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**Date:** 25 May 2015  
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**Subject:** OSJO: Your manuscript entitled Multisensor and multitemporal of Landsat images for damage detection on coral reef, small island, Spermonde Archipelago, Indonesia

Ref.: Ms. No. OSJO-D-14-00107R2  
Multisensor and multitemporal of Landsat images for damage detection on coral reef, small island, Spermonde Archipelago, Indonesia  
Ocean Science Journal

Dear Dr Nurdin,

I am pleased to tell you that your work has now been accepted for publication in Ocean Science Journal.

Thank you for submitting your work to this journal.

With kind regards

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## Multisensor and Multitemporal Data from Landsat Images to Detect Damage to Coral Reefs, Small Islands in the Spermonde Archipelago, Indonesia

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**Abstract** – Coral reefs are important because of their high biodiversity and their key role in the tropical marine biosphere. Furthermore, coral reefs are very valuable as a socioeconomic resource as they make important contributions to the gross domestic product of many countries. Thus, it is very important to monitor dynamic spatial distributions of coral reefs and related habitats dominated by coral rubble, dead coral, and bleached corals. Despite these natural and socio-economic advantages, many factors are threatening coral reefs. The study site was selected in Spermonde archipelago, South Sulawesi, Indonesia because this area is included in the Coral Triangle, recognized as the epicenter of coral diversity and a priority for conservation. Images of Landsat MSS, Landsat TM, Landsat ETM, Landsat ETM+, and Landsat 8 data were used to examine changes in the coral reefs of Suranti Island in the Spermonde Archipelago during forty one years from 1972 to 2013. The image processing includes gap fills, atmospheric corrections, geometric corrections, image composites, water column corrections, unsupervised classifications, and reclassifications. Fill Gap processing was done on Landsat ETM+ SLC-off. Subsequently, a multi-component change detection procedure was applied to define changes. Shallow water bottom types classification was divided into live coral, rubble and sand habitats, dead coral with algae, rubble, and sand. Preliminary results showed significant changes during the period 1972-2013 as well as changes in coral reefs, likely explained partly by destructive fishing practices.

**Key words** – coral reef, landsat, destructive fishing

### 1. Introduction

The world's most species rich coastal ecosystems occur within the Coral Triangle (Veron et al. 2009), a region which

includes all or part of six Indo-Pacific countries; Indonesia, the Philippines, Malaysia (Sabah), Timor-Leste, Papua New Guinea and the Solomon Islands. Coral reefs are one of the most important ecosystems in marine and coastal areas. Coral reef ecosystems are also important for the fish community and various marine biotas as feeding, nursery, and spawning grounds. Ecologically, a coral reef protects other components of the marine and coastal ecosystem from waves and storms. Compared to other ecosystems, coral reefs can be easily destroyed. The coral reefs in the Coral Triangle have been directly threatened by human activities and natural threats. Coral reef destruction has occurred in the small islands of the Spermonde Archipelago as a result of human activity and rising SST (COREMAP II 2010). Suranti Island is one of these small islands in the Pangkep District. Suranti Island contributes a great deal to the local society in the sense that many local people make a living the shallow water resources. However, the condition of the coral reefs will worsen if the illegal fishing and SST in Suranti Island continues to increase every year. Therefore, spatial dynamic mapping and spatial prediction models of coral reefs are needed to create good spatial planning for coastal areas. Satellite or airborne remote sensing has increasingly been employed to map coral reef communities worldwide (Green et al. 1996; Andrefouet and Guzman 2005). While a range of these studies have recently used high spatial resolution data, e.g. IKONOS (Knudby et al. 2013; Andrefouet et al. 2003; Riegl and Purkis 2005; Elvidge et al. 2004), Quickbird (Knudby et al. 2013; Botha et al. 2013; Mishra et al. 2006), Worldview (Botha et al. 2013), and CASI (Botha et al. 2013; Mishra et al. 2006), there are a

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number of studies that have used medium spatial resolution data, e.g. Landsat (Barnes et al. 2014; Torres-Pulliza et al. 2013; Palandro et al. 2008). Thematic mapping can be used as a reference for spatial dynamics and habitat distribution of coral reefs. The objective of this research was to analyze the dynamics of coral reefs by using the multisensor (Landsat MSS, TM, ETM, ETM+, and OLI TIRS) and multitemporal data accumulated over 41 years (1972–2013).

## 2. Data and Method

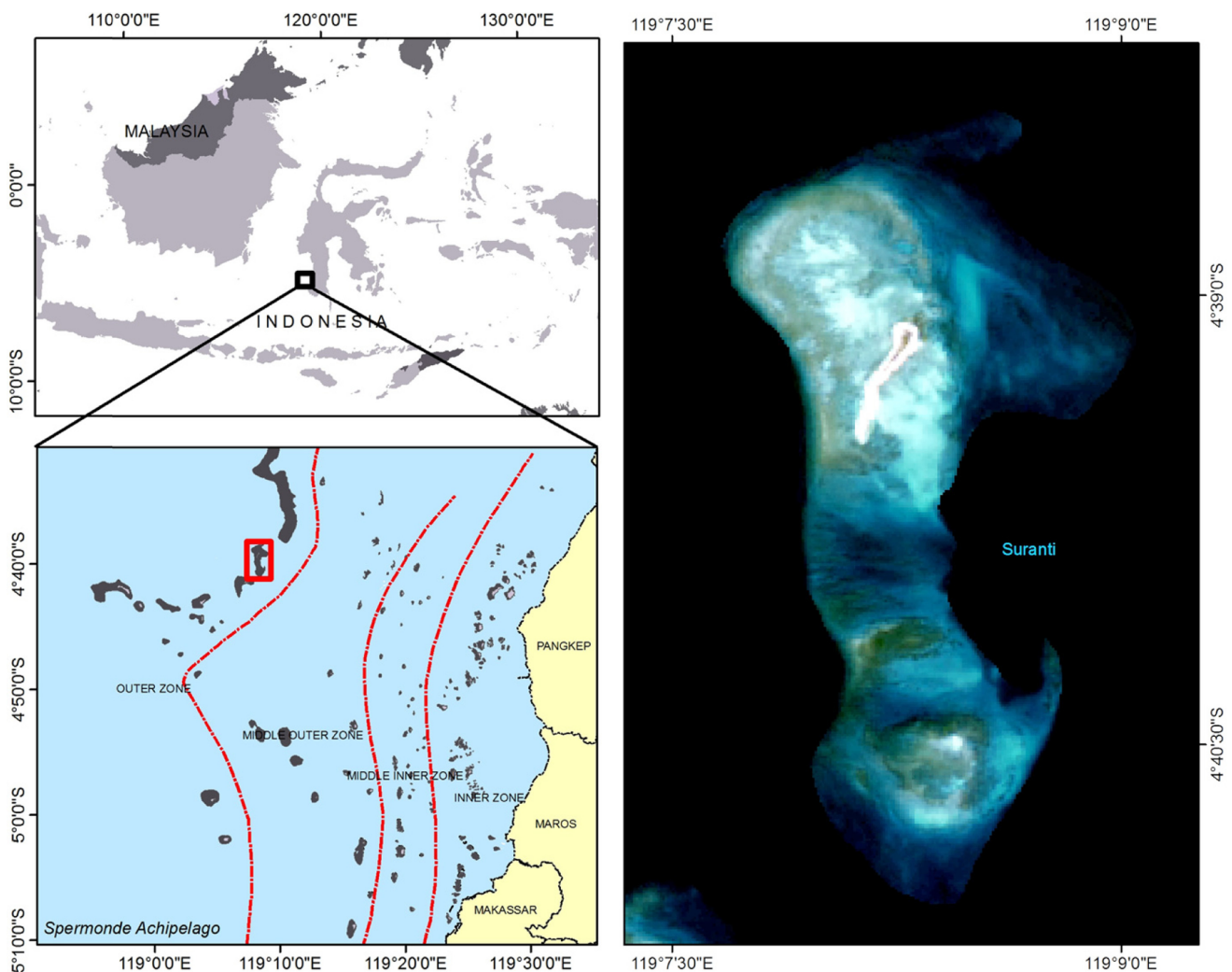
### Study area

Suranti is one of the islands in the Spermonde Archipelago, Pangkep District, Indonesia. Suranti has a land area of 0.044 km<sup>2</sup>. Geographically, Suranti Island is located at longitude 119°8'15.483"E and latitude 04°39'10.135"S.

### Data

The Landsat MSS data have four spectral bands, with a spatial resolution of 60 m. Landsat TM data have seven spectral bands, with a spatial resolution of 30 m for bands 1–5 and 7. The Landsat ETM+ data consisted of eight spectral bands with a spatial resolution of 30 m for bands 1–7. The Landsat 8 data have nine spectral bands with a spatial resolution of 30 m for bands 1–7 and 9. The following table shows the types of data (Table 1).

Classification bottom types consisting of three classes (live coral, rubble and sand, and dead coral with algae) were examined by Landsat MSS which have a 60 meter resolution and Landsat TM, ETM, ETM+, and OLI that have a 30 meter spatial resolution examined four classes (live coral, rubble, sand, and dead coral with algae).



**Fig. 1.** Study area in Suranti Island, one of the small islands in Spermonde Archipelago, Indonesia

**Table 1.** Types of data

No	Satellite	Sensor	Resolution (m)	Acquisition	Path/Row
1	Landsat_1	MSS	60	1972-10-28	122/063
2	Landsat_2	MSS	60	1981-10-26	122/063
3	Landsat_4	TM	30	1990-12-16	114/063
4	Landsat_5	TM	30	1996-04-28	114/063
5	Landsat_7	ETM	30	2002-06-24	114/063
6	Landsat_7	ETM	30	2008-08-19	114/063
				2008-08-03	114/063
7	Landsat_8	OLI_TIRS	30	2013-10-04	114/063

### Image processing

The image processing was composed of seven main steps including: (1) gap filling, (2) atmospheric corrections, (3) geometric correction, (4) image composite, (5) water column correction, (6) unsupervised classification, and (7) reclassification.

#### Filling Gaps

The Landsat 7 ETM+ scan-line corrector is a mechanism designed to correct the under sampling of the primary scan mirror, and it failed in May 2003. This research used the Gap method with Frame and Fill Software developed by Richard Irish at NASA Goddard Space Flight Center. The working principle of this software is to fill gap of Landsat image with an other Landsat image acquired at a different time, as they will have different gaps.

#### Atmospheric Corrections

This research used simple Dark Object Subtraction to method remove the effects of scattering from the image data. It requires only the information contained in the digital image data. It derives the corrected DN (Digital Number) values solely from the digital data with no outside information (Chavez 1998). Haze DN value is directly selected from the DN frequency Histogram of a digital Image.

#### Geometric Corrections

The geometric corrections used the 2013 image as references. Landsat image of 1972 and 1981 was corrected using the Landsat 8 image as a reference (Landsat 8 corrected). The orrected image was considered acceptable if RMSE (Root Mean Square Error) is one-half pixel wide (RMSE = 0.5). Overall, RMSE errors of less than 0,5 pixel were achieved for each transformation.

#### Image Composite (True Color)

The combination band of 321 is used in this interpretation

of Landsat 1, 2, 4, 5, 7 images and the combination band of 432 for Landsat 8. This band combination was used because, in interpretation, the appearance of shallow water bottom types could be seen clearly.

#### Water Column Correction

Water coloumn correction performed the Lyzenga algoritm for reducing the attenuation effect (Lyzenga 1978):

$$Y_{ij} = \ln(b_i) + \frac{k_i}{k_j} \ln(b_j) \quad (1)$$

$$\frac{K_i}{K_j} = a + \sqrt{(a^2 + 1)} \quad (2)$$

$$a = \frac{\sigma^2 b_i - b^2 b_j}{2\sigma(b_i \cdot b_j)} \quad (3)$$

where  $Y_{ij}$  is the result of information extraction channel bottom. Channel bottom are band  $i$  and band  $j$  that have high penetration into water coloum,  $b_i$  is reflectance on band  $i$ ,  $b_j$  is reflectance on band  $j$ ,  $\frac{K_i}{K_j}$  is the ratio of attenuation coefficient between band  $i$  and band  $j$ ,  $\sigma^2 b_i$  is variance of band  $i$ ,  $\sigma^2 b_j$  is variance of band  $j$ ,  $\sigma(b_i \cdot b_j)$  is covariance of band  $ij$ . To obtain the attenuation coefficient between the two bands, the selection of 30 sample points of live coral, dead coral with algae, rubble, and sand was carried out to calculate the variance value of band  $i$  and band  $j$  and the covariance to band  $ij$ .

#### Unsupervised Classification

This research used an Unsupervised Classification ISOCLASS algorithm with 20 unlabelled classes and 100 times of iterations.

#### Ground truth and reclassification

Ground truth was conducted to determine the actual shallow water bottom types on the ground. The result of the ground truth was compared with the result of classification image. The number of sampling points in the field survey is 83. There

**Table 2.** Class definitions

Classes	Class Definitions
Live coral	Habitat dominated by a mix of live scleractinian corals
Dead coral with algae	Substrate predominantly made of dead corals covered by algae (turf and fleshy algae)
Rubble	Pieces of broken corals, generally found in reef flats
Sand	Sediment from carbonate origin (dead corals and skeleton for calcifying organisms)
Rubble and sand	Sedimentary mix of rubble and sand

are five dominant classes of shallow water bottom types. They are live coral, rubble and sand, dead coral with algae, rubble, and sand (Table 2).

### Post classification

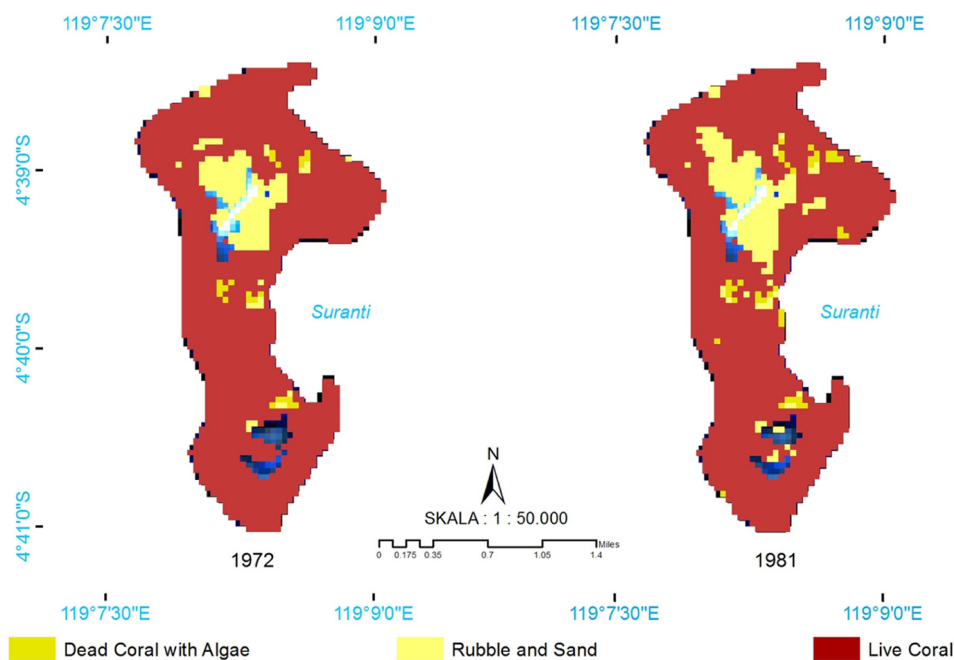
A post-classification change matrix function was applied between 1972 to 1981, 1990 to 1996, 1996 to 2002, 2002 to

**Table 3.** Band combination and attenuation coefficient

No	Satellite/Sensor and acquisition	Band Combination	ki/kj
1	Landsat_4 TM, 1990	1 and 2	0.847919
2	Landsat_5 TM, 1996	1 and 2	0.935253
3	Landsat_7 ETM, 2002	1 and 2	0.893087
4	Landsat_7 ETM, 2008	1 and 2	0.882156
5	Landsat_8 OLI_TIRS, 2013	2 and 3	0.720855

**Table 4.** Areal estimates of major bottom types in 1972, 1981, 1990, 1996, 2002, 2008, and 2013

Classes	Areal of Suranti Island (Ha)						
	1972	1981	1990	1996	2002	2008	2013
Live Coral	527.66	505.51	325.65	258.61	210.97	143.74	119.46
Rubble	0	0	184.46	248.03	289.15	329.45	336.91
Sand	0	0	60.10	56.10	55.87	55.33	68.39
Dead coral with algae	8.49	14.76	50.74	58.42	65.47	93.23	95.78
Rubble and Sand	59.41	78.60	0	0	0	0	0

**Fig. 2.** Coral reef classification maps of 1972 and 1981

2008, and 2008 to 2013 classification results using the ArcGIS 2008, and 2008 to 2013 classification results using the ArcGIS 10.2.1 software.

