Applicability of Satellite Monitoring on Mangrove Forests in Malaysia: A Review of Potential Benefits and Challenges

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ABSTRACT

Malaysia is the second largestcountry after Indonesia for mangrove areas in the Asian countries. The importance of the mangrove ecosystem surrounding the world is well established. They provide various ecological and economic services such as protecting the coastal erosion, providing habitats for aquatic and terrestrial fauna, filtrating pollutionand providing firewood and timbers. In Malaysia, mangrove forests provide a major source of valuable goods of timber and firewood. At the same time, mangrove area in Malaysia is being exploited for the aquacultures activities. The application of satellite monitoring on the tropical wetland forests is well established. Therefore, the aim of this paperis to provide a comprehensive overview on the applicability of satellite monitoring on mangrove forests in Malaysia using the cost-effective satellite data. The recent advancement of mangrove classification technique, the benefits and limitations of the cost-effective data were extensively reviewed. The free-access website of free satellite data is also highlighted.

Keywords: Remote sensing; Landsat; MODIS; mangrove; monitoring

INTRODUCTION

The application of remote sensing technology in mangrove studies has been used widely usingvarious kinds of satellite data such as aerial photographs,medium-resolution data, high-resolution data and hyper spectral data. However, the medium-resolutionsatellite data such as Landsat series, MODIS and SPOT data have been used continuously in mangrove studies (Kuenzer et al., 2011).Due to cost-effective and easy to access, the Landsat series, MODIS, SPOT and aerial photography have been used extensively formangrove monitoring in many developing countries such as Vietnam, Indonesia, China and Brazil (Li et al., 2013, Satapathy et al., 2007,Vo et al., 2013, Wang &Sausa, 2009).These low-cost satellite data also provide a long-term and large-scale data which promotean effective mangrove studies (Green et al., 1996, Lee & Yeah, 2009, Manson et al., 2001, Mumby et al., 1999). The advantages of these data in mangrove studies are well established (Kuenzer et al., 2011). In Malaysia, the application of aerial photography and medium-resolutiondata in mangrove studies have been applied since

1990`s (Sulong& Ismail, 1990, Sulong et al., 2002). According to Sulong and Ismail (1990),both of these data have the potential on classifying mangrove land cover in Peninsular Malaysia. The loss of mangrove forestsis very significantand theimportanceof managing and conserving the mangrove ecosystem was realised especially after the tsunami tragedy in Indonesia in 2004. According to the Department of Statistics Malaysia(2013), almost 30% of the Malaysian mangrove has been lost due to erosion and land clearing for aquaculture pond, resorts and plantation. The Malaysian National Mangrove Committee also strongly recommended that regular monitoring should be established for the development ofmangrove land clearing activities in the future (FOA, 2007).Therefore, satellite remote sensing approach could provide an openingfor retrieving up-to-date information about the extent and condition of the mangrove ecosystems and this is an essential aid to the management, policy and decision-making processes.

Thus, the aim of this paper is to providea comprehensive overview onpublished researchactivities onthe potential benefits of low-cost satellite data on mangrove studies. This overview will be a working principle for Malaysian mangrove monitoring afterwards. A short overview of the Malaysian mangrovedistributions, status and the benefits followed by the descriptions of low-cost satellite remote sensing application in the field of mangrove monitoring and analysis.

In this content, the different types of remote sensingdata and different methodology approaches on the information extractionarealso investigated. A discussion on the benefits, difficulties and future challenges of low-cost satellite data for mangrove will be presentedbefore the conclusion.

OVERVIEW ON THE MANGROVE ECOSYSTEMS IN MALAYSIA

Malaysia has approximately 542, 024 ha of mangrove forest which is the second largest after Indonesia among the Asian countries (Department of Statistics Malaysia, 2013). Out of the total mangrove areas in Malaysia, Sabah has the largest mangrove area which constitutes 331,325 ha (61%) followedby Sarawak 112,470 ha (21%) and Peninsular 98,229 ha (19%) (Department of Statistics Malaysia, 2013).In the Peninsular Malaysia, Perak has the largest area which constitutes 41,617 ha (42.8%) followed by Johor 27,342 ha (20.6%) and Selangor 18,794(19.1%)(Department of Statistics Malaysia, 2013).Mangrove in the Peninsular Malaysia exists along most of the west coasts. The sheltering effect of the Sumatranislands provides relatively calm sea in the straits of Malacca compared with the South China Sea that abuts the east coast of the peninsular. Along the east coast, facing the South China Sea, mangrove formation is generally small and restricted to the river mouth, where it typically extends 0-5-1 km inland (Ibrahim et al., 2000). In the state of Sabah, mangrove islargely found on the east coast facing the Sulu and Sulawesi Seas while in Sarawak it islargely found at the river mouth of the Sarawak and Rajang. Figure 1 shows the estimated geographic distribution of mangrove in Malaysia.

