MAPPING OF INDONESIAN CORAL REEF COVERAGE BASED ON ALOS AVNIR-2 DATA

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1. INTRODUCTION

Coral reefs are shallow marine ecosystem which is very productive[1]. This ecosystem is estimated occupying only about 1% of the world's sea floor. However, it became a shelter to about 25% of species of marine life including fish and other biota[2]. Thus the existence of this ecosystem is very influential for the survival of fisheries production of a certain region which in turn will benefit the fishermen living in the region. In addition to be functioning as a place to live a very rich marine biota in terms of biodiversity, the ecosystem also has several other functions which are very valuable[1]. Those are such as to protect beach from abrasion by waves, to be expected related to the carbon-sinking process, and especially to attract the tourist with their beauty.

In contrast to the ecological and physical functions in such a way, coral reefs are vulnerable to disruption. It is estimated that coral reefs from year to year is declining in term of its extent, its biodiversity as well as its level of health[3]. As a consequence of the declining process, in turn fisheries production will be decreasing, which means that the decline in the welfare of fishermen, and will be disturbed biota that live in it and might be other ecosystems connected with it. One effort to overcome this kind of problem is to serve targeted by the establishment of marine protected area (MPA)[4, 5].

To establish a good MPA to protect coral reef degradation, at least there are required good and reliable information on the distribution and reef health condition of coral reefs[6]. This information will be at best in the form of coral reefs distribution map containing the reef extent and the percentage of live coral cover as an indicator of reef health condition. Indonesia as an archipelagic country has been reported endowing the widest coverage of coral reefs in the world (about 18% of coral reefs worldwide)[7] and since 1998 the Indonesian government has attempted to map the coral reef extent and monitor the health condition[8]. It was marked with the launch of a program called COREMAP addressed to save Indonesian coral reefs from degradation. COREMAP has finished mapping the distribution of Indonesian coral reefs based on Landsat TM data in 3 years period starting from the year of 2000. The map is presented in Fig. 1 below.

The map has been already 10 years of age and needs to be renewed. Furthermore the map was derived based on Landsat TM data with the spatial resolution of 30m, so an attempt to revise it using satellite data having better spatial resolution such as AVNIR-2 of ALOS is needed. It has been done for some certain reef location as case study and reported here. The map derived using ALOS is then compared with the old one. This report is a complement of the previous report (2009) which was more focused in preliminary study on the assessment of AVNIR-2 data for sea grass and coral diversity recognition.

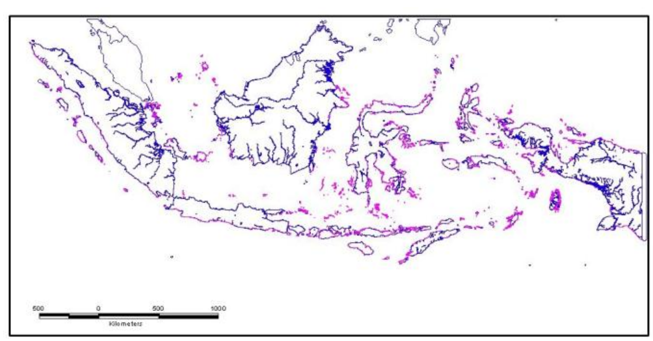

Fig. 1 Map of Indonesian coral reefs coverage derived based on Landsat TM data. Coral reefs are in pink colour

2. METHODOLOGY

2.1. Study sites

In the year of 2010, the study covered some sites representing Indonesian waters in western part, eastern part and northernmost part. There were focused and undertaken in Bunaken, North Sulawesi (northernmost area), Hinako, West Nias, North Sumatera (westernmost area), East Bintan, Bintan Regency, Riau Islands (western area), Sikka Regency, Flores Island (south-eastern area), and Wakatobi, Southeast Sulawesi (eastern area). Those sites were selected due to each reef site represented different environmental condition with regard to geological background, bottom topography, geomorphological process, wind-prevailing direction generating wave, water circulation, and major land-based pollution disturbance. These variables were predicted relating to the distribution of coral reefs [8 Veron]. In addition, on top of that, it was because of the data availability. Beside the availability of AVNIR-2 data covered those reef sites, a yearly collected field dataset of those areas were completely available in COREMAP. Field data played an important role in data processing which used for supervised classification and accuracy assessment of classification result. Fig. 2 below shows the distribution of the study sites.

