Modern Applied Science
www.ccsenet.org/journal.html
Vol. 2, No. 6
November 2008

UPM-APSB AISA Airborne Hyperspectral Technology for Managing Mangrove Forest in Malaysia

Kamaruzaman Jusoff
Yale University, Centre for Earth Observation (CEO)
Environmental Science Centre, 21 Sachem St, New Haven CT 06511, USA
Tel: 203-676-7761 E-mail: jusoff.kamaruzaman@yale.edu

The research is financed by Universiti Putra Malaysia and Aeroscan Precision (M) Sdn Bhd (Sponsoring information)

Abstract

Mangrove forests are one of the most productive and bio-diverse wetlands environments on earth. In Malaysia, Forestry Department of Peninsular Malaysia (FDPM) has always been fully committed to the implementation of the sustainable forest management practices and in line with current concerns such as climate change, conservation of biodiversity and Tsunami, have brought about a heightened expectation on the political, socio-economic, ecological and environmental well-being of the country. Thus, managing mangrove forests is very challenging to the department and a precise geospatial database is urgently required. The objectives of this paper are to assess the capability of UPM-APSB's AISA airborne hyperspectral imaging sensor for developing a geospatial database through an individual mangrove species mapping and to determine the wavelength regions that define the inherent spectral characteristics amongst mangrove species. A total of nine groups of mangrove species spectral separability were identified in Port Klang, Selangor namely Lumnitzera littorea, Rhizophora mucronata, R. stylosa, Sonneratia alba, Avicennia officials, R. apiculata, Bruguiera parviflora, B. gymnorhiza, B. cylindrical and S. caseolaris. The species were easily identified and separated in the NIR range (700 nm to 900 nm) with the following spectral values namely (a) 1,750-6,000:B. cylindrical, (b) 2,000-7,750: B. gymnorhiza, (c) 1,875-8,250: B. parviflora, (d) 1,875-5,500 :A. officials, (e) 1,625-6,250 :S. caseolaris, (f) 1,875-5,250: S. alba, (g) 1,750-7,500: R. apiculata, (h) 2,000-8,000: R. stylosa, (i) 2,200-7,000: R. mucronata. Results of this study indicated that the mangrove species could only be identified at the near infrared (NIR) wavelength (700 nm to 900 nm) and not in the visible (VIS) spectrum. With such a capability, the sensor should be in a position to provide a geospatial database of the Malaysian mangroves for Tsunami management and other purposes of interests. Future management of mangrove forests in P.Malaysia should then adopt an integrated approach by further refining the current management and incorporating latest findings and updated latest geospatial information through more vigorous airborne hyperspectral data acquisition on mangrove forest. With the future geospatial database developed from the sensor, the National Forestry Policy and other policies related to mangrove forests management can be revised from time to time to match latest prevailing conditions and requirement. The future success in developing a mangrove geospatial database using UPM-APSB's AISA data by FDPM will in fact contribute to the sustainability of the wetlands in Malaysia which is crucial to the survival and future health of our Mother Earth.

Keywords: Mangrove, Airborne sensing, Hyperspectral, Mapping, Management, Tsunami

1. Introduction

Mangrove forests are one of the most productive and bio-diverse wetlands environments on earth. The importance of mangrove forests in providing invaluable goods and services both in economics and environmental terms are well understood and documented (Dato' Hj. Dahlan, 2007). In Peninsular Malaysia, mangrove forests forms one of the major wetland types which have been identified as one of the key life support systems on earth. Mangroves in P. Malaysia are found mainly on the sheltered west coast that borders the Straits of Melaka in the states of Kedah, Perak, Selangor and Johor. Major near-shore islands, including the Kelang islands in Selangor and Pulau Kukup in Johore are also predominantly colonized by mangroves. Small patches of mangrove forests occur along the rocky shores and they include those found in Pulau Langkawi, Kedah; in Pulau Pangkor, Perak; and in Port Dickson, Negeri Sembilan. In the south, mangroves are found in the estuaries of Sungai Pulai and Sg. Johor which drain into the straits of Johor, and the remaining mangroves are found along the straits of Johore. On the east coast, mangrove forests are mostly confined to

