dominant area of sand at a depth of 1 to 3 meters on the northeast side. The deepest benthic substrate able to recognize by satellite image was 10 to 14 meters deep (Figure 2).

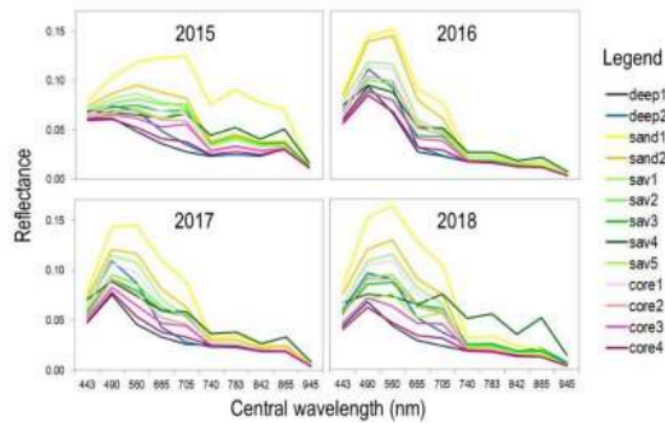
The image classified shows the dynamics of benthic substrate changes on Barrangcaddi Island (Figure 5). Submerged vegetation (SAV) class dominates the reef flats on the western and southern sides of the island. Its distribution tends to increases in 2016 and 2017 and decreases in 2018. In 2015 and 2018, occasionally emerge a new class of sav5, which according to field data in 2018 known to be algae (*Ulva sp.*). Shallow sand substrate exposed at low tide is recognizable <sup>14</sup> the Southside of the island. It only has little changes from year to year. Submerged sand is visible on the Southeast side of the island and expanded somewhat in 2018. Coral reefs found at all sides of the island and are more dominant on the South, Southwest to North sides. This condition is relatively constant every year. Somehow in 2018, the core4 class increase at the northside of the island, but field photo proved that this happen after high algae association.

### 3.4. Thematic accuracy of classified images and benthic substrates area estimation

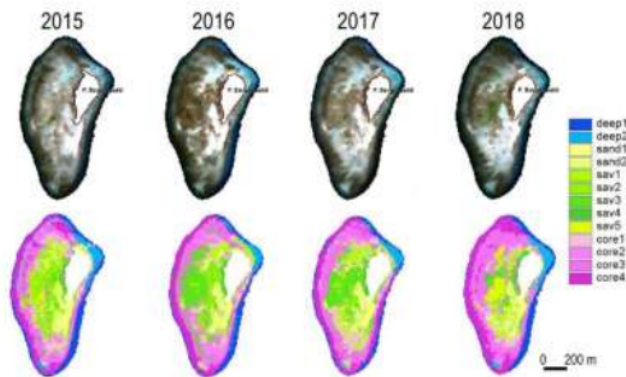
Thematic accuracy tests carried out for all classified images and get overall accuracy ( $91 \pm 3$ ) % as can be seen in Table 2. Total 2.128 geotagged of benthic photos used to verify benthic classes. All classification methods produce thematic accuracy higher than 85%. The area mapped are about  $66.7 \pm 1.8$  hectares. The area of coral and submerged vegetation had significant changes compare to the year 2015. The coral, rubble, submerged vegetation and sand area mapped are  $13.7 \pm 0.8$ ,  $25.6 \pm 3.0$ ,  $20.0 \pm 3.3$  and  $7.4 \pm 1.5$  Hectares respectively. Along 2015 to 2018 sand and submerged vegetation are decreased 5% and 8% respectively. Whilst rubble and the coral area increased about 10% and 4% (Figure 6).

**Table 2.** Thematic accuracy of classification methods of years 2015 to 2018

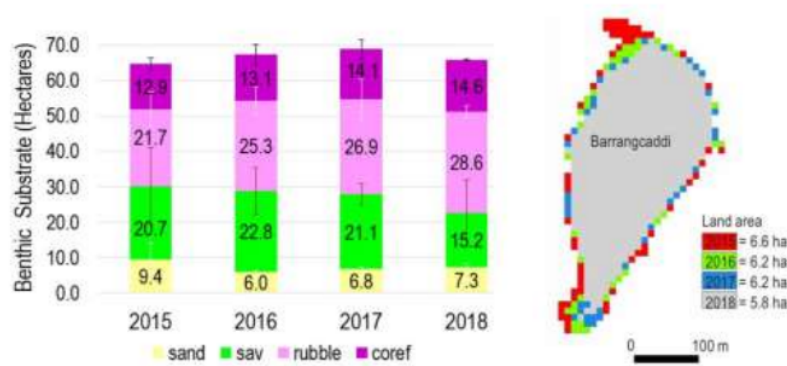
Classification method	2015	2016	2017	2018
<i>Maximumlikelihood</i>	86%	92%	89%	89%
SOM	88%	93%	90%	91%
SegClass	91%	95%	92%	92%



