

**GIS APPLICATION TO DETERMINE CRITICAL CONDITION AND REHABILITATION MODEL OF MANGROVE ECOSYSTEM IN SOUTHERN COAST OF PAMEKASAN REGION MADURA**

**PENERAPAN SIG DALAM MENENTUKAN KONDISI KRITIS DAN MODEL REHABILITASI EKOSISTEM BAKAU PADA DAERAH PESISIR SELATAN PAMEKASAN, MADURA**

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**Abstrak**

Hutan bakau adalah salah satu ekosistem pesisir yang memiliki nilai ekologi dan ekonomi tinggi. Ekosistem ini dikenal karena perannya dalam melindungi pesisir terhadap gelombang dan serangan badai, juga sebagai pendukung kehidupan bermacam-macam organisme laut. Namun, peningkatan jumlah populasi manusia serta kebutuhannya untuk memperluas areal pemukiman dan industri menyebabkan ekosistem bakau terancam. Dimana saat ini luas areal hutan bakau di dunia terus-menerus mengalami pengurangan. Pengalihfungsian hutan bakau menjadi kolam ikan, pemukiman baru, dan penebangan hutan yang tidak terkontrol merupakan faktor utama yang menyebabkan kondisi kritis ekosistem bakau. Terlebih lagi, kecilnya kesadaran dan pengetahuan masyarakat mengenai fungsi dari ekosistem bakau juga memicu hancurnya ekosistem yang berharga ini. Oleh karena hal itu, tujuan dari penelitian ini adalah: untuk mengidentifikasi dan memetakan kondisi kritis ekosistem bakau di daerah pesisir selatan Pamekasan, Madura menggunakan Sistem Informasi Geografis (SIG) dan data citra satelit, untuk merehabilitasi ekosistem dengan mereboisasi vegetasi bakau, untuk meningkatkan kesadaran dan pengetahuan masyarakat mengenai fungsi dari hutan bakau. Identifikasi kondisi kritis bakau dilakukan dengan mengkombinasikan data citra satelit, observasi lapangan, dan wawancara dengan masyarakat local. Selain itu, penanaman kembali vegetasi bakau dan program pengembangan masyarakat dilakukan bersama dengan mahasiswa serta masyarakat local (bersama dengan program KKN)

**Kata kunci :** mangroves, satellite imagery data, GIS, remote sensing

**Introduction**

Mangrove forests are vegetation communities growing in the intertidal zone, between the average sea level and the high tide mark of tropical to subtropical coastlines (Bengen, 2001). A mangrove community consists of a variety of growth forms, from trees, palms, shrubs, vines, epiphytes and ferns. Typical mangrove habitats are periodically subjected to the tidal influence, therefore mangrove plants mostly grow within the sheltered intertidal flat deltaic lands, funnel shaped bays, broad estuarine mouths, shallow or frequently tidal inundated coastlines (Dahuri, 2000).

Despite its significant ecological value, such as protecting coastline from storm surges, supporting aquatic food chains, and filtering coastal waters from pollutants, mangrove forests are threatened by human and natural causes. As a result of rapid coastal developments, expansion of human settlement and the impact of tidal waves and storms, mangrove stands

around the globe declined from 19,809 hectares in 1980 to 14,653 hectares in 2000 (FAO, 2007). Gunarto (2004), reports that the rate of mangroves losses worldwide is around 1 to 2% per year. In 1999 the area of mangrove ecosystems in Indonesia was approximately 8,60 millions Ha. However, almost 5,30 million Ha were in critical condition (Gunarto, 2004). This number was considerably different from the data released by FAO, mentioned that the area of mangrove ecosystems was only 2,5 Ha and continue to decrease.

Related problems were also found by Noor *et.al* (2001) in Indonesia, especially at Jakarta Bay and the North Coast of Java Island. Over 70 percent of Indonesia's remaining mangrove forests are damaged due to human activities. The forestry ministry data shows about 6.7 million of Indonesia's 9.4 million hectares of mangrove forest are damaged, including 2.2 million of which are seriously degraded. The figures do not include mangrove forest that has been cleared or converted for

agriculture (FAO, 2007). Even though the data was different, it was clear that mangrove ecosystems in Indonesia were significantly devastated.

