

# **APLIKASI TEKNOLOGI SISTEM INFORMASI GEOGRAFIS DALAM PENENTUAN KAWASAN KONSERVASI TERUMBU KARANG DI KEPULAUAN KANGEAN MADURA**

Zainul Hidayah<sup>1</sup>, Wahyu Andy Nugraha<sup>1</sup>, Insafitri<sup>1</sup>, Dwi Budi Wiyanto<sup>2</sup>  
Jurusan Ilmu dan Teknologi Kelautan Universitas Trunojoyo Madura  
Jurusan Biologi Universitas Udayana  
E-mail : zain.hidayah99@gmail.com

## **ABSTRACT**

*The location of this research was Kangean Islands of East Java Indonesia. Kangean Islands consist of 60 islands; most of them can be categorized as small islands. This research was focus on 5 main islands, including Kangean, Paliat, Sepanjang, Arjasa and Sapeken Island. Since 2008, some parts of the islands were proposed by the local government to be developed as coral reef conservation areas to protect the ecosystems from destructive fishing. However, the absence of baseline information on the status of coral reef ecosystems has been the main problem that alters the proposal. Therefore, the objectives of this research were to map the distribution of reefs ecosystems in Kangean Archipelago using remote sensing and GIS technology and to determine the suitability of coral reefs protected areas development on the area using water quality parameters and the percentage of living coral covers. Remote sensing and GIS techniques were applied in this study to measure and generate spatial distribution of water quality parameters as well as the coverage of benthic communities on the area. To map the distribution coral reefs ecosystems and water quality parameters, a Landsat TM-5 path row 116-65, acquisition date August 19<sup>th</sup> 2008 was used. According to the result, the coverage of coral reefs was 292.47 km<sup>2</sup> and approximately 72.07% of the area was living corals. Moreover, the results of suitability analysis showed that, only about 19.37% of the coral reefs ecosystems in Kangean Island have met the criteria to be recommended as potential conservation zones.*

**Key Words : Kangean islands, coral reefs, remote sensing, GIS**

## **INTRODUCTION**

Coral reefs are complex ecosystems endangered by a variety of natural and anthropogenic factors (Tissot and Brosnan, 2003). The natural factors that put coral reefs in danger are global warming, earthquake and tsunami waves. Among those factors, scientists consider that global warming is the main threat that cause global destruction of coral reef ecosystems. However, in many developing countries including Indonesia, the rate and the level of coral reef's destruction caused by human activities is becoming a major issue instead of global warming. It happens because the level of people's understanding in the importance of coral reefs is still low and many coral reefs regions are not protected by government regulations.

Some 30 million people live in the coastal region of Indonesian's archipelago, many highly dependent on its marine resources and having a significant impact on resource status. A majority of these coastal communities are categorized as living at or below national poverty lines. Over-fishing and destructive fishing techniques that cause habitat destruction, coupled with a rising population are of increasing concern in Indonesia.

The term destructive fishing has often been used for a wide range of situations spanning from classical overfishing (non sustainable use) to outright destruction of the resource and its environment, as for example when using explosives or other methods with significant and definitive impact. Indeed, many fishing gears could be considered destructive if used in the wrong environment. The use of poisons and explosives are prominently cited in literature, together with the muroami fishing, as examples of destructive practices (FAO, 2009).

Ikawati (2001) mentioned that poverty may be an important influence on the exploitation of marine resources in tropical developing countries. A number of studies have hypothesized that destructive fishing gears, which can degrade habitat, capture high proportions of juvenile fish and

ultimately lead to reduced yields, are primarily used by the poorer segments of society. However, few studies have empirically tested this relationship. For the poor, poisons and explosives are among the most inexpensive methods available, requiring little capital investment. In some instances, it is the only affordable access to a vital resource (FAO, 2009).

According to the result from COREMAP survey, in 2001 the area of coral reef ecosystems in Indonesia was approximately 75,000 km<sup>2</sup> (Ikawati, 2001). However, only 6, 2 % of them were in a fairly good condition (Estradivari et.al, 2007). In previous years, the Ministry of Marine Affairs conducted surveys and rehabilitation programs at many locations in Indonesia. The programs were mainly focused in the Eastern parts of Indonesia, such as Maluku, Nusa Tenggara, Sulawesi and Papua. With this programs, it was possible to monitor and asses the conditions of coral ecosystems. Therefore, many new marine protected areas were developed in several locations. However, because of the budgetary and expertise limitations, not all potential locations were surveyed.