### Accuracy assessment

Accuracy was tested using confusion matrices of the different classifications. *Overall Accuracy* (OA), *Producer's Accuracy* (PA), and *User's Accuracy* (UA) were computed from the confusion matrices (Foody et al. 1992).

### 3. Results

In this study, a geometric correction process was performed using 7 point GCP. The result of the geometric correction shows

that the average RMSE obtained from Landsat images was 0.02.

Based on the calculation of digital values that have been extracted from band i and j at the research location. A coefficient value of  $k_i/k_j$  was obtained (Table 3).

### Areal estimate of changes

Our results show that for this shallow water, coral reef change can be seen by comparing the coral reef maps at different time series. The results of changes in the coral reef areas during the seven acquisition years are represented in Table 4.

Statistically, the change detection obtained from the classified scenes of 1972 to 2013 reveal a significant decrease in the live coral, while dead coral with algae and rubble are increasing every year.

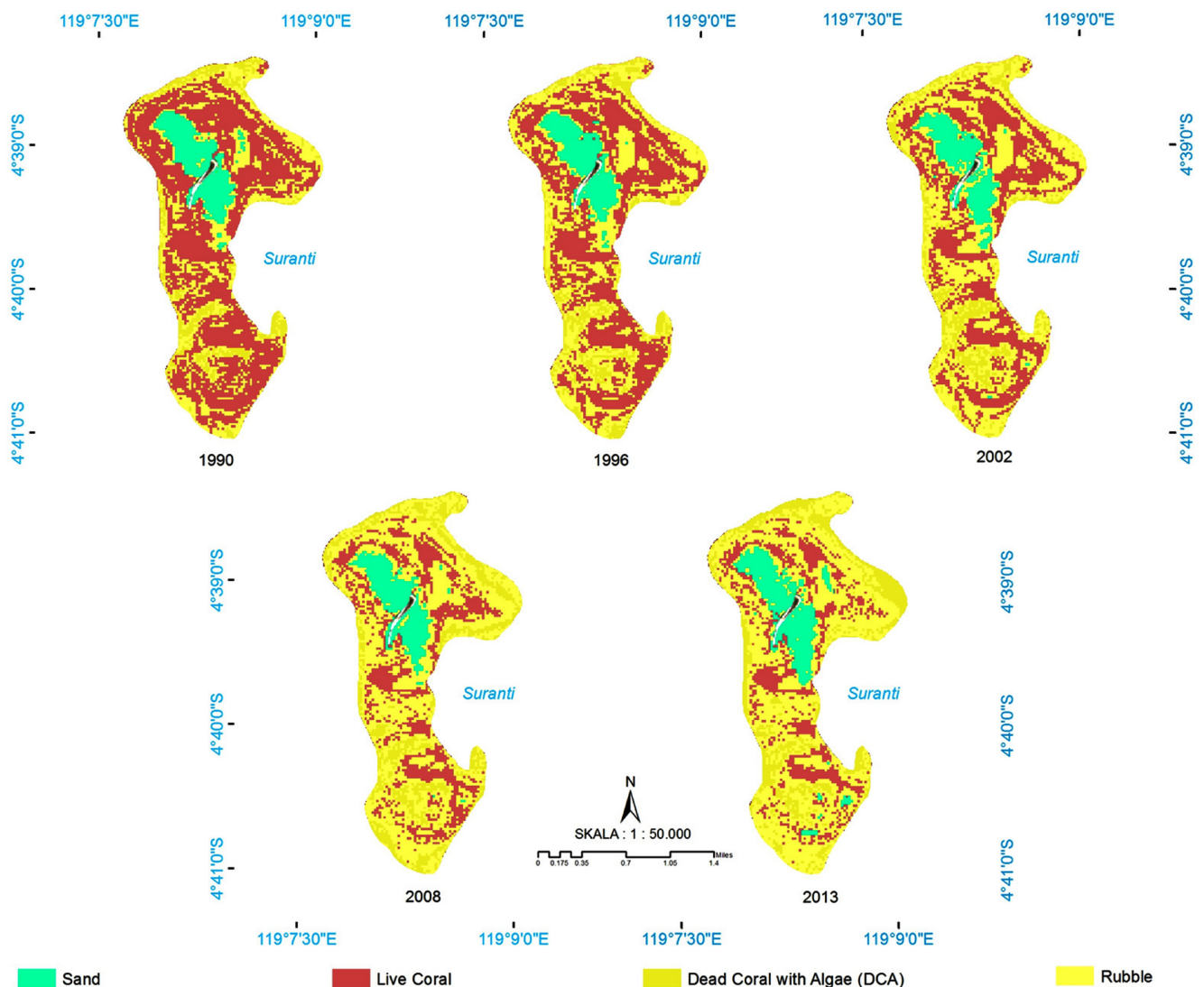


Fig. 3. Coral reef classification maps of 1990, 1996, 2002, 2008, and 2013

**Table 5.** Areal changes of bottom types in 1972 to 1981, 1990 to 1996, 1996 to 2002, 2002 to 2008, and 2008 to 2013

Bottom types	Areal (Ha)				
	Live coral	Rubble	Dead coral with algae	Sand	Rubble and sand
1972 to 1981					
Live coral	505.51	0.00	6.27	0.00	15.87
Dead coral with algae	0.00	0.00	8.49	0.00	0.00
Rubble and Sand	0.00	0.00	0.00	0.00	59.41
1990 to 1996					
Live coral	258.61	63.08	3.96	0.00	0.00
Rubble	0.00	155.45	25.22	3.78	0.00
Dead coral with algae	0.00	21.50	29.24	0.00	0.00
Sand	0.00	8.00	0.00	52.04	0.00
1996 to 2002					
Live Coral	210.97	45.94	1.70	0.00	0.00
Rubble	0.00	212.01	28.14	7.88	0.00
Dead coral with algae	0.00	22.80	35.63	0.00	0.00
Sand	0.00	8.29	0.00	47.80	0.00
2002 to 2008					
Live Coral	143.74	56.11	11.13	0.00	0.00
Rubble	0.00	240.59	39.79	8.65	0.00
Dead coral with algae	0.00	23.16	42.31	0.00	0.00
Sand	0.00	9.60	0.00	46.26	0.00
2008 to 2013					
Live coral	119.46	23.91	0.36	0.00	0.00
Rubble	0.00	272.58	39.41	17.47	0.00
Dead coral with algae	0.00	37.22	56.01	0.00	0.00
Sand	0.00	3.20	0.00	50.93	0.00

The change matrix (Table 5) shows that 6.27 ha of live coral changed between 1972 to 1981 to dead coral with algae, and 15.87 ha had changed to rubble and sand. The largest category of live coral change was loss to rubble (63.08 ha) from 1990 to 1996. Similar patterns of change were observed from 1996 to 2002, from 2002 to 2008, and from 2008 to 2013. The values are presented in Table 5.

Bottom types of shallow water show the changes in coral reef areas during the period between 1972 and 2013. It can be observed that the changes from 1972 to 2013 show that live coral decreased approximately by 408.19 ha (from 527.66 ha to 119.46 ha), while dead coral with algae increased approximately by 87.29 ha (from 8.49 ha to 95.78 ha), and rubble increased approximately by 345.89 ha (from 59.41 ha to 405.30 ha%). Image classification in 1972 - 2008 is validated by interviews with fisherman who settled around Suranti Island 20 to 40 years ago.

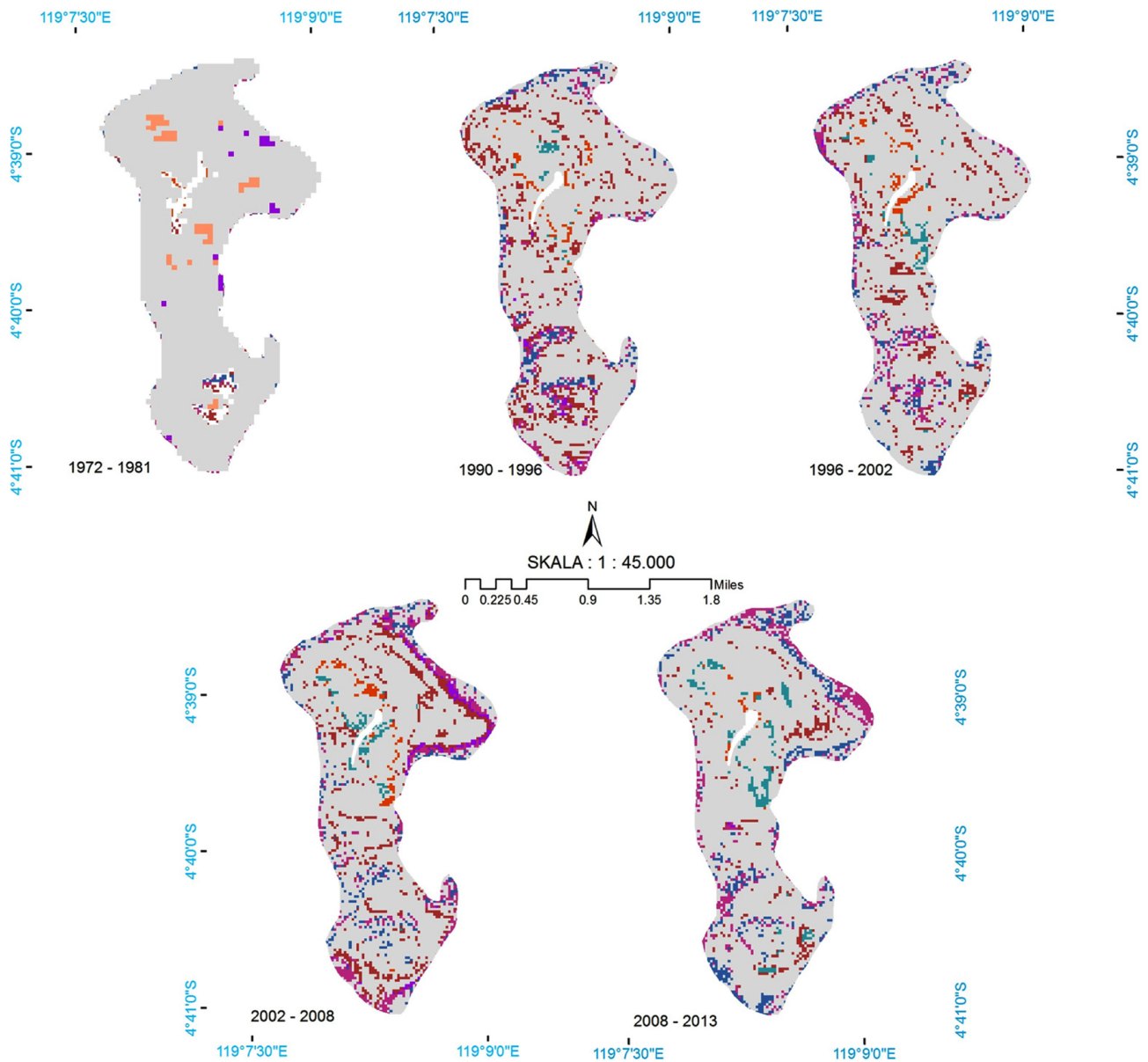
#### Accuracy assessment

The results of coral reef classification maps were checked

with an accuracy assessment method in order to obtain the level of map accuracy. As previously mentioned, standard map accuracy was more than 70%. Based on the confusion matrix on Table 6, it was found that the OA of the classification image for 2013 in Suranti is was 76.14%. Generally, differences between the classification results and reality in the field are caused by water clarity and spatial resolution of satellite derived data. This accuracy assessment is valid only for the present time (2013).

#### 4. Discussion

Although shallow water may change from year to year due to different human activities and oceanographic parameters, destructive fishing is a significant factor in the substantial decrease in the area of live coral and the increase in dead coral, rubble and sand. The phenomenon of coral bleaching that occurred at the end of 2009 and continued until the middle of 2010 was caused by the La Nina phenomena and increased the SST as a result of the westward movement of



**Legend**

<span style="display:inline-block; width:15px; height:15px; background-color:gray; border:1px solid black;"></span> Unchange	<span style="display:inline-block; width:15px; height:15px; background-color:darkred; border:1px solid black;"></span> Live Coral to Rubble	<span style="display:inline-block; width:15px; height:15px; background-color:teal; border:1px solid black;"></span> Rubble to Sand
<span style="display:inline-block; width:15px; height:15px; background-color:purple; border:1px solid black;"></span> Live Coral to Dead Coral Algae	<span style="display:inline-block; width:15px; height:15px; background-color:darkblue; border:1px solid black;"></span> Dead Coral with Algae to Rubble	<span style="display:inline-block; width:15px; height:15px; background-color:orange; border:1px solid black;"></span> Sand to Rubble
<span style="display:inline-block; width:15px; height:15px; background-color:orange; border:1px solid black;"></span> Live Coral to Rubble and Sand	<span style="display:inline-block; width:15px; height:15px; background-color:purple; border:1px solid black;"></span> Rubble to Dead Coral with Algae	

**Fig. 4.** Post classification of coral reef of Suranti Island: From 1972 to 1981, 1990 to 1996, 1996 to 2002, 2002 to 2008, and 2008 to 2013

the warmpool from the Central Pacific to the Indonesian Seas (Yusuf and Jompa 2012).

Destructive fishing methods such as blast and chemical fishing are still widely practiced in many areas around small islands in the Spermonde Archipelago, Indonesia. Blast fishing

is considered to be one of the most destructive anthropogenic threats to coral reefs because of its pernicious effects. Despite national and local government policy to control these illegal methods, destructive fishing is still widely practised by local fishermen. There are several reasons why these practices are

**Table 6.** Confusion matrix for coral reef classification

Data Classify	Reference Data				Row Total	Commisi	UA
	Live Coral	DCA	Rubble	Sand			
Live Coral	25	3	2	1	31	6	96.15
DCA	0	24	2	0	26	2	80.00
Rubble	0	2	13	0	15	2	72.22
Sand	1	1	1	8	11	3	88.89
Coloum Total	26	30	18	9	83	13	
Ommisi	1	6	5	1	0	13	
PA	80.65	92.31	86.67	72.73			

difficult to eradicate: 1) rapid population growth, particularly in small islands: 2) over-fishing in coastal areas due to limited boat capacity and the traditional fishing gears used by fishermen: 3) poor knowledge of the ecosystem's carrying capacity: 4) weak government control and monitoring. All these issues needed to be seriously addressed and managed by the government to conserve the coastal ecosystems of small islands and marine resources. In order to stop blast and chemical fishing practices, the government should assist local fishermen in seeking alternative livelihoods that provide other means of income. This a serious problem and while many blast fishermen are aware of the destruction their practices entail, they argue that they have no real alternatives.

## 5. Conclusion

The results indicate that decreases in live coral areas resulted in increased areas of dead coral with algae and rubble during the forty one year period from 1972 to 2013. Live coral from 1972 to 2013 was decreased, while dead coral with algae and rubble were increased. Field observations on the shallow water of Suranti revealed that coral reef habitat destruction was largely caused by human activities. This could be concluded because a lot of loose fragments of rubble that typically result from destructive activities such as explosive fishing (bombs) were found. Another possible cause of the decrease in the area of live corals in the study sites was probably due to the coral bleaching phenomenon which badly affected many Indonesian coral reefs in 2010.

