Coral Reef and Associated Habitat Mapping Using ALOS Satellite Imagery
(Pemetaan Terumbu Karang dan Habitat Persekitarannya Menggunakan Imej Satelit ALOS)

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ABSTRACT

Coral reefs are rich in biodiversity and ecosystem services. However increase in degradation are still occurring at an alarming rate. In management of this ecosystem, determination of its spatial distribution is of importance. Satellite imageries can be used to map distribution extent using spectral characteristics which is a fundamental parameter in mapping. The aims of this study were to determine the spectral characteristics of corals and associated habitats and to map its spatial distribution using 2009 ALOS advanced visible and near infrared radiometer type 2 (AVNIR-2) satellite imagery. Results indicated that coral and habitats surrounding the area display variation in the spectral characteristics magnitude but displays similar spectral curve. Spectral characteristics from the corals and surrounding habitats were determined by presence of benthic microalgae and calcium carbonate. Maximum likelihood classification on the image produced five main classes. Spatial distribution of coral and associated habitats indicated five main zones which are sandy shore zone, sandy intertidal zone, seagrass zone, coral/submerged sandy zone and rocky zone. Distribution of live corals indicated coverage of 0.54 km^2, sea grass (0.94 km^2), sandy bottom (1.31 km^2) and rocky shores (0.19 km^2). The results of this study indicated that ALOS satellite data was able to determine variation in spectral characteristics of coral reefs and other habitats thus is capable of mapping the ecosystems spatial distribution.

Keywords: ALOS satellite imagery; mapping; reef habitat; spatial distribution; spectral characteristics

ABSTRAK

Terumbu karang merupakan ekosistem yang kaya dengan kepelbagaian biologi. Walau bagaimanapun degradasi ekosistem ini semakin meningkat. Penentuan taburan reruang ekosistem ini amat penting dalam membantu pengurusan. Data satelit berupaya memetakan taburan menggunakan ciri spektrum yang merupakan parameter asas dalam pemetaan. Objektif kajian ini adalah penentuan ciri spektrum karang dan habitat persekitarannya dan memeta taburan reruangnya menggunakan imej satelit ALOS (kemaraan ketara dan inframerah dekat radiometer jenis 2 (AVNIR-2) tahun 2009. Hasil menunjukkan karang dan habitat persekitarannya mempunyai variasi dalam magnitud spektrum tetapi mempunyai lekuk spektrum yang sama. Ciri spektrum karang dan habitat persekitarannya ditentukan oleh kehadiran mikroalga bentik dan kalsium karbonat. Pengelasan kebolehjadian maksimum ke atas imej menghasilkan sejumlah lima kelas. Taburan reruang karang dan habitat persekitarannya menunjukkan lima zon utama iaitu zon pantai berpasir, zon pasang surut berpasir, zon rumput laut, zon karang berpasir dan zon berbatu. Taburan karang hidup meliputi 0.54 km^2, rumput laut (0.94 km^2), habitat berpasir (1.31 km^2) dan pantai berbatu (0.19 km^2). Hasil kajian menunjukkan satelit ALOS berupaya menentukan variasi ciri spektrum terumbu karang dan habitat persekitarannya, dengan itu berpotensi digunakan dalam pemetaan taburan reruang ekosistem terumbu karang.

Kata kunci: Ciri spektrum; habitat karang; imej satelit ALOS; pemetaan; taburan reruang

INTRODUCTION

The world's coral reefs have the greatest genetic diversity and provide substantial global economic benefits. It is an important ecosystem mainly to tropical countries. Reefs and habitats associated with it serve as tourist attraction and generate economic returns. It is considered as important as the tropical rain forest in terms of biodiversity and complexity (Kenchington 1985). In the global scale, coral reef covers an area of 600000 km^2. The waters off Northeast Asia and Indian Ocean are areas with high coral reef abundance. Waters off Northeast Asia alone comprises 30% of world reefs (Lin 1992).

