MONITORING CHANGES IN CORAL REEF AND OTHER BENTHIC HABITATS USING REMOTELY SENSED DATA AND GIS

Nitin Kumar Tripathi and I Nyoman Radiarta

Remote Sensing and GIS Field of Study

Asian Institute of Technology,

P.O. Box 4, Khlong Luang, Pathumthani 12120, Thailand

Tel: 66-2-524 6392, Fax: 66-2-524 5597

Email: nitinkt@ait.ac.th

ABSTRACT

Coral reefs are important resources for the great many tropical country. Indonesia has over 95,000 km coastline. There are 17,000 islands and 51,000 km^2 coral reefs. Conventional methods of mapping the coral resources are direct observations using manta tow, plotless belt, LIT, chain transects, quadrats and photo quadrats. These methods are very slow and expensive. It is also difficult to cover a large tract of the area for mapping. Due to these limitation, vast marine resources are still not mapped. The lack of spatial information results in poor management of marine resources such as corals and sea grass. The study ares was chosen as Riau Archipelagos, Riau Province, Indonesia. Three major islands Mensanak, Medang and Benan Island and several other smaller islands were included for mapping benthic communities.

A methodology based on digital image processing and analytical hierarchical clustering techniques was developed to prepare the maps of underwater benthic coverage for 1996 and 2002. Change detection analysis approach was developed in the GIS. The results and analysis has shown the changes of live corals, sea grass and other features. The highlight of the study was the development of understanding of the dynamics of benthic coverage of this region. It was found the live corals in one area decay but grow in another area. ENSO event in 1997-98 seems to have caused changes in the benthic community of this region. Accuracy assessment of the methodology was also carried out.

1. INTRODUCTION

Coral reefs are important resources for the great many tropical country. Reefs and their habitat associated sandy beaches are important attraction to tourist, major sources of income of tropical countries. Indonesia is the larges tropical archipelagic nation in the world, with a coastline stretching 0ver 95,000 km around more than 17,000 islands. An expensive group of coral reefs protect these islands. Indonesia has approximately 51,000 km^2 coral reefs (Burk *et al.*, 2002), this number does not include reef in remote areas that have not been mapped. For the management of specific coral reefs resources, it is first necessary to identify the reef to be managed A monitoring program can be provide information on the diversity of site, condition of particular habitats and changes in environment.

Dealing with the monitoring program of coral reefs, the conventional methods are commonly used for mapping and monitoring of coral reef habitats. Topographic maps, nautical charts and direct observation are the conventional ways for surveying and mapping coral reefs. All the conventional methods mention above still have the limitation especially by using those methods may not be practical for monitoring large or remote coral reef ecosystem accurately. Other thing this is expensive, cumbersome and logistically and also time consuming.
With respect to this situation, remote sensing may provide the most feasible mean for monitoring and management of coral reefs, particularly for insular (archipelagic) countries. Remote sensing can identify a number of environmental variables associated with habitat that are potential indicators of resources distribution and abundance such as coral reefs, algae and sea grass.
Many researchers (Khan *et al.*, 1992; Luczkovich *et al.*, 1993; Zainal *et al.*, 1993) have examined the usefulness of Landsat data for inventory and mapping of coastal habitats such as coral reefs, however most of them used the oldest Landsat series such as Landsat MSS and Landsat TM (4 and 5).

In this present study, Landsat 7 ETM+ has been used for investigating coral reef habitats. GIS technique and field data also considered in this study. Water column correction algorithm has been employed to enhance the image (Green *et al*., 2000; Mumby *et al*., 1998). This algorithm has not been widely adopted in term of mapping shallow water (Mumby *et al.*, 1998). In addition, band ratio and principal component analysis also applied in this study. In order to classify reef habitats from the image, unsupervised classification using K Mean class was undertaken to identify reef habitat base on water column correction image. An error matrix was used for additional interpretation of classification accuracy within and between each reef habitats.

