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APPLICATION OF REMOTE SENSING IN MANGROVE STUDIES : A LITERATURE REVIEW

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ABSTRACT

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. 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. With the specific application on mangrove studies, remote sensing enables spatial and spectral information to be collected from the mangrove forests environment mostly located in inaccessible areas, where ground measurements become difficult and expensive. This review of the literature emphasizes the application of remote sensing in change detection and mapping of mangrove ecosystems.

Key words : mangroves, remote sensing, mapping, field monitoring, continuity

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. 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 (Lee, 2003; Chatterjee, 2006).

According to Bester (2007), there are 69 mangrove species worldwide which covere approximately 75% of the world's tropical coastlines between 25° N and 25° S.Due to the movement of unusual warm waters from the equator, mangrove forests can exist beyond those zones. For example, along the east coast of Africa, Australia and New Zealand, mangroves can be found 10-15^o farther south whereas in Florida, Japan and the Red Sea, this range extends 5-7^o farther south. In Australia, mangrove forests occur along the north-east coast, occupy approximately 11,600 km^2 where 4,600 km^2 of the area exists in Queensland (Claridge and Burnett, 1993 cited in Lee, 2003; EPA Queensland, 2008).

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, 2000 cited in Coleman et.al, 2004). Kavanagh (2007), reports that the rate of mangroves losses worldwide is around 1 to 2% per year.

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 (Boyd and Tucker,1998;Ramachandran et.al, 1998). Moreover, coral reef and sea grass bed ecosystems are also affected by the destruction of mangrove forests. Mangroves are important buffer as they hold excess sediment and chemicals, preventing infiltration through coastal waters.

PRINCIPLES AND CONCEPTS OF MANGROVE STUDIES USING REMOTE SENSING

Remote sensing technology has already been successfully applied in the field of coastal vegetation research. Vegetation can be distinguished using remote sensing data from most other (mainly inorganic) materials by virtue of its notable absorption in the red and blue wavelengths of the visible spectrum, its higher green reflectance and, especially, its very strong reflectance in the near-IR (Short, 2007).

Controlled by chlorophyll pigment in green-leaf chloroplasts, absorption is centered at about 0.62 – 0.7 μm (visible red). Absorption occurs to a similar extent in the blue band (0.45-0.50 μm). The predominantly but diminished reflectance of visible wavelengths is concentrated in the green band (0.58 – 0.59 μm). Strong reflectance in the near Infra Red band (0.7 and 1.0 μm) can also be detected from vegetation leaf. The intensity of this reflectance is commonly greater than from most inorganic materials; therefore vegetation appears bright in the near-IR wavelengths (Short, 2007).

Variety of Sensors, Spatial and Spectral Resolutions

Multispectral sensors boarded on satellite platforms, including Synthetic Aperture Radar (SAR), Landsat TM, and SPOT XS, are most commonly used for mangrove studies (Green et.al.,1998). These satellites have different spatial and spectral resolutions. According to Simonett (1983) cited in Gao (1998), spatial resolution refers to the ability of a sensor to distinctly record the minimum distance between two objects. Hence, remote sensing data of a higher resolution increases visual interpretations. Whereas spectral resolution describes the ability of a sensor to define fine wavelength intervals or bandwidth (Campbell, 1996). The finer the spectral resolution, the narrower the wavelength ranges for a particular channel or band.

Landsat provides high resolution imagery from the visible and infrared band. The latest Landsat satellite (Landsat 7) has 8 bands with spectral bands ranging from 0.450 – 2.35 μm. The resolution from this sensor is 30 meters and 15 meters for panchromatic sensors (NASA, 2008). Meanwhile, the SPOT-5 satellite is equipped with 5 bands with spectral bands ranging from 0.48 – 1.75 μm. It has a 10 meter resolution and 2.5 – 5 meters for panchromatic sensors (SPOT Image, 2008).