At global scale degradation rate of the coral reefs are increasing. Global warming, tourism activities and development with their corresponding erosion and runoff are significant factors that maybe contributing to the damage and rapid changes in coral communities. It is estimated that with the high rate of degradation now, 60% of the coral reef areas will be destroyed in 20 to 40 years (Jackson 1995). Human activities are destroying the coral reef ecosystems. Resulting sediments, nutrients and exploitation are the main threat (Johannes 1975). Monitoring of these ecosystems is important to obtain data on diversity of an area, its status, health and changes

occurred. Knowledge on the benthic community is important in understanding its ecology. Habitats associated with the reefs for example dead corals, sea grass, sandy and rocky areas are important information in identifying shifts between corals and algae (Done 1992), to understand the productivity and metabolic rate of a community (Kinsey 1985), its biochemical cycle and for target species conservation (Price 1987).

Understanding the ecology of coral reefs is still limited due to difficulties in mapping and monitoring corals and habitat on a wide spatial and temporal scale. Improved methods for mapping coral reef communities and providing rapid assessment of the health and stress response of these ecosystems are now being widely implemented. A number of studies are continuing to investigate the scientific and management applications of detailed reef mapping (Harding et al. 2006; Mumby & Harborne 1999; Spalding & Grenfell 1997). Remote sensing offers an alternative for mapping and evaluating coral health as well as detecting change over time. For example, performance of several satellite sensors were compared for coral reef habitat mapping in South Pacific reefs (Capolsini et al. 2003). Large-scale assessment of reef productivity in French Polynesia was implemented by using SPOT images to scale-up field measurements of production and calcification in individual lagoonal habitats (Andréfouëta & Payri 2001). A new method was developed that explicitly link the species composition of individual communities to maps of community distribution. It calculates measure of diversity from pixels within a window passed throughout a habitat map (Mumby 2001). Such methods attempts to remove arbitrary aspects of habitat mapping and can be scaled to levels of diversity. Thus it can identify hotspots of beta and habitat diversity and aid spatial decision-making. Monitoring and assessment of coral reef and its relative bottom covers are most important. Spectral characteristics of corals are fundamental parameters in coral reef remote sensing. These reefs and associated habitats have been reported to be spectrally distinct from each other. However, because coral reefs are highly heterogeneous, the spatial resolution of currently available, widely used satellite imagery (Landsat TM, Landsat ETM+) is considered to be too coarse to map reefs in detail (Andréfouëta et al. 2001). Several moderate to high-resolution satellite sensors currently orbit the earth and are capable of collecting detailed imagery. Ikonos satellite sensor imagery has been used to detect changes in coral reef communities (Palandroa et al. 2003) and QuickBird multispectral data for identifying and classifying tropical-marine benthic habitats (Mishra et al. 2006). The potential for extracting useful thematic information was significantly increased because of the moderate and high spatial resolution offered by the satellite's multispectral sensor system. The objectives of this study were to determine the spectral characteristics of corals in Tinggi Island, Johor and its associated habitats and to determine its spatial distribution using ALOS satellite imagery.

MATERIALS AND METHODS

STUDY AREA

Tinggi Island Marine Parks consists of 13 widely scattered islands in the state of Johor and Tinggi Island is the largest island and is relatively close to the shoreline of Peninsular Malaysia. Tinggi Island is located at the northeast of Johor, Malaysia (2°18'N, 104°07'E) (Figure 1). It was gazetted as a marine park in 1994 under the Malaysia's Fisheries Act and thereafter, waters up to 2 nautical miles from the lowest low water mark came within the jurisdiction of the Department of Marine Parks, Malaysia. It covers an area of 16 km^2. This island is rich in biodiversity consisting of coastal forest, mangroves, low land forest and dipterocarps. The island is also dominated by sea grasses and coral reefs. It experiences warm temperature and humidity of 90%. The main economic activities of the island are tourism and fisheries related industry. Services such as discarded refuse removal and sewage treatment are not as advanced as in the other states. The proximity of the parks to Singapore facilitates revenue from tourism.

IMAGE ANALYSIS

Satellite data of ALOS advanced visible and near iInfrared radiometer type 2 (AVNIR-2) with 10 m resolution acquired in 2009 focusing on Tinggi Island, Johor was processed using ERDAS Imagine and ArcGIS. ALOS is a visible and near infrared radiometer for observing land and coastal zones (Table 1). It provides spatial land-coverage maps and land-use classification maps for monitoring regional environments.

