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Original Paper

MAPPING OF CORAL REEF ECOSYSTEM IN THE NATUNA ISLANDS USING ALOS IMAGERY

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ABSTRACT

The coral reef ecology of the Natuna Islands has been studied over 10 years. However, none of those studies produced a coral reef map. Maps of coral reef ecosystem are important for planning, management and monitoring tool. The present study integrates the 115 field data and the ALOS satellite data, using depth invariant index algorithm to generate coral reef ecosystem classes. Those classes are: life corals, dead coral and rubble aggregates, mixing of substrates and sand. The algorithm that composed of three visible bands is applicable at clear water rather than at turbid water environment. Hence, vegetation coverage as well as seagrass, seaweed and macro algae which are in small extent and usually covered by fine sand materials and associated with turbid water, cannot be classified.The aim of this research, which is funded by Critic Coremap – LIPI, is to produce map of coral reef ecosystem in the Natuna Islands.

Keywords: Coral reef; remote sensing; ALOS imagery; Natuna islands

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INTRODUCTION

Coral reefs are the most important ecosystem in coastal areas because of their valuable resources for fisheries. The reefs can serve as nursery grounds for marine habitats as well as a natural breakwater and marine tourism resources (Suciati and Arthana, 2008; Hutomo and Moosa, 2005). In the last several decades their presence are easily being threatened by human and natural impacts (Fonseca *et al*., 2010; Cortez and Jimenez, 2003; Giyanto and Budiyanto, 2008).

Satellite data have been widely used as a potential tool for mapping and monitoring the coastal ecosystems. Spatial resolution of the data ranges from 30 m (Landsat TM), 20 m (SPOT), 10 m (ALOS), 4 m (IKONOS), and 0.6 m (Quickbird). Satellite data have also been applied successfully in the Tropical Eastern Pacific region for medium-high resolution mapping of coral reefs in Panama (Guzman *et al.*, 2004; Benfield *et al*., 2007).

Landsat imagery, since launched for 1st generation in 1970's has been used and applied to study the coastal ecosystem. Ahmad and Neil (1994) evaluated Landsat TM data to study the coral-reef zonation at the Heron Reef (Great Barrier Reef), Australia and Matsunaga and Kayanne (1997) used time series of 22 TM images from 1984 to 1995 in a change detection study on the fringing reefs at two sites in Ishigaki Island, Japan. Similarly, researchers have used SPOT (20 m) imagery to survey coral reef abundance (Peddle *et al.1995).* Recently, Purkis and Pasterkamp (2004) was also used Landsat TM 5 image to classify coral reefs and to determine water depth in the Red Sea, with increase accuracy of 76%.

The ALOS Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) is a visible and near infrared radiometer for observing land and coastal zones. It provides better spatial land-coverage maps and land-use classification maps for monitoring regional environments. AVNIR-2 is a successor to AVNIR that was on board the Advanced Earth

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Observing Satellite (ADEOS), which was launched in August 1996.

Suciati and Arthana (2008) used ALOS imagery to classify coral reef ecosystem in the Badung Strait, Bali. They pointed out that many erroneous encountered at the reef slope and suggested that objects which are located on the incline position cannot be all recorded vertically. However, the accuracy of classification result was reported 87%.

Dobson and Dustan (2000) and Dustan *et al*., (2001) noted that coral reefs consist of a mosaic of fine-scale features between 1 to 5 m in size with complex optical signatures that blend as individual fields of view become larger. For these purposes, the relatively coarse spatial resolutions of TM and SPOT may have a limited effectiveness in coral reef studies. Mumby *et al*., (1998) noted that although TM and SPOT can detect benthic signals through clear water to a depth of approximately 25 m, the coarse spatial and spectral resolutions of these systems limit classification results to broad-based geomorphological information, rather than biotic assemblages. The same authors concluded that a pixel size of 3 to 4 m such as Ikonos is probably optimal for surveying tropical marine environments.

Satellite data used in the study are ALOS images with 10 m resolution recorded on 7 April 2010. In order to reduce the shifting of positional transformation between field survey stations in the satellite data and to eliminate some erroneous of interpretation as pointed by authors above, the field data sampling is every 10 m^2 for representing a pixel in the image.