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Reviewers' comments:

Reviewer #2: Review of « Multisensor and multitemporal images for damage detection on coral reef, small island, Spermonde Archipelago, Indonesia »

The paper presents an interesting case study, but needs a thorough revision to be acceptable for publication. There are requested changes, due to poor English and unnecessary technical details that I have highlighted directly in the pdf, plus other suggestions.

Otherwise, my main concern is in the habitat classification scheme and the classification of the image:

I doubt coral cover can be measured with Landsat, so a classification scheme based on classes defined by 0-24% etc... are very questionable. Plus, if the ground is occupied by less than 24% of coral for instance, then what is it? Other classes are sand, dead coral, rock, so these classes can not be part of substrate? This is very unclear. At what scale on ground is the accuracy assessment conducted? I suggest to read Capolsini et al. 2003 for more information on these issues of scales between image resolution and ground perception.  
Capolsini P, Andréfouët S, Rion C, Payri C (2003) A comparison of Landsat ETM+, SPOT HRV, Ikonos, ASTER and airborne MASTER data for coral reef habitat mapping in South Pacific islands. Canadian J. Remote Sensing, 29, 187-200.

Then, the classification itself is poorly explained : how many classes are used in input for the unsupervised classification? In addition to merging (fusion), is there any other pre-processing (water and atmospheric correction?), or empirical inter-calibration between images? Compare and discuss your methods with those applied by Palandro et al. (2003, 2008) who also analysed Landsat time-series on coral reefs.

Palandro D, Andréfouët S, Hu C et al. (2008) Quantification of two decades of coral reef habitat decline in the Florida Keys National Marine Sanctuary using Landsat data (1984-2002). Remote Sensing of Environment, 112, 3388-3399.  
Palandro D, Andréfouët S, Muller-Karger F, Dustan P, Hu C, Hallock P (2003) Detection of changes in coral communities using Landsat 5/TM and Landsat 7/ETM+ data. Canadian J. Remote Sensing, 29, 201-209.

The text needs to be revised by an English editor or corrector.



### Author's Response To Reviewer Comments

Close

This paper has been improved with some additional revisions

1. A number of text correction have been improved
2. There is statement in results that accuracy assessment for classification is valid only for the present time (2013). Image classification in 1972 to 2008 is validated by interview method with fisherman that have been settled since 40 years ago around the Suranti Island
3. We forgot to mention one step, It is Image Composite (True Color). The combination bands of 321 is used in this interpretation of Landsat 1, 2, 4, 5, 7 image and combination band of 432 for Landsat 8.
4. Table 5 (The change matrix ) is important to explain the cover change, for example 6.27 ha from 1972 to 1981 live coral had changed to dead coral with algae, and 15.87 ha had changed to rubble and sand. The largest category of live coral change was loss to rubble (63.08 ha) from 1990 to 1996. Similiar patterns of change were observed from 1996 to 2002, from 2002 to 2008, and from 2008 to 2013.
5. The current section 3.2 have been move after classification results and before discussion on what happened to reefs.
6. The number of references based on alphabetic
7. Thank you very much for the correction

Close

# Multisensor and multitemporal of Landsat images for damage detection on coral reef, small island, Spermonde Archipelago, Indonesia

## ABSTRACT

Coral reefs are important because of their high biodiversity and their key role in the tropical marine biosphere. Furthermore, coral reefs are very valuable as a socioeconomic resource as they make important contributions to the gross domestic product of many countries. Thus, It is very important to monitor dynamic spatial distributions of coral reefs and related habitats such as coral rubble, dead coral, and bleached corals. Despite these natural and socioeconomic advantages, many factors are threatening coral reefs. The study site was selected in Spermonde archipelago, South Sulawesi, Indonesia because this area is included the highest diversity of corals in the world named as Coral Triangle, which is recognized as the global centre of marine biodiversity and a global priority for conservation. Images of Landsat MSS, Landsat TM, Landsat ETM, Landsat ETM+, and Landsat 8 data were used to examine changes on coral reef on small islands for forty one year from 1972 to 2013. The small islands is Suranti Island prior to coral reef bottom-type classification. The image processing are gap fill, atmospheric corrections, geometric correction, water column correction, unsupervised classification, and reclassification. Fill Gap processing was done on Landsat ETM+ SLC-off. Subsequently, a multi-component change detection procedure was applied to these indices to define changes. Shallow water bottom types classification divided into live coral, rubble and sand, dead coral with algae, rubble, and sand. Preliminary results showed significant changes during the period 1972–2013 as well as changes in coral reef. On the other hand, they are threatened by human impacts such as destructive fishing.

Keywords: Coral reef, Landsat, destructive fishing

## 1. INTRODUCTION

The world's most species rich coastal ecosystems occur within the Coral Triangle, a region which includes all or part of six Indo-Pacific countries; Indonesia, the Philippines, Malaysia (Sabah), Timor-Leste, Papua New Guinea and the Solomon Islands. Coral reef is one of important ecosystems in marine and coastal area. Coral reef ecosystem is also important for fish community and various marine biotas as feeding, nursery, and spawning ground. Ecologically, coral reef has a function to protect other components of marine and coastal ecosystem from pressure of wave and storm. Compared with the other ecosystems, coral reef can be easily destroyed. The coral reef in the Coral Triangle has been directly threatened by human activities and natural threats. Coral reef destructions happened in small island, Spermonde Archipelago from human activity and by rising SST [6]. Suranti Island is one of small islands in Pangkep District. Suranti Island provides high contribution to the society, the most livelihoods of whom depends on its shallow water. However, the condition of coral reef will worsen if the illegal fishing and SST in Suranti Island increases every year. Therefore, spatial dynamic mapping and spatial prediction model of coral reef are needed to create good spatial planning for coastal area. Satellite or airborne remote sensing has increasingly been employed to map coral reef communities worldwide [12]–[3]. While a range of these studies have used high spatial resolution data, e.g. IKONOS [1], [2], [17], [9], Quickbird [1], [80], [15], Worldview [8], and CASI [8], [15]. There are studies using medium spatial resolution data, e.g. Landsat [4] [7] [16]. Thematic map can be used as a reference for spatial dynamics and habitat distribution of coral reef. The objective of this research was to analyze dynamic of coral reef by using multisensor data (Landsat MSS, TM, ETM, ETM+, and 8) and multitemporal data for 41 years (1972-2013).

## 2. DATA AND METHOD

### 2.1 Study Area

Suranti is one of the islands in Spermonde Archipelago, Pangkep District, Indonesia. Suranti has a land area of 0.044 km<sup>2</sup>. Geographically, Suranti island is located at longitude 119°08'15.483" East and latitude 04°39'10.135" South.

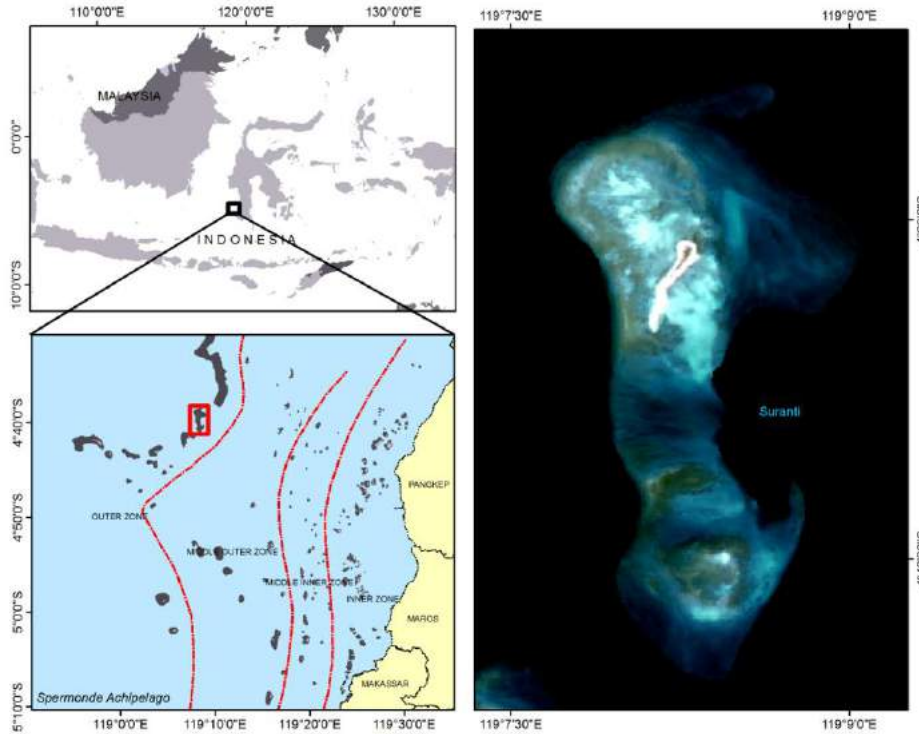


Figure 1. Study area in Suranti Island, one of small island in Spermonde Archipelago, Indonesia.

### 2.2 Data

The Landsat MSS data have four spectral bands, with a spatial resolution of 60 m. Landsat TM data have seven spectral bands, with a spatial resolution of 30 m for bands 1-5 and 7. The TM band 6 (thermal infrared) was acquired at 120 m resolution but was resampled to 30 m pixels. The Landsat ETM+ data consisted of eight spectral bands with a spatial resolution of 30 m for bands 1-7. The ETM+ band 6 (thermal infrared) was acquired at 60 m resolution but was resampled to 30 m pixels. The Landsat 8 data have nine spectral bands with a spatial resolution of 30 m for bands 1-7 and 9. The ETM+ and OLI band 8 (panchromatic band) have a spatial resolution of 15 m. The following table shows types data (Table 1).

Table 1. Types of data

No	Satellite	Sensor	Resolution (m)	Acquisition	Path/Row
1	Landsat_1	MSS	60	1972-10-28	122/063
2	Landsat_2	MSS	60	1981-10-26	122/063
3	Landsat_4	TM	30	1990-12-16	114/063
4	Landsat_5	TM	30	1996-04-28	114/063
5	Landsat_7	ETM	30	2002-06-24	114/063
6	Landsat_7	ETM	30	2008-08-19	114/063
				2008-08-03	114/063
7	Landsat_8	OLI_TIRS	30	2013-10-04	114/063

Classification bottom types ~~divided into~~ three class (live coral, rubble and sand , and dead coral with algae, ~~and~~) for Landsat MSS which have 60 meter and Landsat TM, ETM, ETM+, and OLI with 30 meter spatial resolution ~~divided into~~ four class (live coral, rubble, sand, and dead coral with algae).

### 2.3 Image Processing

The image processing was composed of six main steps including: (1) gap fill, (2) atmospheric corrections, (3) geometric correction, (4) water column correction, (5) unsupervised classification, and (6) reclassification.

#### Fill Gap

The Landsat 7 ETM+ scan-line corrector is a mechanism designed to correct the under sampling of the primary scan mirror, failed on May 2003. This research used Gap method with Frame and Fill Software developed by Richard Irish ~~in affliction with~~ NASA Goddard Space Flight Center. The working principle of this software is filling the gap Landsat with the other Landsat image, ~~which has different sections~~ Gap.

#### Atmospheric Corrections

Atmospheric effects on any satellite imagery consist of both scattering and absorption. This study used radiance conversion to correct the atmospheric effects. Viewing the Calibration file and writing down:

- a.  $L_{min}$  of each band
- b.  $L_{max}$  of each band

The formula is (Markham and Barker 1986):

$$RTM_i = Bias_i + \left( \frac{L_{max_i} - L_{min_i}}{Q_{calmax_i} - Q_{calmin_i}} \right) DN \quad 1)$$

Where  $RTM_i$  is the radiance value for band  $i$ ,  $L_{min}$  is the minimum spectral radiance (the spectral radiance that is scaled to  $Q_{calmin}$  in watts/(meter squared \* ster \*  $\mu m$ ) can be seen from the header file,  $L_{max}$  is the maximum spectral radiance ((the spectral radiance that is scaled to  $Q_{calmax}$  in watts/(meter sq)) can be seen from the header file,  $DN$  is the digital number,  $Q_{calmax}$  is 255; and  $Q_{calmin}$  is 1.

#### Geometric Corrections

The geometric corrections used two kinds of references. Landsat image of 2013 was corrected ~~with the corrected image~~ (ALOS AVNIR corr), while the other image for 1972, 1978, 1981, 1990, 1993, 1996, 1999, 2002, 2005, 2008, 2009, and 2011 used ~~image of the year 2013~~. Corrected image was considered acceptable if RMSE (Root Mean Square Error) is one-half pixel wide (RMSE = 0.5). Overall, RMSE errors of less than 0,5 pixel were achieved for each transformation.

#### Water Column Correction

Water column correction performed ~~using~~ Lyzenga algorithm for reducing the attenuation effect. ~~It is using imagery approach would be done using Lyzenga algorithms that are widely used in the basic cover mapping shallow waters in some areas of the world and has been developed previously by Lyzenga (Lyzenga, 1978):~~

$$Y_{ij} = \ln(b_i) + \frac{k_i}{k_j} \ln(b_j) \quad 2)$$

$$\frac{k_i}{k_j} = a + \sqrt{(a^2 + 1)} \quad 3)$$

$$a = \frac{\sigma^2 b_i - \sigma^2 b_j}{2\sigma(b_i b_j)} \quad 4)$$

Where  $Y_{ij}$  is the result of ~~inform~~ extraction channel bottom,  $B_i$  is Reflectance on channel  $i$ ,  $B_j$  is Reflectance on channel  $j$ ,  $\frac{k_i}{k_j}$  is the attenuation coefficient between channel  $i$  and channel  $j$ ,  $a$  is the varia ~~covariance~~ covariance variable,  $\sigma^2$  is

the variance of the canal, and is the covariance between bands. To obtain the attenuation coefficient between the two channels, the selection of 30 sample points of  $\sigma_{ij}$  to calculate variance value of each band and the covariance to the other bands.

### Unsupervised Classification

Classification is a technique in processing a pixel of the image that has spectral reflectance appearance, which identified to separated objects that contained in the image satellite, and grouped then into certain characteristics in accordance with the real condition. Formerly, this was done by a masking technique to eliminate some of the area that was not needed. This research used Unsupervised Classification of ISOCCLASS algorithm applying schema of shallow water bottom types. Unsupervised classification consist of 20 unlabelled class and 100 times of iterations.

### 2.4 Ground Truth and Reclassification

Ground truth was conducted to determine the actual shallow water bottom types on the ground. The result of ground truth was compared with the result of classification image. Number of sampling points on the field survey is 83 points. There are five dominant classes of shallow water bottom types. They are live coral, rubble and sand, dead coral with algae, rubble, and sand (Table 2). The results of field survey used as a reference in reclassification.

Table 2. Class definitions

Classes	Class Definitions
Live coral	A hard stony substance secreted by certain marine coelenterates as an external skeleton, typically forming large reefs in warm seas
Dead coral with algae	Any non-living parts of the coral in which the corallite structures are covered over with algae
Rubble	Pieces of fragmented corals found in reef flat
Sand	A loose granular material that results from the disintegration of rocks, consists of particles smaller than gravel but coarser than silt
Rubble and sand	Mixture of sea bottom consisted of equal quantity of rubble and sand

### 2.5 Post Classification

A post-classification change matrix function was applied between 1972 to 1981, 1990 to 1996, 1996 to 2002, 2002 to 2008, and 2008 to 2013 classification results and used ArcGIS 10.2.1 software.

### 2.6 Accuracy Assessment

Accuracy test was used to make any calculation matrix for each error's (confusion matrix) on any kind of habitat shallow water cover from result the analysis satellite imagery. Image validation was counted based on the confusion matrix such as Overall Accuracy (OA), Producer's Accuracy (PA), and User's Accuracy (UA).