Image analysis consisted of several processes (Figure 2). Pre-processing was implemented where the image was projected and geometrically corrected. Masking of land and cloud areas were conducted. In order to optimize the satellite imagery for visual interpretation, determination of band ratio was implemented using optimum index factor (OIF) method introduced by Chavez et al. (1982). This was to obtain the color composite that optimally visualizes interpretation of the image. The highest OIF values are the three bands having the most information content. This measure favours the selection of those bands having high variances and low pair wise correlation. The index is given by:

$$OIF = \sum_{i=1}^{3} SDi \Big/ \sum_{j=1}^{3} ABS(CCj), \qquad (1)$$

where SDi is variance of band i, ABS(CCj) is absolute value of correlation within any two bands possible from the 3 band combination.

Analysis of spectral characteristics of benthic habitats is necessary for the classification of satellite data. The analysis of spectral characteristic was based on relationship between band and ALOS digital number (DN). ISODATA classification was implemented on the image. Futher classification by maximum likelihood was then performed
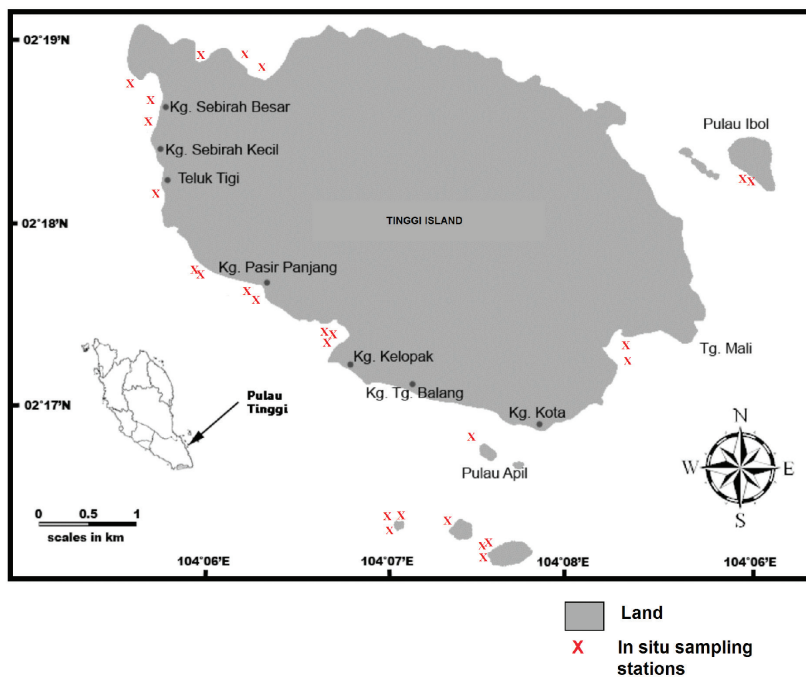
FIGURE 1. Map showing location of Tinggi Island at the northeast of Malaysia and sampling stations (marked X) for *in situ* measurements of the geographical position for verification and accuracy assessment purposes

TABLE 1. ALOS satellite data specifications

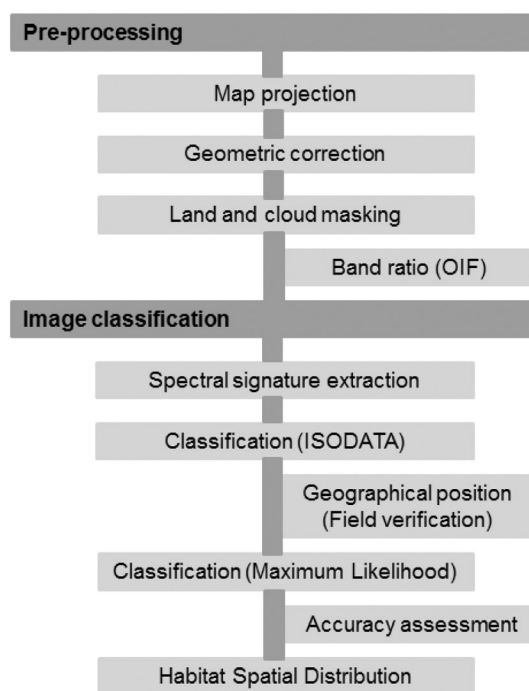|	Channels (Bands)	Wavelength (μm)	Position	Resolution
SENSOR ALOS/AVNIR-2	Band 1	0.42 – 0.50	Red (visible)	10 m
	Band 2	0.52 – 0.60	Green (visible)	10 m
	Band 3	0.61 – 0.69	Blue (visible)	10 m
	Band 4	0.76 – 0.89	Near InfraRed	10 m

FIGURE 2. Flow chart showing analysis method of the ALOS data

on the image. Habitat boundaries were delineated around signatures (areas with specific color and texture patterns) in the imagery corresponding to habitat types. The classification referred to Mumby et al. (2002) was based on the ecological approach to produce different classes. The scheme relies on the analysis to define distinct areas with a unique spectral signature or training sites.