Field survey data used in this study are collected as a part of the CRITIC-COREMAP Project Phase II. About 115 field survey data are collected during June 2008 in the 1^{st} phase and March 2010 in the 2^{nd} phase. The data describe the presence and the percentage of coral coverage, type of seabed substrate and other parameters. The present study demonstrates the effective integration of ALOS satellite data and field survey data for coral reef ecosystem mapping in the Natuna Islands.

MATERIALS AND METHODS

Satellite data used in the study are ALOS AVNIR-2 recorded on 7 April 2010 with identity scene of ALAV2A044933770. The characteristic of data is shown in the table below:

Table 1. The characteristic of ALOS satellite data

Channels (Bands)	Wavelength (µm)	Position	Resolution
Band 1	0.42 – 0.50	Red (visible)	10 m
Band 2	0.52 – 0.60	Green (visible)	10 m
Band 3	0.61 – 0.69	Blue (visible)	10 m
Band 4	0.76 – 0.89	Near Infra Red	10 m

Study site is located in the south part of the South China Sea between 107°50’E - 108°30’E; 3°37’N - 4°16’N, about 570 km northwest of Pontianak (West Kalimantan) and 560 km northeast of Riau Islands (**Fig. 1**).

Instruments used in the field survey are: Garmin GPSmap 76CSx, snorkeling equipment, square transect (1 x 1 m), roll meter, digital camera and under water paper. Field data collection is using line intercept transect (English *et. al.*, 1997). Field surveys are carried out in two phases: 1^{st} phase is in June 2008 and is collecting 45 stations and 2^{nd} phase is in March 2010 and is collecting 70 stations. It is assumed that there is no significant coastal ecosystem changed in the last two years.

The image processing consists of two steps: (1) image pre-processing that includes geometric reposition, atmospheric correction, glint removal, scooping / digitizing; and (2) image processing using *depth invariant index* algorithm of the three visible bands to generate coverage classification. Softwares used in the image pre-processing and image processing are ENVI vers. 4.3 and ArcGIS vers. 9.2 and spreadsheet Excell.

The geometric correction / reposition is performed using 6 easily known ground control points such as bridge, cross road and river mouth to improve the image in the geographic

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position in Universal Transfer Mercator (UTM) WGS84 coordinate system.

The atmospheric correction is aimed to minimize the effect of atmospheric particles such haze in the image. As known that rayleigh scatter in the atmosphere can produce thin fog which have a stronger effect on the shorter wavelength bands (Lillesand and Kiefer, 1994 and Mishra *et al.,* 2006). Method used for atmospheric correction is *dark pixel subtraction* (Spitzer and Dirks, 1987; Armstrong, 1993; Maritorena, 1996). A large number of pixels are sampled from the darkest area at deep water and their average value in each band then is used to subtract from all other pixels in each band respectively:

Atmospherically corrected radiance = $L_i - L_{si}$

Where:
L_i is the pixel radiance in band *i* and
L_{si} is the average radiance for deep water in band *i*.

The atmospheric method relies on the assumption that all radiations fall into the water's surface are either absorbed or reflected. The darkest pixel of deep waters in the image contains minimal reflected light and the rest of energy that is absorbed. Therefore, the remaining radiance values in the pixel represent the atmospheric effects.

The glint removal is to eliminate the glint effect, there are parallel shadows in the image due to reflected light on the crests and slopes of waves generated by winds. The method proposed by Hochberg *et al.* (2003) based on the linear regression between near infra red band and other three visible bands on the glinting area will be used to eliminate this effect. Algorithm to generate the glint removal is:

$$R_i' = R_i - b(R_{nir} - Min_{NIR})$$

Where:
R_i' is the pixel radiance in visible band *i*
R_{nir} is the pixel radiance in near infra red band
Min_{NIR} is the minimum value of the near infra red band in the darkest area (deep sea).
b is gradient of the regression

Information of coastal area through satellite data will optimally collected when land that include all upland features such as land, buildings on the sea water, boats, piers, clouds and deep sea waters are eliminated (Jensen *et al.,* 1991). Elimination all of these features can be done through scooping / masking by on screen digitizing and remain the reef flat areas with using Arc GIS vers. 9.2 software. The polygons generation then be used to crop the image.