sheltered estuaries of the Kelantan Delta and Tok Bali, Kelantan (Kasawani *et. al*., 2007), Kemaman river in Terengganu, Bebar in Pahang. The total area of mangrove forests in Peninsular Malaysia at the end of 2006 is estimated to be 107,802 ha of which 82,091 ha has been gazetted as Permanent Reserved Forests (PRFs). Perak has the largest mangrove reserves, followed by Johore and Selangor. Mangrove reserves of Matang (Perak), South Johor (Johor) and Kelang (Selangor), together constitute 74 percent of the mangrove forest reserves. The importance of managing mangrove forests using hierarchy analysis goes beyond their status as the habitat of many endangered flora and fauna species (Nur Ilayana and Kamaruzaman, 2007). They are a valuable natural resource with distinctive diversity, high intrinsic natural productivity and unique habitat value. Mangrove forests provide invaluable goods and services both in economics and environmental terms. Apart from the production of poles, charcoal and fuel wood, the mangrove ecosystem supports a wide range of functions such as coastline protection, assimilation of waste, source of food, shelter and sanctuary for fauna, spawning and breeding ground for marine life and also recently proven as a barrier to significantly reduce the height and force of the waves of the tsunami. The mangrove forests can be an idyllic retreat for nature and wildlife lovers, photographers, bird-watchers or anyone who wants to relax and appreciate the beauty of the mangrove environment and its diverse flora and fauna. The meandering rivers and rivulets add to the peaceful environment especially to those escaping the tension of city life. Fireflies found at river estuaries have been a major ecotourism attraction, such as in Kampong Kuantan, Selangor (Wan Faridah *et. al*., 2007); Kampong Yakyoh, Trengganu; Kelantan Delta, Tumpat; Sungai Lebam, Johor; and Kuala Linggi, Negeri Sembilan/Melaka. Traditionally, the coastal communities living within or at the fringes of the mangrove forests have been dependent on the mangrove forests for their livelihood. Mangrove forests are a major source of fishery resources. The mudflats are habitats for various types of shellfish, where many species of fish, prawns and other marine fauna spawn and feed. Local communities have been relying on the mangrove forests for consumable plants and medicinal herbs (Amjad and kamaruzaman, 2007). Yet, these unique coastal tropical forests environment are among the most threatened habitats in the world, for instance the degradation of Indus Delta mangroves in Pakistan (Amjad *et. al*., 2007).

Mangroves act as "bio-shield" as they act as a barrier to the coastal waves, but the impact caused by the tsunamis was so devastating that it has resulted in the destruction of many mangrove trees along the southeastern coast lines. An obvious environmental impact of the Tsunami is the physical damage to the mangroves that has resulted from waves and backwash. The deposit of silt may lead to the clogging of pores of the aerial roots of mangroves and cause total destruction of the plant species. The degree and extent of damage of the mangrove is not known. Their loss can certainly prove to be disastrous in terms of coastline ecosystem functions. An integrated comparative approach to mangrove vegetation mapping using advanced remote sensing and GIS technologies has been well reported by many researchers Aschbacher *et. al.,* 1995; Amjad *et. al.,* 2007; and Kasawani *et.al*., 2007). For Tsunami-effected areas, as all other disaster-effected areas, utilization of hyperspectral sensing data, in particular airborne hyperpsectral imaging technology can offer a real-time synoptic view for quick detection, quantification and monitoring in real-time. Moreover, remote sensing and GIS can be used to model the impact of disasters such as Tsunami. The benefits of spectral imaging have been addressed in university research, especially in Malaysia for more than four years. Several airborne instruments especially UPM-APSB's AISA sensor have been available for applications development and studies (Kamaruzaman, 2006); in addition, new airborne instruments with refined capabilities have been recently flown or are nearing completion. The use of airborne instruments is a natural way to develop algorithms and techniques. Typically, the image resolution is determined by instrument design and aircraft altitude and this can be varied to understand resolution impacts on phenomenological processes. In addition, aircraft systems allow opportunistic collections because of their scheduling flexibility with respect to weather. Satellite systems, on the other hand, permit broader, recurring views to address larger scale and regional issues. Until now, there have been no space-based hyperspectral instruments to provide this option. Hyperspectral imaging is the simultaneous collection of images covering many narrow, contiguous wavelength bands. From each pixel in the image spectral responses that are indicative of what material is exposed on the Earth's surface can be extracted. Absorption features in these spectra are determined by chemical composition and physical structure and as such can be used to identify a wide range of materials. Subtle variations in composition or structure lead to shifts in position and shape of absorption features which allows the differentiation of many similar substances and the depth of absorption features that provide the measure of abundance. These capabilities are what make airborne hyperspectral imaging such a powerful tool in remote sensing (Kamaruzaman, 2006). The objective of this paper is therefore to demonstrate the capabilities and usefulness of UPM-APSB's AISA airborne hyperspectral imaging technique for future geospatial database development towards sustainable management of the mangroves with a specific individual species mapping case study in Port Klang, Selangor, Malaysia.