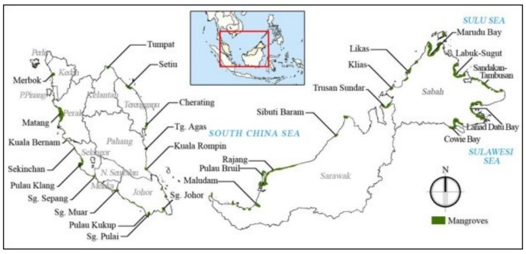

Figure 1: Distribution of mangrove in Malaysia

Mangrove forest is a unique ecosystem and provides a variety of important ecosystem goods and services. Examples of ecosystem goods and services include timber and firewood, habitats for rare terrestrial fauna, economically important fisheries, filtration of pollution and a potential reduction in the impact of tsunami and storm surge (Giri et al., 2010, Walter et al., 2008). The importance of the mangrove ecosystem in providing ecosystem goods and services is well established (Zhang et al., 2003).In Malaysia, mangrove forest provides a major source of valuable goods of timber and wood fuel (FOA, 2007, Zhang et al., 2003). The timber industry in Matang mangrove forest located on the west coast of PeninsularMalaysiaemploys 2,400 people with the revenue of US$ 6 million per year and the associated fishing industry in the area employs about 10, 000 people with annual revenue of US$ 12-30 million (FOA, 2007).

However, uncontrolled exploitation on mangrove forest areas has led into some degradation of the coastal environments such as coastal erosion and the loss of wildlife habitats. According to Giri et al. (2008),the conversion of mangrove area to aquaculture area especially shrimp farming has spread quickly in the Asian countries. A survey by FAO (2007) found that high economic return of shrimp farming has been promoted to increase the national economy as a potential source of income for local communities especially for developing countries.Malaysia lost about 110 000 ha of mangrove from 1980 to 2005. During the first decade (1980-1990), mangrove losses were primarily due to the conversion of land for agriculture, shrimp farming or urban development (FOA, 2007). However, shrimp farming spreadsvery quickly in the country especially in Peninsular Malaysia and this leads to the reclamation and conversion of the large area of mangrove to ponds. The Malaysian National Mangrove Committee has strongly recommended that strict guidelines and regular monitoring should be established for the development of this industry in the future (FOA, 2007).

CHARACTERISTICS FOR IDENTIFYING MANGROVES IN REMOTELY SENSED DATA

Mangroves grow at the land-sea interface. Therefore, the three major features contributing to the pixels composition in remotely sensed imagery are vegetation, soil and water. However, any mixture of the individual surfaceappearance is also influenced by seasonal and diurnal intertidal interaction. According to Blasco et al. (2002), these circumstances are themajor obstacles to rigorous radiometric and they greatly affect the spectral characterization. Additionally, the diversity of mangrove species especially in Asia which is higher than in tropical and subtropical regions aggravate discrimination difficulties as the result of a higher amount of spectrally unique species (Kuenzer et al., 2011). In Malaysia, there were 36 main mangrove species recorded in Peninsular and 34 species in Sabah and Sarawak, respectively (Hamdan et al., 2012, MohdLokman et al., 2001, Sabah Forestry Department, 2012).However, the most important species in Malaysia belong to genera *Rhizophora, Avicennia, Sonneratia*, and *Laguncularia* (Hamdan et al., 2012).Kairo et al. (2002) suggested that the textural and spectral characteristics of the canopy and leaves are the main features used to distinguish among mangrove communities. Their structural appearance, partially more homogenous or heterogeneous depends on several factors such as species composition, distribution pattern, growth form, density growth and stand height. The spectral signature of a single species is defined by age, vitality, phonological and physiological characteristics (Blasco et al., 1998). Kuenzer et al. (2011) describedthat the near-infrared signal of the remote sensing reveals different reflections in relation to the internal leaf structure and facilitates mangroves discrimination. Furthermore, the spectral distinction caused by other leaf components interacting with electromagnetic radiation at longer wavelengths in the near- and mid-infrared regions might work even better(Vaiphasa et al., 2005). Study by Jones et al. (2004), confirmed that the different spectral signature of*Rhizophora*and *Avicennia*species in the near-infrared signal of satellite data was the reflection of the principal biophysical and chemical properties such as water, cellulose and chlorophyll pigments.