The *in situ* measurements of the geographical position for verification and accuracy assessment purposes were acquired. Field survey using square transect (1 × 1 m) was carried out by SCUBA diving and photos of corals and habitats (sandy, rocky and sea grass) were captured. Field data collection was done by using line intercept transect (English et al. 1997). Reliability of classification was tested using kappa coefficient.

RESULTS

HABITAT SPECTRAL CHARACTERISTICS

Analysis of spectral characteristics of the coral reef and the habitats is necessary for the classification of the ALOS satellite data. Band combination of 1, 2 and 3 which had the highest OIF value was chosen to analyze the spectral characteristics of the habitat (Figure 3). The highest OIF value also indicates the combination with the most information. These three bands have the capability of reading water column reflectances. In this study live coral consisted of different species of live corals in the area. Other habitats were dead corals, sand, rocks and sea grasses. There is a need to explore the hyperspectral

domain in remote sensing to understand the spectral behaviour of coral colonies. The value of the spectral characteristics in this study indicated significant difference (at level 95%). Coral reefs and habitats surrounding the area displayed variation in magnitude of the spectral characteristics (Figure 4).

All features had greater DN at band 1 and similar prominent peaks at bands 2 and 4. Meanwhile the lowest DN was observed at band 3. In all the bands, sand had an overall higher DN followed by dead corals, rocks, live corals and sea grass. Sand, dead corals and rocks were of similar range of higher magnitudes and curve. Meanwhile live corals and sea grass displayed similar lower magnitude curve.

HABITAT MAPPING

Habitat mapping represents classified habitat spatialy. Habitats are identified as spatially recognizable areas where the physical, chemical and biological environment is distinctly different from surrounding environments. Presence of substrates in the coral reef ecosystem were sometimes heterogeneous and homogeneous. Benthic features distinguished included live corals, dead corals, sand, sea grass, rocks and mixing among them.

Unsupervised classifications resulted in several classes that were not distinguishable (Figure 5(a)). However, the supervised classification location and boundary of classes were more separable (Figure 5(b)). Still, there were some mixing of classes between boundaries and in deeper portions of the reef. Evaluation of the habitat classification image revealed accuracy of 85% with Kappa analysis
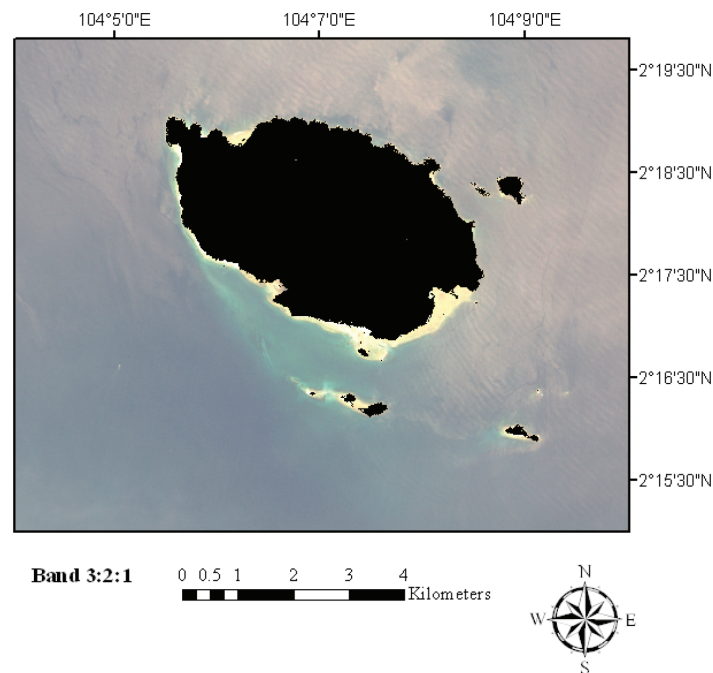