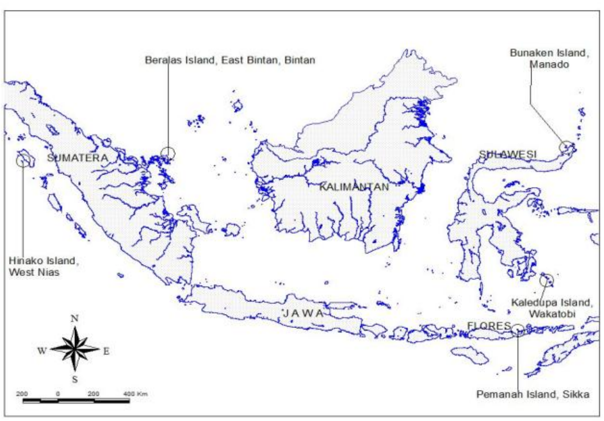

Fig. 2 Distribution of the study sites in Indonesian waters

2.2. Satellite data and coral reefs map

A digital dataset of ALOS AVNIR-2 acquired in 2007 covering those study sites were used as a primary digital data. The dataset has been already geo-corrected to universal transverse Mercator (UTM) coordinate system with the geodetic datum of WGS'84. It has been described in the previous report (2009) that AVNIR-2 data had better capability than Landsat TM data for coral reefs habitat mapping in Lembeh Strait reef system. The result was then implemented in this study where AVNIR-2 data were used to map coral distribution of the selected reef sites spreading out from the westernmost to eastern part of Indonesian waters.

Another data used in the analysis process is coral reef habitat map of Indonesian waters produced by and deposited in COREMAP. These maps were derived based on digital image analysed of Landsat 5 data which were mostly acquired in 1995 until 1997. Image processing to derive these maps was done during the year of 2000 and 2002. The map represents three major benthic habitat categories i.e. coral assemblage, sea grass and algae assemblage, and sand. The procedure used to analyse the Landsat data to produce these maps was adopted from the method developed by Lyzenga[9, 10].

2.3. Field dataset

Field data used in the image processing stage was 3 major benthic cover categories as mentioned before i.e. coral assemblage, sea grass assemblage, and sand. Coral assemblage is consisted of live coral cover and recently dead coral cover. Sea grass assemblage is consisted of sea grass meadow, algae assemblage, and dead coral covered by algae. Those data already deposited in COREMAP database and could be retrieved whenever needed.

COREMAP, since its establishment in 1998, continuously collected coral reef data from the field in a yearly basis for monitoring of the reef health condition. The data is in two types i.e. a 70m permanent line intercept transect (LIT) and a point-based observation of reef resources inventory (RRI). LIT applied in COREMAP was developed and modified based on LIT method used by Loya (1972)[11] and English et.al. (1997)[12]. On the other hand, RRI adopted in COREMAP was referred to the method described by Long et.al. (2004)[13]. Field data used in this report was simplified from the LIT and RRI data collected by and deposited in COREMAP. In this regard, we selected and used field data of 2007 only since AVNIR-2 data was recorded in 2007. Exception was for Bunaken where the field data was collected independently using the same method in 2009. Bunaken does not include in COREMAP site where the reef condition is monitored regularly every year.

2.4. Image analysis

Prior to be used in further analysis, the AVNIR-2 data were corrected from atmospheric scattering. Digital number (DN) of each band was subtracted by the minimum DN of each corresponding band. The minimum DN of each band was theoretically predicted as the result of atmospheric scattering[14]. Geometric correction was not needed in the image pre-processing stage since the data was already in the UTM format. Therefore, after radiometric correction process was done the data was then directly used in classification process.