## 3. RESULT AND DISCUSSION

Geometric correction process was done to obtain good accuracy image position of each class in coral reef and the real world. In this study, geometric correction process was performed using 7 point GCP. The result of geometric correction shows that the average RMSE obtained from Landsat images was 0.02. It is in accordance with the standard mapping of the United States.

Based on calculation of digital values that have been extracted from band 1 and 2 at the research location. It was obtained coefficient value  $k_i/k_j$  (Table 3). Correction of water column using Lyzenga algorithm in this study showed a good result without conducting field observatio

Table 3. Band combination and attenuation coefficient

No	Satellite/Sensor and acquisition	Band Combination	ki/kj
1	Landsat_4 TM, 1990	1 and 2	0.847919
2	Landsat_5 TM, 1996	1 and 2	0.935253
3	Landsat_7 ETM, 2002	1 and 2	0.893087
4	Landsat_7 ETM, 2008	1 and 2	0.882156
5	Landsat_8 OLI_TIRS, 2013	2 and 3	0.720855

### 3.1 Areal estimate of coral reef

Our results show that for this shallow water, coral reef change can be seen by comparing the coral reef maps at different time series. The result of coral reefs area changing during the seven acquisition years are represented in Table 4.

Table 4. Areal estimates of major bottom types in 1972, 1981, 1990, 1996, 2002, 2008, and 2013

Classes	Areal of Suranti Island (Ha)						
	1972	1981	1990	1996	2002	2008	2013
Live Coral	527.66	505.51	325.65	258.61	210.97	143.74	119.46
Rubble	0	0	184.46	248.03	289.15	329.45	336.91
Sand	0	0	60.10	56.10	55.87	55.33	68.39
Dead coral with algae	8.49	14.76	50.74	58.42	65.47	93.23	95.78
Rubble and Sand	59.41	78.60	0	0	0	0	0

Statistically the change detection obtained from the classified scenes of 1972 to 2013 reveal a significant decrease in the live coral, however, dead coral with algae and rubble are increased every year.

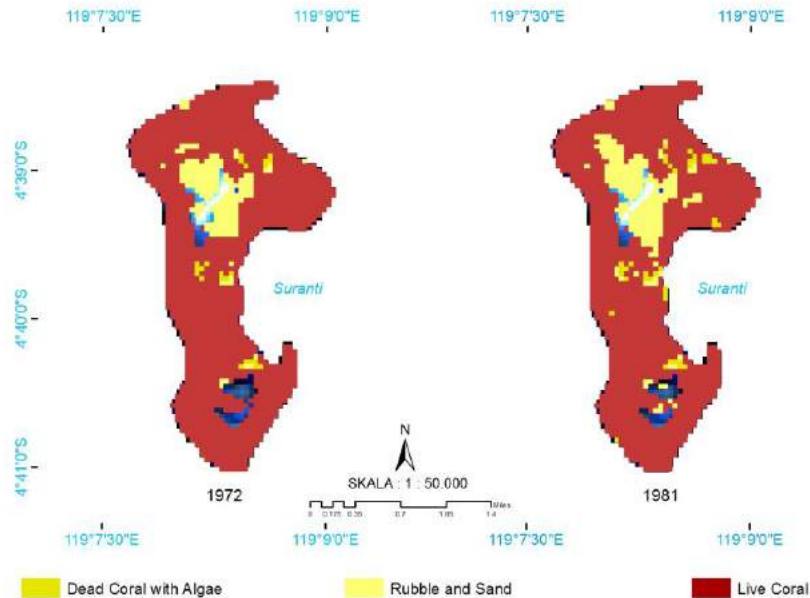


Figure 2. Coral reef classification maps of 1972 and 1981

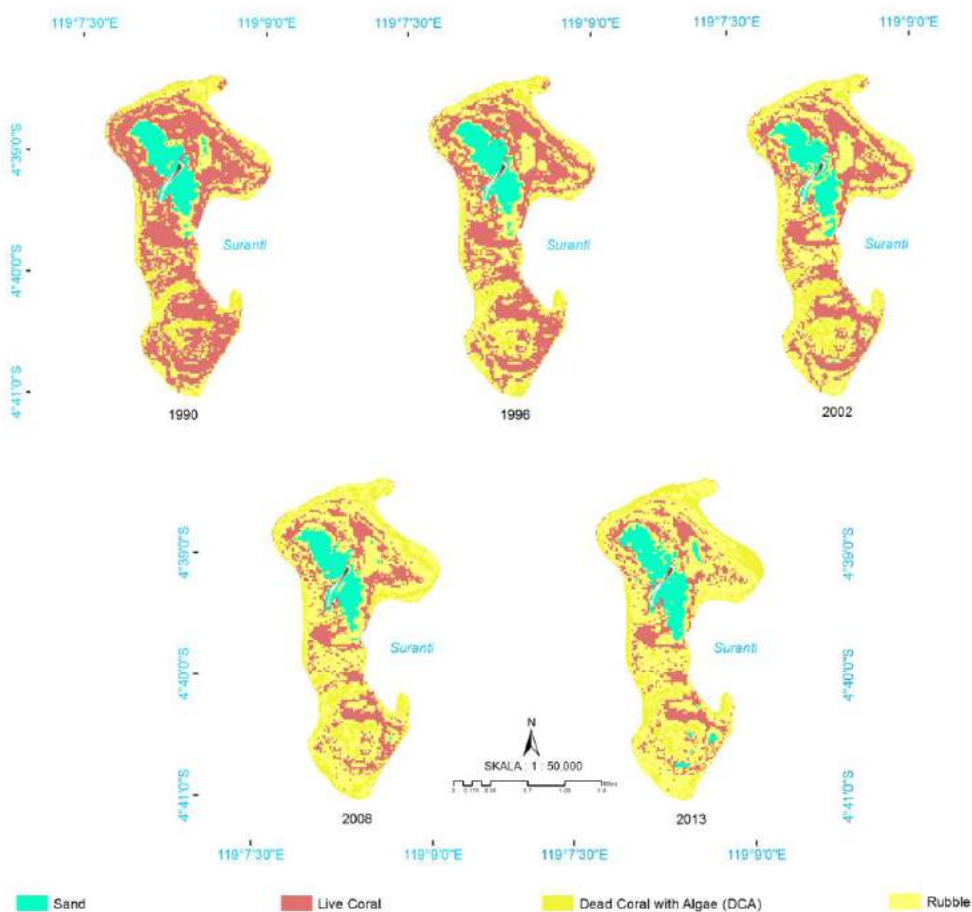


Figure 3. Coral reef classification maps of 1990, 1996, 2002, 2008, and 2013

Show water bottom types of live coral, rubble and sand, dead coral with algae, rubble, and sand, from 1972 to 1981 are change as well as. The value are presented in Table 5.

Table 5. Areal changes of bottom types in 1972 to 1981, 1990 to 1996, 1996 to 2002, 2002 to 2008, and 2008 to 2013.

Bottom types	Areal (Ha)				
	Live coral	Rubble	Dead coral with algae	Sand	Rubble and sand
<b>1972 to 1981</b>					
Live coral	505.51	0.00	6.27	0.00	15.87
Dead coral with algae	0.00	0.00	8.49	0.00	0.00
Rubble and Sand	0.00	0.00	0.00	0.00	59.41
<b>1990 to 1996</b>					
Live coral	258.61	63.08	3.96	0.00	0.00
Rubble	0.00	155.45	25.22	3.78	0.00
Dead coral with algae	0.00	21.50	29.24	0.00	0.00

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Sand	0.00	8.00	0.00	52.04	0.00
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<b>1996 to 2002</b>					
Live Coral	210.97	45.94	1.70	0.00	0.00
Rubble	0.00	212.01	28.14	7.88	0.00
Dead coral with algae	0.00	22.80	35.63	0.00	0.00
Sand	0.00	8.29	0.00	47.80	0.00
<hr/>					
<b>2002 to 2008</b>					
Live Coral	143.74	56.11	11.13	0.00	0.00
Rubble	0.00	240.59	39.79	8.65	0.00
Dead coral with algae	0.00	23.16	42.31	0.00	0.00
Sand	0.00	9.60	0.00	46.26	0.00
<hr/>					
<b>2008 to 2013</b>					
Live coral	119.46	23.91	0.36	0.00	0.00
Rubble	0.00	272.58	39.41	17.47	0.00
Dead coral with algae	0.00	37.22	56.01	0.00	0.00
Sand	0.00	3.20	0.00	50.93	0.00
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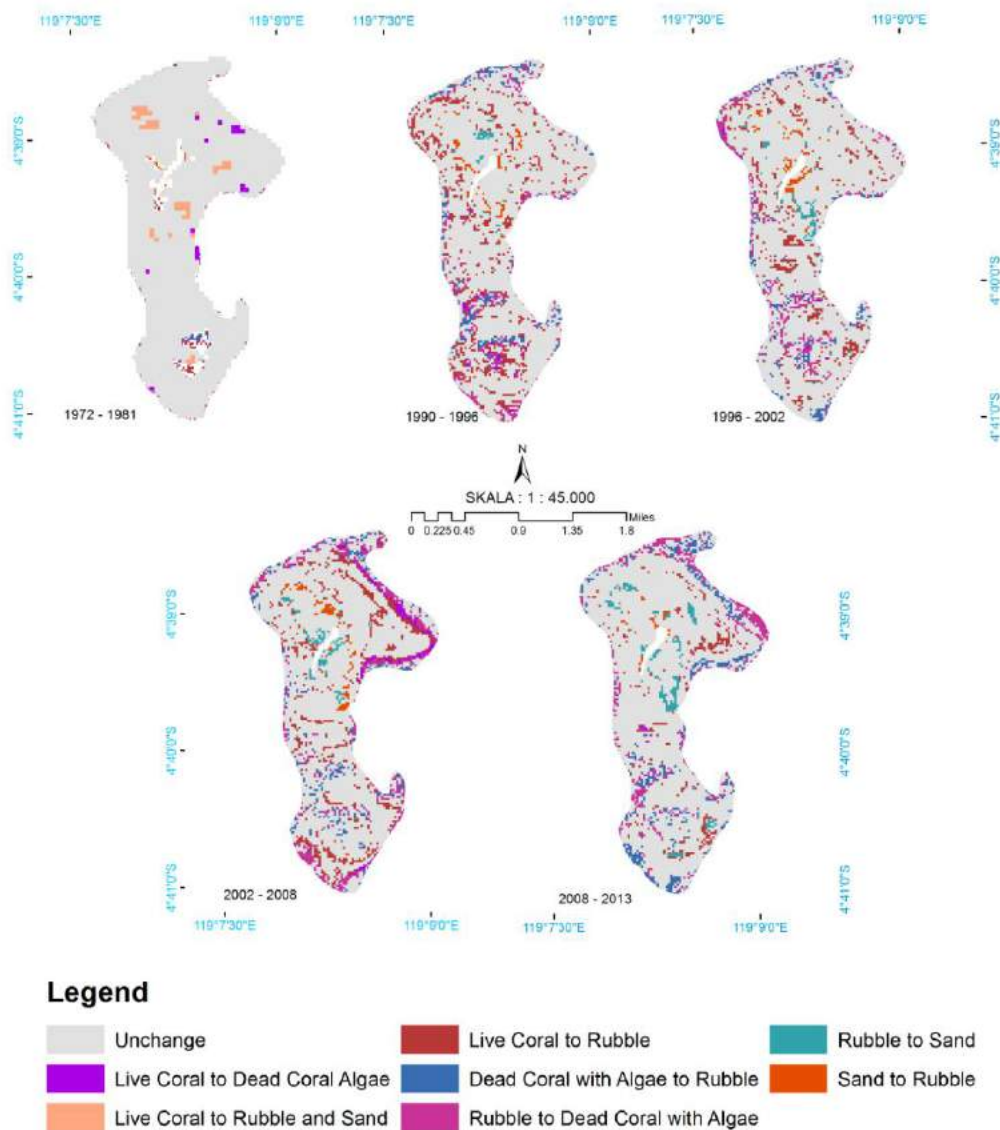


Figure 4. Post classification of coral reef of Suranti Island: From 1972 to 1981, 1990 to 1996, 1996 to 2002, 2002 to 2008, and 2008 to 2013

Bottom types of shallow water shows the trend of coral reef change areas during the periods of 1972 to 2013. It can be observed that the changes from 1972 to 2013 show that live coral decreased approximately to 408.19 ha (77.36%), while dead coral with algae increased to 87.29 ha (91.13%), rubble increased 277.51 ha (82.37%). Although the extent of shallow water may change from year to year due to varying human activities and oceanographic parameters, and destructive fishing are a dominant factors that significantly decreased the area of live coral and increased dead coral, rubble and sand.

The phenomenon of coral bleaching that occurred at the end of 2009 until middle of 2010 was caused by the La Nina phenomena increasing the SST by the westward warmpool movement from the Central Pacific to the Indonesian Seas, due to the strengthening of trade winds, that significantly decreased the quality of coral reefs in the Spermonde Archipelago (Yusuf and Jompa, 2012).

Destructive fishing methods such as blast and chemical fishing are still widely found in many areas around small island, Spermonde Archipelago, Indonesia. Blast fishing is considered as one of the most destructive anthropogenic threats to coral reef with serious damaging effects. Despite of nation and local government policy to control these illegal methods, destructive fishing is still widely ~~been~~ practised by local fishermen. There are several reasons why this practice are difficult to be solved i.e. 1). rapid population growth particularly in small islands, 2) over-fishing in coastal areas due to limited boat capacity and traditional fishing gears of the fishermen, 3) poor knowledge of local fishermen on the ecosystem's carrying capacity, 4) weak government control and monitoring. All-of these factors are needed to be seriously managed by the government to conserve coastal of small islands and marine resources. In order to stop the blast and chemical fishing, the government should develop alternative livelihoods that provide other income opportunities for the local fishermen. This a serious problem, many blast fishermen have realized their destructive behaviour, ~~however,~~ they argued that they have no other alternatives.



### Accuracy Assessment

The results of coral reef classification maps were checked with accuracy assessment method in order to obtain the level of map accuracy. As previously mentioned, standard map accuracy was more than 70%. Based on confusion matrix on Table 6 is found the OA of classification on image 2013 in Suranti is 76.14%. Generally, the difference between the classification results and reality in the field is caused by water clarity and spatial resolution of satellite-derived data.

Table 6. Confusion matrix for coral reef classification

Data Classify	Reference Data				Row Total	Commisi	UA
	Live Coral	DCA	Rubble	Sand			
Live Coral	25	3	2	1	31	6	96.15
DCA	0	24	2	0	26	2	80.00
Rubble	0	2	13	0	15	2	72.22
Sand	1	1	1	8	11	3	88.89
Coloum Total	26	30	18	9	83	13	
Ommisi	1	6	5	1	0	13	
PA	80.65	92.31	86.67	72.73			

### 3.3 Conclusion

The results indicate that decreases in live coral areas ~~mainly formed into~~ dead coral with algae and rubble during the forty one year period from 1972 to 2013. ~~The changes of~~ live coral from 1972 to 2013 ~~are~~ decreased approximately ~~to~~ 408.19 ha (77.36%), while dead coral with algae increased ~~to~~ 87.29 ha (91.13%), rubble increased ~~to~~ 277.51 ha (82.37%). Based on observations in the field, the coral reef habitat destruction in Suranti Island was largely caused by human activities. It is proven by many fragments of rock (rubble) and the activities of explosive fishing such as bombs and chemicals in shallow water of Suranti. Another phenomenon is coral bleaching that has been caused by decreases of live coral cover while the dead coral increased.

### Acknowledgments

We would like to thank Khairul Amri, Marine Biology Laboratory, Hasanuddin University, Indonesia, for his insight in preparing the manuscript. We gratefully acknowledge the sponsors of this study which was conducted under the network of the Asian CORE Program of the Japan Society for the promotion of Science, "Establishment of research and education network on coastal marine science in Southeast Asia", and the Ocean Remote Sensing Project for Coastal Habitat Mapping (WESTPAC-ORSP: PAMPEC III) of Intergovernmental Oceanographic Commission Sub-Commission for the Western Pacific supported by Japanese Funds-in-Trust provided by the Ministry of Education, Culture, Sports, Science and Technology in Japan.