One of the potential area that can be developed as a conservation zone for coral reefs is Kangean Archipelago. Kangean Archipelago is located about 107 km north from the eastern part of the main island of Madura, one of the biggest islands in East Java. The Kangean Archipelago consists of 60 islands, some of which are not inhabitants. The islands are integrated administratively as part of Sumenep district. Almost 87% of the local people are traditional and semi-modern fishermen. Their fishing grounds are mostly situated in the Java Sea in the North, the Madura strait in the South and Flores Sea in the East. Coral reefs ecosystems are distributed along the surrounding of the islands. However, scientific research to determine the condition of the reef's ecosystems has not been conducted. As the consequence, no recent data available to describes the condition of coral reef ecosystems in these islands. With the absence of such data, it is difficult to asses the current condition and determine the appropriate strategies in order to preserve the existing coral ecosystems.

Remote sensing technology and Geographic Information Systems (GIS) are tools that have been used in various ranges of marine environment studies. To understand processes of reef degradation, for example, it would first be useful to obtain a synoptic measure of change in community structure across the entire system (Mumby et.al, 2004). Since field surveys are usually too time consuming and expensive to conduct over a continuum of scales, remote sensing techniques can be used as an alternative. One main advantage of a remote sensing system is its ability to provide a synoptic view of a wide area in a single frame. Although remote sensing and GIS offer many advantages, however, in accordance to the coral reefs studies in East Java, this technology has not been applied widely.

Regarding the lack of coral reefs ecosystems data over the islands, thus the objectives of this research are:

1. To locate and map the distribution of reefs ecosystems in Kangean Archipelago using remote sensing and GIS technology.
2. To determine the coral reef ecosystems and status in Kangean Archipelago.
3. To determine the suitability of coral reefs protected areas development in the Archipelago using several criteria.

## **METHODOLOGY OF THE RESEARCH**

In general this study will be divided into 3 parts. Each part is representing the main activities of the study. The divisions of the study are explained as the following:

1. Part I : Satellite imagery data analysis.

In this part, the study will focus on the identification of coral reefs distribution and water quality parameters in the Kangean Archipelago. Information on spatial distribution of coral reefs can be obtained through observations from space. Remote sensing technology is a technology that can support it. Coral reef ecosystem found in shallow waters, so that still can be observed from remote sensing image using visible spectrum (Andrefouete and Riegle, 2004). Visible spectrum has a range of wavelength between 0.4  $\mu$  m to 0.7  $\mu$  m (Susilo, 2000), consisting of blue spectrum (0.4 to 0.5 m), the green spectrum (0.5 to 0.6  $\mu$  m), and red spectrum (0.6 to 0.7 m). Visible spectrum can penetrate the water column to depths of 20 meters (Campbell, 1996), so that objects that are under water to depths that can be detected. According to Susilo (2000), information on reefs location and distribution can be extracted from Landsat TM-5 or ETM-7 imagery data using a

specific algorithm also be used to detect the condition of the reefs, whether under critical condition or not (Moloney, 2008). The identification of benthic cover as well as coral reefs condition will be the input to create maps of reefs locations and distributions (Hidayah, 2008). Moreover, several water quality parameters such as chlorophyll-a concentration, dissolved oxygen, and total suspended solid are also examined by the analysis of satellite imagery data. The algorithms and their mathematical equation for each parameter are summarized in this following table:

