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**Article**

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

**Nurjannah Nurdin[1,3]*, Teruhisa Komatsu[2], Agus[3], M. Akbar AS[3], Abdul Rasyid Djalil[1], and Khairul Amri[1]**
[1]*Marine Science Department, Hasanuddin University, Makassar 95245, Indonesia*
[2]*Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa 277-8564, Japan*
[3]*Center for Regional Development & Spatial Information, Hasanuddin University, Makassar 95245, 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 toother 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 contibutes 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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*Corresponding author. E-mail: nurj_din@yahoo.com

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

Surantiis one of the islands in the Spermonde Archipelago, Pangkep District, Indonesia. Suranti has a land area of 0.044 km$^2$. 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).

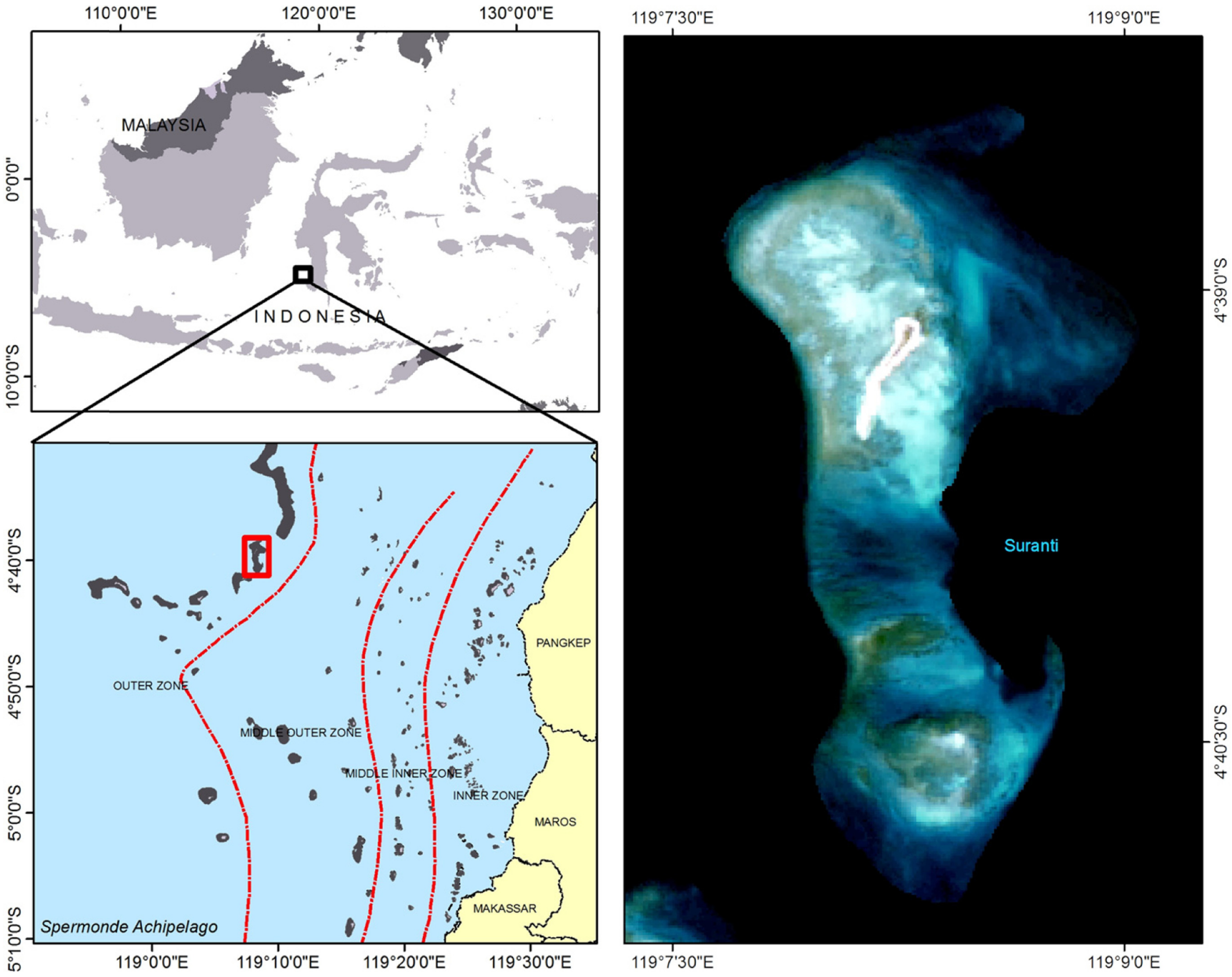