Several studies have been conducted to compare the accuracy of remote sensing data in mangrove mapping. In a comparison between Landsat and SPOT data, Gao (1998) suggests that 30 meters resolution Landsat data has greater accuracy against 20 meters SPOT XS data. The lower accuracy is caused by the limited spectrum coverage of the SPOT satellite data. Therefore, Vaipassa (2006) highlights the need for using sensors with higher spectral resolution. For instance, AVIRIS (Airborne Visible/Infrared Imaging Spectrometer) sensor with 224 bands ranging from 400 nm – 2450 nm and the 220-bands HYPERION sensor with band width range from 400 nm – 2500 nm. Nonetheless, the uses of these sensors and their accuracy have not been examined.

Techniques in Mangrove Studies Using Remote Sensing

Many image processing and analysis techniques have been developed to aid the interpretation of remote sensing images and to extract as much information as possible from the images. According to Green et.al (1998), there are 4 methods that can be employed to classify remotely sensed data on mangroves.

The first method is the visual interpretation. This method is highly dependent on the interpreter's ability to recognize and analyze various character of the study area, for example shape, size and patterns with reference to spectral bands and brightness value from field data or aerial photographs (Sivakumar, 2002). Moreover, Green et.al (1998) emphasize that the decision on different mangrove structures are achieved without further computational and statistical processes. However, to facilitate visual comprehension of the imagery information, radiometric enhancement (contrast or pseudo-color) is applied.

The second method is the vegetation index. A vegetation index is a number that is generated by some combination of remote sensing bands and may have some relationship to the amount of vegetation in a given image pixel (Ray, 1994). An example of this technique is Normalized Difference Vegetation Index (NDVI). The NDVI is calculated from the following equation, NDVI = $\frac{(IR - \mathrm{Re}\,d)}{(IR + \mathrm{Re}\,d)}$ where Red and IR refer to the spectral reflectance measurements acquired in the red and infrared wavelengths, respectively. For mangrove studies, this index can be calculated by comparing spectral reflectance from Landsat TM bands 3 and 4 (Mohd and Ahmad, 1994), also from SPOT XS bands 2 and 3 (Green et.al, 1998).

Different land cover types of mangrove forest in an image can be discriminated by way of image classification algorithms using spectral features. The classification procedures can be supervised or unsupervised. In supervised classification, the spectral features of some areas of known land cover types are extracted from the image. These areas are known as the training areas. Every pixel in the whole image is then classified as belonging to one of the classes depending on how similar its spectral features are to the spectral features of the training areas.

In unsupervised classification, the computer program automatically groups the pixels in the image into separate clusters, depending on their spectral features. Each cluster will then be assigned a land cover type by the analyst (Liew, 2001). An advantage of unsupervised classification is that no prior knowledge of the scene is required; however without further information from ground investigation or published sources, the result can not be attributed directly to a particular area (Gibson and Power, 2000).

REMOTE SENSING RESEARCH ON MANGROVES MANGROVE LEAF AREA INDEX

Leaf Area Index (LAI) is defined as the single-side leaf area per unit ground area. This index has been used to assess ecological processes in mangroves ecosystem such as rates of photosynthesis, transpiration, evapotranspirations and net primary production (Green et.al, 2000). Measurement of LAI using a plant canopy analyzer is utilized to predict future growth, yield and to monitor changes due to pollution and climate change (Kaufmann, et.al, 1982 cited in Green et.al, 2000).

In mangrove studies, LAI can not be measured directly from satellite imagery. However, Ramsey and Jensen (1996) report that there is a linear relationship between mangrove and NDVI obtained from satellite data. By conducting field surveys to measure LAI in accessible mangrove areas, the results subsequently can be used to establish a relationship to NDVI using regression analysis. Once this relationship is known, then NDVI values for the remainder of the mangrove areas can be converted to LAI.

Several studies have been conducted to

determine LAI of mangrove ecosystems. Green et.al (1997) derived NDVI from mangrove forests in South Coicos, British West Indies through Landsat TM and SPOT XS data and LAI was measured at 29 sites. A linear regression model was LAI = 12.74 NDVI + 1.34 with a fine coefficient of determination obtained ($R^2 = 0.74$, $p < 0.001$, $n = 29$). Then the model was used to estimate LAI for the entire mangrove areas. With similar method, Kovacs et.al (2004) used IKONOS image to measure LAI within degraded mangrove forests of Agua Brava Lagoon, Mexico.