No	Parameter	Algorithm	Information
1	Reefs distribution	$Y = \ln TM1 + \left(\frac{ki}{kj}\right) \times \ln TM2$ $\frac{ki}{kj} = a + \sqrt{a^2 + 1}$ $a = \frac{(\text{var } TM1 - \text{var } TM2)}{2 \times (\text{cov } TM1 \times \text{cov } TM2)}$	TM 1 : Channel 1 of Landsat imagery TM 2 : Channel 2 of Landsat imagery Ki , kj : Attenuation coefficients
2	Sea Surface Temperature (SST) (°Celcius)	$SST = \frac{T_{Landsat}}{\left(\sqrt{\sqrt{0.5}}\right)} - 273$ $T_{Landsat} = \frac{k2}{\ln\left(\frac{k1}{L\lambda} + 1\right)}$	k1 : Calibration constant 1 (669.09 watts/(m <sup>2</sup> *ster*µm) k2 : Calibration constant (1282.7 Kelvin) Lλ : Spectral radiation (watts/(m <sup>2</sup> *ster*µm))
3	Chlorophyll-concentrati (mg/l)	$C = 8,655 + 0,129(TM1 - TM5) + 0,258\left(\frac{TM3}{TM4}\right)$	TM 1 : Channel 1 of Landsat imagery TM 5 : Channel 5 of Landsat imagery TM 3 : Channel 3 of Landsat imagery TM 4 : Channel 4 of Landsat imagery
4	Total Suspended Solids (TSS) (mg/l)	$TSS = 100.67 + (5.5085 \times TM3) + (0.45 \times TM3^2) + (0.9775 \times TM2 \times TM3)$	TM 3 : Channel 3 of Landsat TM 2 : Channel 2 of Landsat imagery

## 2. Part II : Field surveys and measurements

This part is intended to identify the reefs condition and status as well as the water quality. Status of the reefs can be determined by the percentage of living coral cover. English et.al (1997) suggest that the Line Intercept Method (LIT) is suitable to obtain such data. Information that can be obtained by using LIT to asses coral reefs condition including percentage cover of benthic communities e.g. hard coral, soft coral, sponges, algae, rock, dead coral.

Results of this method were then used to determine the “health” status of coral ecosystems in the study area. Mathematical equation for this method is :

$$\%Cover = \frac{\sum Li}{Lt} \times 100\%$$

Li : length of coverage of life form species-i

Lt : total length of the transect

Classifications of living coral percent coverage according to Suharsono (1992) are :

- Low : % coverage < 20%
- Medium : % coverage ranges from 26 – 50
- Good : % coverage ranges from 51 – 75
- Very Good : % coverage > 75.

### 3. Part 3 : GIS mapping and analysis

In this part, multi thematic maps will be created using GIS technology. Theme of the maps will base on the results of the field surveys and imagery analysis. The function of these maps is to describe the condition of the reefs as well as the water quality parameters. The maps also act as layers for further GIS analysis to asses the suitability level of the area for the development of a coral reefs conservation zones. This table below informs main criteria that will be used in the analysis.

No	Parameters	Weight	Suitability Levels		
			Suitable	Moderately Suitable	Not Suitable
			( Score = 3)	(Score = 2)	(Score = 1)
1	Living coral coverage (%)	20	> 75	51 - 75	< 50
2	Coral reefs area (%)	10	> 75	26 - 50	< 25
3	Distance from rivers (km)	15	> 12	6-12	< 5
4	Sea Surface Temperature ( <sup>0</sup> Celcius)	10	28 - 30	25 - 28	< 25
5	Salinity (ppm)	15	30 - 34	25 - 29	< 25
6	Water clearness (cm)	10	> 20	10-15	< 15
7	Chlorophyl-a (mg/L)	5	> 20	10-20	< 10
8	Total Suspended Solids (mg/L)	10	< 20	20-25	> 25
9	Dissolved Oxygen (mg/L)	5	> 6.5	5.5-6.5	< 5.5
Total Weight x Score		100	3	2	1

Source : Wulandari and Siregar (2005)

Classifications :

- Suitable (S1) : Total Score > 45
- Moderately Suitable (S2) : Total Score 39 – 45
- Not Suitable (S3) : Total Score < 39

## RESULTS AND DISCUSSION

### Coral Reef Mapping

From the result of the satellite image processing, the location where living corals exist can be identified. The map below shows the distribution 3 types of substrates at the study areas. The 3 types of substrates are: living corals, sand and dead corals. According to the result, the total area of living coral ecosystem was 210.79 km<sup>2</sup>. On the other hand, approximately 81,68 km<sup>2</sup> of the area can be classified as dead coral ecosystems.