The decline of mangrove forests has become a major environmental issue. The clearance and conversion of mangrove forests is known to have significant effects on the surrounding environments. The destruction of mangrove ecosystems can reduce production of coastal fisheries, because mangrove forests serve as breeding and nursery grounds for many commercial species of fish, crustaceans and mollusks. Mangroves also act as an important buffer as they hold excess sediment and chemicals, preventing infiltration through coastal waters.

In order to assess the extent of the decline of mangrove ecosystems, extensive mapping and monitoring programs are needed. To monitor the change in large-scale coverage of mangrove areas over certain periods of time, remote sensing technology offers many advantages compared to conventional field monitoring (Moloney,2008)

The main benefit of using remote sensing is related to its speed and continuity in collecting space images of a broad area of the Earth's surface. Additionally, periodical data could be obtained in order to assess the change in environment through certain period of time (Prahasta, 2001). By combining remote sensing and Geographic Information Systems (GIS), it is also possible to incorporate other important data from field surveys, statistics of the region and many others. Therefore the condition of mangrove ecosystems from various indicators can also be made (Nath and Sandler,2000)

The lack of awareness and understanding from local people to protect mangrove ecosystems is also giving significant contribution to the destruction. This happens because they do not have knowledge and skill to turn mangrove resources into something with economic value.

To address the issues, this research was conducted to meet these objectives: Firstly, to identify and map the critical mangrove ecosystems of southern cost Pamekasan region Madura using Geographic Information Systems (GIS). Secondly, to rehabilitate the ecosystems by replanting mangrove vegetations, and finally to increase community's awareness and knowledge on the function of mangrove ecosystems.

## **Material and Method**

In general this study was divided into two major activities. The first activity was a comprehensive research to determine the ecological condition of mangrove ecosystems of the study area. The second activity was a series of community development programs to raise local people's awareness in protecting mangrove ecosystems. This study was conducted at southern coast of Pamekasan region Madura.

To determine the ecological status of mangrove ecosystems, three different methods were applied. The first method was used Landsat TM-5 satellite imagery data to measure the coverage area of mangrove forests. To obtain the change of mangrove's area, satellite images from 1990, 2002 and 2012 were obtained. Another important data collected for this study was the 1:25.000 basic map of the study area. This map was obtained from the National Mapping and Survey Agency (Bakorsurtanal) and contained important geographic features, such as administration boundaries, coastlines and land use. Beside mangrove's area, other information could also be gathered, such as NDVI, substrates and the correlation of mangrove forests with other land use classifications. To analyze and visualize the data, two important softwares (ArcGIS 9.3 and ErMapper 7) were employed. Further mathematical analysis was done using Microsoft Excel.

Ecological condition of mangrove forest can also be determined using field observations. The observation was meant to identify mangrove species distribution at the study area, number of vegetations per hectare and the width of mangrove's green belt. Results from field observation can also be used to understand the diversity or dominance of certain mangrove species.

Nonetheless, the status of mangrove ecosystems are not only determined by ecological factors, but also by social factors, for example : knowledge on economical function of mangrove ecosystems or how local people tend to make use of mangrove resources. Therefore, to gather such information, a set of questionnaire was designed and then it was distributed to local communities. The whole information was then scored and weighted to produce several indexes that represent the status of mangrove ecosystem of the study area.

The criteria from the table above were then used to determine the status of mangrove ecosystems of the study areas. The most critical area was then appointed as the location of

Table 1. Criteria to Determine The Critical Condition of Mangrove Ecosystems (Dept of Forestry, 2005)