OVERVIEW ON LOW-COST SATELLITE REMOTE SENSING DATA-BASED STUDIES AND METHODS ON MANGROVE ECOSYSTEM

For more than two decades, low-cost satellite data has been used extensivelyto obtain facts and data onthe condition and extent of the threatened mangrove ecosystems.**Table 1**represents the large variety of mangrove studies using the low-cost satellite data and methodologies applied over the last 20 years. More than 70 studies using the low-cost satellite data in more than 16 countries have been reviewed. Most of the studies applied the data for mangrove mapping, classification of the mangrove and non-mangrove vegetation, mangrove land cover change detections and monitoring. Numbers of the different methods have been used to extract the mangrove information.

Applications and Methods

(i) Overview of Mangrove studies based on AerialPhotography

For several decades, aerial photography has been a dominantremote-sensing technology applied to analyse surface event. However, only a very few studies on mangroves have been published. Green et al. (1996) remarked that the lack of appropriate publications orpresentations makes it difficult to obtain an overview of realized studies. Based on this review, several studies were conducted in Australia (Manson et al., 2001), Kenya (Kairo et al., 2002), Vietnam (Binh et al., 2005), Texas (Everit et al., 1991) and Malaysia (Sulong& Ismail, 1990,Sulonget al., 1999,Sulong et al., 2002). Most studies suggested that the aerial photography is suitable for highly detailed mapping in very small and narrow coastal areas (Sulong& Ismail, 1990). Furthermore, using the different scale of aerial photograph can classify the mangrove forest into different forest types (Sulong& Ismail, 1990,Tarmizi et al., 1998; Kairo et al., 2001,Sulong et al., 2002). Although the larger scale aerial will reduce the accuracy of aggregation, it will provide details of individual trees.**Table 2**shows a summary of themangrove forest types mapping by aerial photo-interpretation. The visual interpretationmethod such as colour, texture, structures and other image attribute were used extensively for species identification (Sulong& Ismail, 1990). The colour of aerial photography has potential to be used for the detection of mangrove forest. A study by Manson et al. (2001)used the colour of aerialphotographs for the detection the ofthe Mangrove forest changes in the northern Australia. The combination of ISODATA-clustering algorithm method has successfullyextracted the changes of mangrove in this study area.

Table 1: Summary of selected work on Mangroves studies during past 20 years.