According to previous study, conducted by Nahib and Dewi (2004), the area of living coral ecosystems in 5 locations in Kangean Islands has been depleted. They used relatively similar method to determine the distribution of reefs ecosystem on the area. However, their study limited to 5 locations only : South Kangean Island, Saobi Island, Sabuntung Island, Mamburit Island and East Paliat Island. Moreover, Nahib and Dewi (2004) study showed that in 1994, the area of living coral ecosystem was 182,17 km<sup>2</sup>, however in 2004 the area decreased into only 115,77 km<sup>2</sup>. On the contrary, during the same period, dead coral area increased significantly from 399,87 km<sup>2</sup> to approximately 415,80 km<sup>2</sup>. Nonetheless, results from Nahib and Dewi (2004) can not be compared with this study, because this study comprised wider area with more islands to examine. However, Nahib and Dewi's study showed that there was a serious threat that caused coral reef ecosystems in the Kangean Islands suffered major destruction.

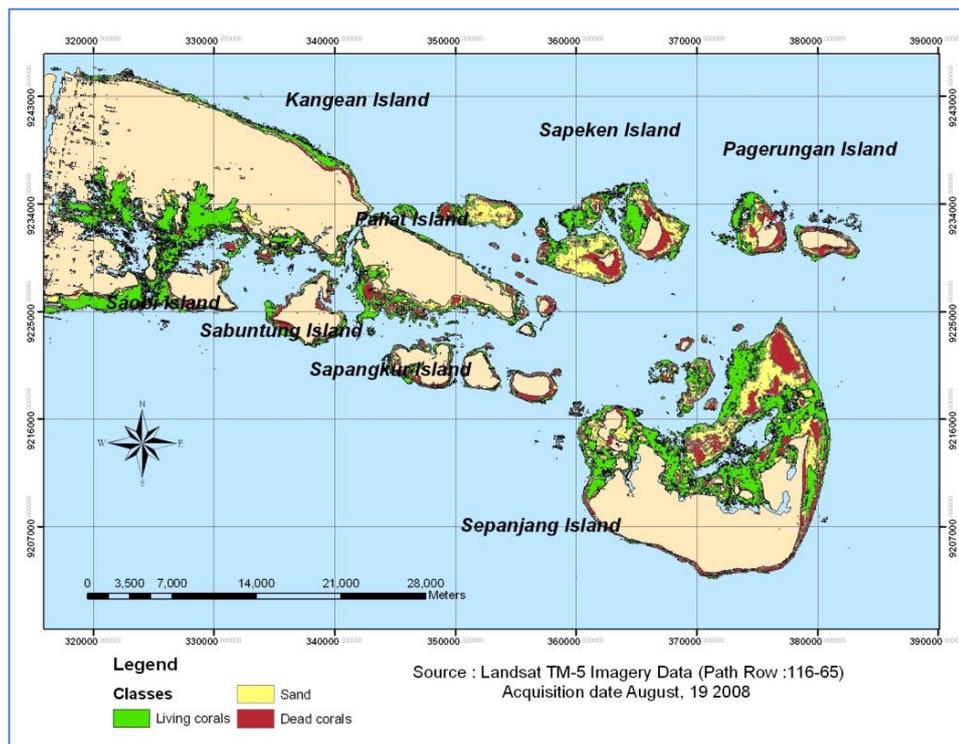


Figure 1. Coral Reefs Habitat Mapping of the Study Area

Although remote sensing techniques is very useful in detecting objects in shallow water such as coral reefs, however it can not be used to identify the reef's life form that exist in the study area. For that reason, field observations are needed to gather more complete information regarding the condition of coral reefs ecosystem in the study area. Moreover, field observation is also importance to check the accuracy the identification of coral reefs ecosystem using remote sensing data.

### Results from Field Observation

For the duration of the field observations, coral life forms that were found including coral branching, digitata, coral massive, coral sub-massive, mushroom coral, coral encrusting, coral foliouse, tabulate and soft coral. They come from approximately 36 genera, including family *Faviidae*, *Fungiidae*, *Poritidae*, *Mussidae*, *Pectinidae*, *Agariciidae*, *Euphyllidae*, *Pocilloporidae*, *Acroporidae*, *Caryophyllidae*, *Astrocoeniidae*, *Merulinidae*, *Siderastreidae*, *Tubiporidae*, *Trachyphylliidae*, *Oculinidae*, and *Dendrophyllidae*.

From Table 1, it is mention the dominant condition of the coral reef ecosystems in the Kangean Archipelago was low, with living coral coverage area ranges from 2,71% to 18,06% in 3 meters depht. However, at the same depht, a relatively good condition of reefs ecosystems was also found. We observed that at 3 locations (Paliat 1,2 and Sapeken 2), the coverage of living coral was over 50%. Furthermore, at 10 meters depth, the status of coral reefs ecosystems was dominated by medium conditions, with coverage varies from 33% to 41,85%. At this depth, we also found a spot with living coral coverage approximately 57,52%. This site was located at Paliat Island.