The image processing based on the concept of bottom reflected radiance is a linier function of the bottom reflectance and an exponential function of the water depth. The intensity of light penetration decreases exponentially with the increase of water depth. This process is known as *depth invariant index* proposed by Lizenga (1978). Three steps to build the algorithm are:

1) Linear relationship between depth and radiance
   In relatively clear water, the intensity of light will decay exponentially with increasing depth. If values of light intensity (radiance) are transformed using natural logarithms (ln), this relationship with the depth of water becomes linear.
2) Calculate the ratio of attenuation coefficients for band pairs
   Two visible bands are selected and a bi-plot made of (log transformed) reflectance for the same substratum (sand) at differing depths. Since the effect of depth on measured radiance has been linearized and the substratum is constant, the pixel values for each band will vary linearly according to their depth, with the slope representing the ratio of the attenuation coefficients of the two visible bands.
3) Generate a *depth-invariant index* of bottom type
   If reflectance values for other habitats are added to the bi-plot, similar lines with the same slope will be obtained, with each differing in position (and intercept at the y-axis) according to the reflectances of the different habitats. Each pixel can be converted mathematically to its intercept value (or depth-invariant index) to remove the effect of depth. The equation to generate one depth-invariant band from each band-pair is simple formula:

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$$depth - invariant\ index_{ij} = \ln(L_i) - \left[\left(\frac{k_i}{k_j}\right) . \ln(L_j)\right]$$

Where:

ln Is the natural logarith

L_{ij} are the pixel radiances in band i and band j

k_i/k_j is the ratio of their attenuation coefficients as determined from sand patches at varying depth.

The new composite image generated from the three above algorithms and the plot of field data are then used as a training area. Type of maximum likelihood of supervised classification will generate a map of coastal ecosystem.

Fig. 1. Location of the study site around the Bunguran Island.

RESULTS AND DISCUSSION

Image Pre Processing Geographic reposition.

As we know, the original ALOS imagery is not corrected geographically and usually it is shifted 100 m eastward. The method used in geographic reposition is geocoding polynomial transformation based on nearest neighbor. The geographic reposition of image in the study area and the plot of field survey data are shown in the **Fig. 2**.

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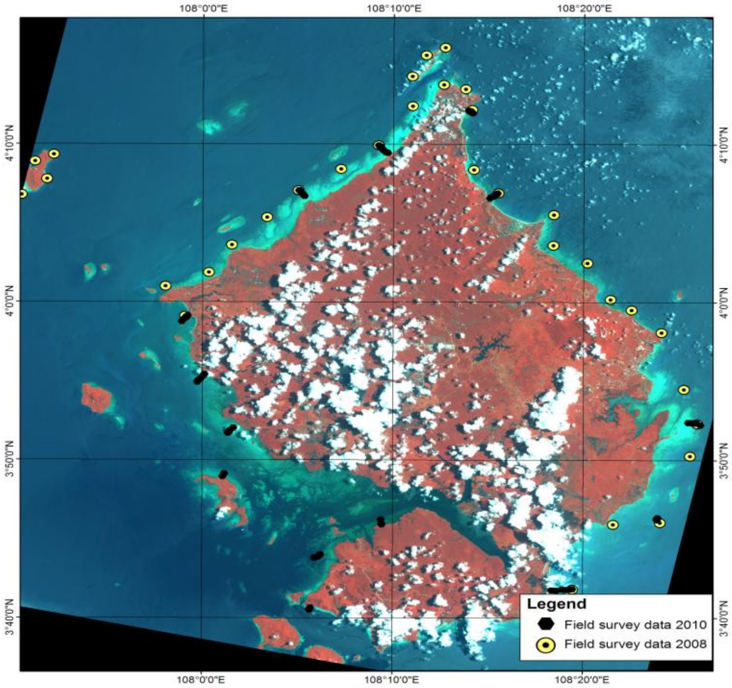

Fig. 2. RGB composite image of Band 4 (Red), 2(Green) and 1 (Blue) of the ALOS after geographic reposition. Black and yellow dots are the field sampling points.