No	Methods	Classification	Score	Weight		
1	Critical evaluation based on remote sensing data Total Score = (LU x 45)+(NDVI x 35)+(SU x 20) Categories by score : Total Score 100-166 : heavily damaged Total Score 167-233 : damaged Total Score 234 – 300 : good	<i>Land Use (LU) :</i>				
		1.Mangrove forest	3	45		
		2.Mix forest	2			
		3.Mix with urban areas	1			
			<i>Mangrove Coverage and Density (NDVI)</i>			
			1.70-100% coverage, (0.43<NDVI<1.00)	3	35	
			2.50-69% coverage, (0.33<NDVI<0.42)	2		
			3.< 50% coverage, (-1.0<NDVI<0.32)	1		
			<i>Substrates (SU)</i>			
			1.Mud and clay	3	20	
			2.Mix (mud, clay and sand)	2		
			3.Sand and gravel	1		
2	Critical evaluation based on on-site surveys Total Score = (LU x 30) + (NU x 25) + (GB x 30) + (AR x 15) Categories by score : Total Score 100 -200 : heavily damaged Total Score 201-300 : damaged Total Score > 300 : good	<i>Land Use (LU) :</i>				
		1.Mangrove forest	5	30		
		2.Mangroves mix with other vegetations	4			
		3.Mangrove forest surrounded by fish ponds	3			
		4.Mangrove forest located nearby urban areas	2			
		5.Unvegetated areas	1			
			<i>Number of mangrove vegetations/Ha (NU)</i>			
			1. > 2000 vegetations/Ha	5	25	
			2.1500-2000 vegetations/Ha	4		
			3.1000-1500 vegetations/Ha	3		
			4. 500-1000 vegetations/Ha	2		
			5. < 500 vegetations/Ha	1		
			<i>Mangrove green belt thickness (GB)</i>			
			1. 100% (130 x tidal range)	5	30	
			2. 80% - 100% (130 x tidal range)	4		
			3. 60% - 80% (130 x tidal range)	3		
			4. 40% - 60% (130 x tidal range)	2		
			5. < 40% (130 x tidal range)	1		
			<i>Abrasion rate (AR)</i>			
			1. < 1 meter/year	5	15	
	2. 1-2 meters/ year	4				
	3. 2-3 meters/year	3				
	4. 3-5 meters/year	2				
	5. > 5 meters/year	1				

mangroves rehabilitation programs. The rehabilitation program was conducted by plant over 3000-5000 mangrove vegetations. The new planted mangrove vegetations are very vulnerable, especially from strong waves and currents. To protect the new vegetations from waves and currents, several protectors from concrete were also placed in front of the location. Therefore it will increase the possibility of mangrove vegetations to live and grow.

The second activity was aimed to increase the awareness of local communities in protecting coastal environment, especially mangrove ecosystems as well as to give new knowledge on how to make use of mangrove resources. To achieve it, a series of community development programs was conducted. The

program was performed by university students as part of their field activities. In addition, the program was designed to meet local people's issues on mangrove environment, including: focus groups discussion to talk about how to manage mangrove's area and protect mangrove forest from illegal logging. Another program was several training to produce syrups and other kind of supplementary food from mangrove's fruit.

**Results and Discussion**

1. Mangrove's Area Mapping

To identify and calculate mangrove's area, two satellite imagery data were utilized. The data were Landsat ETM/7 image from 2002 and 2012. Data from previous research in 1990

by Suprakto was also used to compare the area as well as to calculate the change.

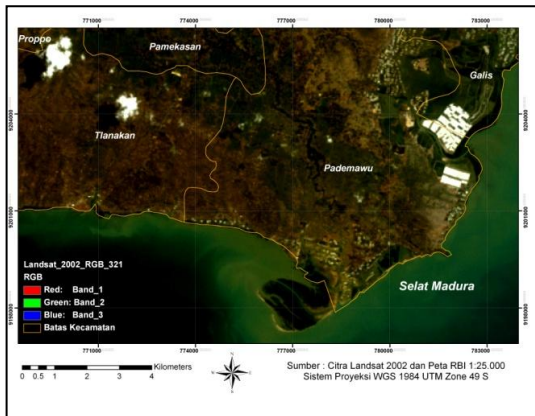


Figure 1. Satellite Image of The Study Area(Landsat 2002)

Four regions of southern coast of Pamekasan were identified to have mangrove ecosystems. The regions were Tlanakan, Pademawu, Galis and Larangan. According to the data analysis, there was a significant decline of mangrove’s area for the entire area. The results are shown in this Table :

