MANGROVE MAPPING USING LANDSAT IMAGERY AND AERIAL PHOTOGRAPHS: KEMAMAN DISTRICT, TERENGGANU, MALAYSIA

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Abstract. Classification and distribution of mangrove vegetation are vital information for the proper development of a mangrove management plan. In this study, classification for the mangroves of the district of Kemaman were done using both 1 : 5000 aerial photographs and Landsat TM imageries. The coverage by aerial photographs is limited to the coastal and estuarine areas only. Thus, for areas further upstream of the aerial photo coverage, Landsat TM imageries were used. Analysis of aerial photographs and remote sensing images revealed that the mangroves of Kemaman could be classified into 14 different classes of vegetation. All the 14 classes were identified from areas covered by the aerial photographs. For areas covered by the Landsat images only 7 classes of vegetation were identified. The accuracy for aerial photograph and Landsat images are 91.2% and 87.8%, respectively. It can be concluded that although both techniques are useful in determining the mangrove vegetation classes, the large 1 : 5000 aerial photographs are more accurate and provided more detailed information comparatively.

Key words: aerial photograph, classification, Malaysia, mangrove, remote-sensing.

1. Introduction

Mangroves on the west coast of Peninsula Malaysia are more widespread than the east coast. This may be due to the different wave patterns of water bodies bordering the east and west coasts of the peninsula. The eastern side of Peninsula Malaysia is bordered by the South China Sea that has larger and more energetic waves while the west coast is bordered by the Straits of Malacca that has a limited wind fetch and is thus relatively calmer (Mohd Lokman and Yaakob, 1995). This accounts for the more widespread and rapid deposition of fine sediments and mangroves on the west coast of the Peninsula. The east coast mangroves totalled less than 12 000 ha compared to over 91 000 ha found along the west coast (Shaharudin et al., 2001).

The east coast mangroves are found almost entirely inside the estuaries, while the west coast mangrove are found fringing the coastline fronting the Straits of Malacca and also inside river estuaries. The east coast mangroves are normally found inside the estuaries, lining the banks up to the tidal limit, which may reach

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up to 20 km upstream. They are normally fragmented and found in small pockets. As mangroves have thus far been known for their ecological links to nearshore fisheries, the small and fragmented patterns of the east coast mangrove has rendered them to be viewed as unimportant. Many areas of mangroves have been removed to make way for development, particularly at the shores of the estuaries as these areas are considered as prime real estate. The physical role of mangroves, particularly, in protecting the riverbanks has failed to receive attention. Mangrove removal coupled with increasing water traffic has resulted in severe bank erosion in estuaries (Mohd Lokman and Sulong, 2001).

Prior to 1990 Malaysia had lost almost 30% of her mangroves and the rate is expected to continue at a rate of 1% a year (Gong and Ong, 1990). During the recent economic downturn, the National Economic Action Council (1998), the highest advisory body to the Malaysian government, emphasised the need to preserve estuarine mangrove as a measure to mitigate riverbank erosion. In this context the Forestry Department of Peninsula Malaysia (FDPM) has been charged with identifying suitable mangrove areas to be gazetted as Mangrove Forest Reserve. FDPM with the help from the Mangrove Research Unit of the Institute of Oceanography, Kolej Universiti Sains dan Teknologi Malaysia has embarked on a nationwide survey of mangroves in order to classify and study the dominant roles of each mangrove area so that they can be categorised according to their main functions and thus used accordingly. The application of aerial photography and remote sensing techniques for mapping of mangrove forest is not a new technique and has been conducted by many researchers previously, e.g. Green et al. (1988) and Ramsey and Jensen (1996). On a more recent paper, Anderson (1997) found aerial photographs still useful in mapping wetlands. Furthermore, aerial photographs are well adapted for stereo preparation and they are relatively cheap to analyse especially if the areas covered are small, such as mangroves (Spalding et al., 1997).

Application of remote sensing and aerial photograph analysis to Malaysian mangroves is limited. The available studies are those by Sulong and Ismail (1990) on a part of the Kemaman mangroves using 1 : 10 000 aerial photographs that revealed the existence of 7 classes of vegetation. Later other studies on mangroves using remote sensing were small section within a larger environmental sensitivity index reports. Two of such reports were authored by Sulong (1988, 1999).