FIGURE 3. Band combination of 1, 2 and 3 with the highest OIF value
indicating the combination with the most information was chosen to analyse
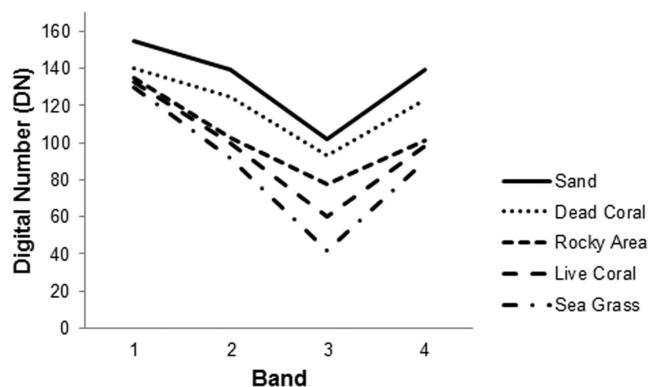the spectral characteristics of the habitat

FIGURE 4. Spectral characteristics based on relationship between
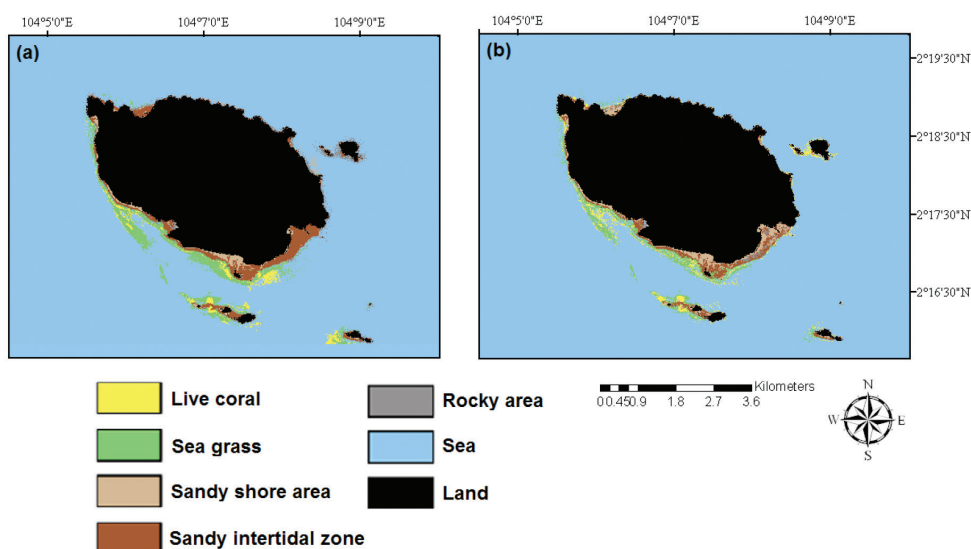band and ALOS digital number (DN)

FIGURE 5. (a) Unsupervised classification using ISODATA classifier and (b) supervised
classification using Maximum Likelihood classifier of ALOS image indicating distribution of
coral reef and its associated habitats at Tinggi Island

derived coefficient of 71.21%. Accuracy assessment was based on a total of 130 individual points surveyed and the information was divided into training data for the image classification. In average a total of 26 points for each of the coral and other habitat types were surveyed. The diver recorded the habitat type in the transect along with depth and the co-ordinates measured using a handheld GPS with position accuracy of ±10-15 m. Classification of the imagery indicated spatially five main zones of habitats around Tinggi Island (Table 2). The results indicated locations and distributions of sandy shore areas, sandy intertidal zones, seagrass, coral reefs and rocky zones.

Sea grass is the dominant habitat around Tinggi Island covering a total area of 0.94 km² (Table 3). It is mainly located at the southwest part of the island (Figure 6). Meanwhile, coral reefs cover an area of 0.55 km². *Acropora* sp. is the most dominant coral in this area. Live corals are dominant over the southwest at areas sheltered by waves.

Sandy and rocky habitat occupies an area of 1.31 and 1.19 km², respectively. It mainly covers the area of shores and intertidal zones. Sandy habitats are found at the south of the island at areas with extensive spread of beach. Rocky habitats are mainly located at the north of the island facing the South China Sea. This area is influenced by strong waves and extreme tidal patterns.