2. STUDY AREA

The study area is located around three major islands (Mensanak, Medang and Benan Islands) and several smaller islands in Riau Archipelagos, Riau Province. It stretches from latitudes $0^{o}20'$-$0^{o}30'$ North and longitudes $104^{o}20'$-$106^{o}35'$ East. This area is situated approximately 120 km Southeast of Singapore. The study area is one of the Coral Reef Management Program (COREMAP) areas. Major habitats in this area are representative of the general environmental in the Riau Archipelagos. Therefore the findings of this study could be useful for large mapping of coral reef habitats along the islands.

3. METHODOLOGY

A Landsat 7 ETM+ image (path 125 row 60) that covered the study area, acquired on 6 September 2001 was used in this study. The image was system corrected using UTM 48 and WGS 84 as the projection and reference ellipsoid, respectively.

The field survey (in situ) data is very important when working with remote sensing images. The field data will be used to compare ground feature and corresponding image feature. This study was concentrated on the reef top areas in which water depth varied between 0-5 m. The Rapid Reef Assessment (RRA) technique (COREMAP, 2001) was used in this study. Distribution of sampling reefs were determined using GIS to randomly allocate stations to sample on the reef top. The benthic data was recorded by the percentage coverage. Several enhancement techniques have been used in this study such as band ratio, principal component analysis (Khan *et al*., 1992) and water column correction (Mumby *et al*., 1998;

Green *et al.*, 2000). Unsupervised classification method using K-mean classification was carried out in this study based on the water column corrected image. To assign meaningful labels to the spectral classes, ground truth data was used. In this study, through the used of hierarchical cluster analysis and simple statistical approach (analysis of variance, ANOVA) as a guide to class amalgamation and selection of the final groups, which correspond with bottom types. The reliability of reef habitat classification has been tested using error matrix and kappa coefficient.

4. RESULT AND DISCUSSION

The complexity of coral reef habitats is one of the problems when dealing with mapping benthic habitats using remote sensing. The benthic communities where the reflectance spectral of the object commonly smaller than spatial resolution of view most satellite sensor (i.e. 30 m spatial resolution of Landsat 7), the spectral reflectance of the individual pixel will generally not represent the reflectance of single object but rather mixed of reflectance of two or more object present with ground resolution. Significant mixing of several different benthic types within relatively large pixels compounds the issue of classification inaccuracy. Because the complexity of the object represent in the ground resolution, some of the object are mixed together to make ease for the analysis.

5. SPECTRAL CHARACTERISTICS OF BENTHIC HABITAT

Analysis of spectral characteristics of benthic habitats is necessary for the classification of satellite data. Typical characteristics of benthic habitats (sand, substrate, live coral, sea grass and algae) in the study area were shown in the Figure 1. The analysis of spectral characteristic was based on relationship between band and Landsat ETM+ digital number (DN). This study found that sand bottoms had greater digital number for all bands. On the image bare sand areas are easily to determine, they appear very bright. On the other hand, sea grass/algae had greater digital number than live coral and live coral had greater digital number than substrate.