This paper reports on a more detailed study than those mentioned above, conducted in the administrative district of Kemaman (Terengganu state), concerning distribution and classification of mangrove vegetation using remote sensing and aerial photographs.

2. Materials and methods

2.1. Description of the study area

The study area is located in the district of Kemaman, situated in the state of Terengganu within latitude 4°35′ North and longitude 102°50′ East and latitude

3°50′ North and longitude 103°40′ East (Figure 1). The district of Kemaman is relatively underdeveloped, except for areas along the coastline that are close to the Chukai town and port area, where steel and petrochemical plants are sited.

Typical of the Malaysian climate, the Kemaman district has a wet equatorial climate, which is characterised by all year round high temperatures and seasonally

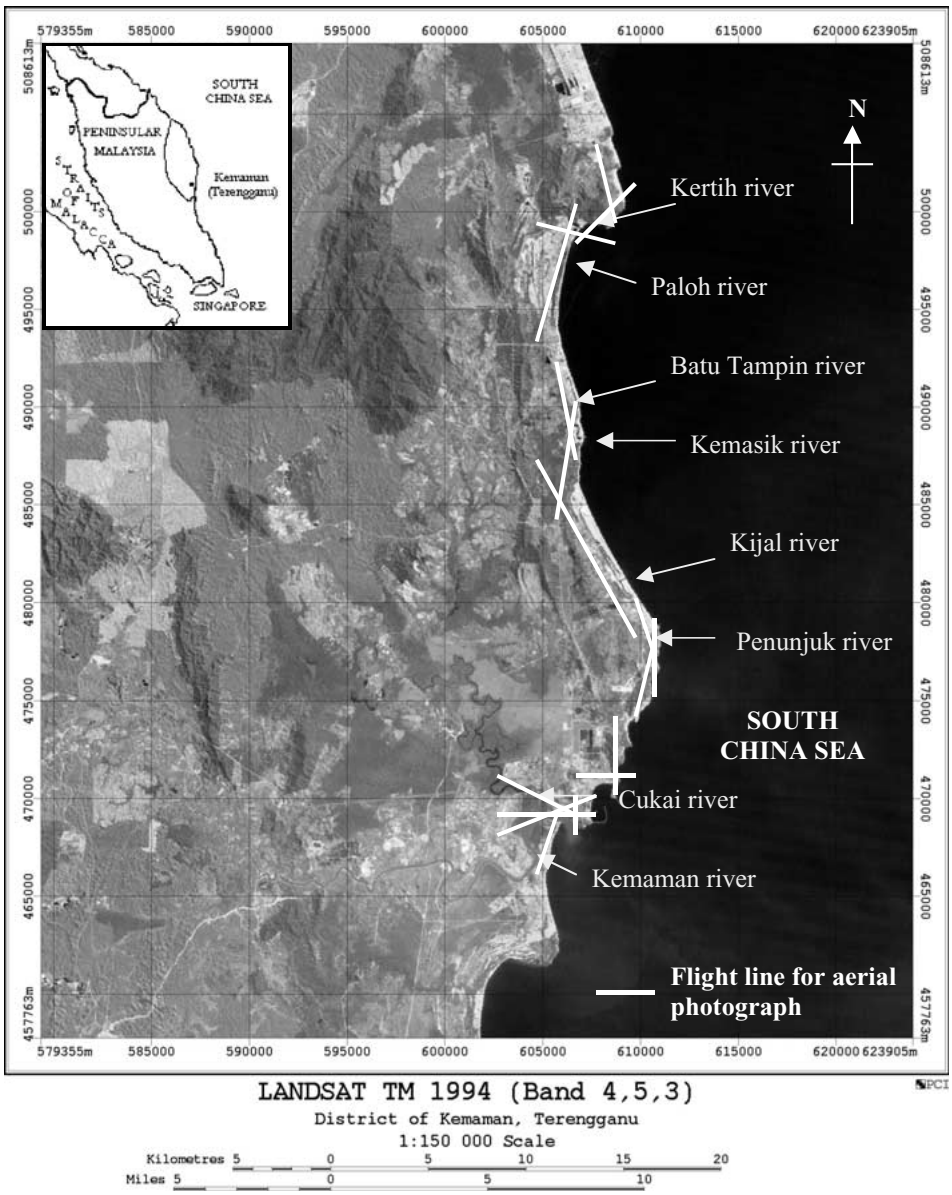

Figure 1. The raw data of Landsat TM imagery showing rivers within the study area and flight lines for aerial photographs.