Table 2. The change in mangrove’s area (1990-2002)

Regions	Landsat 1990 (Ha)	Landsat 2002 (Ha)	Change (Ha)
Galis	188.37	166.29	- 22.08
Larangan	5.85	7.09	+ 1.24
Pademawu	504	355.50	- 148.5
Tlanakan	40.91	53.59	+12.68
Total Area	739.13	582.46	-156.66

According to Table 2, among the 4 regions the largest mangrove’s area was located in Pademawu region. However, the region faced significant decline of mangrove’s area. Between 1990 until 2002, there were approximately 148.5 Ha of mangroves have been destroyed or converted into fish ponds and salt ponds. Another factor that caused the declined was illegal logging. People usually use mangrove’s timber for firewood and clay industries. The same trend also occurred between 2002 and 2012, as it describes in this table.

Table 3. The change in mangrove’s area (2002-2012)

Regions	Landsat 2002 (Ha)	Landsat 2012 (Ha)	Change (Ha)
Galis	166.29	68.06	-98.23
Larangan	7.09	2.66	- 4.43
Pademawu	355.50	237.43	-118.07
Tlanakan	53.59	18.68	-34.91
Total Area	582.46	326.83	-255.64

To constrict the study area, we choose a particular region that according to our analysis was more vulnerable. Therefore, we choose Pademawu region as our main study site, because its rapid decline of mangrove’s areas compare to others. Pademawu region consist of five villages which are located close to the coast. The villages are: Baddurih, Tlesah, Pagagan, Padelegan and Majungan. Moreover, to determine the most suitable area for mangrove re-plantation and rehabilitation, the critical condition of each village should be investigated.

## 2. Critical Evaluation of Mangrove Ecosystems

Observation on the critical status of mangroves ecosystems of the study area was conducted using several criteria as it showed in Table 1. To asses the level of mangrove critical condition of the study area, 3 analyses were made. A satellite imagery data analysis was conducted to determine the mangrove coverage area.

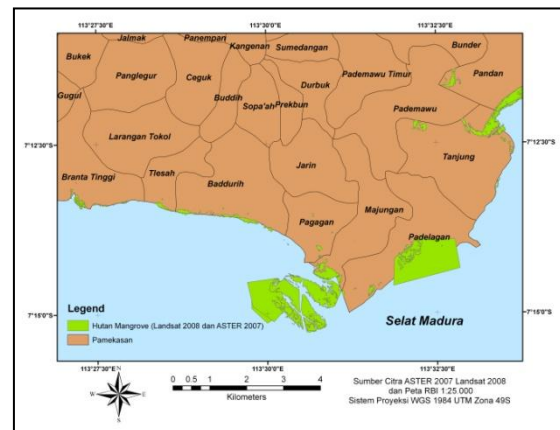


Figure 2. Distribution of Mangrove Ecosystems of the Study Area

Furthermore on-site surveys were conducted to determine mangrove species and its physical condition and finally a social-economic survey was performed to obtain

important information from local people on mangrove's exploitation of the area. Each of analyses was then used to categorize the level of mangrove's critical condition using some criteria. These criteria were developed from The Manual of Mangrove Survey published by The Department of Forestry (2005).

There were 3 main parameters observed during the study, including salinity, pH and water temperature. The results showed that salinity in the study area ranged from 23 – 27 ppm. This feature was lower than general sea water salinity which usually above 30 ppm. It happened because there were fresh water inputs from a river which close to the study area. The results also identified that the average of water temperature was not fluctuate ranged from 27 – 31°C. Within this range of temperature, mangrove vegetation can grow effectively. According to Bengen (2001), mangrove vegetations grow well in water environment with pH ranges from 5 – 9. The ph of the study area vary from 7.4 – 7.7, therefore based on the pH measurements, the study area was suitable as a habitat for mangrove vegetations.

Species which found along the study including *Rhizopora mucronata*, *Rhizopora apiculata*, *Sonneratia alba* and *Avicennia marina*. To calculate the domination of each species, the INP index was applied. The result showed that *Avicennia marina* was more dominant compare to other vegetations (average INP index 147,73). Furthermore, according to the calculation using satellite imagery data, NDVI value of mangrove ecosystems of the study area ranged from -0.64 to 0.25, and can be categorized as sparse to dense coverage.