2. Methodology

2.1 Description of the study area

Few area of interest (AOIs) was selected in this study covering Sabah and Peninsular Malaysia. However, in this paper only Port Klang mangrove forests located in Klang River and Northport of Klang in the state of Selangor have been selected (Fig.1). The geographical position of Port Klang mangrove forest is located at latitudes 2º59'24" N-2º59'12" N

and longitudes 101º22'36" E-101º23'12" E. The study area comprises of four major families of mangrove species (Avicenniaceae, Rhizophoraceae, Bruguiera and Sonneratiaceae). A total of 19 samples of mangrove trees were randomly selected for this study. The mangrove species that were randomly selected in the area includes *Rhizophora mucronata* (Bakau Kurap), *Rhizophora stylosa* (Bakau), *Rhizophora apiculata* (Bakau Minyak). *Bruguiera parviflora* (Lenggadai), *Bruguiera gymnorhiza* (Tumu), *Bruguiera cylindrical* (Bakau Putih), *Sonneratia caseolaris* (Berembang), *Sonneratia alba* (Perepat), *Lumnitzera littorea* (Teruntum Merah) and *Avicennia officials* (Api-api Ludat).

<Fig. 1 A map of Peninsular Malaysia showing the location of study site (in red circle) >

2.2 Systems overview of UPM-APSB's AISA hyperspectral airborne sensing technology

UPM-APSB'S AISA airborne hyperspectral system is a commercial hyperspectral sensor product that was manufactured by Finnish Company SPECIM, Spectral Imaging Ltd. and is operated by Forest Geospatial Information & Survey Lab (FGISL)/Aeroscan Precision (M) Sdn. Bhd. in Lebuh Silikon, Universiti Putra Malaysia to acquire hyperspectral imaging data from the sky about mangrove canopy (Fig.2). This sensor is a small, lightweight (15 kg) portable instrument and easy to handle. Recent enhancements to the hardware and software of the Caligeo system have produced a significant reduction in the integration time, which has improved its overall spectral and spatial capabilities. The swath width of the aircraft is 360 m with a 10% overlap and Field of View (FOV) that will be flying in cross track with the direction of 20º and can produce a spatial ground resolution from 1 km altitude approximately 1 m at a flight speed of 120 knots (60 m/s). UPM-APSB's AISA airborne hyperspectral sensor is capable of collecting data within a spectral range between 430 to 1,100 nm and have 286 spectral channels. Current operational collection configurations range from 10 to 70 spectral bands depending on the aircraft speed, altitude and mission goals.

<Fig. 2 A complete UPM-APSB's AISA airborne hyperspectral sensor system >

The UPM-APSB's AISA sensor system also incorporates the Fiber Optic Downwelling Irradiance System (FODIS). The FODIS allows for the concurrent measurement of downwelling and upwelling radiance by the UPM-APSB's AISA sensor head. A diffuse collector installed on the top of the plane is connected to the UPM-APSB's AISA head via fiber optic cable and collects downwelling irradiance in the same bandwidth configurations as the areas being imaged. The calibration of the FODIS coupled with the UPM-APSB's AISA sensor allows for the calculation of apparent at-platform reflectance.

2.3 Data pre and advance processing

In order to provide accurate location of the remotely sensed data, an Inertial Navigation System (INS) and Differential GPS (DGPS) are integrated into the UPM-APSB's AISA sensor suite. The INS and UPM-APSB's AISA data streams are combined in the collection computer to provide frame by frame geo-referencing of the imagery. Pitch, roll, and yaw are encoded with the DGPS information to provide accurate locations of areas of interest on the ground. The UPM-APSB's AISA pre-processing software (CaliGeo) provides for the automatic geometric correction, rectification, mosaicking, and calculation of radiance or apparent at-platform reflectance (FODIS ratio). The program uses the DGPS and attitude information from the INS to perform the geometric, geo-referencing and mosaicking operations. Automated batch processing provides for rapid turnaround times for data delivery. To ensure the accurate measurement and calculation of radiance and "reflectance", the UPM-APSB's AISA system is frequently calibrated using's own NIST traceable integrating sphere. The generated calibration files were used by the CaliGeo software to output images in either radiance ($mW/cm^2/sr/nm/ms$ – times a scaling factor) or apparent reflectance. Hyperspectral imaging data is typically formatted into cubes in which the base of the cube is a two-dimensional spatial image of the observed scene at a given wavelength and the height of the cube is built up of many 2-D image layers, each from a different spectral channel. The resultant cubes are typically very large.