heavy rainfalls, especially during the northeast monsoon from November to January each year. The mean maximum and minimum annual temperatures are 31°C and 22°C, respectively, while the average annual rainfall is 2181.3 mm (Malaysian Meteorological Service, 1997).

There are eight rivers in the district of Kemaman namely Kertih, Paloh, Batu Tampin, Kemasik, Kijal, Penunjuk, Cukai and Kemaman. The tide for the Kemaman area is predominantly diurnal, with a tidal range of less than 2 m. It is only during the highest astronomical tide that the tidal range exceeds 2 m. Tidal intrusion inside the rivers can reach up to 20 km upstream (Kamaruzaman, 1994).

This study was conducted in two main phases: interpretation of black and white aerial photographs with a scale of 1 : 5000 taken in 1992 and analysis of satellite Landsat TM imagery of 1994. The results were carried out during ground truthing to assess the accuracy of classification mangrove forest types map compared the real condition on the ground. Both phases were linked to GIS processing for spatial analysis and digital map production.

2.2. Aerial photo-interpretation

The area studied was covered by a total of 160 aerial photos from 18 flight lines. Four sheets of topographic maps with a scale of 1 : 50 000 were used to support the preliminary survey and aerial photo-interpretation throughout this study and also as reference maps for fieldwork. The mangrove forest types along the river mouths and riverbanks were interpreted and classified into several spectral classes based entirely on the elements of 'tone' and 'texture'. Tone refers to the relative brightness or colour of objects on aerial photographs and can be classified into three conditions: light, medium and dark. Texture, on the other hand, is the frequency of tonal change on the photographic image and can be classified into coarse, medium or fine. The mangrove forest types, which were delineated, based on the combination of characteristic photo 'tone' and 'texture' were traced onto tracing papers and used as the provisional mangrove forest type maps. At this stage the provisional mangrove forest type maps were not identified and named as they contained only 'zones' (Sulong and Ismail, 1990). The naming of these zones was done after checking the dominance of mangrove vegetation in the field. A total of 113 reference points were checked for errors of photo-interpretation during ground truthing. These provisional maps were then digitised or converted into a suitable digital format in geographic information system (GIS) to produce digital mangrove forest types map.

2.3. Digital image processing

The study was conducted using Landsat TM imagery taken on the 30th of June 1994 with a spatial resolution of 30 m for path 126 and row 57, acquired from the Malaysian Centre for Remote Sensing (MACRES). The digital processing of the Landsat TM imagery was performed using the PCI EASI/PACE Version 6.2

image processing system. The study area was identified on the imagery (Figure 1) and a subset of the study area was made for further analysis. After regular pre-processing and processing of the data, a false colour of thematic band of 4–5–3 (R–G–B) was prepared for visual interpretation. The visual image classification was done by observing the differences in the spectral responses and image contrast. Finally, a supervised classification of the sub image was performed by the maximum likelihood algorithm. After completing the classification procedure, the results were assessed for accuracy. A total of 33 reference points were chosen and visited during ground truthing. Then the supervised classification maps were digitised into ArcInfo GIS version 7.2.1 to produce digital mangrove forest types map for further spatial analysis.

2.4. Ground truthing and naming of forest types

The study area was visited two times, 14 days each between August 1998 and June 1999. The Bitterlich method of point sampling was carried out for this purpose (Husch et al., 1982). A total of 113 sampling points were established among the mangrove forest types. The points were randomly allocated proportionally according to size or area of different forest types. The parameters recorded were: mangrove tree species, size (diameter breast height, dbh) and tree count.