**Fig. 1.** Study area in Suranti Island, one of the small islands in Spermonde Archipelago, Indonesia

**Table 1.** Types of data

| No | Satelite | 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<br>2008-08-03 | 114/063<br>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):

$$Yij = \ln(bi) + \frac{ki}{kj}\ln(bj) \tag{1}$$

$$\frac{Ki}{Kj} = a + \sqrt{(a^2 + 1)} \tag{2}$$

$$a = \frac{\sigma^2 bi - b^2 bj}{2\sigma(bi.bj)} \tag{3}$$

where Yij is the result of information extraction channel bottom. Channel bottom are band i and band j that have high penetration into water coloum, *bi* is reflectance on band i, *bj* is reflectance on band j, $\frac{Ki}{Kj}$ is the ratio of attenuation coefficient between band i and band j, $\sigma^2 bi$ is variance of band i, $\sigma^2 bj$ is variance of band j, $\sigma(bi.\ bj)$ 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 | Sedmient 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 | Satelite/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 |

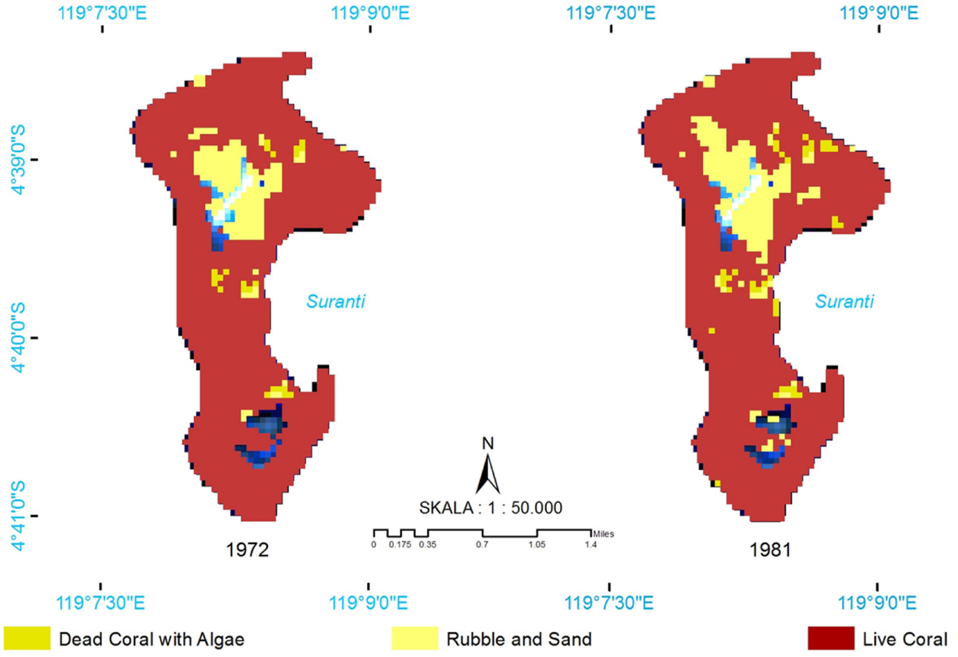

**Fig. 2.** Coral reef classification maps of 1972 and 1981

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 ki/kj 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.

Statisfically, 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.