ENVI 4.0 which combines a complete image-processing package with the most advanced yet easy-to-use spectral tools was used for the digital image analysis in this study. This powerful amalgam creates a complete data analysis and visualization environment perfect for today's advanced earth science courses. The ease of use, ability to handle airborne hyperspectral data, powerful algorithms and flexible parameters make ENVI 4.0 an excellent choice for hyperspectral analysis. In the data analysis process, factors such as the sensor and attitude alignments, accuracies of the attitude measurement system, DGPS, ground control points and the digital elevation model were all required to be taken into consideration. This ancillary data, in combination with the hyperspectral data (in the 400 nm to 1,100 nm band range, depending on the application requirements), adds up to more than two gigabytes of data amassed during each operational remote sensing flight. In addition, multiple flights are routinely required to scan the entire area under study, further compounding the volume of data until complete images, sometimes as large as 50 gigabytes, are created. ENVI's spectral analysis tools, for example the spectral angle mapper and unmixing algorithms, to analyse the data includes an extensive spectral library for mangrove forest species, as well as masking and classification routines which complement ENVI's many other image processing and data analysis routines were fully utilized in this study. Additional mangrove

forest analysis algorithms were developed using IDL and incorporated with ENVI.

3. Results and discussion

3.1 Development of spectral signatures for individual mangrove forest species mapping and identification

The spectral libraries for 19 randomly selected mangrove trees at Port Klang using analysis image from UPM-APSB's AISA airborne sensor through ENVI software were obtained. From the 19 samples that were randomly selected, a total of nine mangrove species was identified and mapped using the UPM-APSB's AISA sensor (Fig.3). Through the visible (VIS) light region (650 - 680 nm), mangrove forest tree is very low in spectral reflectance, with the exception of small rise in the green. The spectral profiles for nine species from 19 selected trees showed different spectral profile and wavelength absorption because each tree species emitted or radiated varying VIS and Near Infrared (NIR) light at different wavelength. In this study, different spectral patterns were observed from different mangrove species. These results encourage us to further study mangrove areas in the tropics as well as to acquire information on local distribution of different mangrove species for sustainable management and conservation in preparation for the second Tsunami, if any. Fig. 3 shows that the wavelength range between 450-700 nm absorbed sunlight below 2,000 values and all emittance at this range did not show much different from each other. In the wavelength range of 700 nm to 800 nm, there are increased of spectral value from 1,750 to nearly 8,500. The spectral profiles of 19 selected trees were inseparable within this wavelength range because the intensity of solar energy reflected by trees is in dependent on the chlorophyll's ability to absorb the red and blue energy and the spongy layer to reflect the NIR energy. Perhaps, this is the reason why multi-spectral based satellites do not have such capability to identify individual mangrove tree species (Kamaruzaman, 2006; Kamaruzaman and Kasawani, 2007; and Kasawani *et. al*., 2007).

<Fig. 3 The spectral signature profile of nine mangrove species developed using the UPM-APSB's AISA sensor >

The trend of spectral profiles for nine species from 19-selected trees depends on the color of the canopy. The arising colors from the image showed that those four major colors can be separated in order to determine the dominant families of mangroves species (Fig.3). From the range of major colours (red, orange, green and yellow) they could then be distributed into nine different colours with various bands. The red canopy from AISA image can only be divided into one type of red (dark red) while the orange canopy could extract three more types of orange (dark orange, intermediate orange and light orange).A total of 10 of tree species were registered in the NIR region approximately at 700-900 nm wavelengths. These include families from Rhizophora, Bruguiera, Avicennia and Sonneratia. As displayed in on the electromagnetic spectrum that covers approximately 450-700 nm, the spectral profiles look similar. However, in the NIR region of the spectrum, the spectral profiles can be separated from each other.