Moreover, substrate analysis was also conducted during the study. The results revealed that most of the mangroves ecosystem of the study area was dominated by sand (percentage > 70%) and mixed between mud and clay . Sand dominated substrate is considered prone to abrasion due to strong waves and current compare to substrate with high percentage of mud and clay (Moloney, 2008). Although the size of sand particle is bigger, the bound between particles is not as strong as mud and clay. Therefore, the wave energy could easily move sand particles and results on abrasion (Hidayah, 2008)

The three analyses were than combined to produce a critical evaluation of the mangrove ecosystems. Mangroves forest at all observation sites were categorized as critical, except for Majungan village. The status mainly contributed by the NDVI value. From the previous explanation, based on NDVI all mangrove

ecosystems in the study areas can be classified as in the sparse condition. It means that, the area were lack of mangrove coverage in most of the area.

Table 4. Critical Evaluation Based on Remote Sensing Data

Villages	NDVI	Land Use	Type of Substrates	Total Score
Baddurih	135	35	20	190
Tlesah	90	35	40	165
Padelegan	90	35	60	185
Pegagan	90	70	20	180
Majungan	135	70	60	265

Table 4 describes the condition of mangrove ecosystems of the study area using criteria from remote sensing data. It was obvious that most of the mangrove area were under critical condition, except at the Majungan villages which had the highest score, and could be categorized under good condition.

Furthermore, data analysis from on-site observation showed slightly different results. As it explains previously, the critical evaluation with this method is using different criteria, such as: association with other vegetations, number of vegetations/Ha, green belt thickness and abrasion rate.

All mangrove ecosystems on the study areas were not detached, but they were associated with other vegetations. Most of these vegetations were inland trees, flowering shrub and grass. This condition occurred, because mangrove ecosystems of the study area were located not on river's delta, but at the edge of the mainland (Suprakto, 2005). In addition, the similarity between types of substrate was considered to be a factor that makes inland vegetations could grow mutually with mangroves. Moreover, 3 observation sites (Pagagan, Padelegan and Tlesah) had less than 1000 trees/ Ha and only 2 sites (Baddhurih and Majungan) had approximately 1000-1500 trees/Ha.

Moreover, there were variations of the thickness of mangrove's green belt on the sites. The thickest green belt was located at Padelegan and Majungan (127.3 and 175.45 meters respectively), in contrast the less thick green belt was only 10 - 21 meters located on other sites. Abrasion rate on each site was also different. At several locations, abrasion rate reached 1 meters/ year while at the other locations, especially Pegagan, the abrasion reached 2-3 meters/year. Because the rate of abrasion at this location was much higher than the others, it is recommended that the

rehabilitation process could be done at Pegagan village.

The main factors that cause the condition were the utilization of mangrove leaves for cattle food and sand mining. Although mangrove vegetations could regenerate their leaves and timbers, it still needs a sufficient recovering time. When the rate of mangroves leaves exploitation higher than their recovering time, the ecosystems might not be able to restore. Furthermore, if the exploitation continues in daily basis, the existences of the ecosystems are under a serious threat.

Sand mining was also a serious problem for the ecosystems. Local people exploit sand from mangrove forest as materials to build houses. Even tough mangroves have unique root systems that make them capable to grow on soft substrates; rapid exploitation of the sediment could easily destroy the ecosystems. Local people usually cut the root to make them easier to accumulate the sand before it transported to the land. As the root damages, the ability of mangrove vegetations to absorb oxygen and nutrient is lost and as the consequences, the vegetations might lost their ability to grow and die.