DISCUSSION

Classification of corals and associated habitats is influenced by spectral sensitivity and spectral overlaps between optically similar objects. Occurrences of mixed pixels (resulting from patch reefs which include mixture of sand, seagrasses, dead corals and live corals) often causes classification confusions (Maeder et al. 2002). In this study, when extracting thematic information from water bodies, it is important to eliminate all upland and terrestrial

TABLE 2. Description of the habitat zones mapped around Tinggi Island

Zones	Habitats
Zone 1	Sandy shore zone: occupied the smallest area
Zone 2	Sandy intertidal zone: most dominant sandy zone found near coral reef and seagrass
Zone 3	Seagrass zone: most dominant seagrass coverage consisting of variety of spesies growing around live corals
Zone 4	Coral/submerged sandy zone: characterized with high live coral and surrounded by sandy area. Dead corals are also dominant
Zone 5	Rocky zone: dominated by rocky areas and surrounded by exposed and submerged sandy area

TABLE 3. Total area (in km^2) covered by the habitats at Tinggi Island

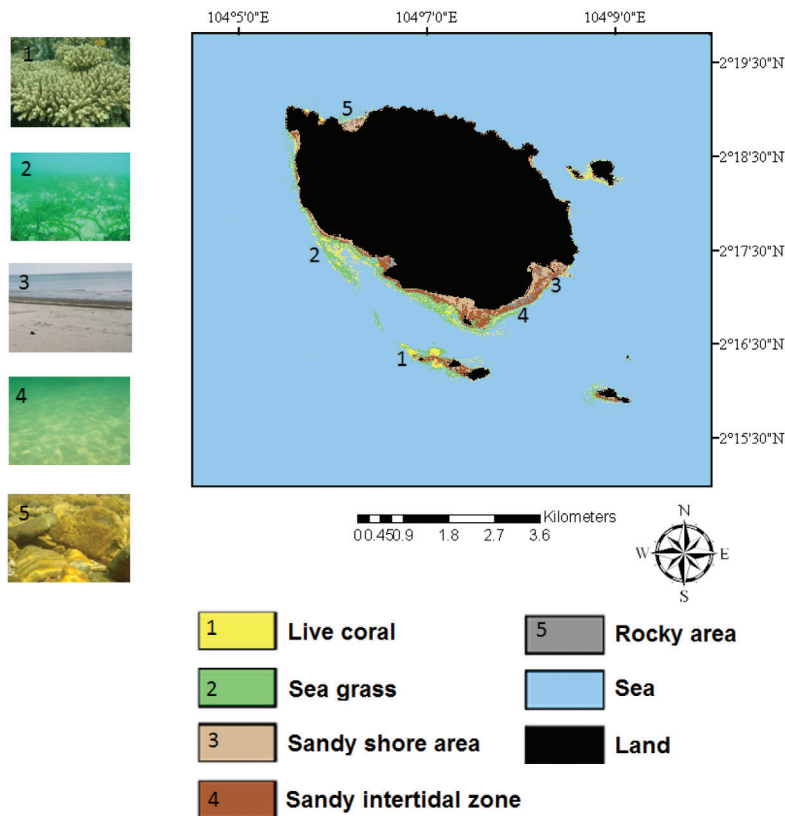| Habitat	Area (km^2)
Live coral	0.55
Sea grass	0.94
Sandy area (shore and tidal zone)	1.31
Rocky area	0.19

FIGURE 6. Spatial distribution of benthic and associated habitats around Tinggi Island as a result of supervised classification. Number associates with type of habitats

features. Thus land and other terrestrial features were masked out from the image. This was applied to restrict the spectral range of brightness values to aquatic features and allow for detailed feature discrimination. Variation in the spectral chracteristics magnitude of coral reefs and habitats surrounding Tinggi Island was observed. The differences among the spectral characteristics of corals in the area would provide a satisfactory attempt in efforts of

delineating and defining their different features in a satellite image. However the problem is the spectral characteristics of the corals and habitats is a function of pigmentation, structure and orientation of their branches and their internal characteristics (Newman et al. 2006).

In this study, the habitats displayed distinct spectral differences and similar curves. It has been shown that spectral chracteristics of dead corals, sandy habitat and rocky area indicated similar reflectance (Miyazaki & Harashima 1995, 1993). Meanwhile, the spectral patterns of seagrass were also appeared similar to that of live coral reef (Hochberg et al. 2003).