3.2 Limited geospatial information in managing mangrove forests of Malaysia

There is limited geospatial information or documentation on mangrove degradation and destruction along the Malaysian coastlines. Similarly, many statements have been made about the impact on biological diversity loss, but there are lacks of scientific data or evidence especially real-time remote sensing geospatial database to support these statements. However, shrinking mangrove areas resulting from developmental decisions of the past, as well as signs of strain on the remaining mangroves provides evidence of threat to this ecosystem (Kasawani *et. al*., 2007). Being a fragile ecosystem, mangroves tend to fluctuate as a result of slight changes in the natural environment. Rapid development has led to clearing of mangrove areas to make way for urban and infrastructure development, beach resorts and aquaculture ponds. Industries and factories situated near the rivers and streams might discharge their effluent into the water systems, polluting and choking the riverine habitat, and eventually adversely affecting the aquatic biodiversity. The disruption of mangrove functions as part of our wetland ecosystem has a high cost: economically, socially and ecologically. The disturbance of their natural balance can destroy critical gene pools required for medical and agricultural purposes, affecting their ability to protect the coastline naturally and ruined their use for educational and recreational purposes. Constant sedimentation has endangered a variety of fishes and other marine species, particularly the corals. Destruction of mangroves led to a dramatic loss to the commercial and recreational fishing industry, coastal erosion, and endangered many floral and faunal species.

The mangrove ecosystem is a sensitive ecosystem that has continued to be affected by the rapid economic growth of the country. The familiar development-environment frictions have always been a major concern. Population pressures and the increasing demand for land continue to pose threat to the coastal and marine resources. Mangrove forests have been the most vulnerable, under severe pressure and the first to be cleared when the need for land arises. There have been perceptions that mangrove areas are considered wasteland, thus, converting mangrove to other uses will fetch a higher financial returns. To many, mangroves are considered an eyesore that need to be cleared, while to some, mangroves are a waterfront that need to be developed, failing to recognize the essential functions of mangroves in maintaining the coastal ecosystem. Another issue is jurisdiction between federal and state government. Matters related to land use and natural resources remains within the exclusive jurisdiction of the state. The vast natural resources sectors such as forests, fishery, wildlife, mining and agriculture are under different agencies/authority with separate sets of regulatory

laws, which at times creates overlaps in prescriptive and enforcement jurisdiction. The establishment of the National Forestry Council has successfully tackled this issue at policy level, and the various committees formed at the federal and state levels has helped to further improve towards conservation, sustainable use, management and development of the mangroves. Public awareness regarding mangroves and their conservation is on the rise. But some still do not appreciate the role of mangroves to the environment and quality of life. Despite the many benefits and functions, mangroves is seen not much more than timber, charcoal and woodchips, Indirect benefits offered by mangroves are easily forgotten and set aside when quick profits can be generated by converting mangroves to other uses. Absence of proper evaluation on mangrove forests results in the undervaluation of the mangrove forests. This in turn, has sent the wrong signals to the market. Therefore, there is need for a comprehensive valuation of our mangrove forests. More applicable inputs from research are needed.

3.3 Implications on the management of mangrove forests and Tsunami

Managing mangrove forests has been very challenging especially in combating the next Tsunami. The policy and management have great impact on political, social, economic, ecological and environmental (particularly Tsunami) well-being of the country. Forestry Department Peninsular Malaysia (FDPM) holds the responsibility and obligation in managing and safeguarding the Malaysian's mangrove resources. FDPM has taken steps to designate mangrove forest reserves to ensure they are efficiently and sustainably managed while preparing for the unpredictable natural disaster, Tsunami along the targeted Malaysian coastline as the first priority. In this particular preparation, UPM-APSB's AISA airborne hyperspectral imaging data which can be automatically inputted into a GIS-ready format should be able to locate the most suitable sites for Tsunami-warning tower installation. Factors that were taken into consideration in locating the sites include the risk of the area for tsunami, effectiveness of tower working range and the towers must not block the good view of scenery could be easily planned using this near real-time data. In addition to the sustainable management of mangrove forests along the coastlines of Malaysia, airborne hyperspectral images are also extremely useful and beneficial to Tsunami warning management in term of accuracy, quality, up to datedness, timely availability and cost effectiveness.