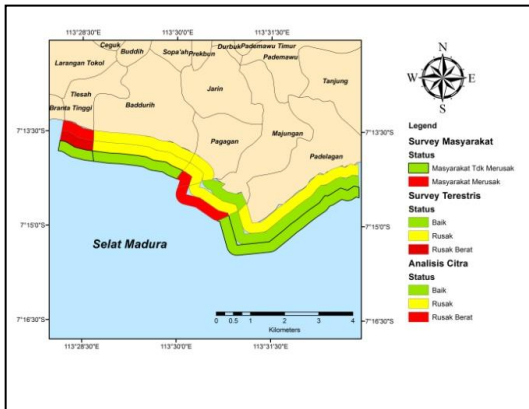


Figure 3. Critical Condition of Mangrove Ecosystems

Based on all information above, a map showing condition of mangrove ecosystems in 5 observation villages was produced. From the above map, rehabilitation or re-plantation location can be identified. The Pegagan village was chosen to be that location, because its vulnerability against abrasion. Beside that reason, it was observed that the rate of mangrove's exploitation at that village was higher than the others. Moreover, Pegagan village was suggested to be the location of rehabilitation because people of the village rely on mangrove for fish stocks. Therefore, a series of conservation and community development

program is needed to increase the quality of the environment as well as increasing community's awareness in protecting mangrove ecosystems.

### 3. Community Development Programs - Mangrove Rehabilitation

The rehabilitation program included seedlings and reforestation activities that involving local communities. A total of 5,000 mangrove trees had been planted. The program in Pegagan village was launched in collaboration with students from Trunojoyo University, local government and communities. By re-planting mangrove trees, it is estimated that the coastal region of Pegagan village will be more protected from abrasion.



Figure 4 .Mangrove Rehabilitation Programs

According to Gunarto (2004) perception of society about mangrove ecosystem should have been change along with community development activity by certain party. Preservation of mangrove ecosystem programs in collaboration of local society, government institution and certain party could make society become subject and have opportunity to actively participate, so they have sense of belonging and can become activists for preservation mangrove ecosystem at their own area.



Figure 5. Mangrove Rehabilitation Location (After two months)

- Training on The Utilization of Mangrove Fruits

Beside their timber and leaves, another mangrove resource that can be utilized is their fruit. It requires simple technique to make beverage from mangrove fruits. However, this knowledge is still unknown by local people, especially those who live in Pegagan village. Therefore, to share this knowledge as well as to increase people's interest in protecting mangrove ecosystems, several training was conducted. The training was aimed to introduce simple technology to make beverage and other supplementary food from mangrove's fruit. In addition the participant we specialized to house wives.

Before we did the training, a laboratory analysis was performed to understand the substances contain within the fruit. We analyzed two species: *Sonneratia* and *Brugueira*. The result showed that *Sonneratia* contains 70.4% vitamin C and only 1.74% carbohydrate. Whereas, *Brugueira* contains 7.92% vitamin C and 82.1% carbohydrate. According to the results, species *Sonneratia* is more suitable as main material for beverages and species *Brugueira* can be used as rice substitutions (Santoso, et.al, 2005)

The training was held several times at different locations. As source persons, we invited experts from Wonorejo Surabaya. This person is a leader of The Wonorejo Farmer Group, who are famous with their ability in making various food and beverages from mangrove fruits. Together with our students, he shared his knowledge and skill in making food and beverage products from mangrove's fruit. There were two products that became the main focus during the training. They were how to make syrup and bulgur (a substitution for rice).

The enthusiasm of villagers to attend and follow the training was reasonably high. Because for them this knowledge was new, and beforehand they thought that mangrove's fruit was inedible. The villagers only harvested mangroves for their leaves and timbers. The high interest of the villagers was also because the good response and support from local authority. They provided places, equipments and other facilities to conduct the training. It showed that they also need to learn more on how to manage and make use of mangrove resources at their village.



Figure 5. Mangrove's Fruit (*Sonneratia* and *Brugueira*)



Figure 6. Beverages Made From Mangrove's Fruit

- Focus Group Discussions on Mangrove's Management

It was also important to give local people knowledge regarding the ecological function of mangroves ecosystems. It is understandable that such knowledge was not easy to deliver to the villagers because most of them do not have high education level. However, it was possible to carry out the idea

through informal talk or discussion. Of course, support from local authority was needed. Therefore, another part of this study was an activity which consists of several discussion sessions with villagers on ecological issues of the ecosystems.