Atmospheric correction

The image received from the provider is atmospherically corrected. The atmospheric correction here is to remove scattering in the atmosphere and external reflection from water surface through dark pixel subtraction in the dark area (deep sea). However, the result is not different significantly.

Glint removal

Natuna Islands are located in the South China Sea and its eastern coast is open to the ocean. The waves that generated by winds will move to the coast, and hence will cause glint effect in the recorded image. Based on the bi-plot of pair bands of visible (band 1, 2 and 3) and near infra red (band 4), the pixels that are collected over the glint areas show linear regression (**Fig. 3**). **Fig. 4** shows crop of the image sample after glint removal at the eastern coast of the study area and the under water sands are clearly shown.

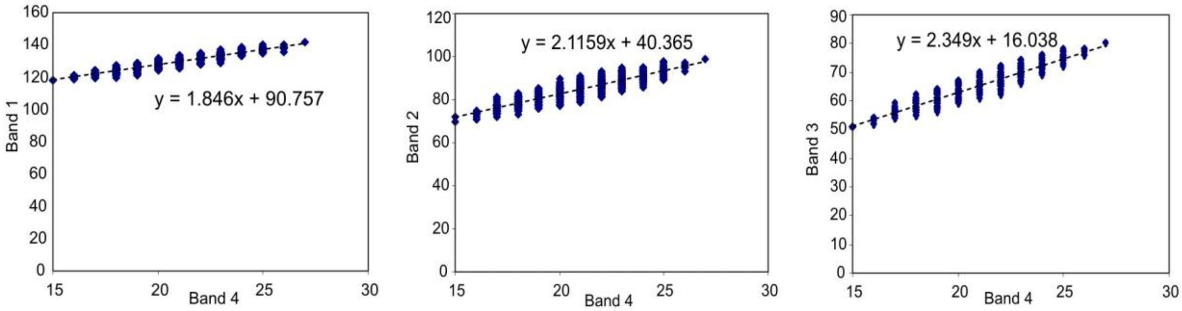

Fig. 3. Bi-plot and linear regression of pair bands of visible (band 1, 2 and 3) and near infrared (band 4) from pixels collected over the glint areas.

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Fig. 4. The image before glint removal (left) and after glint removal (right)

Scooping / masking

Scooping / masking is aimed to generate vectorized map of the coral reef ecosystem area that will be used to crop the focused area from the full scene image. When the satellite data remain focused on the coral reef ecosystem area, the values of spectral data collected through the image can be stretched wider. Wider range of spectral data means greater detail variability in the image that will generate better classifications. The map of coral reef ecosystem area in the Natuna Islands is about 2270 hectares.

Image processing

After pre-processing the image, we can easily distinguish sand material and other materials such as rocks, corals, deep sea sand, etc. The natural logarithmic (ln) of reflectance values collected through sand materials from various depth of the image in each visible band and the plot of pair bands in the study area are shown in the **Fig. 4.**

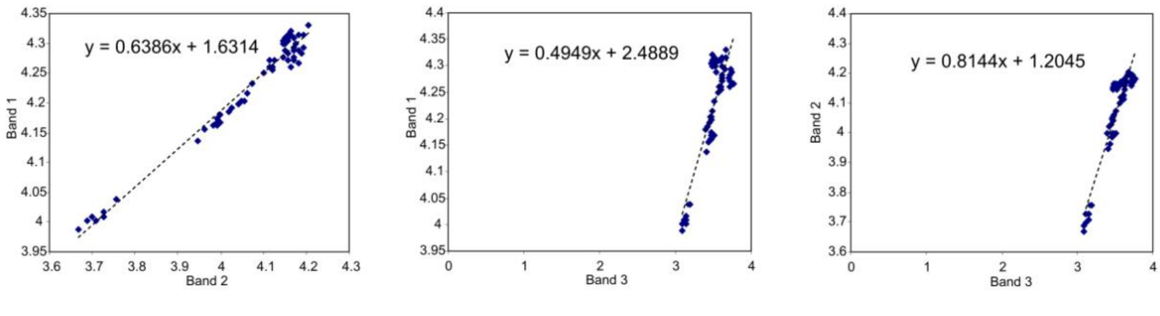

Fig. 5. Bi-plot and linear regression of pair bands from pixels collected over the sand areas in various depths.