Mangrove forest reserves are managed with the overall goal of conserving and managing the sustainability of forest through sustainable management, and maintaining its important roles in the national economy and environmental stability (Dato Hj Dahlan, 2007). This goal was approved by the National Forestry Council through the National Land Council in 1992 and is binding for the states in Peninsular Malaysia. Large mangrove areas were excised for residential, agricultural and industrial purposes. These are in direct conflict with the ecologically sound multiple-use management system and prompted an urgent need for the formulation of a national mangrove management plan to ensure rational management and utilization as well as resolving conflicts in resource utilization by the various sectors. It is expected that UPM-APSB's AISA airborne hyperspectral system technology should be able to provide an updates on the existing mangrove four broad classifications of the Malaysian mangrove forest namely, (a) Protection Forest for ensuring favorable climatic and physical conditions of the country, safeguarding of water resources, soil fertility, environmental quality, conservation of biological diversity and the minimization of damage by floods and erosion to rivers and agricultural land (ha), (b) Production Forest for the supply in perpetuity at reasonable rates of all forms of forest produce which can be economically produced within the country and are required for agricultural, domestic and industrial purposes as well as for export (ha), (c) Amenity Forest for the conservation of adequate forest areas for recreation;. eco-tourism and in promoting public awareness in forestry (ha), and (d) Research and Education forest for the conduct of research, education and conservation of biological diversity (ha) (Dato Hj Dahlan, 2007). Certainly, this broad classification can be easily mapped, monitored, quantified and updated in near real-time and precision with the UPM-APSB's AISA airborne hyperspectral imaging data as per the State Forestry Department's demand and request.

3.4 Future strategy in managing mangrove forests

FDPM have been successful in managing and conserving the mangrove forests in Peninsular Malaysia since the early 1900s. However, there is room for further improvement with the use of airborne hyperspectral sensing technology. It is therefore possible to revise the NFP and other related policies from time to time (pending on airborne request and schedule) to match prevailing conditions and requirements, and to ensure the realization of its multi-functions in perpetuity. The co-operation and co-ordination of relevant agencies will be fostered with respect to specific objectives in safeguarding the mangrove ecosystems for conservation and management of Tsunami. Future management of mangrove forests in P. Malaysia will continue to adopt an integrated approach by further refining the current management approach and incorporating latest findings and updated geospatial information through more vigorous airborne hyperspectral imaging data capture and acquisition on mangrove forests. The remaining mangrove forests will be mapped, quantified, classified and protected to ensure its biological diversity remained intact and not lost in the name of development. Disruption to the mangrove ecosystems and functions must cease, the diversity of remaining mangroves must be retained, and where possible rehabilitation, restoration and re-creation of mangroves habitats must continue to be pursued for Tsumani.

4. Conclusion

There is no doubt that FDPM recognizes the significant role of mangroves and is fully committed to ensure that the Malaysian mangrove resources are well-managed, sustained, utilized, conserved and preserved for the benefits of present and future generations. It is expected that with the newly introduced UPM-APSB's AISA airborne hyperspectral imaging technology, FDPM will move a step forward and take a more positive approach by giving increasing emphasis on the geospatial database development for conservation aspects of mangroves forest management. The future success in the sustainable management of mangrove forests by FDPM using a geospatial database of mangroves will in fact contribute to the sustainability of the wetlands in Malaysia which is crucial to the survival and future health of our Mother Earth. Further investigation on the use of UPM-APSB's AISA airborne hyperspectral sensor technology for different management applications of mangrove forests is recommended to assess the full reliability of the system.

References

Amjad, A. Shah and Kamaruzaman Jusoff. (2007). Mangrove conservation through community participation in Pakistan: The case of Sonmiani Bay. The 5th WSEAS International Conference on Environment, Ecosystems and Development(EED'07), Puerto De La Cruz, Tenerife, Canary Islands, Spain, December 14-16, 2007.7p.

Aschbacher, J.K., Ofren, R.B., Delsol, J.P., Suselo, T.B., Vibulsresth, S.K. and Charrupat, T.K. (1995). An integrated comparative approach to mangrove vegetation mapping using advanced remote sensing and GIS technologies: Preliminary results. *Hydrobiologia.* 295, 285–294.

Amjad, A. Shah, Kasawani, I., and Kamaruzaman, J. (2007). Degradation of Indus Delta mangroves in Pakistan. *In*: Procs/CD of International Seminar on Wetlands & Sustainability, 4-6 September, 2007, Puteri Pacific Hotel, Johor Bharu, Johor, Malaysia. pp.347-360.