Satellite Data	Methods											
	Visual Interpretation		Vegetation Indices (NDVI, LAI)		Pixels based Classification (Unsupevised & Supervised)		Neural network classification		Decision Tree classification		Object-based Method	
	Authors	Study Area	Authors	Study Area	Authors	Study Area	Aut hors	Study Area	Authors	Study Area	Authors	Study Area
Aerial Photography	Sulong & Ismail, 1990	Kemaman, Malaysia			Manson et al. 2001	Australia						
	Sulong et al. 1999	Sabak Bernam, Malaysia			Everitt et al. 1991	Texas Gulf Coast, America						
	Sulong et al. 2000	Kemaman, Malaysia	None				None		None		None	
	Kairo et al. 2002	Gazi, Kenya										
	Binh et al. 2005	Ho Chin Minh, Vietnam										
Landsat MSS	Vasconcelos et al. 2002	Guinea-Bissau	Giri et al. 2007	Sundarbans, Bengal	Seto et al. 2007	Ramsar wetland, Vietnam	None					
			Seto et al. 2007	Ramsar wetland, Vietnam					None		None	
Landsat-5 TM	Green et al. 1998	Turks and Caicos Island	Green et al. 1998	Turks and Caicos Island	Green et al. 1998	Turks and Caicos Island	Seto et al. 2007	Ramsar wetland, Vietnam				
	Sulong et al. 2002	Terengganu, Malaysia	Seto et al. 2007	Vietnam	Manson et al. 2001	Australia						
	Wang et al. 2003	Tanzania	Giri et al. 2007	Sundarbans, Bengal	Giri et al. 2007, 2008	Sundarbans, Bengal			Liu et al. 2008	Pearl River Estuary, China	Green et al. 1998	Turks and Caicos Island
			Thu & Populus, 2004	Mekong Delta, Vietnam								
			Alongi et al. 2008	Florida								
Landsat -7 ETM+	Mumby et al. 1999	Turks and Caicos Island	Luo et al. 2012	Southeastern China	Fatoyinbo et al. 2008	Mozambique, Africa	None		None		None	
			Green et al. 1998	Turks and Caicos Island	Alongi et al. 2008	Florida						
SPOT	Green et al. 1998	Turks and Caicos Island			Rasolofoharinoro et al. 1998	Madagascar			Colstoun et al. 2003	Milford, USA	Green et al. 1998	Turks and Caicos Island
	Rasolofoharinoro et al. 1998	Magadascar			Green et al. 1998	Turks and Caicos Island	None		Zhang et al. 2011	Guangxi, China	Conchedda et al. 2008.	Senegal
	Fromard et al. 2004	Guyana, French			Blasco et al. 2001	Bay of Bangal & South China Sea						
					Thu & Populus. 2004	Mekong Delta, Vietnam						
					Saito et al. 2003	Arabian Gulf, Arab						
MODIS	Vo et al. 2013	Mekong Delta, Vietnam	Jiang et al. 2013	China					Rivera et al. 2012	Central American	None	
			Rahman et al. 2013	Mahakam Delta, Indonesia	None		None					
			Vo et al. 2013	Mekong Delta, Vietnam								

Table 2: Summary of mangrove forest types mapping by aerial-photointerpretation.

Authors	Year	Scale of Aerial Photographs	Results
Sulong & Ismail	1990	1 : 40 000	3 forest types
Tarmizi et al.	1998	1 : 5000	12 forest types
Kairo et al.	2001	1 : 25 000	7 forest types
Sulong et al.	2000	1 : 20 000	9 forest types
Sulong et al.	2002	1 : 5000	14 forest types

A verification based on the field survey indicated a high accuracy. Furthermore, Binh et al. (2005) used58 aerial photographs from 1968 and 154 images from 1992 and assembled into a photographic overview mosaic to identify land cover changes over this long-term period.They identified a rapid increase in the shrimp farming from 1997 onward, and a forest area decline (mainly mangroves) of 75%, of which 60% was due to demand for agricultural land, and 40% was due to the development of new shrimp farms. Based on the previous studies, most aerialphotographs data were used for mangrove classification and mangrove change detections. Most studies showed the potential of using this satellite data on the mangrove studies. However, only a few methods have been used for extracting the mangrove information using the aerial photography.

(ii) Overview Landsat data series on Mangrove studies

Landsat satellite has been providing the multispectral data of earth environment since early 1970`s. The Landsat data have been used in variety of studies such as land-water management, land surface change detections, pollution monitoring and classifying various types of vegetation including mangroves (Blasco et al., 1998, Giri et al., 2007, Green et al., 1998, Karthisen&Birgham, 2001).The Landsat data series (MSS, TM, and ETM+) are free dataprovided by the National Aeronautics and Space Administration (NASA) and U.S Geological Survey (USGS). More than 20researchstudies applyingthe Landsat data series in more than tencountries have beenreviewed. This Landsat data have been used extensively for classifying,mapping, change detections and monitoring of mangrove forest (Green et al., 1998, Giri et al., 2007, Sulong et al., 2002)**(Table 1).**

Among these data, Landsat TM and ETM+ have been used widely in the mangrove studies. The improvement with several additions of infrared bands and spatial resolution (30 meters) of TM and ETM+ have promoted the application of both data for mangrove monitoring (Green et al., 1998). The availability of multi-temporal Landsat data series develops the application of the change-detection analysis on mangrove ecosystem. Change-detection analysis using the satellite data is a powerful tool to visualize, measure, and thus to better understand trends in mangrove ecosystems (Binh et al., 2005,Seto et al., 2007, Thu &Populus, 2004,Wang et al., 2003). It enables the evaluation of subtle changes over a long period of time (trends) as well as the identification of sudden changes due to natural or dramatic anthropogenic impacts (e.g., tsunami destruction or conversion to shrimp farms) (Thu &Populus, 2004, Giri et al., 2008, Sirikulchayon et al., 2008).