**Figure 4.** Spectral signatures of benthic substrates extracted from different date of satellite image



**Figure 5.** Natural composite images (top) and classified images (bottom) of year 2015 to 2018



**Figure 6.** Benthic substrates area (left) and land area changes (right) during 2015 to 2018

3.5. *Benthic spatial ratio index and Island deformation*

The definitive shoreline requires an accurate hydrographic survey and decades tide observations. This study only indicates an actual shoreline, so then the actual tidal must also be considered. Sentinel 2 satellites have sun-synchronous orbits, where it will record an area always at the same local time at 10:20 a.m. Satellite passing occurred at low tide for 2015 image while for 2016, 2017 and 2018 image it passes during high tide. The water level difference between 2015 and the next three year range from 0.1 to 0.5 meters. The highest water level difference occurred in 2017, which is about 0.5 meter.

The shoreline of Barrangcaddi Island indicated to have erosion from 2015 to 2018 (Figure 6). The northwest had the highest abrasion in 2016. As a result, the land area of Barrangcaddi Island had changed about  $(8 \pm 3) \%$  from 2015 to 2018 or 6% compared to 2015. The highest level of land decreasing occurred in 2018, which was around 12%.

The benthic spatial ratio index (BSI) of 2018 shows that the North, East and Southern side of the island have low level of spatial ratio (Table 2). It indicates the low presence of coral reef and seagrass hence natural protection are not optimum. This condition may affect the shape of the island as proven by satellite images (Figure 6). The facts that wave energy is higher on this point, probably by the accumulation of current energy coming from North and South, and the missing of coral reef as well (Figure 2). As result this sides are facing to high pressure of coastal formation by abrasion or accretion annually. Compare to 2015, the 2018 index are slightly lower for almost all side of the island, shows us the depleted of coral reef and seagrass ecosystem services as natural fortress.

**Table 2.** Benthic spatial ratio in 2015 and 2018

Years	Benthic Substrates Spatial Fraction					BSI
	Direction	SAV	Sand	Rubble	Coral reef	
2018	North	5%	9%	8%	0%	0.03
	North East	0%	5%	7%	0%	0.01
	East	6%	0%	0%	0%	0.02
	South East	9%	0%	7%	0%	0.03
	South	6%	0%	24%	2%	0.05
	South West	20%	24%	18%	16%	0.18
	West	31%	0%	40%	9%	0.18
	North West	28%	0%	40%	9%	0.17

2015	North	5%	11%	5%	0%	0.02
	North East	5%	0%	8%	0%	0.02
	East	0%	0%	10%	0%	0.01
	South East	0%	0%	16%	13%	0.10
	South	5%	0%	22%	5%	0.07
	South West	46%	9%	11%	9%	0.18
	West	51%	0%	27%	9%	0.21
	North West	45%	0%	26%	8%	0.19

Notes: SAV=submerged aquatic vegetation, BSI = benthic spatial ratio index

#### 4. Discussion

The coral reefs ecosystems are in threaten by natural forces and human activities [13]. In most of small islands at Spermonde archipelagos, like many other coral islands throughout the world is depending to coral reef and seagrasses as the main natural protection from sea wave and currents. Spermonde is the geographic name to arc of small island at four second level administrative areas, namely Barru (9 islands), Pangkep (140 islands), Makassar (14 islands), and Takalar (9 islands) so in total 172 small islands [14]. Most of these small islands are inhabitat and have been suffered to coral reefs degradation due destructive fishing practices [15] [16], coral mining [17] [18] and coral bleaching [19]. More specific [1] stated that a degradation rate for Spermonde at Pangkep regency alone approximately 174 hectares per year, and coral rubble is more dominant recently than other substrates based on 20 years satellite image classification. Based on long term monitoring of coral reef health by Indonesian Institute of Sciences, Makassar reef health index are range from 3 to 6 or on average 4 for scale of 10. Reef health index 1 means the worst and 10 means the healtist coral reef. Barrangcaddi in case is categorised as the location with reef health index of 3 meaning that the live coral cover and resilience are in low level but has moderate coral fish biomass [20].