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# Multisensor and multitemporal images for damage detection on coral reef, small island, Spermonde Archipelago, Indonesia



## ABSTRACT

Coral reefs are important because of their high biodiversity and their key role in the tropical marine biosphere. Furthermore, coral reefs are very valuable as a socioeconomic resource as they make important contributions to the gross domestic product of many countries. This is very important to monitor dynamic spatial distributions of coral reefs and related habitats such as coral rubble, dead coral, and bleached corals. Despite these natural and socioeconomic advantages, many factors are threatening coral reefs. The study site was selected in Spermonde archipelago, South Sulawesi, Indonesia because this area is included in the highest diversity of corals in the world named as Coral Triangle, which is recognized as the global centre of marine biodiversity and a global priority for conservation. Images of Landsat MSS, Landsat TM, Landsat ETM, Landsat ETM+, and Landsat 8 data were used to examine changes on coral reef on the small islands for forty one year from 1972 to 2013. The small islands is Suranti Island prior to coral reef bottom-type classification, The image fusion technique were done to combain relevant information for two images into single image to produce the high spatial resolution and fill gap processing was done on Landsat ETM+ SLC-off. Subsequently, a multi-component change detection procedure was applied to these indices to define changes. Coral reef bottom types classification devided into live coral (percent cover 0-24.9%, 25-49.9%, 50-74.9% and 75-100%), dead coral, rubble, rock, and sand. Preliminary results showed significant changes during the period 1972–2013 as well as changes in percent cover of coral reef. On the other hand, they are threatened by human impacts such as destructive fishing.

Keywords: Coral reef, image fusion, fill gap, destructive fishing

## 1. INTRODUCTION

The world's most species rich coastal ecosystems occur within the Coral Triangle [17], a region which includes all or part of six Indo-Pacific countries; Indonesia, the Philippines, Malaysia (Sabah), Timor-Leste, Papua New Guinea and the Solomon Islands. Coral reef is one of important ecosystems in marine and coastal area. Coral reef ecosystem is also important for fish community and various marine biotas as feeding, nursery, and spawning ground. Ecologically, coral reef has a function to protect other components of marine and coastal ecosystem from pressure of wave and storm. **Despitefully, coral reef function as an interesting tourism place. If** compared with the other ecosystems, coral reef can be easily destroyed. The coral reef in the Coral Triangle **Asia** has been directly threatened by human activities and natural threats. **The** coral reef destructions happened in small Island, Spermonde Archipelago from human activity and by rising SST [6]. Suranti Island is one of small islands in Pangkep District, **which has high potential ecosystem especially coral reef distribution.** Suranti Island provides high contribution to the society, the most livelihoods of whom depends on its shallow water. However, the condition of coral reef will worsen if the illegal fishing and SST in Suranti Island increases every year. Therefore, spatial dynamic mapping and spatial prediction model of coral reef are needed to create good spatial planning for coastal area. **Coral reef ecosystem areas should become protected. Through this spatial prediction model, the spatial problem of coral reef can be solved.** Satellite or airborne remote sensing has increasingly been employed to map coral reef communities worldwide [12]–[3]. While a range of these studies have used high spatial resolution data, e.g. IKONOS [1], [15], [9], Quickbird [1], [80], [14], [1], [8], and CASI [8], [14]. There are studies using medium spatial resolution data, e.g. Landsat [4] [7]. Thematic map can be used as a reference for spatial dynamics and habitat distribution of coral reef. **This map is important for planners and scientists**

because it can be used to simplify the management planning and change detection. There are many approaches for mapping habitats in reef waters, such as remote sensing techniques and surveying. Remote sensing data can produce coral reef change and derive several oceanographic parameters such as SST, salinity, current, tides and TSS. Visible spectrum, infrared and microwave satellite data can be used to create map of some objects on earth surface. Satellite remote sensing data is the best tool to create map of shallow water. Shallow water ecosystem detections such as coral reef, seagrass and health of coral can be created by satellite remote sensing with different spatial resolutions such as Ikonos Multispectral, Quickbird, Alos and Landsat. The objective of this research was to analyze dynamic of coral reef by using multisensor data (Landsat MSS, TM, ETM, ETM+, and 8) and multitemporal data for 41 years (1972-2013).

## 2. DATA AND METHOD

### 2.1 Study Area

Suranti is one of the islands in Spermonde Archipelago, which is located in Pangkep District, Indonesia. Suranti has a land area of 0.044 km<sup>2</sup>. Geographically, Suranti island is located at longitude 119°08'15.483" East and latitude 04°39'10.135" South.

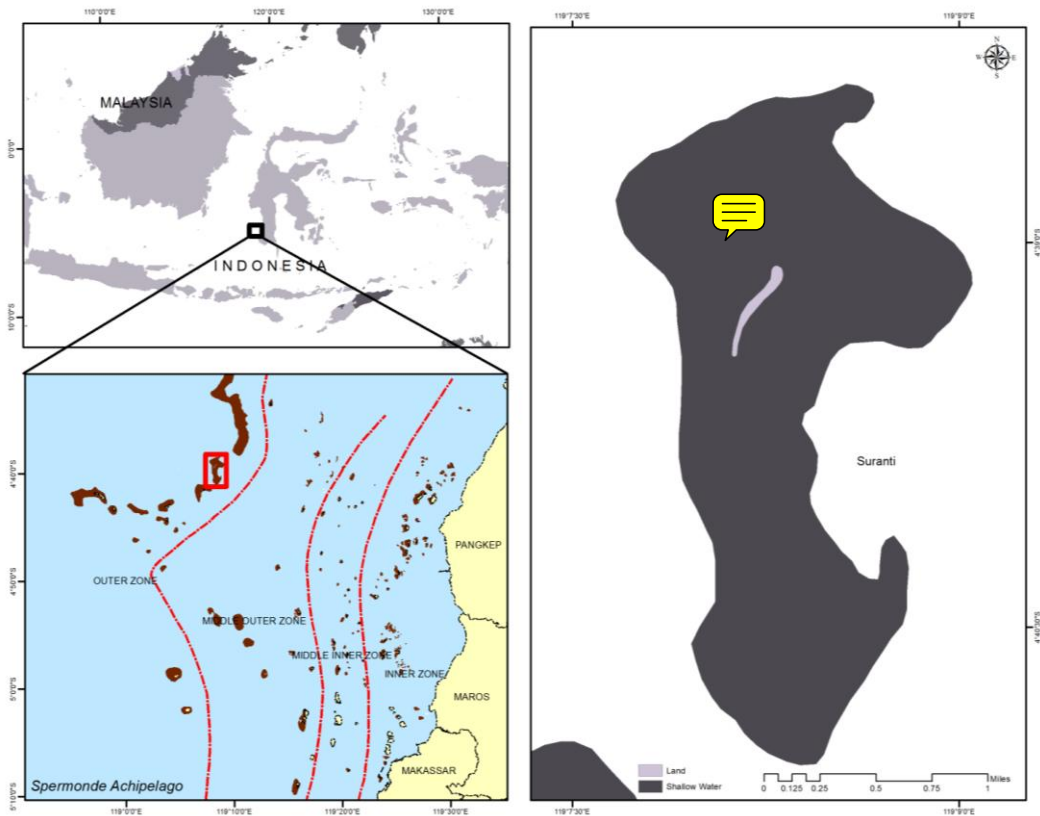


Figure 1. Study area in Suranti Island (gray color is land, black color is shallow water), one of small island in Spermonde Archipelago, Indonesia.

### 2.2 Data

The Landsat MSS data have four spectral bands, with a spatial resolution of 60 m. Landsat TM data have seven spectral bands, with a spatial resolution of 30 m for bands 1-5 and 7. The TM band 6 (thermal infrared) was acquired at 120 m resolution but was resampled to 30 m pixels. The Landsat ETM+ data consisted of eight spectral bands with a spatial resolution of 30 m for bands 1-7. The ETM+ band 6 (thermal infrared) was acquired at 60 m resolution but was resampled to 30 m pixels. The Landsat 8 data have nine spectral bands with a spatial resolution of 30 m for bands 1-7 and 9. The ETM+ and OLI band 8 (panchromatic band) have a spatial resolution of 15 m. The spectral bands were generally between the optical and short-wavelength-infrared regions, except for band 9 of Landsat 8 data, which had a

1 cirrus wavelength between 1.36 and 1.38  $\mu\text{m}$ . This research used several different data. Those data were satellite image  
 2 and ground truth. The following table shows types data (Table 1):

3 Table 1. Types of data

No	Satelite	Sensor	Resolution (m)	Acquisition	Path/Row	Info
1	Landsat_1	MSS	60	1972-10-28	122/063	
2	Landsat_3	MSS	60	1978-11-02	122/063	
3	Landsat_2	MSS	60	1981-10-26	122/063	
4	Landsat_4	TM	30	1990-12-16	114/063	
5	Landsat_5	TM	30	1993-06-23	114/063	
6	Landsat_5	TM	30	1996-04-28	114/063	
7	Landsat_7	ETM	15	1999-09-20	114/063	• fusi
8	Landsat_7	ETM	15	2002-06-24	114/063	• fusi
9	Landsat_7	ETM	15	2005-09-04	114/063	• gaf filled+ fusi
				2005-03-12	114/063	• gaffilled
10	Landsat_7	ETM	15	2008-08-19	114/063	+fusi
				2008-08-03	114/063	• gaffilled
11	Landsat_7	ETM+	15	2011-09-05	114/063	+fusi
				2011-09-21	114/063	• fusi
12	Landsat_8	OLI_TIRS	15	2013-10-04	114/063	

20  
 21 Classification bottom types devided into four class (coral, dead coral, rubble, and sand) for Landsat MSS and TM data  
 22 which have 60 meter and 30 meter spatial resolution. There are eight class (coral cover 0-24.9%, 25-49.9%, 50-  
 23 74.9%, 75-100%, dead coral, rubble, rock, and sand) for Landsat ETM, ETM+, and OLI which have 15 meter spatial  
 24 resolution.

25 Table 2. Class definitions

Classes	Class Definitions
Rubble	Broken coral
Dead Coral	Loss of zooxanthellae
Rock	A large mass of stone
Coral Cover	Live coral in percent (0-24.9%, 25-49.9%, 50-74.9%, 75-100%).

33  
 34 **2.3 Image Processing**

35 Image preprocessing consists of a process to prepare image data for subsequent analysis that attempt to correct  
 36 systematic errors. Landsat Image delivered to the user may consist of some error, which may be caused by atmospheric,  
 37 or sensor condition when capturing data from the earth surface. The Landsat 7 ETM+ scan-line corrector is a  
 38 mechanism designed to correct the under sampling of the primary scan mirror, failed on May 2003. This research used  
 39 Gap method with Frame and Fill Software developed by Richard Irish in affliction with NASA Goddard Space Flight  
 40 Center. The working principle of this software is filling the gap Landsat with the other Landsat image, which has  
 41 different sections Gap.

42  
 43 Multisensor fusion is used to achieve high spatial and spectral resolutions by combining images from two sensors, one  
 44 of which has high spatial resolution and the other one high spectral resolution. Image fusion between multi-spectral  
 45 and panchromatic Landsat 7 ETM, ETM+ and Landsat 8 OLI images was done to achieve higher spatial resolution  
 46 15m.

47  
 48 The geometric corrections used two kinds of references. Landsat image of 2013 was corrected with the corrected image  
 49 (ALOS AVNIR corrected), while the other image for 1972, 1978, 1981, 1990, 1993, 1996, 1999, 2002, 2005, 2008,  
 50 2009, and 2011 used image of the year 2013 as references this process is called registration. Corrected image was  
 51 considered acceptable if RMSE (Root Mean Square Error) is one-half pixel wide (RMSE = 0.5). Overall, RMSE errors  
 52 of less than 0,5 pixel were achieved for each transformation. RMSE error is the distance between the input (sources)  
 53 location of a GCP, and resampled location of the same GCP.

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Classification is a technique in processing a pixel of the image that has spectral reflectance appearance, which identified to separated objects that contained in the image satellite, and grouped then into certain characteristics in accordance with the real condition. Formerly, this was done by a masking technique to eliminate some of the area that was not needed. This research used Unsupervised Classification of ISOCCLASS algorithm applying schema of habitat condition (live coral, dead coral, rubble, rock and sand).

## 2.4 Ground Truth

Ground truth was conducted to determine the actual habitat on the ground. The result of ground truth was compared with the result of classification image. This method used transect quadrant 10 x 10 m<sup>2</sup> at each point of observation (sampling) which had been determined, then the percentage of each habitat of shallow water cover was assessed. The field survey was limited by reflection of the bottom habitat which was detected by sensor satellite. The results of the were sea observation categorized based on Gomez and Yap, 1988 (Table 3).

Table 3. The criteria of coral cover

Percentage of coral cover (%)	Condition
75 - 100	Excellent
50 - 74.9	Good
25 - 49.9	Fair
0 - 24.9	Poor

Source: Gomez and Yap, 1988

## 2.5 Post Classification

A post-classification change matrix function was applied between 1972 to 1978, 1978 to 1981, 1990 to 1993, 1993 to 1996, 1999 to 2002, 2002 to 2005, 2005 to 2008, 2008 to 2011, and 2011 to 2013 classification results.

## 2.6 Accuracy Assessment

Accuracy test was used to make any calculation matrix for each error's (confusion matrix) on any kind of habitat shallow water cover from result the analysis satellite imagery. Image validation was counted based on the confusion matrix such as *Overall Accuracy (OA)*, *Producer's Accuracy (PA)*, and *User's Accuracy (UA)*.

# 3. RESULT AND DISCUSSION

Geometric correction process was done to obtain good accuracy image position of each class in coral reef and the real world. In this study, geometric correction process was performed using 7 point GCP. The result of geometric correction shows that the average RMSE obtained from Landsat images was 0.02. It is in accordance with the standard mapping of the United States.

## 3.1 Areal estimate of coral reef

Our results show that for this shallow water, coral reef change can be seen by comparing the coral reef maps at different time series. The result of coral reefs area changing during the twelve dates is represented in Table 4.

Table 4 Areal estimates of major bottom types in 1972, 1978, 1981, 1990, 1993, and 1996

Classes	Areal of Suranti Island (Ha)					
	1972	1978	1981	1990	1993	1996
Coral	527.66	508.83	505.51	402.14	334.06	325.39
Dead coral	8.49	13.65	14.76	52.95	74.69	81.91
Rubble and sand	59.41	75.28	75.28	144.28	189.46	191.53

The change detection statistics obtained from the classified scenes of 1972 to 1996 reveal a significant decrease in the live coral. Live coral is decrease in 1972 to 1978 by 3.57%, 1978 to 1981 is 0.65%, 1981 to 1990 is 20.45%, 1990 to 1993 is 16.93%, and 1993 to 1996 is 2.59%. Eventhough, dead coral, rubble and sand are increased every year. The classified bottom types area in 1999 to 2002, coral cover 0-24.9% increased by 0.09%, coral cover 25-49.9% decreased by 10.75%, coral cover 50-74.9% increased by 3.13%, and coral cover 75-100% decreased by 14.68%. In 2002 to 2005, coral cover 0-24.9% decreased by 28.49%, coral cover 25-49.9% decreased by 18.06%, coral cover 50-74.9% increased by 7.68%, and coral cover 75-100% decreased by 13.68%. In 2005 to 2008, coral cover 0-24.9% decreased

by 26.63%, coral cover 25-49.9% decreased by 18.71%, coral cover 50-74.9% increased by 5.53%, and coral cover 75-100% decreased by 9.79%. In 2008 to 2011, coral cover 0-24.9% decreased by 5.72%, coral cover 25-49.9% decreased by 2.60%, coral cover 50-74.9% decreased by 15.72%, and coral cover 75-100% decreased by 4.19%. In 2011 to 2013, coral cover 0-24.9% increased by 1.35%, coral cover 25-49.9% increased by 1.98%, coral cover 50-74.9% increased by 0.28%, and coral cover 75-100% decreased by 10.21%.