Many previous studies successfully measured, visualized and monitored the changes of mangrove forest using the multi-temporal of Landsat data. Sirikulchayon et al. (2008) examined the impact of the 2004 tsunami on mangrove vegetation in Phangnga Bay, Thailand using the Landsat 7 ETM+ data set. The Landsat data provided data before and after the tsunami impact. According to this investigator, a mangrove belt of 1,000-1,500m, parallel to the coast, would be optimal to weaken the destructive impacts of tsunami waves in the hinterland. Thu and Populus (2004) successfully measured and visualized the changes of mangrove forests in TraVinh province in the Mekong Delta, Vietnam between 1965 and 2001 using the Landsat ETM+ data. The changes of mangrove in this area was affected by the conversion to the shrimp`s farming activities. Furthermore, Seto et al. (2007) analysed the time series of Landsat MSS and TM of Delta Red River Delta in Vietnam between 1975 and 2002 calculating the mangrove extent and density, extent of aquaculture, and landscape fragmentation to assess the land cover condition as a function of time. Their findings indicated that multi-temporal of Landsat data series were able to analyse the changes of mangrove forest.

Furthermore, various methods have been used to extract the mangroveinformation on the Landsat data series. More than five of the image-processing methods have been used extensively for extracting the mangrove information **(Table 1).** The methods were applied exclusively or in combination. Visual interpretation, unsupervised classification such as ISODATA and supervised classification such as Maximum likelihood methods are frequently used in mangrove mapping(Giri et al., 2007, 2008,Sulong& Ismail, 1990,Sulong et al., 1990, 2002, Wang et al., 2003).

Other common approaches for the classification of mangroves using multispectral imagery include spectral vegetation indices such as Normalize Vegetation Indices (NDVI) and Leaf Area Indices (LAI). The vegetation indices have been used widely in pre-classification steps to separate vegetation from non-vegetationand mangrove from non-mangrove vegetation (Alongi et al., 2008, Thu &Populus, 2007, Green et al., 1998, Giri et al., 2007). Several studies have been carried out to investigate and compare the suitability of variousclassification algorithms for the spectral separation of mangroves (Green et al., 1998). In general, according to the literature, the application of the supervised Maximum Likelihood Classifier (MLC) is the most effective and robust method for classifying mangroves based on traditional satellite remote-sensing data (Giri et al., 2007, Green et al., 1998).

Although there is a wide application of these traditional satellite remote sensing data and methods, there remain several limitations and challenges to the traditional approaches to mangrove remote sensing. Confusion between mangroves and other vegetation is a commonly reported source of classification error (Benfield et al., 2005, Green et al., 1998). Another source of classification error is the omission of fringe mangroves that are less than the pixel size, resulting in mixed pixels (Manson et al., 2001).

Therefore, a new classification approach such as neural network, decision tree-learning and object-based method have been developed or adapted to improve theaccuracy of mapping the extent of mangrove and detecting change over a time (Green et al., 1998,Liu et al., 2008,Seto et al., 2007). Most studies showed the high potential of recent classification approach compared to the common methods. Liu et al. (2008) used the decision tree-learning approach to identify the mangrovein the Pearl River Estuary using multi-temporal Landsat TM data and ancillary GIS data. According to this author, this approachcan produce superior mangrove classification results to using only imagery or ancillary data.Furthermore, According to Zhang et al. (2011) the decision tree-learning method significantly improved the separabilitybetween mangrove and water-vegetation mixed pixels. The results of this study showed that theKappacoefficient, commission error of mangroveidentification were 0.90, 7.9%, respectively.

Only a few of an object-based approach has been used in mangrove studies. The object-based methods allow for use of the additional variable such as texture, shape, context and other cognitive information provided by the image analyst to segment and classify imagefeatures, and thus, improve classifications (Blaschke, 2010). Vo et al. (2013) successfullydetected areas with mixed aquaculture-mangrove land cover with high accuracies in the Ca Mau province, Vietnam. However, not much of the mangrove studies have been explored using the recent approaches.

(iii) Overview MODIS data on Mangrove studies

MODIS (Moderate Resolution Imaging Spectroradiometer) data has been used in environmental monitoring, natural resource management in global, regional and country in wide scale. The application of MODIS data in mangrove studies has been used widely after the year 2000 since it was launched to the earth orbit in 1990 and 2000 on board Tera and Aqua satellite, respectively. MODIS data also can be accessed freely as were provided by the National Aeronautics and Space Administration (NASA) and U.S Geological Survey (USGS).