Mangrove Mapping

Mangrove mapping is the process of identifying land cover changes using multi-date digital images that commonly acquired from satellite based multispectral sensors. To quantify change in mangrove coverage and mapping, broad range techniques in remote sensing are available. The major remote sensing systems which are acknowledged to be extensively used in mangrove mapping including aerial photography, multispectral scanners (MSS) and radar. The simplest technique is the visual interpretation of aerial photography. However, this technique is highly dependent on the ability of the interpreter and it has to be analyzed manually. Whereas MSS provides automatic data processing and satellite applications. To avoid weather disturbance and to conduct regular monitoring, radar analysis is the suitable method (Chatterjee, 2006).

According to Chatterjee (2006) the changes in land cover generally result in changes in radiance values than radiance changes caused by other factors. Many studies have been conducted to map and measure the changes of mangrove coverage area worldwide. Ramirez-Garcia et.al (1998) conducted an assessment of mangrove area in Santiago River Mouth, Nayarit of West Mexico. Coverage area and distribution of mangrove in the study area were mapped using supervised classification from a 1993 Landsat TM-5. Histogram stretching was applied to each band as well as edge enhancement filtering to visually enhance the information and to generate color composites that could ease the geo-reference procedure. The color composites used were from bands 3-4-5 that could explain 99.06% of the total data variance. The results were then compared with the 1973 map of the same area produced by CENTENAL. It showed that there was a 32% loss of mangrove forest in a 23 years period.

Using a similar method, Yang and Liu (2005) carried out a study to map land use and land cover of the Pensacola estuarine using Landsat Enhanced Thematic Mapper (ETM) imagery from 1989, 1996 and 2002. They concluded that mangrove forests in the study area declined from 366,109 Ha in 1989 to 271, 189 Ha in 2002. Several other studies in mangrove mapping were also conducted by Saito et.al (2008), using SPOT-4 to analyze mangrove cover in the Persian Gulf; Rasolofoharinoro et.al (1998) using SPOT-1 and SPOT-2 to measure change of mangrove area in Madagascar and Chatterjee (2006) with Indian Remote Sensing Satellite (IRSS) studied the degree and extent of damage of the mangroves in the Gulf of Mannar of India, caused by the 2004 Indian Ocean tsunami.

Despite its ability to obtain spatial and spectral information from vast mangrove areas, there are some factors that might obstruct the accuracy of remote sensing in mangrove studies. Blasco et.al (1998) identify major flaws in mangrove studies. One of the flaw is the uncertainty in mangrove definitions in different countries or by different authors. There are four definitions that refer to mangrove: mangrove ecosystems, mangrove forests, mangrove land and mangrove areas. Each definition has different interpretation regarding the form of vegetation and their location within estuary zone which can be categorized as mangrove plants. Therefore, it is difficult to assess the area of mangroves from available maps and data bases if different categories are required.

Another factor affecting the accuracy is the spectral limitations of the sensor. Although remote sensing is useful to discriminate mangrove forests from other objects, it has limitations to be used to study mangroves in finer details, for example to distinguish different mangrove species. Blasco et.al (1998) found high similarity in spectral reflectance of three mangrove classes (*Rhizopora*, *Avicennia* and *Laguncularia*). Further studies conducted by Hirano et.al (2003) suggest that it was difficult to distinguish mangrove species if the study area was dominated by few species.

Finally, the constant changes and instability of coastal ecosystems is also considered to have a significant effect on the accuracy of remotely sensed data (Blasco et,al.,1998). As a coastal zone is subject to frequent tidal inundation, they concluded that the spectral signal of these plant communities is strongly influenced by tidal effects on the soils.

CONCLUSIONS

In conclusion, remote sensing technology offers considerable advantages in mangrove studies and has become a useful tool to monitor the change of mangrove ecosystems. The output of satellite imagery analysis could be used as basic information in conservation planning and policy. To ensure accuracy of the analysis, important factors such as spectral and spatial resolution and image classification techniques should be the main consideration.

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