Previous study at Barrangcaddi found that the current velocities were 0.02 to 0.58 m/s and wave height vary from 0.04 to 0.20 m [21]. The wave probably the main factor that change the shoreline. This study finding of current velocity quite similar which range from 0.21 m/s at reef slope and 0.06 m/s at reef flat (Figure 2), so then the current energy reduction is about 71%. The wave reduction at reef flat on average is 19% lower than other study that found wave height reduction range from 40% to 60% [22]. When live coral and seagrass exist at fringing reef it may reduce wave height up to 40%. If live coral absent and only seagrass present, the optimum protection only achieved in shallow waters [23]. The seagrasses are able to reduce about 40% wave energy only when the leaf approximately as long as the depth [24]. In case of Barrangcaddi, the Northside habitat of the island did not able to reduce the longshore current or wave coming from southern or west part of the reef (Figure 2). Normally, the reef flat depth profile affects the wave height on high tide and low tide condition [25]. During low tide the wave energy may loss by bottom friction. But when the coral reef and seagrass absent or limited then the rugosity of reef flat is low hence the bottom friction is not significant to reduce wave.

The spectral reflectance curves are useful for remote sensing coastal habitats specially to differentiate benthic substrates. Sand, submerged aquatic vegetation (SAV) and coral reef at Barrangcaddi have different reflectance pattern as shown in Figure 4. The sand has highest reflectance at 560 nm (nanometer) whilst SAV and coral reef peak at 490 nm. The wavelength 530 to 580 nm are optimal for discrimination seagrass species [26]. SAV reflectance at 665 nm are lower than at 560 nm and 705 nm due the chlorophyll absorption peak [27][28] [29]. All of the benthic objects have reflectance declining from 740 nm to 945 nm since it belongs to infra red spectrum where water highly absorb the light and limit the reflectance. The spectral reflectance supports the image classification process and analysis such in thematic accuracy valuation. The thematic accuracy provides a confidence level of each classes being investigated actually represent riil object, in this case benthic substrates. When it related to area has been map then classes with high thematic accuracy may give us

a high probability that the existence areas are relatively true (Table 2). Pixel based classification method traditionally used in remote sensing but now the object base classification such as segmentation method is common. The object base produce higher level of thematic accuracy [30].

The sand on small islands beach are biogenic and mostly compose of carbonate produce by dead marine biotas. Although the sediment dynamically moving by wave and current forces but usually able to recover. This recovery somehow related to coral reef ecosystem services. Live coral combined with seagrass serve a moderate protection impact of wave event though the effectiveness depends on habitat location [25]. The benthic substrates spatial composition at Barrangcaddi show that the significant increasing level of rubble area during 2015 to 2018 (Figure 5 and 6). The rubble source commonly from dead coral [10] that loss due many factor i.e blast fishing, cyanide use and other human activities. The elevated sea temperature may trigger coral bleaching and mass coral mortality [19] hence increase energy reaching to shoreline and forming new shape of the island. In other situation coral recovery may happen if structural complexity is high. Structural complexity is depending to live coral cover and the existence of branching coral [31].

Island deformation by meaning of coastal change at Barrangcaddi has occurred at least in the last five years. The most critical points are at Northwest side of the island where inhabitant live more closer to the water due this change. The benthic spatial ratio shows that the eastern to northern part of the island have index magnitude 10% lower Southern or Western part of the island. This index even lower in 2018 compare to 2015 and positively indicate the shoreline change of the island. The island deformation may occur repetitively on periods of time and longterm historical data are needed to able doing deep analysis of the situation. Some facts may observe on field are damaged coastal protection structures, shifting shorelines and coast profile changing (Figure 7).

The environment engineering is an obligatory option to mitigate coastal abrasion at Barrangcaddi Island. Some scenario may choose as an option, using hard methods, soft methods or mixed of them. The shore protection structure made by concrete potentially collect sand and change the beach profile. It may also introduce unbalance benthic communities where new colonies occupy the concrete and changes local biodiversity. To minimise this impact the soft protection system may use as complement to maintain sediment balance [37]. In short term hard construction of shore protection is the best choice but in longterm restoring the coral reefs and seagrass beds is an obligatory. The application of the "spider" network technique at damaged coral locations can expand the live coral distribution and massive seagrass transplantation may implement as well to restore seagrass beds.



**Figure 7.** Some evidences of shoreline change by abrasion and accretion at Barrangcaddi at 2018. The ruin of shore protection structure (left), the houses become near to shoreline (middle) and right, the second layer of concrete build to protect the shore but damage by erosion (Photos by author)

This study successfully maps the benthic spatial changes at Barrangcaddi using Sentinel 2A images and field data as a basis to generate benthic spatio ratio index. This index potentially uses as indication of environmental services portion of benthic substrates (coral reef, submerge aquatic vegetation, rubble and sand) on shoreline protection. The comprehensive study at other small island is needed to enhance the understanding of the index and its relation to shoreline change on small island.

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