Fig. 5 shows the values of regression gradient (ki/kj) of each pair band. The new image generation from the depth invariant index algorithm is RGB (red green blue) composite image, which R is generation through Band 1/Band 2, R is Band 1 / Band 3 and B is Band 2/Band 3.

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Field survey data

Habitat mapping is the spatial representation of the classified habitat units. In general, habitats are identified as spatially recognizable areas where the physical, chemical, and biological environment is distinctly different from surrounding environments.

Collected field data have details about description, percent of coverage, type and other parameters of substrates. In order to reduce the erroneous positional transformation of field stations into the image pixel, each field station should covered an area of 10 m square to represent a pixel in the image. As we know the presence of substrates in the coral reef ecosystem are heterogeneous rather than homogeneous. Major benthic features are distinguished including life corals, death corals, rubble, sand and even more mixing among them. However, it is difficult to separate between dead corals and rubbles in the classification due to these substrates are intimately associated.

Vegetation coverage as well as seagrass, seaweed and macro algae are found in some spots with small extent and their crops are usually covered by fine sand materials. In such this case, it will appear as sand material rather than as vegetation. It has been suggested that *depth invariant index* will perform well at clear water rather than at turbid water environment where vegetation growing rapidly.

Integration of field data to generate classification map of coral reef ecosystem

Based on the type and percent of substrate coverage collected through field survey data, the following five classes of coral reef ecosystem in the Natuna Islands are proposed **(Table 2**). The classification referred to Mumby *et al.,* (2002) based on the ecological approach and is using of maximum likelihood to produce different classes. The scheme relies on the analysis to define distinct areas with a unique spectral signature or training sites. The training sites that consist of 115 field survey data will perform as a seed pixel where polygons are growing automatically and drawn around contiguous area which having similar spectral properties. The accuracy of the classification depends on the number of the extent for each class. Once the training sites are generated, the similarity of the signatures for each class has been measured using statistical methods.

Table 2. Classification proposed of the coral reef ecosystem in the study area.

No.	Class	Major component	Other components
1	Life corals	Life corals > 55%	death corals, rubble, sand, vegetation
2	Dead corals and rubbles aggregates	Dead corals and rubble aggregates	life corals, rubbles, sand, vegetation
3	Mix of substrates	No components > 51%	life corals, dead corals, rubbles, sand, vegetation
4	Sand	Sand > 51%	life corals, dead corals, rubbles, sand, vegetation

Map of the coral reef ecosystem in the Natuna Islands is shown in **Fig. 6.** Our results show that the western part of the Islands has a life coral area of 147 ha., while the eastern part is about 50 ha. It is suggested that geographical position play an important role in the existence of the coral reefs. The presence of small islands in the western part will perform as a natural breakwater.

CONCLUSION

The ALOS satellite data with 10 m resolution and the depth invariant index are applied to study the coral reef ecosystem in the Natuna Islands.

The 10 m resolution image is unable to identify vegetation coverage such as seagrass, seaweed and macro algae with small extent and due to their crops are usually covered by fine sand materials.