Table 6 Areal estimates of major bottom types in 1999, 2002, 2008, 2011, and 2013

Classes	Areal of Suranti Island (Ha)					
	1999	2002	2005	2008	2011	2013
Coral cover 0 - 24.9%	130.93	131.05	93.72	68.76	64.83	65.72
Coral cover 25 -49.9%	98.28	87.71	71.87	58.42	56.90	58.05
Coral cover 50-74.9%	35.63	36.78	39.84	42.17	35.54	35.64
Coral cover 75-100%	48.15	41.08	35.46	31.99	30.65	27.52
Dead Coral	44.59	49.56	56.29	64.86	68.57	67.76
Rock	20.50	29.79	65.44	70.51	73.08	73.82
Rubble	50.23	52.32	62.70	71.54	78.68	79.00
Sand	120.78	120.81	134.92	157.66	157.66	158.40

Bottom types of live coral, dead coral, rubble and sand from 1972 to 1996 are change. Live coral was change from in 1972 to 1978 to dead coral by 0.98%, and to rubble and sand by 2.59%. In 1978 to 1981, live coral was change to dead coral by 0.22%, and to rubble and sand by 0.43%. In 1990 to 1993, live coral was change to dead coral by 5.40%, to rubble and sand by 11.53%. In 1993 to 1996, live coral was change to dead coral by 1.49%, and to rubble and sand by 1.10%.

Table 7. Areal changes of bottom types in 1972 to 1978, 1978 to 1981, 1990 to 1993, and 1993 to 1996.

	Areal (Ha)		
	Live coral	Dead coral	Rubble and Sand
<b>1972 to 1978</b>			
Live coral	508.83	5.17	13.66
Dead coral	-	8.49	-
Rubble and sand	-	-	59.40
<b>1978 to 1981</b>			
Live coral	505.51	1.11	2.21
Dead coral	-	13.65	-
Rubble and sand	-	-	73.06
<b>1990 to 1993</b>			
Live coral	334.06	21.73	46.35
Dead coral	-	52.95	0.00
Rubble and sand	-	-	143.11
<b>1993 to 1996</b>			
Live coral	325.39	4.98	3.69
Dead coral	-	74.69	-
Rubble and sand	-	-	187.21

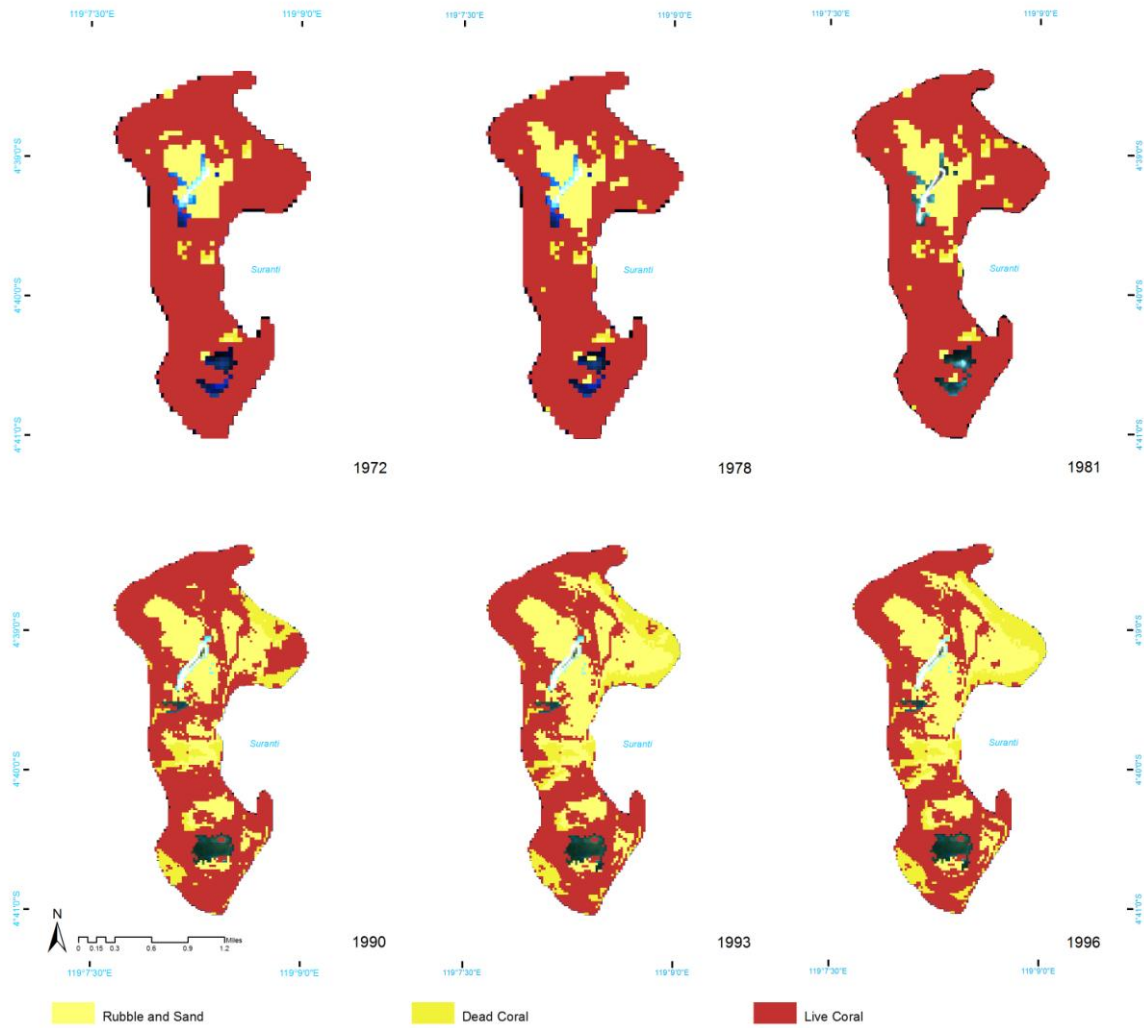


Figure 2. Coral reef classification maps with different time series 1972, 1978, 1981, 1990, 1993, and 1996

Areal changes of bottom types in Suranti Island from 1999 to 2002, 2002 to 2005, 2005 to 2008, 2008 to 2011, and 2011 to 2013 (Coral cover 0-24.9%, 25-49.9%, 50-74.9%, 75-100%, dead coral, rubble, rock, and sand) have spatial resolution of 15 meter. Percent of coral cover from 1999 to 2013 are dynamic. In 1999 to 2002, the coral cover 0-24.9% to dead coral by 1.67%, and to rock by 4.81%. Coral cover 25-49.9% to dead coral by 5.87%, to rubble by 2.13%, and to coral cover 0-24.9% by 2.75%. Coral cover 50-74.9% to coral cover 0-24.9% by 16.59%, and Coral cover 75-100% to coral cover 50-74.9% by 14.68%. The greatest change is coral cover 50-74.9% to coral cover 0-24.9% in 1999 to 2002. Shallow water of Suranti Island in 2002 to 2005, coral cover 0-24.9% to dead coral by 3.18%, to rubble by 3.21%, to rock by 11.33%, and to sand by 10.76%. Coral cover 25-49.9% to dead coral by 9.49%, and to rubble by 6.34%. Coral cover 50-74.9% to rubble by 6.97%, and coral cover 75-100% to coral cover 50-74.9% by 13.69%. The greatest change area is coral cover 75-100% to 50-74.9% in 2002 to 2005. In 2005 to 2008, coral cover 0-24.9% to dead coral by 8.71%, to rubble by 7.64%, to rock by 6.07%, and to sand by 6.24%. Coral cover 25-49.9% to dead coral by 3.51%, to rubble sebesar 14.15%, and to coral cover 0-24.9% by 1.05%. Coral cover 50-74.9% to coral cover 25-49.9% by 2.88%, and to coral cover 75-100% to coral cover 50-74.9% by 9.79%. The greatest of change bottom types are coral cover 0-24.9% to dead coral and rubble, and coral cover 75-100% to coral cover 50-74.9% in 2005 to 2008. Bottom types area in 2008 to 2011 show that coral cover 0-24.9% to dead coral by 4.12%, to rubble by 5.07%, and to rock by 1.22%. Coral cover 25-49.9% to dead coral by 2.97%, to rubble by 4.98%, and to coral cover 0-24.9% by 4.88%. Coral cover 50-74.9% to dead coral by 1.71%, to rubble by 2.14%, and to coral cover 25-49.9% by

14.16%, and coral cover 75-100% to coral cover 50-74.9% by 3.02%, and to coral cover 0-24.9% by 1.15%. Dynamic of coral reef in 2011 to 2013 are coral cover 0-24.9% to rubble by 0.24%, coral cover 25-49.9% to rubble by 0.63%, and to coral cover 0-24.9% by 1.18%. Coral cover 50-74.9% to rubble by 1.33%, to coral cover 25-49.9% by 1.90%, and coral cover 0-24.9% by 1.08%, and coral cover 75-100% to coral cover 50-74.9% by 5.32%, and to coral cover 25-49.9% by 4.91%.

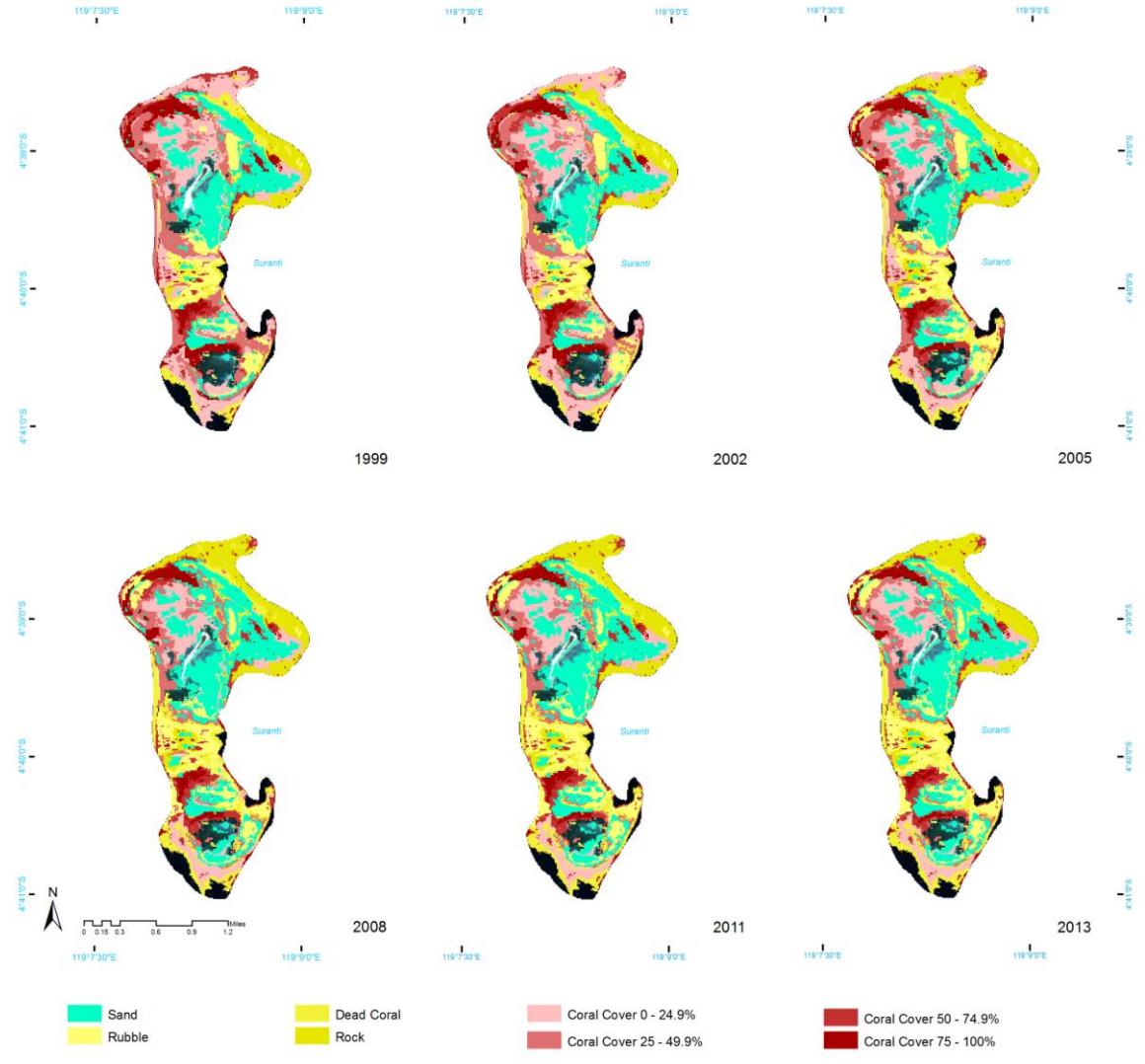


Figure 3. Coral reef classification maps with different time series 1999, 2002, 2005, 2008, 2011, and 2013.

Bottom types of shallow water shows the trend of coral reef change areas during the periods of 1972 to 2013. It can be observed that the changes from 1972 to 1996 show, live coral are decreased approximately to 202.26 ha (38.33%), while dead coral increased to 73.43 ha (89.64%), rubble and sand increased 132.12 ha (68.98%). Live coral (coral cover) area decreased to 126.06 ha (40.28%) from 1999 to 2013, dead coral increased to 23.17 ha (34.19%), rubble increased to 37.62 ha (47.62%). Although the extent of shallow water may change from year to year due to varying human activities and oceanography parameters, destructive fishing is a dominant factors that significantly decreased the area of live coral and increased dead coral, rubble and sand.

The phenomenon of coral bleaching that occurred at the end of 2009 until middle of 2010 was caused by the La Nina phenomena increasing the SST by the westward warmpool movement from the Central Pacific to the Indonesian Seas,

due to the strengthening of trade winds, that significantly decreased the quality of coral reefs in the Spermonde Archipelago (Yusuf and Jompa, 2012).

Table 9. Areal changes of bottom types in Suranti Island from 1999 to 2002, 2002 to 2005, 2005 to 2008, 2008 to 2011, and 2011 to 2013.