Since the classification result will be used for comparison with the available coral reef map, so we adopted the classification procedure had been used to process the Landsat 5 data to derive coral reefs coverage map. The method was depth invariant index[9, 10]. Based on this method we only employed blue and green band as an input in the image analysis process. By this method, principally, we calculate DN of the reef bottom (DNB) using blue and green band[15]. In calculating DNB, we need information about DN and attenuation coefficient. The attenuation coefficient was represented by the gradient of the linear regression equation between DN of blue and green band for the same object. The DNs used to build the regression equation were sampled on the same underwater object starting from the shallowest area close to the coastline and ending on the deepest area. In this regard we used field data for guiding the sampling process. The notion behind this procedure is that DN of a certain underwater object will decrease along with the depth gradient, and the decrease is caused by the water attenuation.

Once we had DNB calculated using the depth invariant procedure, then we classified the DNB image using unsupervised classification procedure or iso-data classification. Field data were used to assign the result to three classes i.e. coral, sea grass and sand. In addition to that, we also assigned the benthic classes into 5 and 7 categories. For the 5 categories, we classified coral becoming live and dead coral, and sea grass assemblage becoming sea grass and algae. While for the 7 categories we added live coral with low and high coverage, and sea grass with low and high coverage. We used coverage threshold of 50% to classify the live coral cover and sea grass coverage. The coverage was classified as low if it was less than 50% and classified as high if it was higher than or equal to 50%. So, we had three different levels of benthic class i.e. 3, 5 and 7 categories. We only used half of the field data in assigning process of the benthic classes, and we used the rest for accuracy assessment.

2.5. Post-classification analysis

This stage consisted of two activities namely accuracy assessment and comparative analysis. We assessed the accuracy of classification result of each site using the half of the available field data based on omission and commission matrix[16]. The classification results were crosschecked with the references. In this regard field data were used as references.

Comparative analysis was addressed to compare the map derived using AVNIR-2 data and the old one derived using Landsat 5 data. Since the coordinate of the two used different geodetic datum and were not co-registered, the comparison was made on the island basis. We selected a certain island of each site and the comparison was made only on that part. We compared the extent of three classes of benthic coverage.

3. RESULTS

3.1. Map of coral reef coverage and its accuracy

Maps of coral reef coverage of each site are presented below. The new and old maps are presented in one figure to see the change of both. The left map is the new one derived using AVNIR-2 data and the right map is the old one derived using Landsat 5 data. The coordinate grid of both maps is different due to the difference of geodetic datum used in the two maps. In general, it can be seen that most of the coral reef area drawn in the old map has changed to other benthic coverage.

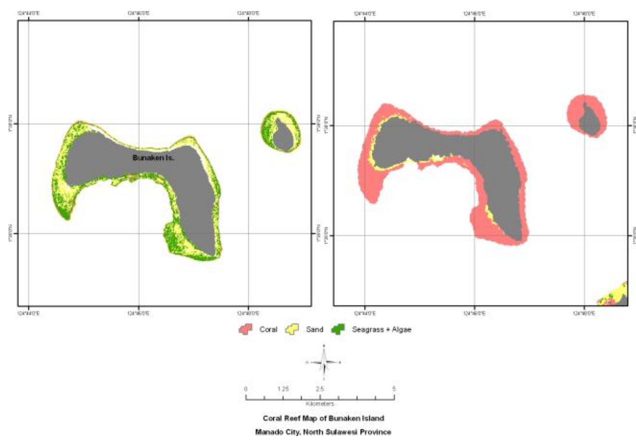

Fig. 3 Coral reef benthic map (3 categories) of Bunaken Island, Manado City, North Sulawesi