### Figure 2. Line Intercept Transect to Identify Coral Life Forms in Sapeken Island

The poor conditions at most of the site in 3 meters depth were mainly caused by human activities. From our observations during the field survey, coral reefs ecosystem at the study area was facing a major threat from the destructive fishing. Destructive fishing not only contributes to destroy the habitat on which exploited fish depend but also have significant role to over-fishing. Over-fishing means that fishers extract more fish than nature can produce over the long term. Besides decreasing the profitability and long-term prospects of the fisheries sector, over-fishing results in the extirpation of highly-valued species such as grouper and Napoleon wrasse. Fisheries experts from Indonesia find that the large majority of Indonesia's fisheries are over- or fully exploited, which means that any expansion of the fishing fleet is ill-advised. Sadly, over-fishing is exacerbated by perverse subsidies that enable the fishing sector to continue fishing already over-exploited stocks (The Nature Conservancy, 2008).

Table 1. Results from Field Observations

Locations	Coordinate		Depth	% coverage of living corals	Status
	Latitude	Longitude			
Sepanjang 1	07°08'19"	115°44'47"	3 meters	10,45	Low
Sepanjang 1	07°08'19"	115°44'47"	10 meters	5,77	Low
Sepanjang 2	07°08'55"	115°44'32"	3 meters	3,87	Low
Sepanjang 2	07°08'55"	115°44'32"	10 meters	12,45	Low
Sapangkur 1	07°02'27"	115°36'43"	3 meters	28,1	Medium
Sapangkur 1	07°02'27"	115°36'43"	10 meters	6,15	Low
Sapangkur 2	07°02'80"	115°36'43"	3 meters	31,3	Medium
Sapangkur 2	07°02'80"	115°36'43"	10 meters	41,85	Medium
Paliat 1	07°00'35"	115°41'39"	3 meters	61	Good
Paliat 1	07°00'35"	115°41'39"	10 meters	57,52	Good
Paliat 2	07°00'45"	115°41'58"	3 meters	57,04	Good
Paliat 2	07°00'45"	115°41'58"	10 meters	19,8	Low
Kangean 1	06°58'13"	115°32'38"	3 meters	9,1	Low
Kangean 1	06°58'13"	115°32'38"	10 meters	N/A	N/A
Kangean 2	06°55'13"	115°34'10"	3 meters	18,06	Low
Kangean 2	06°55'13"	115°34'10"	10 meters	33	Medium
Sapeken 1	07°00'13"	115°42'14"	3 meters	2,71	Low
Sapeken 1	07°00'13"	115°42'14"	10 meters	39,8	Medium
Sapeken 2	07°00'47"	115°42'50"	3 meters	50,2	Good
Sapeken 2	07°00'47"	115°42'50"	10 meters	37,52	Medium

Furthermore, blast fishing, either with home-made or industrial explosives, is perhaps the best known example of destructive fishing. Other examples are bottom trawling, fishing with poisons, and fishing with certain kinds of fish traps. According to our investigation, coral reefs are often dynamited to harvest small fish. Although it is illegal, it is practiced in many countries worldwide and is a major threat to coral reefs. This destructive fishing method uses bottles filled with explosives made from potassium nitrate (a common fertilizer). The explosives create an underwater shock wave that ruptures fish swim bladders, so they float to the surface where fisherman can easily collect them. Not only fish are killed but also other inedible reef animals. Often a certain reef area is dynamited twice, first to kill the smaller fish, and then again to kill the larger predators attracted by the carnage. But the most damage is caused by the destruction of the corals by the blast, reducing the surrounding area to lifeless rubble. Destructive fishing using dynamites can directly break the massive structure of the reefs into small fractures (Suharsono, 2003). Therefore, at our observation sites we discovered abundant reefs fracture that already mixed with sand and inhabitant by algae.

In other case, local fishermen often use potassium cyanide and other poisons to stun and capture valuable reef fish. Divers squirt a cyanide solution from bottles directly onto fish resting on corals, killing the corals and stunning the fish. The fish often escape into crevices and the fishermen have to break apart the coral to get to their paralyzed prey. With this technique not only the fish are poisoned, but also the coral polyps and other creatures in the area. Places where cyanide was spread will first form black slime, and then they will just become dead coral rock.