The life corals in the western part of the Islands are found wider than that in the eastern part. It is suggested that the presence of small islands in the western part will protect them from the incoming waves

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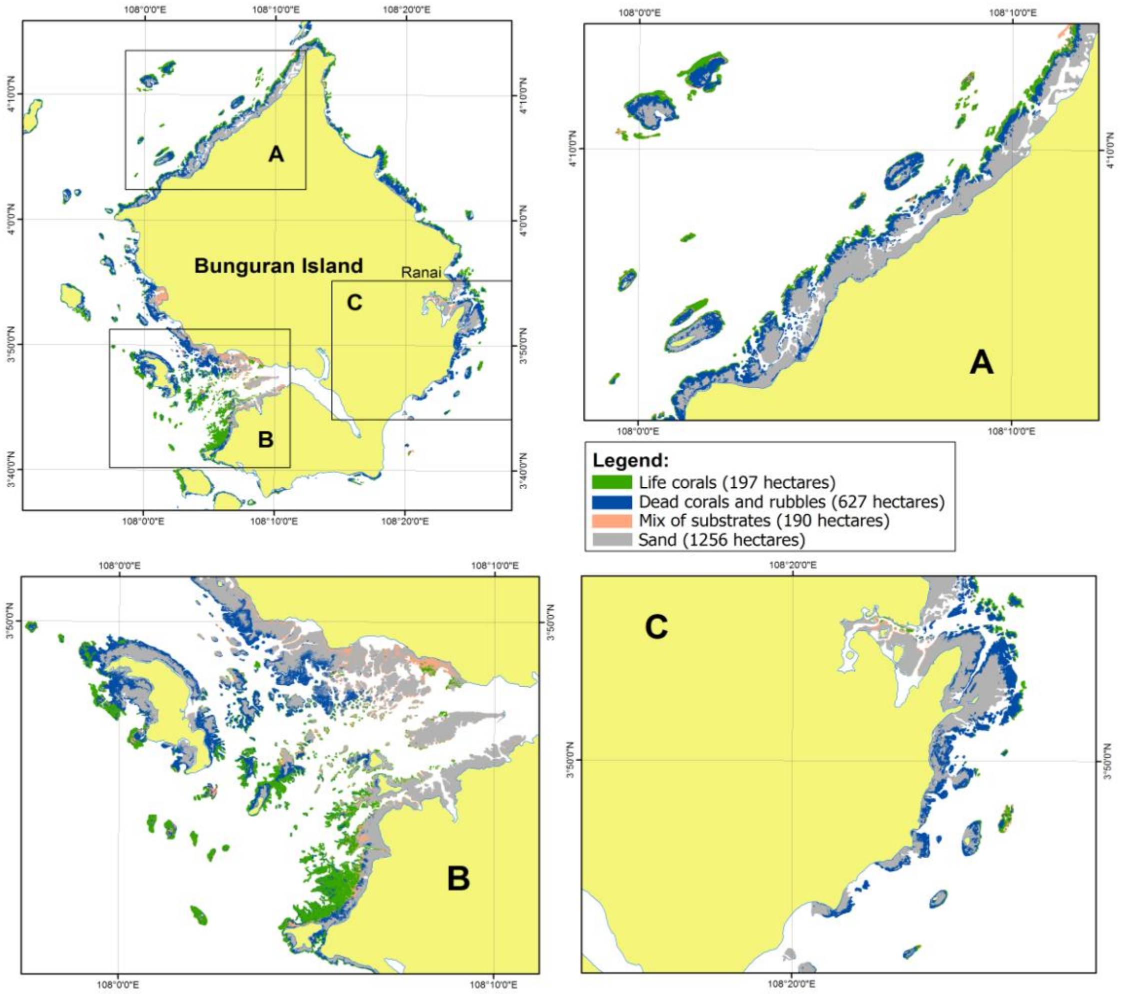

Fig. 6. Map of coral reef ecosystem classification in the Natuna Islands

REFERENCES

Ahmad, W. and D. Neil, 1994. An evaluation of Landsat Thematic Mapper digital data for discriminating coral reef zonation: Heron Reef (GBR), *Int. J.Remote. Sens.* 15(13):2583–2597.

Armstrong, R.A. 1993. Remote sensing of submerged vegetation canopies for biomass estimation. *Int. J. Remote. Sens*. 14, 621–627.

Benfield, S.L, H.M. Guzman, J.M. Mair and J.A.T. Young. 2007. Mapping the distribution of coral reefs and associated sublittoral habitats in Pacific Panama: a comparison of optical satellite sensors and classification methodologies. *Int. J. Remote. Sens.* 28: 5047-5070.