		Suranti Island							
		Coral Cover				Dead Coral	Rubble	Rock	Sand
		0-24.9%	25-49.9%	50-74.9%	75-100%				
<b>1999 to 2002</b>									
Coral Cover	0-24.9%	122.44	0	0	0	2.19	0	6.3	0
	25-49.9%	2.7	87.71	0	0	5.77	2.09	0	0
	50-74.9%	5.91	0	29.72	0	0	0	0	0
	75-100%	0	0	7.07	41.08	0	0	0	0
Dead Coral		0	0	0	0	41.61	0	2.99	0
Rubble		0	0	0	0	0	50.23	0	0
Rock		0	0	0	0	0	0	31.63	0
Sand		0	0	0	0	0	0	0	120.78
<b>2002 to 2005</b>									
Coral Cover	0-24.9%	93.72	0	0	0	4.17	4.21	14.85	14.11
	25-49.9%	0	71.87	0	0	9.49	6.34	0	0
	50-74.9%	0	0	34.22	0	0	2.56	0	0
	75-100%	0	0	5.63	35.46	0	0	0	0
Dead Coral		0	0	0	0	42.63	0	6.94	0
Rubble		0	0	0	0	0	52.32	0	0
Rock		0	0	0	0	0	0	40.92	0
Sand		0	0	0	0	0	0	0	120.81
<b>2005 to 2008</b>									
Coral Cover	0-24.9%	66.86	0	0	0	8.17	7.16	5.69	5.85
	25-49.9%	0.76	58.42	0	0	2.52	10.17	0	0
	50-74.9%	0	1.15	38.70	0	0	0	0	0
	75-100%	0	0	3.47	31.99	0	0	0	0
Dead Coral		0	0	0	0	54.17	0	2.12	0
Rubble		0	0	0	0	0	54.21	0	11.23
Rock		0	0	0	0	0	0	62.70	0
Sand		0	0	0	0	0	0	0	140.59
<b>2008 to 2011</b>									
Coral Cover	0-24.9%	61.61	0	0	0	2.83	3.49	0.84	0
	25-49.9%	2.85	50.93	0	0	1.73	2.91	0	0
	50-74.9%	0	5.97	34.57	0	0.72	0.90	0	0
	75-100%	0.37	0	0.97	30.65	0	0	0	0
Dead Coral		0	0	0	0	63.29	0	1.58	0
Rubble		0	0	0	0	0	71.38	0.16	0
Rock		0	0	0	0	0	0	70.51	0
Sand		0	0	0	0	0	0	0	157.66
<b>2011 to 2013</b>									
Coral Cover	0-24.9%	64.67	0	0	0	0	0.16	0	0
	25-49.9%	0.67	55.87	0	0	0	0.36	0	0
	50-74.9%	0.38	0.68	34.01	0	0	0.47	0	0
	75-100%	0	1.51	1.63	27.52	0	0	0	0
Dead Coral		0	0	0	0	67.76	0	0.59	0.22
Rubble		0	0	0	0	0	78.01	0.68	0
Rock		0	0	0	0	0	0	72.56	0.51
Sand		64.67	0	0	0	0	0.16	0	0

Destructive fishing methods such as blast and chemical fishing are still widely found in many areas around small island, Spermonde Archipelago, Indonesia. Blast fishing is considered as one of the most destructive anthropogenic threats to coral reef with serious damaging effects. Despite of nation and local government policy to control these illegal methods, destructive fishing is still widely been practised by local fishermen. There are several reasons why this

practice are difficult to be solved i.e. 1). rapid population growth particularly in small islands, 2) over-fishing in coastal areas due to limited boat capacity and traditional fishing gears of the fishermen, 3) poor knowledge of local fishermen on the ecosystem's carrying capacity, 4) weak government control and monitoring. All of these factors are needed to be seriously managed by the government to conserve coastal of small islands and marine resources. In order to stop the blast and chemical fishing, the government should develop alternative livelihoods that provide other income opportunities for the local fishermen. This a serious problem, many blast fishermen have realized their destructive behaviour, however, they argued that they have no other alternatives.

### 3.2 Accuracy Assessment

The result of coral reef classification maps were checked with accuracy assessment method in order to obtain the level of map accuracy. As mentioned previously, standard map accuracy was more than 70%. **It can be said that these map has been classified by representing good coral reef and ground area, which were then transformed into digital paper maps.** Based on confusion matrix on (Table 6) is found the OA of classification on image 2013 in Suranti is 71.95%. Generally, the difference between the classification results and reality in the field is caused by water clarity and spatial resolution satellite-derived data.

Table 6. Confusion matrix for coral reef classification

Data Classify	Reference Data								Row Total	Commisi	UA
	Live Coral				Seagrass	Sand	Rubber	Dead Coral			
Live Coral	0 - 24.9%	25 - 49.9%	50 - 74.9%	75 - 100%							
0 - 24.9%	22	2	1	0	0	1	2	1	29	7	75.86
25 - 49.9%	3	19	0	1	0	1	1	1	26	7	73.08
50 - 74.9%	2	0	25	2	0	0	1	0	30	5	83.33
75 - 100%	0	2	1	21	0	0	0	2	26	4	80.77
Coloum Total	27	23	27	24	0	2	4	4	111	23	
Ommisi	5	4	2	3	0	2	4	4	222	24	
PA	81.48	82.61	92.59	87.50	0	0	0	0			

### 3.3 Conclusion

The results indicate that decreases in live coral areas mainly formed into dead coral and rubble during the forty one year period from 1972 to 2013. The changes of live coral from 1972 to 1996 are decreased approximately to 202.26 ha (38.33%), while dead coral increased to 73.43 ha (89.64%), rubble and sand increased 132.12 ha (68.98%). Live coral (coral cover) area decreased to 126.06 ha (40.28%) from 1999 to 2013, dead coral increased to 23.17 ha (34.19%), rubble increased to 37.62 ha (47.62%). In 1972 to 1996 (24 years), increasing area of dead coral, rubble and sand is higher than 1999 to 2013 (14 years). Based on observations in the field, the coral reef habitat destruction in Suranti Island has been largely due to human activities. It has been proven by many fragments of rock (rubble) and the activities of explosive fishing such as bombs and chemicals in shallow water Suranti. Another phenomenon is there has been coral bleaching that has been caused by decreases of live coral cover while the dead coral increased.

### Acknowledgments

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# **Multisensor and multitemporal of Landsat images for damage detection on coral reef, small island, Spermonde Archipelago, Indonesia**

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# Multisensor and multitemporal of Landsat images for damage detection on coral reef, small island, Spermonde Archipelago, Indonesia

## ABSTRACT

Coral reefs are important because of their high biodiversity and their key role in the tropical marine biosphere. Furthermore, coral reefs are very valuable as a socioeconomic resource as they make important contributions to the gross domestic product of many countries. Thus, It is very important to monitor dynamic spatial distributions of coral reefs and related habitats dominated by coral rubble, dead coral, and bleached corals. Despite these natural and socioeconomic advantages, many factors are threatening coral reefs. The study site was selected in Spermonde archipelago, South Sulawesi, Indonesia because this area is included in the Coral Triangle, recognized as the epicenter of coral diversity and a priority for conservation. Images of Landsat MSS, Landsat TM, Landsat ETM, Landsat ETM+, and Landsat 8 data were used to examine changes on coral reefs of Suranti Island in the Spermonde Archipelago for forty one year from 1972 to 2013. The small islands is Suranti Island prior to coral reef bottom-type classification. The image processing are gap fill, atmospheric corrections, geometric correction, image composite, water column correction, unsupervised classification, and reclassification. Fill Gap processing was done on Landsat ETM+ SLC-off. Subsequently, a multi-component change detection procedure was applied to define changes. Shallow water bottom types classification divided into live coral, rubble and sand habitats, dead coral with algae, rubble, and sand. Preliminary results showed significant changes during the period 1972–2013 as well as changes in coral reefs, likely explained partly by destructive fishing.

Keywords: Coral reef, Landsat, destructive fishing

## 1. INTRODUCTION

The world's most species rich coastal ecosystems occur within the Coral Triangle (Veron et al. 2009), a region which includes all or part of six Indo-Pacific countries; Indonesia, the Philippines, Malaysia (Sabah), Timor-Leste, Papua New Guinea and the Solomon Islands. Coral reef is one of important ecosystems in marine and coastal area. Coral reef ecosystem is also important for fish community and various marine biotas as feeding, nursery, and spawning ground. Ecologically, coral reef protects other components of marine and coastal ecosystem from waves and storms. Compared to other ecosystems, coral reef can be easily destroyed. The coral reefs in the Coral Triangle have been directly threatened by human activities and natural threats. Coral reef destructions happened in the small islands of the Spermonde Archipelago from human activity and by rising SST (COREMAP II 2010). Suranti Island is one of these small islands in Pangkep District. Suranti Island provides high contribution to the society with most livelihoods based on the shallow water resources. However, the condition of coral reefs will worsen if the illegal fishing and SST in Suranti Island increases every year. Therefore, spatial dynamic mapping and spatial prediction model of coral reefs are needed to create good spatial planning for coastal area. Satellite or airborne remote sensing has increasingly been employed to map coral reef communities worldwide (Green et al. 1996; Andrefouet and Guzman 2005). While a range of these studies have recently used high spatial resolution data, e.g. IKONOS (Anders et al. 2013; Andrefouet et al. 2003; Riegl and Purkis 2005; Elvidge et al. 2004), Quickbird (Anders et al. 2013; Elizabeth et al. 2013; Mishra et al. 2006), Worldview (Elizabeth et al. 2013), and CASI (Elizabeth et al. 2013; Mishra et al. 2006), there are a number of studies that have used medium spatial resolution data, e.g. Landsat (Brian et al. 2014; Damaris et al. 2013; Palandro et al. 2008). Thematic map can be used as a reference for spatial dynamics and habitat distribution of coral reefs. The

objective of this research was to analyze dynamic of coral reefs by using multisensor (Landsat MSS, TM, ETM, ETM+, and OLI TIRS) and multitemporal data for 41 years (1972-2013).

## 2. DATA AND METHOD

### 2.1 Study Area

Suranti is one of the islands in Spermonde Archipelago, Pangkep District, Indonesia. Suranti has a land area of 0.044 km<sup>2</sup>. Geographically, Suranti island is located at longitude 119°08'15.483" East and latitude 04°39'10.135" South.

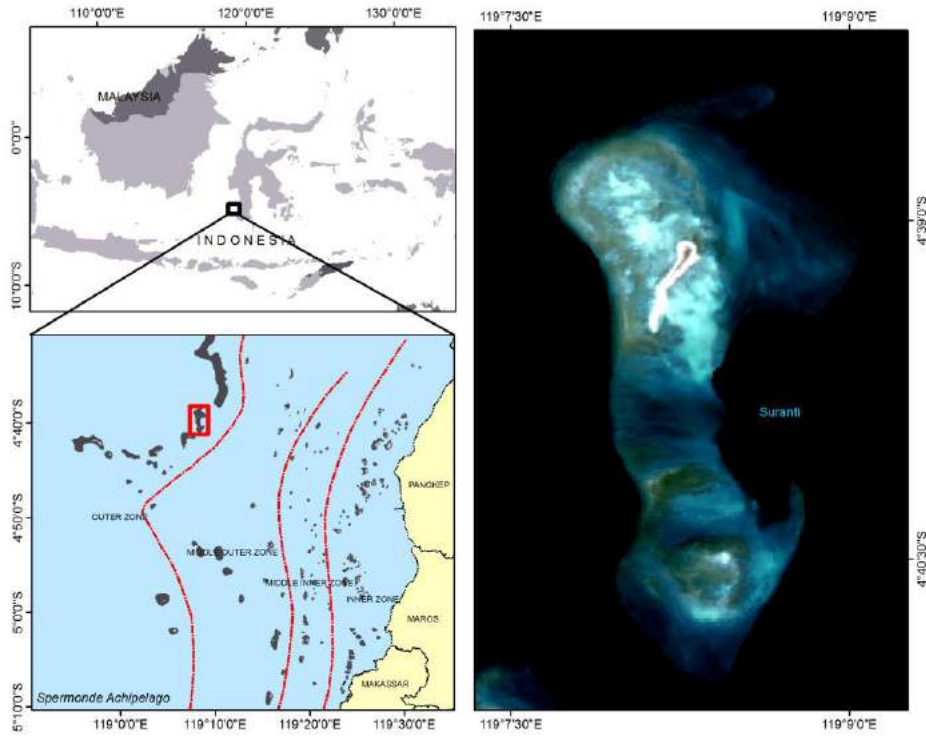


Figure 1. Study area in Suranti Island, one of small island in Spermonde Archipelago, Indonesia.

### 2.2 Data

The Landsat MSS data have four spectral bands, with a spatial resolution of 60 m. Landsat TM data have seven spectral bands, with a spatial resolution of 30 m for bands 1-5 and 7. The Landsat ETM+ data consisted of eight spectral bands with a spatial resolution of 30 m for bands 1-7. The Landsat 8 data have nine spectral bands with a spatial resolution of 30 m for bands 1-7 and 9. The following table shows types data (Table 1).

Table 1. Types of data

No	Satellite	Sensor	Resolution (m)	Acquisition	Path/Row
1	Landsat_1	MSS	60	1972-10-28	122/063
2	Landsat_2	MSS	60	1981-10-26	122/063
3	Landsat_4	TM	30	1990-12-16	114/063
4	Landsat_5	TM	30	1996-04-28	114/063
5	Landsat_7	ETM	30	2002-06-24	114/063
6	Landsat_7	ETM	30	2008-08-19	114/063
				2008-08-03	114/063
7	Landsat_8	OLI_TIRS	30	2013-10-04	114/063

Classification bottom types considered three class (live coral, rubble and sand , and dead coral with algae) for Landsat MSS which have 60 meter and Landsat TM, ETM, ETM+, and OLI with 30 meter spatial resolution considered four classes (live coral, rubble, sand, and dead coral with algae).

### 2.3 Image Processing

The image processing was composed of seven main steps including: (1) gap filling, (2) atmospheric corrections, (3) geometric correction, (4) image composite, (5) water column correction, (6) unsupervised classification, and (7) reclassification.

#### *Filling Gaps*

The Landsat 7 ETM+ scan-line corrector is a mechanism designed to correct the under sampling of the primary scan mirror, and it failed on May 2003. This research used Gap method with Frame and Fill Software developed by Richard Irish at NASA Goddard Space Flight Center. The working principle of this software is filling the gap Landsat with the other Landsat image acquired at a different time, as they will have different gaps.

#### *Atmospheric Corrections*

This research used simple Dark Object Subtraction to method remove the effects of scattering from the image data. It requires only the information contained in the digital image data. It derives the corrected DN (Digital Number) values solely from the digital data with no outside information (Chavez 1998). Haze DN value is directly selected from the DN frequency Histogram of a digital Image.

#### *Geometric Corrections*

The geometric corrections used the 2013 image as references. Landsat image of 1972 and 1981 was corrected using the Landsat 8 image as a reference (Landsat 8 corrected). Corrected image was considered acceptable if RMSE (Root Mean Square Error) is one-half pixel wide (RMSE = 0.5). Overall, RMSE errors of less than 0,5 pixel were achieved for each transformation.

#### *Image Composite (True Color)*

The combination bands of 321 is used in this interpretation of Landsat 1, 2, 4, 5, 7 image and combination band of 432 for Landsat 8. This band combination was used because in interpretation, the appearance of shallow water bottom types could be seen clearly.

#### *Water Column Correction*

Water coloumn correction performed the Lyzenga algorithm for reducing the attenuation effect (Lyzenga 1978):

$$Y_{ij} = \ln(b_i) + \frac{k_i}{k_j} \ln(b_j) \quad 1)$$

$$\frac{k_i}{k_j} = a + \sqrt{a^2 + 1} \quad 2)$$

$$a = \frac{\sigma^2 b_i - \sigma^2 b_j}{2\sigma(b_i \cdot b_j)} \quad 3)$$

Where  $Y_{ij}$  is the result of information extraction channel bottom. Channel bottom are band  $i$  and band  $j$  that have high penetration into water coloum,  $b_i$  is reflectance on band  $i$ ,  $b_j$  is reflectance on band  $j$ ,  $\frac{k_i}{k_j}$  is the ratio of attenuation coefficient between band  $i$  and band  $j$ ,  $\sigma^2 b_i$  is variance of band  $i$ ,  $\sigma^2 b_j$  is variance of band  $j$ ,  $\sigma(b_i \cdot b_j)$  is covariance of band  $ij$ . To obtain the attenuation coefficient between the two bands, the selection of 30 sample points of live coral, dead coral with algae, rubble, and sand to calculate variance value of band  $i$  and band  $j$  and the covariance to band  $ij$ .

## Unsupervised Classification

This research used a Unsupervised Classification ISOCCLASS algorithm with 20 unlabelled class and 100 times of iterations.

### 2.4 Ground Truth and Reclassification

Ground truth was conducted to determine the actual shallow water bottom types on the ground. The result of ground truth was compared with the result of classification image. Number of sampling points on the field survey is 83 points. There are five dominant classes of shallow water bottom types. They are live coral, rubble and sand, dead coral with algae, rubble, and sand (Table 2).

Table 2. Class definitions

Classes	Class Definitions
Live coral	Habitat dominated by a mix of live scleractinian corals
Dead coral with algae	Substrate dominantly made of dead corals covered by algae (turf and fleshy algae)
Rubble	Pieces of broken corals, generally found in reef flats
Sand	Sediment from carbonate origin (dead corals and skeleton for calcifying organisms)
Rubble and sand	Sedimentary mix of rubble and sand

### 2.5 Post Classification

A post-classification change matrix function was applied between 1972 to 1981, 1990 to 1996, 1996 to 2002, 2002 to 2008, and 2008 to 2013 classification results using the ArcGIS 10.2.1 software.