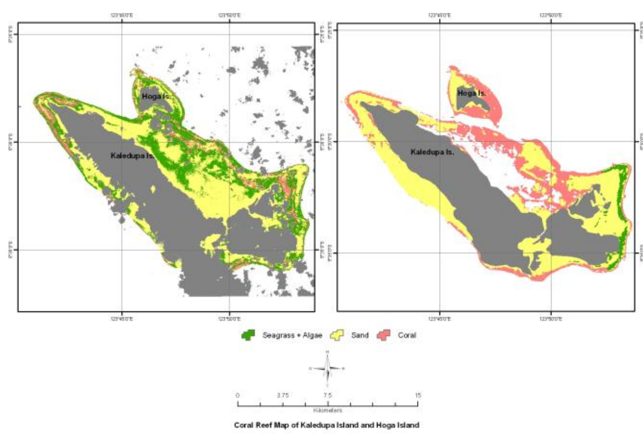

Fig. 4 Coral reef benthic map (3 categories) of Kaledupa Island, Wakatobi Regency

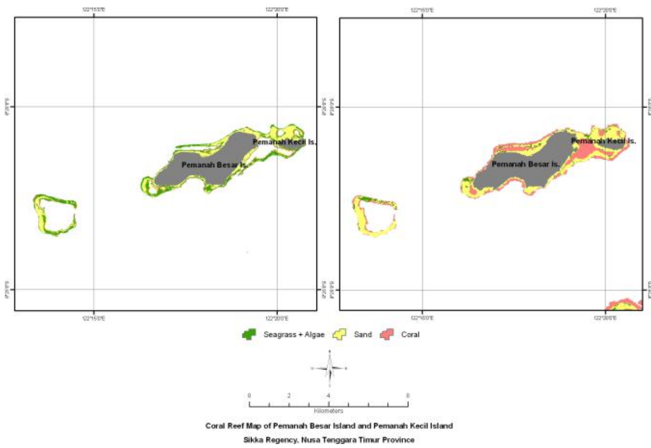

Fig. 5 Coral reef benthic map (3 categories) of Pemanah Besar Island, Sikka Regency

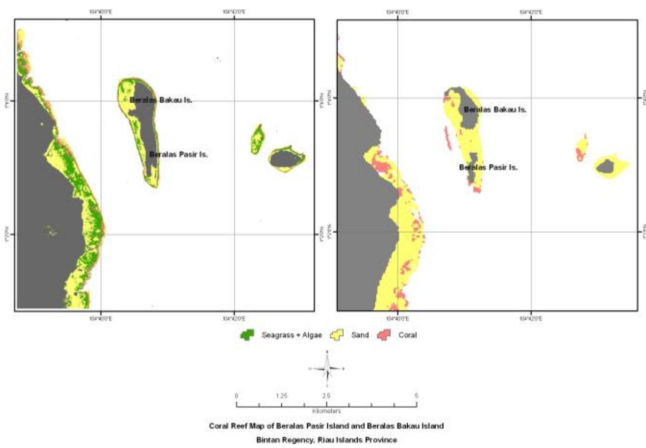

Fig. 6 Coral reef benthic map (3 categories) of Beralas Bakau Island, Bintan Regency

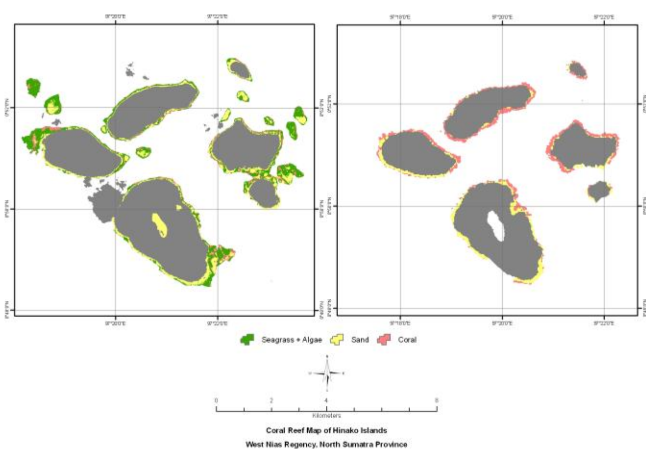

Fig. 7 Coral reef benthic map (3 categories) of Hinako Islands, West Nias Regency

The accuracy assessment results for each site are summarized in Table 1. It is clear that the accuracy decreases following the number of benthic categories. The accuracy also varies amongst reef sites.