Based on the previous studies **(Table 1),**MODIS data has been used widely in the mapping and monitoring of the mangrove forest. Due to the advantages of MODIS data such as providing multispectral data and low spatial resolution (250-1000 m) stimulated the application of this data extensively in mangrove mapping at large scale (Vo et al., 2013). More than ten studies inten countries using MODIS data in the mangrove studies have been reviewed.

Rahman et al. (2013) analyzed the time series (200-2010) of MODIS data for monitoring the changes of mangrove forest in Mahakam Delta, Indonesia. Results of this study showed that 21,000±152 ha of mangrove land in the Mahakam Delta were deforested and converted to shrimp ponds in 11 years. Furthermore, Duong (2004)analyzedMODIS 500m 32-day global composite data for mangrove land cover mapping in Vietnam.

The special characteristics of MODIS data in providing a large spatial coverage was it enables to observe the region or whole country in the same time, almost the same atmospheric conditions which simplifies much data processing and analysis (Doung, 2004, Rahman et al., 2013, Vo et al., 2013).Furthermore,the MODIS data available in short revisit time (2 to 4 days) is offering possibility to create cloud-free composite which is essential for the establishment of multi-temporal dataset that is the most important element for environment monitoring. Therefore, the availability of continuousacquisition of MODIS data has promoted the application of this data on mangrove monitoring and mapping (Rahman et al., 2013,Voet al., 2013). The pixels-based classification such as Maximum Likelihood and Vegetation Indices such as Normalize Different Vegetation Index (NDVI) and Leaf Area Index (LAI) method have been used extensively to extract the mangrove in the MODIS data (Jiang et al., 2013). Rivera et al. (2012) proved that, the MODIS data are very affordable and successfulto identify and discriminatethe land use classes at the country level. According to this author, the accuracyassessment of the map was very high particularly for some classes such as mangrove forest and commercial agriculture especially in the tropical country.

(iv) Overview SPOT data on Mangrove studies

Compared to other low-cost satellite data, SPOT data has high resolution that promoted application of this data on mangrove studies. Many studies have been used widely on the SPOT data for mangrove mapping, mangrove change detections and monitoring (Giri et al., 1996,Rasolofoharinoro et al., 1998,Tong et al., 2004,Thu et al., 2007). Tong et al. (2004) assessed the ecological status of mangrove discriminated by age, density and species in

Phangnga Bay, Thailand using the SPOT XS data. In a similar environment, Thu and Populus (2007) assessed the status and change of mangrove forest in TraVinh province in the Mekong Delta, Vietnam between 1965 and 2001.

Rasolofoharinoro et al. (1998) produced the first inventory map of a mangrove ecosystem in the Mahajamba Bay, Madagascar based on SPOT data. Blasco et al. (2002) presented a mangrove-ecosystem mapping on a regional scale using the SPOT multispectral data. They analyzed ecosystem along three major rivers in the tropical Bay of Bengal, the Irrawaddy and the Mekong which included criteria such as phenology, physiognomy and density of the mangrove stands. According to this author, mangrove density is influenced by natural factors as well as by human such as aquaculture occurrence and density. Tong et al. (2004) assessed the impact of shrimp aquaculture on mangrove ecosystem in the Mekong Delta using SPOT scenes from 1995 and 2001. They identified five ecologically distinct landscape classes but had difficulty in applying the same method in a second study area a few hundred kilometres away.

Similar with other satellite data, several common methods have been used to extract the mangroves in the SPOT data. Fromard et al. (2004) successfully used the visual interpretation for SPOT XS data in Mida Creek, Kenya to map the extent and status of mangroves. Study by Rasolofoharinoro et al. (1998) used the vegetation index (VI) such as NDVI to the multispectral-layer stack for a supervised classification of a SPOT data. The study showed that the NDVI clearly improved the discrimination of non-mangrove and mangrove vegetation. Green et al. (1998) found that NDVIdata derived from SPOT XS were correlated to a high degree (r = 0.913) with the percentage of mangrove canopy closure.