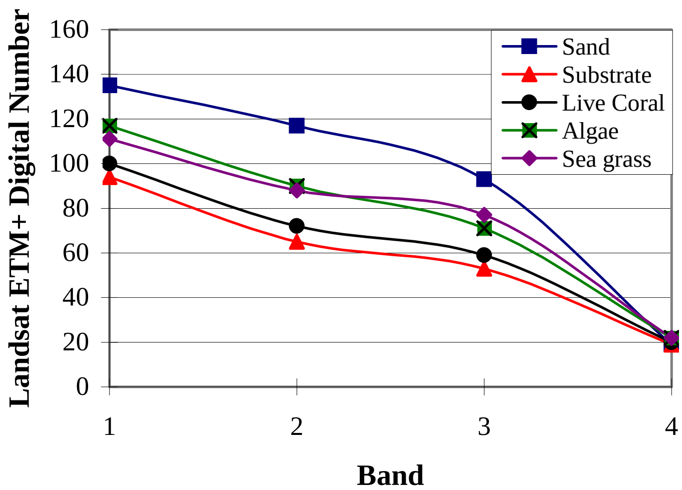

Figure 1. Spectral signature of benthic habitats

6. REEF HABITAT CLASSIFICATION

Water column image has been calculated base on equation: ln (L1) + (0.639*ln(L2), where, L1 and L2 is Landsat ETM + band 1 and band 2, respectively. Based on the water column image, this study was successfully classified image into eight classes. The image classification of study area was obtained by using K Mean (Unsupervised) classification. Eight classes have been reduced into six classes based on cluster analysis. The six classes have been tested using analysis of variance. All the benthos among the class was showed significant at level 99% (sand, substrate and live coral) and 95% (bio habitat). The statistical results of ANOVA suggest that the distribution benthic of each reef habitats were unique population. In other word there is significant different in substratum and biota among reef habitats. Table 1 shows the six classes of reef habitat. The following is a description of the major reef habitat zone mapped in this study

Reef Habitat 1 – Bare Sand Zone: Sandy zone was found the dominant reef top benthic habitat in this study.

Reef Habitat 2 – Exposed Sand/Substratum Zone: This reef zone occupied the smallest area of entire reef habitat and there was scattered along the reef area.

Reef Habitat 3 - Reef Crest Substratum Sandy Zone: This zone was characterized by high live coral colonies. However, the coverage of live coral is smaller than reef crest/submerged reef zone (reef habitat 4).

Reef Habitat 4- Reef Crest / Submerged Reef Zone: This zone consisted of large/very high live coral colonies with few and narrow separation by sandy area. In addition, substrate also found high in this zone. It was indicated there were activities regarding with destruction of coral reef.

Reef Habitat 5 – Substrate Sandy Zone: This zone is dominated by substrate cover and followed by sandy cover. Substrate sandy zone occupied the second large area, which is approximately 24% coverage of the total reef area.

Reef Habitat 6 - Reef Flat Sea grass/Algae Zone: Bio habitat (sea grass/algae) cover was found large in this zone. According the proportion of the substrate and sand, it was indicate that seagrass/alge was grown on the substrate and sand and also between the live coral.

Table 1 **Descriptive for the field survey data by reef classes obtained from the classification of Landsat ETM + satellite imagery.**

Reef Habitat	N	S	R	TR	DC	DCA	SBT	LC	ALG	SG	BH
1	22	65.95	8.63	9.55	0.68	7.71	26.57	0.75	1.77	4.96	6.73
2	4	37.88	16.69	28.50	0.00	7.50	52.69	1.50	5.81	2.13	7.94
3	7	43.89	4.43	1.43	0.00	34.29	40.14	8.86	4.57	2.54	7.11
4	5	18.44	10.21	16.06	2.00	28.66	56.93	12.89	9.36	2.39	11.74
5	13	24.11	13.81	6.54	0.81	29.36	50.52	7.01	8.46	9.91	18.37
6	15	49.18	8.34	5.33	0.76	11.48	25.91	2.74	4.24	17.93	22.17

Reef Habitat: habitat classification; N: number of stations; S: average percentage cover of bare sand; R: average percentage cover of bare rubble; TR: average percentage cover of terrestrial rock; DC: average percentage cover of dead coral; DCA: average percentage cover of dead coral with algae; SBT (Substrate): average percentage cover of R+TR+DC+DCA; LC: average percentage cover of live coral; ALG: average percentage cover of algae; SG: average percentage cover of sea grass; BH (Bio Habitat): average percentage cover of sea-grass + algae.

In this study, the accuracy of the classified image was tested using 20 ground truthing sites throughout the study area. An overall accuracy of 76.12% was determined by dividing the total number of correctly classified spectra (the sum of the count along the major diagonal) by the total number of spectra considered in this study. In addition, Kappa analysis also calculated. Kappa coefficient (KHAT value) of 69.64% was achieved in this study.

7. RELATIONSHIP AMONG SUBSTRATUM/BENTHOS

The relationship among substratum/benthos was evaluated in this study. The purpose of this analysis was evaluated the relationship among the benthos and investigate the capability of Landsat ETM+ for delineating of substratum/benthos. The correlation and coefficient determination among substratum/benthos is given in Table 2.