Dato' Hj. Dahlan Hj. Taha. (2007). Policy and management of mangrove forests in Peninsular Malaysia. A keynote paper presented at The International Seminar on Wetlands & Sustainability (ISWS'07), 4-6 September, 2007, Puteri Pacific Hotel, Johor Bharu, Johor, Malaysia. 10p.

Kamaruzaman Jusoff. (2006). UPM-APSB's AISA airborne hyperspectral imaging for individual mangrove mapping in Port Klang. *In*: Procs. National Seminar on Science, Technology & Social Science STSS2006, 30-31 May, 2006, Swiss Garden Resort & Spa, Kuantan, Pahang, Malaysia.pp.751-759.

Kamaruzaman J. and Kasawani, I. (2007). Spectral signatures of some mangrove species in Malaysia. The 5th WSEAS International Conference on Environment, Ecosystems and Development (EED'07), Puerto De La Cruz, Tenerife, Canary Islands, Spain, December 14-16, 2007.10p.

Kasawani, I., Kamaruzaman J., and Nurun Nadhirah, M.I. (2007). A study of forest structure, diversity index and above-ground biomass at Tok Bali Mangrove Forest, Kelantan, Malaysia. The 5th WSEAS International Conference on Environment, Ecosystems and Development (EED'07) Puerto De La Cruz, Tenerife, Canary Islands, Spain, December 14 -16, 2007.9p.

Kasawani, I., Najiha S. Amjad, A. S., and Kamaruzaman, J. (2007). Wetland cover changes in Kuala Trengganu District using Landsat^{TM} imagery. *In*: Procs/CD of International Seminar on Wetlands & Sustainability, 4-6 September, 2007, Puteri Pacific Hotel, Johor Bharu, Johor, Malaysia. pp.111-118.

Nur Ilayana Mohd Zukki and Kamaruzaman Jusoff. (2007). Applikasi proses analisis hierarki untuk pengurusan persis hutan paya bakau. (*In Malay*). A Poster Paper presented at the *Bengkel Hutan Pesisiran Pantai Negara: Kesedaran dan Tindakan Bersama*, 5-7 November 2007. Residence Resort Paka, Terengganu Darul Iman, Malaysia. 5p.

Wan Faridah Akhmal W. Jusoh, Kamaruzaman Jusoff and Zelina Zaiton Ibrahim. (2007). Meningkat kesedaran bakau melalui eko-pelancungan kelip-kelip. (*In Malay*). A Poster Paper presented at the *Bengkel Hutan Pesisiran Pantai Negara: Kesedaran dan Tindakan Bersama*, 5-7 November 2007. Residence Resort Paka, Terengganu Darul Iman, Malaysia. 5p.

Figure 1. A map of Peninsular Malaysia showing the location of study site (in red circle)

Figure 2. A complete UPM-APSB's AISA airborne hyperspectral sensor system

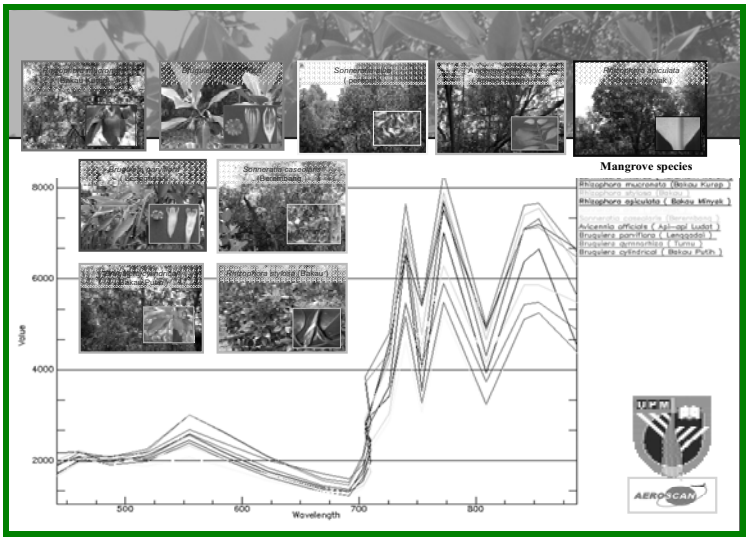

Figure 3. The spectral signature profile of nine mangrove species developed using the UPM-APSB's AISA sensor