Cortes, J. and C.E. Jimenez. 2003. Corals and coral reefs of the Pacific of Costa Rica: history, research and status. Latin American Coral Reefs. *In*: Cortes, J.

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

(ed.): 361-385. Elsevier Science, Amsterdam, Netherlands.

Dobson, E. and P. Dustan. 2000. The use of satellite imagery for detection of shifts in coral reef communities, *Proceedings of the American Society for Photogrammetry and Remote Sensing Annual Meeting*, 22–26, May, Washington, D.C., unpaginated CD-ROM.

Dustan P, E. Dobson and G. Nelson. 2001. Landsat TM: detection of shifts in community composition of coral reefs. *Conserv. Biol.* 15:892–902.

English S, C. Wilkinson and V. Baker. 1997. *Survey manual for tropical marine resources*. Australia of Marine Science, Townsville: 390 p.

Fonseca A.C., H. M. Guzman, J. Cortes and C. Soto. 2010. Marine habitats map of Isla del Cano Costa Rica, comparing Quickbird and Hymap images classification results. *Int. J. Trop. Biol.* 58 (1): 373-381.

Giyanto dan A. Budiyanto. 2008. Struktur komunitas karang batu dan kondisi terumbu karang di perairan Teluk Lampung. *Oseanologi dan Limnologi di Indonesia* 34(2):199-221. (in Indonesian)

Guzman, H.M, C.A. Guevara and O. Breedy. 2004. Distribution, diversity and conservation of coral reefs and coral communities in the largest marine protected area of Pacific Panama (Coiba Island). *Envir. Conserv.* 31: 1-11.

Hochberg E.J., S. Andrefouet and M. Tyler. 2003. Sea surface correction of high spatial resolution Ikonos images to improve bottom mapping in near-shore environments. *IEEE Transact. Geosci. and Remote Sens.* 41(7): 1724 – 1729.

Hutomo, M and M.K. Moosa. 2005. Indonesian marine and coastal biodiversity: present status. *Indian J. Mar. Sci.* 34(1):88-97.

Jensen J.R., S. Narumalani, O. Weatherbee and H.E. Mackey. 1991. Remote sensing offers an alternative for mapping wetlands. *Geo Info Systems* 1(8): 46-53.

Mishra D, S. Narumalani, D. Rundquist, and M. Lawson. 2006. Benthic Habitat Mapping in Tropical Marine Environments Using QuickBird Multispectral Data. *Photogrammetric Engineering and Remote Sense* 72 (9):1037–1048.

Lilliesand, T.M. and R.W. Kiefer. 1994. *Remote sensing and image interpretation*. John Wiley and Sons, Inc. New York, 750 p.

Lyzenga, D.R. 1978. Passive remote sensing techniques for mapping water depth and bottom features. *Appl. Opt.* 17: 379-383.

Maritorena, S. 1996. Remote sensing of the water attenuation in coral reefs: a case study in French Polynesia. *Int. J. Remote Sens.*, 17, 155–166.

Mumby P.J, C.D Clarke, E.P. Green and A.J. Edwards. 2002. Benefits of water column correction and contextual editing for mapping coral reefs. *Int. J. Remote. Sens.* 19 (1):203–210.

Purkis, S.J. and R. Pasterkamp. 2004. Integrating in situ reef-top reflectance spectra with Landsat TM imagery to aid shallow-tropical benthic habitat mapping. *Coral. Reefs.* 23: 5–20.

Peddle, D., E. LeDrew, and H. Holden, 1995. Spectral mixture analysis of coral reef abundance from satellite imagery and in-situ ocean spectra, Savusavu Bay, Fiji, Proceedings, third thematic conference on remote sensing for marine and coastal environments, 18-20 September, Seattle, Washington, 2:563-575.

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Accredited : 83/Kep/Dikti/2009

Spitzer, D., and R.W.J. Dirks. 1987, Bottom influence on the reflectance of the sea. *Int. J.Remote Sens.* 8: 279–290.

Suciati and I.W. Arthana. 2008. Study of coral reef distribution around Badung Strait using Alos satellite data. *Ecotrophic* 3(2):87-91.