Table 1. List of percentage accuracy of each reef site at different level of the benthic class number

	3 classes	5 classes	7 classes
Bunaken	84%	76%	64%
Wakatobi	81%	70%	60%
Sikka	82%	74%	61%
Bintan	84%	75%	62%
Hinako	79%	62%	56%

3.2. Comparative analysis

This analysis was addressed to see the difference of the benthic coverage extent calculated using the old map and the new map. In this regard we only calculated the extent in a certain island. On the reef site of Bunaken Islands, we only calculated the benthic extent of Bunaken Island. In line with that, we computed the benthic extent of Kaledupa Island, Pemanah Besar Island, Beralas Island, and Hinako Island representing the reef of Wakatobi, Sikka, Bintan, and Hinako Islands, respectively. The results are presented in Table 2 below.

Table 2. List of the benthic coverage extent (in hectare) derived using the new and old maps of some certain islands representing the reef site of the study area

Name of island	Coral		Sea grass + algae		Sand		Total	
	New	Old	New	Old	New	Old	New	Old
Bunaken	110	908	242	2	658	380	1010	1290
Kaledupa	386	1620	1468	101	1998	2104	3852	3825
Pemanah	52	601	556	7	596	712	1204	1320
Beralas	46	68	109	0	452	612	607	680
Hinako	6	98	66	0	70	46	142	144

Based on Table 2, in general the extent of coral assemblage is decrease, while the two other benthic classes are increase. It can also be seen that there are dissimilarity between the total extents of benthic coverage calculated using the new and old map.

4. DISCUSSION

4.1. Capability of AVNIR-2 data for coral reef mapping

Accuracy value of image classification results, as presented in Table 1, indicates the capability of the image in differentiating objects to be classified. The value determines how effective pixels were grouped into the correct feature classes in the area under investigation. In this case, the value decreases along with the increasing number of feature classes been classified. The decrease of accuracy value from 3 to 5 class and from 5 to 7 class are almost same although the difference of the first is less than

10 and the second one is more than 10, respectively. It indicates that 5 benthic classes might be the optimum number can be distinguished by AVNIR-2 data.

If we compare the value between reef sites, Hinako is the lowest one and the others are relatively at the similar value. It might be related to the reef condition and composition. Hinako reef was dominated by patches underwater object and there were no dominant benthic cover. In contrast, it was quite easy to find dominant benthic cover on the other reefs. These facts might be influenced the classification accuracy.

Apart from that, the classification accuracy resulted from image interpretation and analysis also and mostly relates to the quality of the image source. In this case, the variation of the accuracy values presented in Table 1 may relate to the image quality recorded by AVNIR-2 sensor in each reef site. The image of Bunaken, Sikka and Bintan used in this study were mostly clear if compared with the two other sites where they were covered by cloud of about 20%.

When we compared the accuracy value with the same classification method using the same satellite data, especially 3 and 5 benthic class as reported in the previous report (2009), these results are not so different. We got the accuracy value of 84% and 76% for the benthic classes of 3 and 5, respectively, on the reef system of Lembeh Strait. This was exactly the same value with Bunaken reef. It may indicate that those accuracy values are the optimum capability of AVNIR-2 data for coral reef benthic mapping in Indonesian waters. Therefore, the overall accuracy values presented in Table 1 above are measures of the AVNIR-2 capability for coral reef mapping. It is predicted that when we employ AVNIR-2 data for coral reef habitat mapping in different reef system with the same procedure and benthic classes will have a similar result in term of the overall accuracy.

Unlike the image interpretation and analysis on terrestrial area, up to now there is no idea or any suggestion on how better the level of accuracy is. Mather [17] recommended that a standard of 85% accuracy is acceptable level in the digital image classification of terrestrial features. In this regard, we do agree that the acceptable level of the image classification accuracy is mostly depending on the individual purpose and the goal of such work[18].