To conduct the discussion we invited villagers to have dinner at the chief's house on particular days. Afterwards, we made presentations using pictures and examples of mangroves function for the villagers. The discussions were done several times, yet with the same participants. The objective was to introduce particular functions of mangrove ecosystems to support daily activities, especially for fisheries. We also provided examples and shared experience on mangrove's management from other places such as Surabaya and Sidoarjo.

Beside lectures on mangrove's function, we also deliver information on negative effects if people cut down mangrove trees continually. Abrasion could happen easily and valuable aquatic organism could disappear from the environment. However, it all can be avoided if the villagers aware on how to exploit mangrove resources without ignoring conservation ethics. With the series of discussion sessions we hope that it can increase capacity building of local communities on fostering and sustaining the growth of mangrove ecosystems.

### Conclusions

To conduct continues monitoring programs in supporting mangrove's conservation, remote sensing and GIS technology have been proved as highly useful tools. Using remote sensing, GIS techniques and a combination of field surveys, critical condition of mangrove can be determined using criteria developed by The Department of Forestry. The awareness and education programs as well as involving local communities in rehabilitation activities will enhance understanding of the mangrove ecosystem at all levels of local government and local communities. This will in turn empower and enable the local government and local communities to contribute towards the management of this ecosystem.

### References

- Bengen, G.D., 2000. *Pedoman Teknis Pengenalan Ekosistem Mangrove*. Pusat Kajian Sumberdaya Pesisir dan Lautan. IPB, Bogor.
- Dahuri, R.2000. *Pendayagunaan Sumberdaya Kelautan Untuk Kesejahteraan Rakyat (Kumpulan Pemikiran Rokhmin Dahuri)*. Lembaga Informasi dan Studi Pembangunan Indonesia (LISPI). Jakarta. vi+146 p.
- Departemen Kehutanan. 2007. *Pedoman Teknis Pemantauan Ekosistem Mangrove*. Jakarta.
- FAO. 2007. *The World's Mangroves 1980–2005*. Forest Resources Assessment Working Paper No. 153. Food and Agriculture Organization of The United Nations. Rome.
- Gunarto. 2004. Konservasi Mangrove Sebagai Pendukung Sumber Hayati Perikanan Pantai. *Jurnal Litbang Pertanian*, 23 (1). 15-21.
- Hidayah, Z. (2008). Current and Sediment Movement throughout Different Tidal Stages. A Field Trip Report. School of Earth and Environmental Sciences. James Cook University.
- Khomsin. 2005. *Studi Perencanaan Konservasi Kawasan Mangrove Di Pesisir Selatan Kabupaten Sampang Dengan Teknologi Penginderaan Jauh Dan Sistem Informasi Geografis*. Pertemuan Ilmiah MAPIN XIV. ITS. Surabaya.
- Moloney, J. 2008. *Advance Geographic Information System*. Lecture Materials. School of Earth and Environmental Studies. James Cook University. Queensland, Australia. Townsville.
- Nath, C. & Sandler, A. 2000. *GIS Application for Fish Farming in Vietnam*. *International Journal of Remote Sensing*. Vol (7). 157 – 171 p.
- Noor, Y., Khazali, Y.M., & Suryadiputra, I.N.N. 1999. *Panduan Pengenalan Mangrove di Indonesia*. PHKA/WI-IP, Bogor.
- Prahasta, E. 2001. *Konsep-Konsep Dasar Sistem Informasi Geografis*. Informatika Bandung. Bandung. 334 p.
- Santoso, N., Nurcahya, B.N, Siregar, F., & Farida, I. 2005. *Resep Makanan Berbahan Baku Mangrove dan Pemanfaatan Nipah*. Lembaga Pengkajian dan Pengembangan Mangrove. Jakarta.
- Suprakto, B. 2005. *Studi Tentang Dinamika Mangrove Kawasan Pesisir Selatan Kabupaten Pamekasan Provinsi Jawa Timur Dengan Data Penginderaan Jauh*. Pertemuan Ilmiah MAPIN XIV. ITS. Surabaya.