## Suitability Analysis

The main data input of the suitability analysis are from the satellite imagery data and results from field observations. Using GIS techniques, all of the data were combined into a spatial database. From this database, the spatial data then can be displayed into different thematic maps. Furthermore, using the spatial database, all the data were classified based on the criteria showed in Table 3. Afterwards, certain scoring and weighting were applied to determine the suitability status of each parameter. Finally, the classification results of each parameter were over-layed to produce the final suitability maps for conservation area of coral reefs ecosystems.

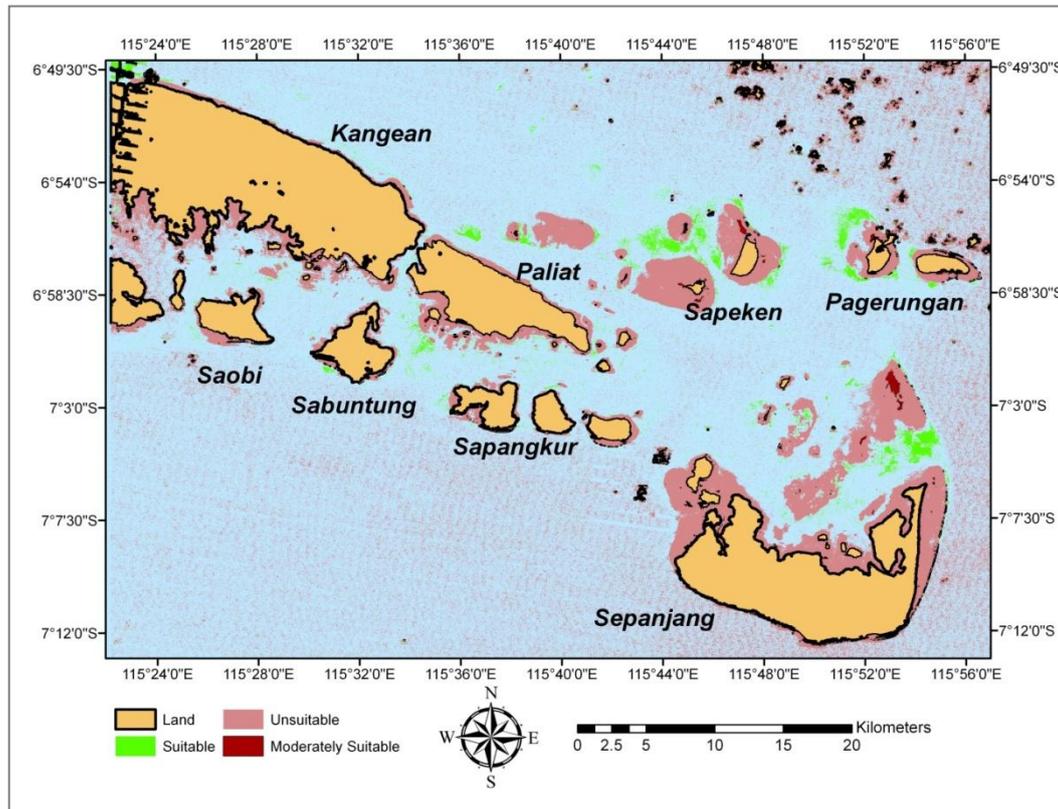


Figure 3. Suitability Map for Coral Reefs Conservation Zones

According to the results of suitability analysis, only about 19,37% of the coral reefs ecosystems in Kangean Island have met the criteria to be recommended as potential conservation zones. In addition, another result shows that approximately 7,15% considered to be a moderately suitable area and the rest (approximately 73,48%) is unsuitable area for coral reefs conservation zones. The suitable areas are distributed at different locations, including: the North side of Sepanjang Island, Paliat, Sapeken and Pagerungan.

This suitability analysis is just an early step to develop a conservation zone for coral reefs in Kangean Islands. This result is produced only based on information of marine environment. Beside that, a conservation zone plan needs to be supported by other data or information. One of the most important information that should be obtained to support the conservation plan is the interconnection between the proposed zones with the surrounding areas. Since the marine environment is dynamic, the existence of bio-diversity in certain location really reliant on the condition of the surrounding environment. For example, the condition of coral's health is highly dependent on the absence of pollutant from near-shore land or the rate of particle run-off from the rivers. Moreover, the reef's conservation zones should be free from any fisheries activities, especially the destructive ones. This kind of information is greatly needed to support the integral plan to facilitate the development of coral reefs conservation zone in Kangean Islands.