4.2. The extent of benthic coverage based on Landsat 5 and AVNIR-2 data

The extent of coral assemblage decreases significantly on the map derived using AVNIR-2 data. This decrease was probably caused by two different reasons. First, the coral assemblage already changed to different coverage due to ecological process. There are some plausible processes such as corals were died and covered by algae, or corals were died because of bombing and then occupied by algae or might be sea grass. These two examples may cause coral assemblage change to different benthic coverage. Second, the decrease is caused by the different capability of Landsat 5 and AVNIR-2 data in distinguishing underwater object especially coral, sea grass and sand. From the two plausible reasons, the second one may be the best answer. AVNIR-2 data has better spatial resolution than Landsat 5 data which is in turn will give better classification results. This notion is supported by the finding that benthic map derived using Landsat 5 has lower accuracy than the one derived using AVNIR-2 data, 74% against >80%, as reported in the report of 2009. Therefore, the benthic map derived using AVNIR-2 data is more close to the field condition as what we found during field observation. The first reason is almost impossible. Coral could not change to be sand or sea grass in the period of about ten years (cf. [19-21]), as the acquire time different between Landsat 5 and AVNIR-2 data used to map the benthic coverage was only about ten years. Even if soon after coral died can be occupied and covered by algae [20], the decreasing extent would not so extensive since there were no indication of massive dead coral happened during that period of time.

The decrease ratio of the coral assemblage extent derived from AVNIR-2 data compared to the one derived from Landsat 5 TM data varies between about one-sixteenth for Hinako reef and two-third for Beralas reef. The median is in between one-eighth and one-ninth. The decreases are significant enough in some reefs. The main reason is that the image with a better spatial resolution will give a better solution to discriminate feature classes [22, 23]. AVNIR-2 data has spatial resolution of 10 m if compared to Landsat 5 TM data with the spatial resolution of 30 m. AVNIR-2 data provides sub-pixel information nine-times of Landsat 5 TM pixel. It seems that AVNIR-2 data has nine-time capability in detecting the benthic feature variation.

The extent of sand does not change so much because this object is the most detectable feature and recognizable in satellite image data. Generally sand has higher digital number than the two other benthic features. Sand can be differentiated easily form coral assemblage and sea grass + algae assemblage. In contrast, sometime there was very difficult to separate coral assemblage and sea grass + algae assemblage. As a result almost of features classified as coral assemblage in the old map are classified as sea grass + algae assemblage in the new map. It is because the two features sometimes having the same appearance in the image [24]. Both benthic classes have low digital number if compared with sand [24, 25].

Total area of all three classes of benthic cover calculated based on the new and old maps are not the same. There are disparities of coverage extent between them. It could be due to the differences in pixel size of both sensors which may give different precision. One pixel of Landsat 5 TM equals to nine pixel of AVNIR-2. It means that one benthic cover class mapped from Landsat could be one, two or three different covers when mapped using AVNIR-2. In addition, the different of data acquisition time will gives different quality of recorded image even using the same sensor because of the different condition of atmospheric scattering as well as water clarity. As a result, a certain feature was classified as deep water by Landsat but it could be recognized as sand or coral assemblage or even sea grass + algae assemblage by AVNIR-2, and vice-versa. There were clearly be seen in Fig. 4 and Fig. 7, while Fig. 2 and Fig. 5 shown the opposite examples.

5. CONCLUSION

Based on the results gained so far and discussion undertaken above, we end up with two main conclusions as follow. First, on the reef system of Indonesian waters we predict that the overall accuracy of benthic classification analysis based on AVNIR-2 data will fall around the values as listed in Table 1. Those accuracy values are predicted as the optimum value. Secondly, AVNIR-2 data has better capability in detecting the variation of benthic features than Landsat 5 TM. A better spatial resolution of such satellite data employing the visible spectra will give a better solution in discriminating the coral reef benthic features. AVNIR-2 data are able to solve and recognize the sub-pixel information of Landsat 5 TM.

6. REFERENCES

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