Table 2. Correlation (r) and coefficient determination (r^2) among substratum/benthos

	Sand	Substrate	Live Coral	Bio Habitat
Sand	1			
Substrate	0.89 (0.79)	1		
Live Coral	0.79 (0.62)	0.56 (0.32)	1	
Bio Habitat	0.38 (0.15)	0.15 (0.02)	0.24 (0.06)	1

*Correlation (coefficient determination)

This study found that relation live coral and sand has high coefficient determination (r^2= 0.62) and follow by live coral and substrate (r^2=0.32) and live coral and bio habitat (r^2= 0.056). The highest coefficient determination meaning that two benthos could be differentiated easily. The relation between substrate and sand has the highest coefficient determination (r^2= 0.79) and also coefficient correlation as mention above. It was mean, differentiation of this benthos easier when we compared with differentiation live coral and sand. The relation between bio habitat and other benthos was found very low. Based on these relationships, we could be interpreted that it was difficult to differentiate between bio habitat and others benthos (sand and substrate).

8. CONCLUSION

This study attempted to investigate the applicability of Landsat 7 ETM+ for mapping coral reef habitat. Due to the complexity of coral reef environment and the spatial resolution of Landsat 7 (30 m), some benthic habitat have been mixed together for easier to classification such as sea grass and algae become bio habitat and dead coral, terrestrial rock, dead coral with algae and rubble become substrate. Several techniques related to image enhancement have been applied for getting more information about benthic habitat. Water column correction image has been used for image classification. Using hierarchical cluster analysis, the study achieved six classes of reef habitat base on the zonation. The reliability of reef habitat classification has been tested using error matrix and Kappa coefficient, which is achieved 76 % and 0.68, respectively. This overall accuracy indicated the reef habitat has been achieved in this study is reliable.

Based on the result was found in this study, it was indicated that using Landsat 7 ETM+ with the spatial resolution of 30 m, sand could be separated with other benthic habitat easily. However, difficultness separation of bio habitat to other benthic habitat was found in this study. Separations between live coral and sand more ease than live coral and bio habitat, which is on the image both of them appeared relatively dark.

9. ACKNOWLEDGEMENTS

The Authors wishes to acknowledge the funding support of the Ministry of Agriculture, Integrated Tropical Coastal Zone Management Program-AIT and AMSAT Indonesia. And also would like to thank Dr. Brian Long for his assistance during the field work preparation, and Mr. Sam Suherman and Mr. Muin for their collaboration during the field work in January 2002.

10. REFERENCES

Burk, L., Selig, E. and Spalding, M., 2002. *Reef at Risk in Southeast Asia*.World Resources Institute. 72 pp.

Coremap, 2001. Riau Reef Resources Assessment Workshop. Phase I: Field Survey Design. GIS Reef Basemap Training Course 13-18 December 1999.

Green, E. P., Mumby, P. J., Edwards, A. J. and Clark, C. D., 2000. *Remote sensing handbook for tropical coastal management*, 316p. Paris: UNESCO.

Khan, M.A., Fadlallah, Y.H., and Al-hinai, K.G., 1992. Thematic Mapping of Subtidal Coastal Habitats in Western Arabian Gulf Using Landsat TM Data-Abu Ali Bay, Saudi Arabia. *International Journal of Remote Sensing*, Vol. 13, No. 4, pp. 605-614

Luczkovich, J.J., Wagner, T.W., Michalek, J.L., and Stoffle, R.W., 1993. Discrimination of Coral Reefs, Seagrass Meadows, and Sand Bottom Types from Space: A Dominican Republic Case Study. *Photogrammetric Engineering & Remote Sensing*, Vol. 59, No. 3, pp. 385-389

Mumby, P.J., C.D. Clark, E.P. Green and A.J. Edwards, 1998. Benefits of water column correction and contextual editing for mapping coral reefs. *International Journal of Remote Sensing*. Vol. 19, No. 1, 203-210.

Zainal, A.J.M., Dalby, D.H., and Robinson, I.S., 1993. Monitoring Marine Ecological Change on the East Coast of Bahrain with Landsat TM. *Photogrammetric Engineering & Remote Sensing*, Vol. 59, No. 3, pp. 415-421