## CONCLUSIONS

In conclusion, this research has demonstrated the usefulness of remote sensing and GIS technology as a tool to develop a potential marine conservation area. Using this method, a large number of different types of information can be integrated into one single spatial database to be used as a decision support system. It is also estimated that, although many locations have been discovered and the results showed that there are major disturbance to the ecosystems, the restoration programs is still possible to do. This reason rise due to findings showed that in some locations, coral communities are in relatively healthy condition. Therefore it can be inferred that at some levels, the environment is still reliable. The larvae from coral organism and algae can move naturally using water current and develop new coral communities. Scientists or local people can also help to enhance the process by conducting coral transplantation. However, a further study might be needed to discover more information and possible scenarios to deal with the fisheries activities.

## ACKNOWLEDGEMENT

The authors would like to thank the Seed Fund for Research and Training (SFRT) Program of the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) for providing financial support of this research.

## REFERENCES

- Andrefouete S and AB Riegle. 2004. Remote Sensing: A Key Tool for Interdisciplinary Assesment of Coral Reef Processes. *Coral Reefs*. Vol **23** (1-4).
- Campbell DW. 2003. *Introduction to Environmental Remote Sensing*. Blackwell Publisher. London.
- English SA, C Wilkinson and V Baker. 2001. *Survey Manual for Tropical Marine Resources*. Australian Institute of Marine Science. Townsville
- Estradivari, M Syahrir, N Susilo, S Yusri and S Timotius. 2007. *Coral Reefs of Thousand Islands of Jakarta: Long Term Observation and Monitoring Program*. Indonesia Coral Reefs Foundation, David and Lucille Packard Foundation.
- FAO.2009. *Coral Reef Status of the World*. On-Line. <http://www.fao.org>.
- Hidayah Z. 2008. The Use of GIS for Prawn Farm Development in Tully Cardwell Townsville, North Queensland. *Embryo*. Vol **9** (137-145).
- Ikawati Y. 2001. *Indonesian Coral Reefs*. Science and Techonology Society Indonesia. Jakarta.
- McKenna SA dan GA Allen. Coral Reefs Biodiversity: Assessment and Conservation. *Bulletin of Wildlife Society* Vol : **27** (92-94).
- Moloney J. 2008. *Advance Geographic Information System*. Lecture Materials. School of Earth and Environmental Studies. James Cook University. Queensland, Australia. Townsville.
- Mumby PJ, EP Green, AJ Edwards and CD Clark. 1997. Marine Biology. Vol **130** (193-202).
- Mumby PJ, W Skirving, AE Strong, JT Hardy, dan EF LeDrew. 2004. Remote Sensing of Coral Reefs and Their Physical Environment. *Marine Pollution Bulletin*. Vol **48** (219-228).
- Nahib I, RS Dewi. 2004. Pemanfaatan Citra Landsat Untuk Inventarisasi dan Evaluasi Terumbu Karang : Studi Kasus Kepulauan Kangean. *Jurnal Ilmiah Geomatika* Vol.**10** No.2 (15-29).
- Populus J, W Hastuti, JL Martin,O Guelorget and A Wibowo. 1999. Remote Sensing As a Tool for Diagnosis of Water Quality in Indonesian Seas. *Ocean and Coastal Management*. Vol (**27**).197-215 p.
- Suharsono. 2003. *Introduction to the Coral Reefs Ecosystem*. P3O-LIPI. Jakarta.
- Susilo SB. 2000. *Advance Remote Sensing*. Lecture Materials. Departement of Marine Science and Technology. IPB. Bogor.
- Tissot BN and DM Brosnan. 2003. Long Term Coral Reefs Monitoring Program : Working Towards Scientific, Management and Policy. *Bulletin of Wildlife Society* Vol : **27** (89-91).
- Wulandari dan VP Siregar. 2005. *Application of GIS and Remote Sensing for Marine Protected Areas Development*. [Unpublished Undergraduate Thesis. Departement of Marine Science and Technology. IPB. Bogor]