Furthermore, supervised classification such as Maximum Likelihood and unsupervised classification ISODATA approaches have been used to detect and delineatemangrove in the SPOT data (Blasco et al., 2002,Giri et al., 1996,Rasolofoharinoro et al., 1998, Saito et al., 2003,Thu et al., 2007,Tong et al., 2004). These processing methods have been acceptable for the application on mangrove habitat maps in management, including mangrove inventory and mapping, change detection (deforestation) and management of aquaculture activities. According to Rasolofoharinoro et al. (1998) the SPOT images can classify and identify mangrove forest with the 81 – 95% accuracy achieved using the Maximum Likelihood classification. Recent approaches such as object-based classification also have been used to map and detect the changes of mangrove forest. Conchedda et al. (2008) mapped the mangrove land cover in Low Casamance, Senegal using SPOT XS data and an object-based–classification method. The change-detection approach was performed by means of a region-growing algorithm on a multi-date composite for the years 1986 and 2006. The classification results of SPOT data supplied in 2006 allowed a clear separation between the different land cover classes within the research area, as well as within the mangroves classes.

BENEFITS AND LIMITATION OF LOW-COST SATELLITE DATA ON MANGROVE STUDIES

Numerous studies on remote-sensing based on mapping, monitoring of mangrove have been published over the last two decades. However, most studies have been used on the low-cost of satellite data such Landsat, MODIS, Aerial photographs and SPOT data. Therefore, in this paper we have focused on the benefits and limitations of low-cost satellite data on mangrove studies. **Table3**shows the benefits and limitations of all these data types for mangrove studies. A lot of benefits of aerial photography, Landsat, MODIS and SPOT data have been reviewed. The benefits of aerial photography in providing information with high spatial details which is suitable for detecting the subtle changes in species composition and distribution,health condition, growth pattern, and more, which is of the utmost importance for the local or regional agencies responsible for the protection and management of mangroves (Kairo et al.,2002). The available long-term satellite data promoted the aerial photography and Landsat, and MODIS data are applying it for long-term mangrove monitoring. Furthermore, the availableof free access of Landsat and MODIS data contributed to the capability ofthese satellites data.According to USGS (2013), United States Geological Survey announcedon April 21, 2008 that they would provide all Landsat and MODIS data archive for free, and it is possible to be downloaded from several websites**(Table 4).**The websitesprovide thousands of free satellite data of Landsat and MODIS for any interest of study area.

Table 3: Benefits and limitation of low-cost satellite data types for mangrove studies

Satellite Data Characteristics	Aerial Photography		Medium-Resolution Data (Landsat, MODIS, SPOT)	
	Benefits	Limitations	Benefits	Limitations
Spectral resolution	Red-NIR spectral information with red-edge slope	None at all or very low (R,G,B,NIR)	Several multispectral bands (R,G,B, NIR mid-NIR & thermal bands)	Skilled trained personnel are required
Spatial resolution	Very high (centimeter to meter)	Only small area is covered	Ideal for mapping on a large regional scale	Too coarse for local observations requiring in-depth species differentiation
Temporal resolution	Always available on demand	Complex acquisition of equipment	Frequent mapping (e.g. rainy season and dry season within 1 year)	Repetition rate may be too low to record impact of extreme events (e.g. floods)& very weather dependent (clouds)
Costs	Low costs for small areas	Increasing costs with increasing spatial coverage	Depending on sensor, freely available (e.g. Landsat, MODIS), costly (e.g. SPOT) but all are cost efficient compared with field surveys	Software for image processing needed (common software, such as Erdas, ENVI, and ArcGIS, have high license fees)
Long-term monitoring	Data available for >50 years	-	Data availability over three decades	Depending on the future duration of the systems and subsequent comparable sensors
Purpose	Local maps of mangrove ecosystems, parametrization, change detection	Only local-scale studies	Inventory and status maps; change detection, assessment of impact damages & deforestation	For some species-oriented botany-focused studies, resolution may already be too coarse
Discrimination Level	Species communities, density parameters	Sometimes too much detail	Mangrove–non-mangrove, density variations, condition status, mangrove zonation, in rare cases also species discrimination	High regional differences; classification result depends highly on the ecosystem conditions (biodiversity of forests)
Methods	Visual interpretation with on-screen digitizing and object-oriented approaches	Automatization usually not possible, considerable analyst bias and comparability	Visual interpretation with on-screen digitizing, pixel-based, object based & hybrid classification approaches	To exploit the full potential of the data skilled analysts needed