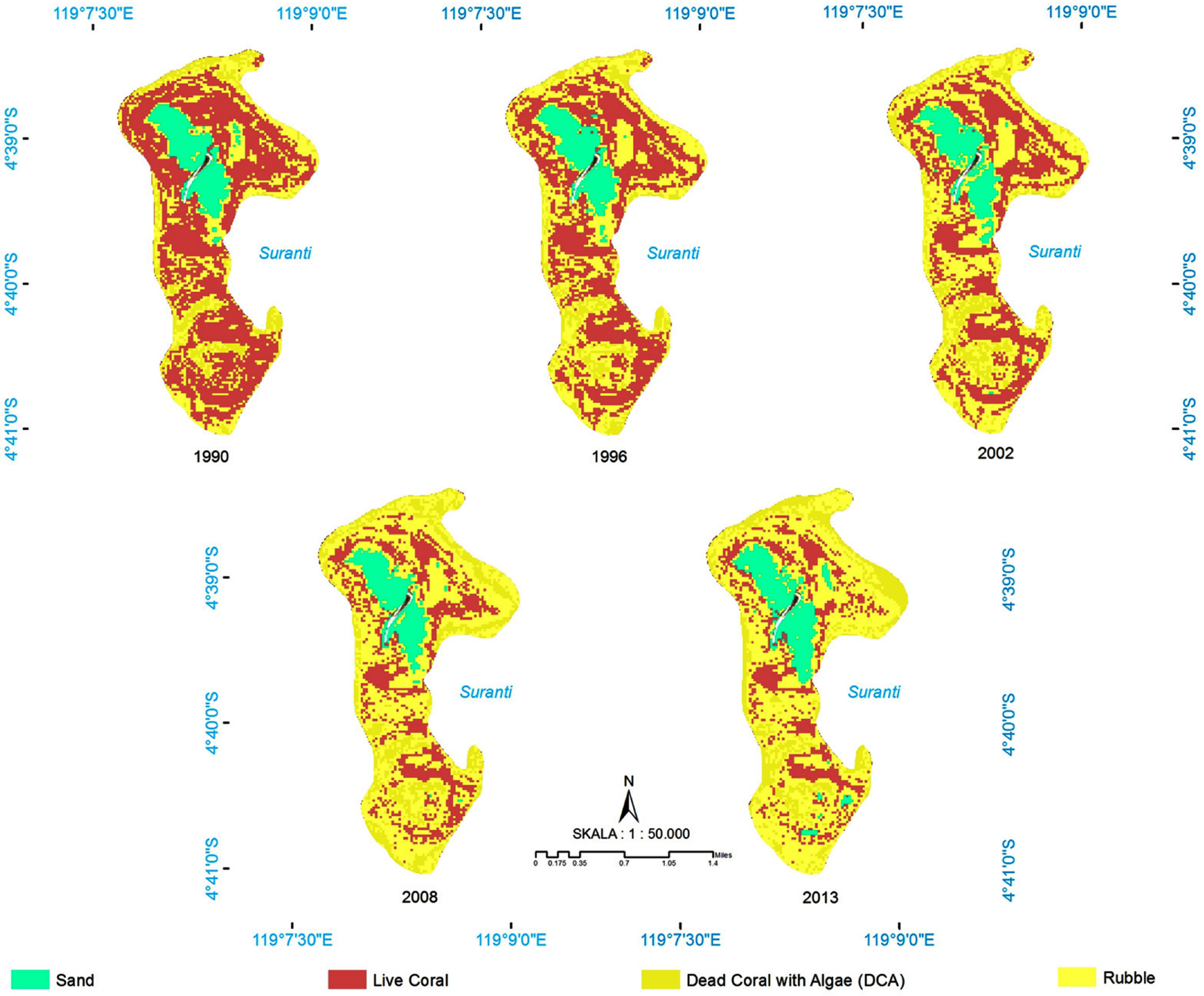

**Fig. 3.** Coral reef classification maps of 1990, 1996, 2002, 2008, and 2013

**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. Similiar 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

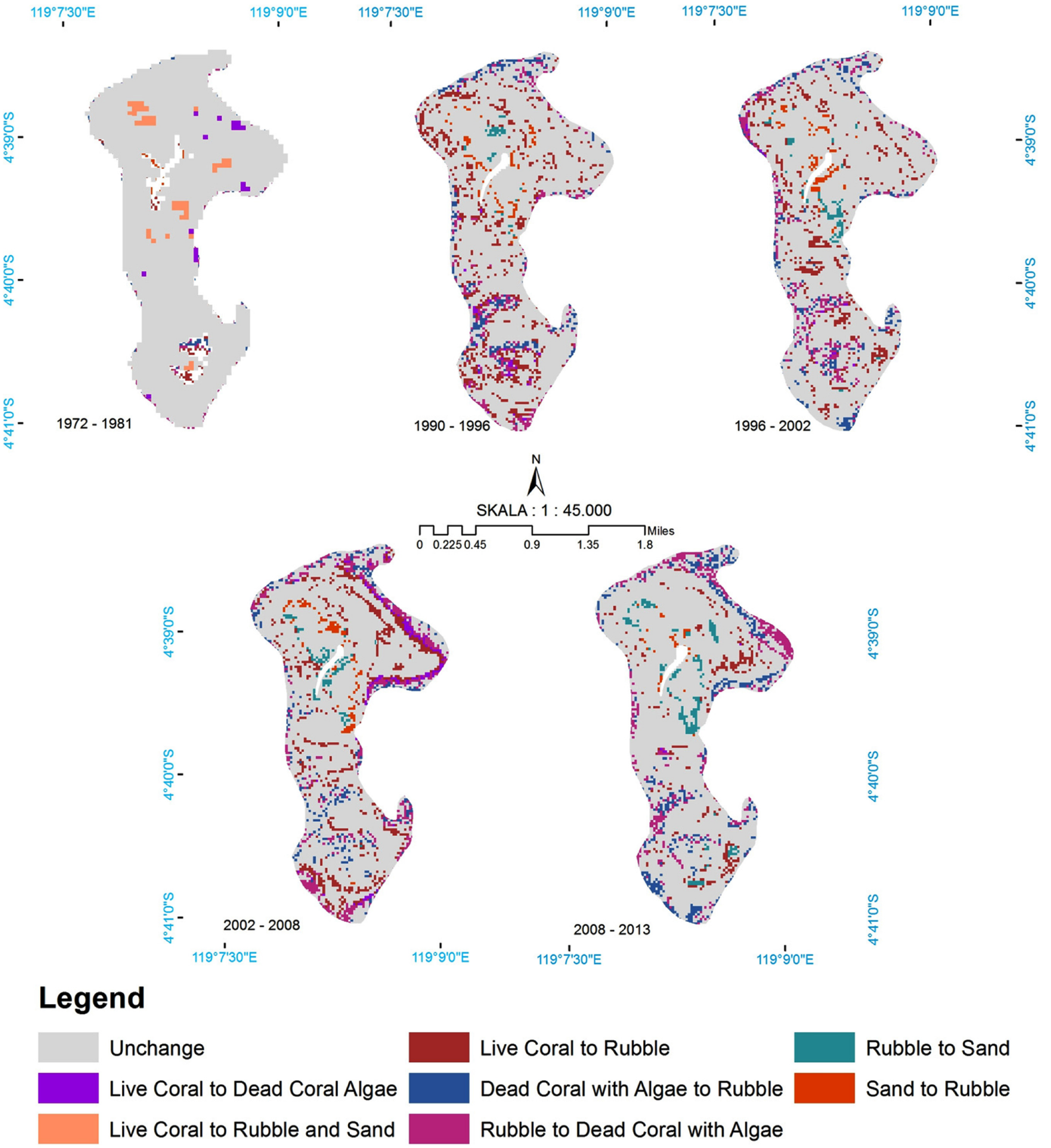

**Fig. 4.** Post classification of coral reef of Suranti Island: From 1972 to 1981, 1990 to 1996, 1996 to 2002, 2002 to 2008, and 2008 to 2013

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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