Mumby et al. (1997) indicated that reflectance of sand is easily recognized. This was also observed in this study. Sand had higher spectral chracteristics. Dead corals is similar to sand compared to live coral. Spectral characteristics of dead corals are between sand habitat and live coral. Sand and dead corals have similar spectral curve and DN value because both consist of calcium carbonate. The loss of zooxanthallae in dead corals exposes the coral reef carbonate skeleton (Kleppel et al. 1989). Spectral chracteristics of sand indicates combination of absorption effects by calcium carbonate and chlorophyll of benthic microalgae (Roelfsema et al. 2002). Sand has higher DN than dead corals because absorption by pigments in the zooxanthellae of dead corals still occurs whereas the benthic mikroalgae in the sands absorbs low. Habitat mapping has shown that dead corals, rocks and sand have similar spectral chracteristics due to existence of the algae with sand indicating a higher spectral value. Live coral and sea grasses on the other hand show lower spectral chracteristics. This is because of high absorption from the algae thus resulting in lower spectral signature (Kutser et al. 2003).

Holden and LeDrew (1998) reported that variation in spectral characteristics from different coral types is influenced by the health of the corals. Live corals and algae have similar reflectance because of the presence of zooxanthallae. Fluorescence from the coral contributes to the spectral reflectance, therefor the spectral curve depends on the absorbance by zooxanthellae pigments. It has also been reported that different structure of corals (branching, tabular and plate) reflect differently (Joyce & Phinn 2002). However, in this study all living corals were grouped as live corals.

Although the reef habitats displayed different spectral characteristics and could be classified, there can be significant amount of intermixing between these features. Several factors that can influence classification results are combinations of benthic sandy areas with algal, variation in color, texture and size of corals and coral stress. Corals lose their pigmentation as a result of stress, and this exposes the calcium carbonate skeletons. Calcium carbonate skeletons have high reflective characteristics and this can be easily confused with reflective signal from sand and rock habitats. The loss in pigmented zooxanthellae from corals as an effect of stress results in a strong optical signal from the remaining skeletons that can be detected by remote sensing

(Yamano & Tamura 2004). These dead corals will soon be covered with algae and this may reduce the optical signal and thus this will be mistaken as signals from live corals or microalgae habitats.

Using the spectral characteristics of the reef and associated habitats, ALOS image classification indicated that sea grass thrives in the coastal areas of the island. Sea grass is a community that lives well in shallow waters of tropical areas (Den Hartog 1970). Apart from that, variability in temperature, nutrient and salinity are among factors contributing to distribution of sea grasses (Robblee et al. 1991). Eutrophication and habitat destruction are also factors influencing the species composition and structure (Short & Wylie-Echeverria 1996). Sea grass occurs mainly in the southern part of the island. The topography of this area is shallow sandy and covered from strong waves which is most suitable for growth of sea grass (Green & Short, 2003; Scopelitis et al. 2009). Furthermore this area is located far from the mainland. Live corals are also found at the south and at areas sheltered by waves. According to Barnes (1982), corals thrive well in coastal areas that are influenced by minimal wave action in comparison to rocky areas. At Tinggi Island, rocky areas are found on the northern part of the island which is exposed to the rough waves of the South China Sea.

This research was conducted to assess the capability of the moderate spatial resolution of ALOS satellite image for mapping reef and associated habitats. Discrimination between habitats was possible and the study produced high classification accuracies. However with inclusion of detailed atmospheric and water-column corrections and image classification techniques, this satellite data is capable of mapping benthic habitats. This can assist in long term monitoring programs in the identification of areas that requires protection and contribute in management and conservation of coral reef ecosystems.

CONCLUSION

The corals and habitats display variation in spectral characteristics but displays similar spectral curve. Spectral characteristics from the corals and surrounding habitats were determined by presence of benthic microalgae and calcium carbonate. The main habitats around Tinggi Island were seagrass followed by coral reefs, sandy shores, intertidal zones and rocky areas. This study demonstrated the ability of the ALOS satellite imagery to classify the coral reef and surrounding habitats based on their spectral characteristics thus capable of mapping the spatial distribution of this ecosystem.

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