Table 4: Free-access websites of Landsat series and MODIS data

Satellites Data	
Landsat series (TM, ETM+& OLI_TIRS)	**MODIS**
Websites Provided	Websites Provided
Global Visualization Viewer (http://glovis.usgs.gov/)	The Land Processes Distributed Active Archive Center (LP DAAC) (https://lpdaac.usgs.gov/)
EarthExplorer (http://earthexplorerusgs.gov/)	Global Land Cover Facility (http://glcf.umd.edu/)
Landsat.org. (http://www.landsat.org)	Reverb (http://reverb.echo.nasa.gov/reverb)
Global Land Cover Facility (http://glcf.umd.edu/)	Data Pool (https://lpdaac.usgs.gov/datapool/datapool.asp)

The Landsatdataprovided have recently applied the standard processing algorithms and terrain correction making them very easy to use. There are three types of Landsat data level corrections; standard terrain correction (Level 1T), systematic terraincorrection (Level 1GT), systematic correction (Level 1G) (USGS, 2013). The selection of the data types depends on the users' studies. However, all these types of Landsat data are very compatible for mapping, change detections and monitoring of mangrove ecosystem (Fatoyinbo et al., 2008, Liu et al., 2008, Churches et al., 2014).There are several types of MODIS land data product that could be useful for the mangrove studies such as Land Cover Type (MCD 12C1), Leaf Area Index (MCD15A2), Surface Reflectance Bands (MD09A1), Gross and Net Primary Production (MOD 17A) and Vegetation Indices (MQ13) (Vo et al., 2013). A MODIS Vegetation Index (MQ13) is of particular interest for vegetation phenology research. It comprises the Normalize Vegetation Index (NDVI) and Enhance Vegetation Index (EVI) (USGS, 2013). However, there are several limitation and challenges of using low cost of satellites data. Too coarse of spatial resolution of Landsat data required deep-species differentiationand parameterization(Kuenzer et al., 2011). High resolution in spatial data of aerial photography was compatible only for the small area (Kairo et al., 2001, Kuenzer et al., 2011, Sulong et al., 2002, Tarmizi et al., 1998,).Thus, these limitations could be a challenge for mapping the diversity mangrove species in Malaysia.

Therefore, the combination on the application of satellite data such as aerial photography, Landsat and MODIS data could be an option on mangrove mapping using satellite data for the tropical countryespecially in Malaysia. According to Kuenzer et al. (2011), the selection of satellitedata in the mangrove studies depends on the users'study objectives.

Furthermore, recent advanced approaches of mangrove classification method could be applied for the low-cost satellite data.

Furthermore, the clouddata is the utmost limitation on using of temporallow-cost satellite data(Nezry et al. 1993,Kuenzer et al. 2011). Limited review of the sources of free satellitedata access could be a reason in circumstanceto get a cloud cover free data(Kuenzer et al., 2011). As discussed above, there are several websites that provide thousands of free satellite data which could be an option for selecting low-cost satellite data.

CONCLUSION

This paper provides a comprehensiveoverview on the applicability of low-cost satellite data in mangrovestudiessince the last two decades, including studies in different regions using different sensors and different image-processing methods. Well over 70 studies have been published and the majority studies were conducted in Asia (Vietnam, Thailand, Bangladesh, Malaysia, India, Sri Lanka, and Taiwan) followed by Australia,North, Central and South America (Florida, Texas, Brazil, Panama and Madagascar). The application of low-cost satellite such as Landsat and MODIS data have been used widely in mangrove mapping, change detections and monitoring. The visual interpretations, pixel-based classification and vegetation index approaches are the most frequently applied method. Recent advanced and hybrid-classification techniques combinedwith the pixels-based approaches have been used in some studies. This demonstrates that even using the low-cost satellite data with lower resolution level, mangrove mapping is highlyinteractive;it needs to be exploredfurther using the recent advance method. The low-cost satellite data (Landsat series, MODIS, Aerial photography) are excellent for the mapping of mangrove ecosystems (however, usually not at the species level), the monitoring of largescale changes, and assessment of the condition of mangroves (vigor, age, density, etc.). Global mangrove loss numbers have been derived solely from the analysis of medium-resolution data. Therefore, the information presented in this paper will serve from basic information to the recent advance and future opportunities of the low-cost satellite data for mangrove studies in Malaysia.

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