### 2.6 Accuracy Assessment

Accuracy was tested using confusion matrices of the different classification. *Overall Accuracy (OA)*, *Producer's Accuracy (PA)*, and *User's Accuracy (UA)* were computed from the confusion matrices (Foody et al. 1992).

## 3. RESULT AND DISCUSSION

In this study, geometric correction process was performed using 7 point GCP. The result of geometric correction shows that the average RMSE obtained from Landsat images was 0.02.

Based on calculation of digital values that have been extracted from band i and j at the research location. It was obtained coefficient value  $k_i/k_j$  (Table 3).

Table 3. Band combination and attenuation coefficient

No	Satellite/Sensor and acquisition	Band Combination	$k_i/k_j$
1	Landsat_4 TM, 1990	1 and 2	0.847919
2	Landsat_5 TM, 1996	1 and 2	0.935253
3	Landsat_7 ETM, 2002	1 and 2	0.893087
4	Landsat_7 ETM, 2008	1 and 2	0.882156
5	Landsat_8 OLI_TIRS, 2013	2 and 3	0.720855

### 3.1 Areal estimate of changes

Our results show that for this shallow water, coral reef change can be seen by comparing the coral reef maps at different time series. The result of coral reefs area changing during the seven acquisition years are represented in Table 4.

Table 4. Areal estimates of major bottom types in 1972, 1981, 1990, 1996, 2002, 2008, and 2013

Classes	Areal of Suranti Island (Ha)						
	1972	1981	1990	1996	2002	2008	2013
Live Coral	527.66	505.51	325.65	258.61	210.97	143.74	119.46
Rubble	0	0	184.46	248.03	289.15	329.45	336.91
Sand	0	0	60.10	56.10	55.87	55.33	68.39
Dead coral with algae	8.49	14.76	50.74	58.42	65.47	93.23	95.78
Rubble and Sand	59.41	78.60	0	0	0	0	0

Statistically the change detection obtained from the classified scenes of 1972 to 2013 reveal a significant decrease in the live coral, while dead coral with algae and rubble are increasing every year.

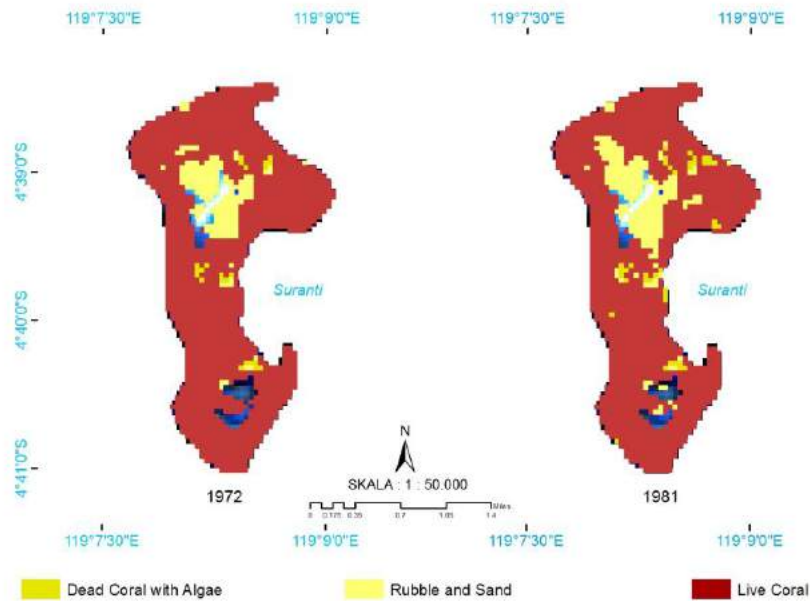


Figure 2. Coral reef classification maps of 1972 and 1981

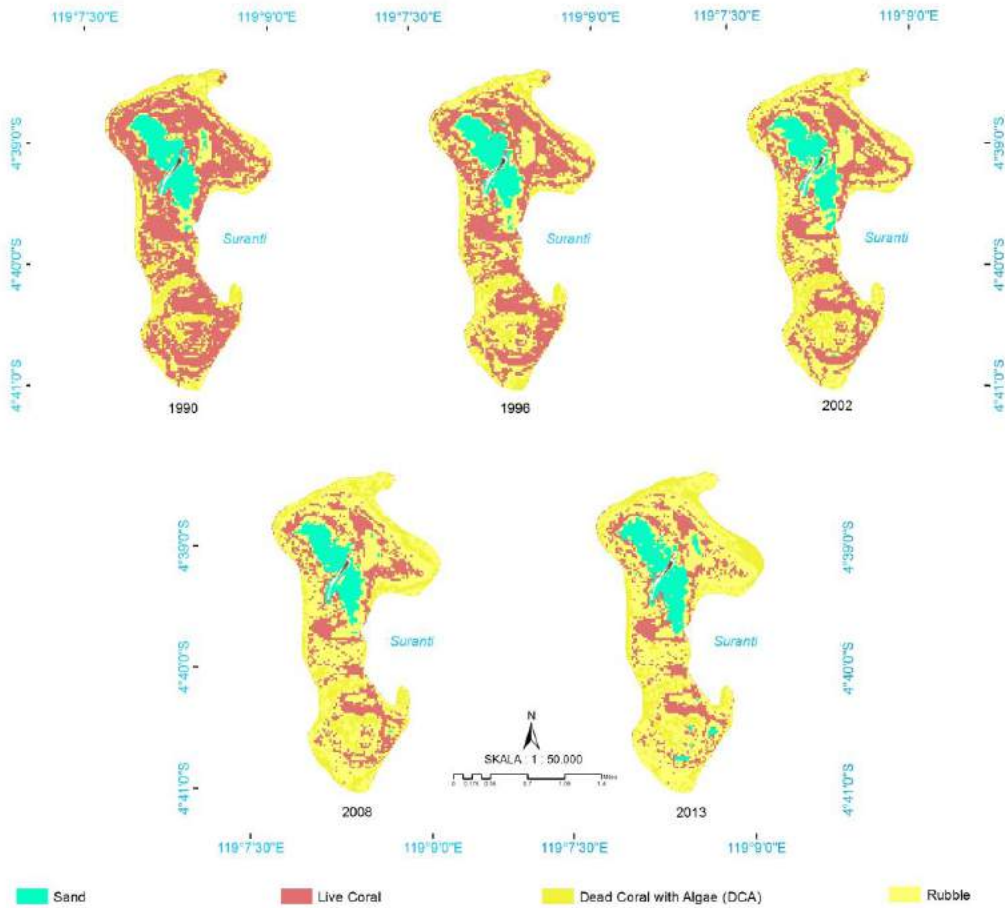


Figure 3. Coral reef classification maps of 1990, 1996, 2002, 2008, and 2013

The change matrix (Table 5) shows that 6.27 ha from 1972 to 1981 live coral had changed to dead coral with algae, and 15.87 ha had changed to rubble and sand. The largest category of live coral change was loss to rubble (63.08 ha) from 1990 to 1996. Similar patterns of change were observed from 1996 to 2002, from 2002 to 2008, and from 2008 to 2013. The value are presented in Table 5.

Table 5. Areal changes of bottom types in 1972 to 1981, 1990 to 1996, 1996 to 2002, 2002 to 2008, and 2008 to 2013.

Bottom types	Areal (Ha)				
	Live coral	Rubble	Dead coral with algae	Sand	Rubble and sand
<b>1972 to 1981</b>					
Live coral	505.51	0.00	6.27	0.00	15.87
Dead coral with algae	0.00	0.00	8.49	0.00	0.00
Rubble and Sand	0.00	0.00	0.00	0.00	59.41
<b>1990 to 1996</b>					
Live coral	258.61	63.08	3.96	0.00	0.00
Rubble	0.00	155.45	25.22	3.78	0.00
Dead coral with algae	0.00	21.50	29.24	0.00	0.00

1	Sand	0.00	8.00	0.00	52.04	0.00
2	<b>1996 to 2002</b>					
3	Live Coral	210.97	45.94	1.70	0.00	0.00
4	Rubble	0.00	212.01	28.14	7.88	0.00
5	Dead coral with algae	0.00	22.80	35.63	0.00	0.00
6						
7	Sand	0.00	8.29	0.00	47.80	0.00
8	<b>2002 to 2008</b>					
9						
10	Live Coral	143.74	56.11	11.13	0.00	0.00
11	Rubble	0.00	240.59	39.79	8.65	0.00
12	Dead coral with algae	0.00	23.16	42.31	0.00	0.00
13						
14	Sand	0.00	9.60	0.00	46.26	0.00
15	<b>2008 to 2013</b>					
16	Live coral	119.46	23.91	0.36	0.00	0.00
17	Rubble	0.00	272.58	39.41	17.47	0.00
18	Dead coral with algae	0.00	37.22	56.01	0.00	0.00
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20	Sand	0.00	3.20	0.00	50.93	0.00
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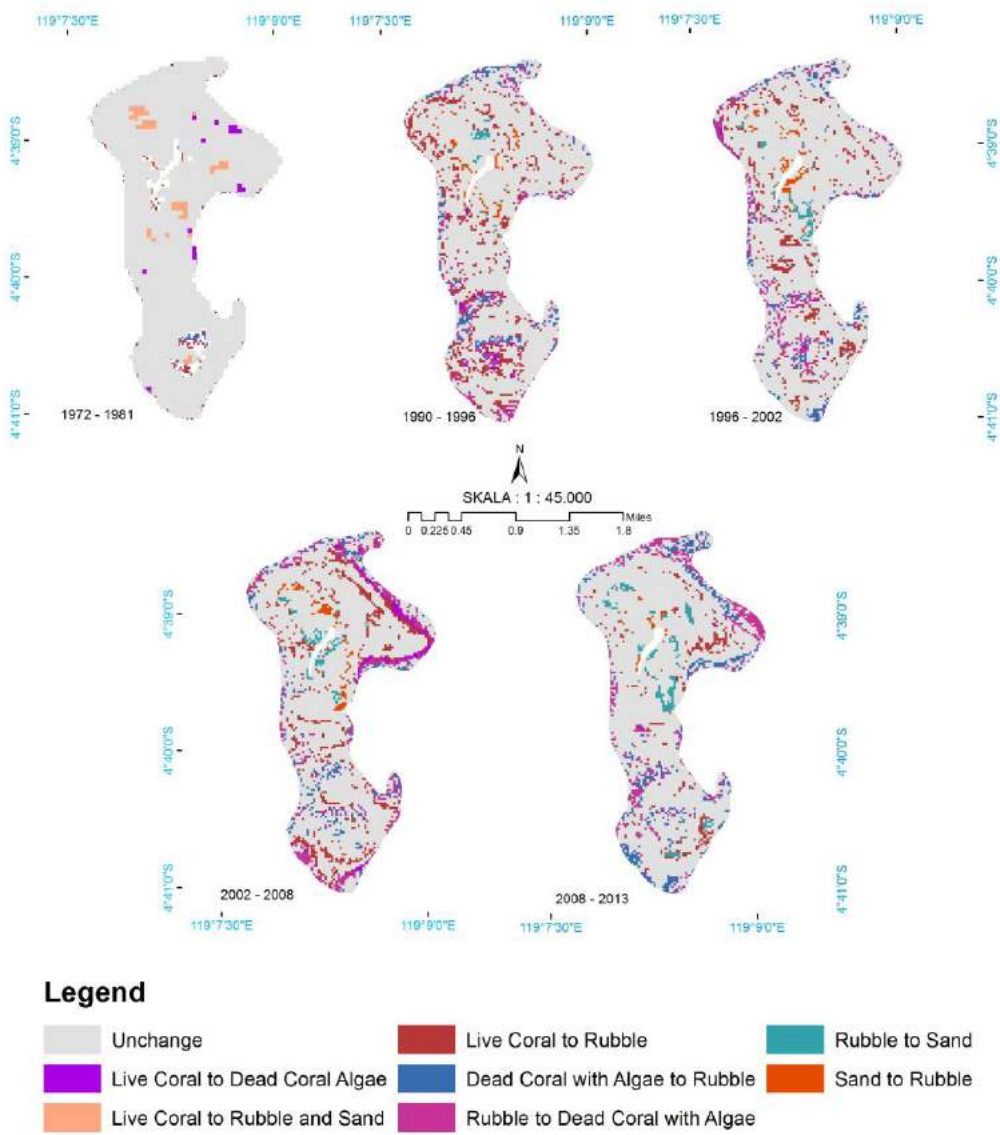


Figure 4. Post classification of coral reef of Suranti Island: From 1972 to 1981, 1990 to 1996, 1996 to 2002, 2002 to 2008, and 2008 to 2013

Bottom types of shallow water shows the trend of coral reef change areas during the periods of 1972 to 2013. It can be observed that the changes from 1972 to 2013 show that live coral decreased approximately to 408.19 ha (77.36%), while dead coral with algae increased to 87.29 ha (91.13%), rubble increased 277.51 ha (82.37%). Image classification in 1972 - 2008 is validated by interview method with fisherman that have been settled since 20-40 years ago around the Suranti Island.

### 3.2 Accuracy Assessment

The results of coral reef classification maps were checked with accuracy assessment method in order to obtain the level of map accuracy. As previously mentioned, standard map accuracy was more than 70%. Based on confusion matrix on Table 6 is found the OA of classification on image 2013 in Suranti is 76.14%. Generally, the difference between the

classification results and reality in the field is caused by water clarity and spatial resolution of satellite-derived data. This accuracy assessment is valid only for the present time (2013).

Table 6. Confusion matrix for coral reef classification

Data Classify	Reference Data				Row Total	Commisi	UA
	Live Coral	DCA	Rubble	Sand			
Live Coral	25	3	2	1	31	6	96.15
DCA	0	24	2	0	26	2	80.00
Rubble	0	2	13	0	15	2	72.22
Sand	1	1	1	8	11	3	88.89
Coloum Total	26	30	18	9	83	13	
Ommisi	1	6	5	1	0	13	
PA	80.65	92.31	86.67	72.73			

### 3.4 Discussion

Although the extent of shallow water may change from year to year due to varying human activities and oceanographic parameters, destructive fishing is a dominant factor that significantly decreased the area of live coral and increased dead coral, rubble and sand. The phenomenon of coral bleaching that occurred at the end of 2009 until middle of 2010 was caused by the La Nina phenomena and increase the SST by the westward movement of the warmpool from the Central Pacific to the Indonesian Seas (Yusuf and Jompa 2012).

Destructive fishing methods such as blast and chemical fishing are still widely found in many areas around small island, Spermonde Archipelago, Indonesia. Blast fishing is considered as one of the most destructive anthropogenic threats to coral reef with serious damaging effects. Despite of nation and local government policy to control these illegal methods, destructive fishing is still widely been practised by local fishermen. There are several reasons why this practice are difficult to be solved i.e, 1) rapid population growth particularly in small islands, 2) over-fishing in coastal areas due to limited boat capacity and traditional fishing gears of the fishermen, 3) poor knowledge of local fishermen on the ecosystem's carrying capacity, 4) weak government control and monitoring. All these factors are needed to be seriously managed by the government to conserve coastal of small islands and marine resources. In order to stop the blast and chemical fishing, the government should develop alternative livelihoods that provide other income opportunities for the local fishermen. This a serious problem and while many blast fishermen have realized their destructive behaviour, they argued that they have no other alternatives.

### 3.3 Conclusion

The results indicated that decreases in live coral areas turned into dead coral with algae and rubble during the forty one year period from 1972 to 2013. Live coral from 1972 to 2013 decreased approximately by 408.19 ha (77.36%), while dead coral with algae increased by 87.29 ha (91.13%) and rubble increased by 277.51 ha (82.37%). Field observations on shallow water of Suranti revealed that coral reef habitat destruction was largely caused by human activities. These were indicated by a lot of loose fragments of rubble which were typical appearances resulted from destructive activities such as explosive fishing (bombs). Another possible causes of decreased live corals in the study sites was probably due to coral bleaching phenomenon which badly affected many Indonesian coral reefs in 2010.

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