The species and the number of individuals in the forest type were recorded during ground survey. If the number of a particular dominant species is more than 80% then 'zones' is named after that species. For zone, which has two dominant species (both less than 80%) then that zone is named using both species. If more than three dominant species are present then the class is referred to as mixed mangrove. The criteria for naming of forest types by an information zones or spectral classes are the presence of one or more dominant species on the ground. The 'dominant' tree is referred to a tree whose crown extends above the ground level of the crown cover and receiving full light from above and larger than the average tree in the stand and with a crown somewhat crowded on the side (Smith, 1986). Mangrove species in categories exclusive and non-exclusive were considered to determine the dominant species on the ground. Exclusive species referred to mangrove tree species that restricted to the mangrove habitat whereas non-exclusive species may be important in the mangrove habitat but which are not restricted to it (Saenger et al., 1983).

3. Result and discussion

3.1. Availability of mangrove from aerial photo-interpretation

Mangrove forests in the Kemaman district were found at eight sites particularly at the river mouths and along the riverbanks of the following rivers: Kertih, Paloh, Batu Tampin, Kemasik, Kijal, Penunjuk, Cukai and Kemaman. The mangrove forests

along the Kertih, Cukai and Kemaman rivers were quite extensive while the remaining was small and fragmented. Approximately 938 ha of the mangrove forests bordering Cukai and Kemaman rivers are designated forest reserves by the FDPM. These reserves form a part of the country's Permanent Forest Estate while the remainder are considered as stateland mangrove forests and thus not managed and accounted for by FDPM. Since stateland mangroves are not monitored, they are the ones that are normally converted for other purposes by other government agencies. Accurate records of their existence and extent have not thus far been made. Nevertheless, their importance to the environment and economies of the local populace are now being realised.

Based upon the analyses of aerial photo-interpretation, the mangrove forests along the rivers were classified into several forest types. The combination of photo 'tone' and 'texture' for each mangrove forest type is shown in Table I.

From the interpretation of aerial photographs of scale 1 : 5000, 14 different types of mangrove forest were identified, namely: *Avicennia–Sonneratia*, *Avicennia–Bruguiera, Bruguiera*, *Bruguiera–Rhizophora*, young *Rhizophora*, mature *Rhizophora*, *Rhizophora*, *Ceriops*, *Kandelia*, *Lumnitzera, Excoecaria, Nypa,* mixed mangrove and dryland mangrove forest. In this study, young *Rhizophora* and mature *Rhizophora* were classified based on average dbh of *Rhizophora* trees. Young *Rhizophora* have average dbh 11.7 cm compared to mature *Rhizophora* with average dbh 21.4 cm. Table II shows the mangrove forest types along the eight rivers in the district of Kemaman. However, the black and white aerial photographs only covered the mangrove forests alongside Paloh, Batu Tampin and Penunjuk rivers, while for the remaining rivers, the coverage was restricted along the mouths and to some areas of the riverbanks only.

There were nine digital mangrove forest type maps produced from aerial photo-interpretation using GIS application. Examples of the mangrove forest type map produced for the Cukai and Kemaman Rivers are as shown in Figures 2 and 3, respectively.

TABLE I. Tone and texture of mangrove forest types.

No.	Mangrove forest types	Photo characteristics of forest types
1	*Avicennia–Sonneratia*	Light tone and coarse texture
2	*Avicennia–Bruguiera*	Medium tone and coarse texture
3	*Bruguiera*	Dark tone and moderate texture
4	*Bruguiera–Rhizophora*	Dark tone and coarser texture
5	Young *Rhizophora*	Darker tone and coarse texture
6	Mature *Rhizophora*	Darker tone and coarser texture
7	*Rhizophora*	Darker tone and moderate texture
8	*Ceriops*	Dark tone and coarse texture
9	*Kandelia*	Dark tone and fine texture
10	*Lumnitzera*	Very dark tone and very fine texture
11	*Excoecaria*	Medium tone and coarse texture
12	*Nypa*	Medium tone and moderate texture
13	Mixed mangrove	Dark tone and coarser texture
14	Dryland mangrove	Medium tone and very coarser texture

TABLE II. The mangrove forest types along the eight rivers within the study area.

Name of the river	Mangrove forest types	Number of forest types			
		Aerial photo-interpretation		Digital image processing	
Kertih	*Bruguiera–Rhizophora*	√	2	√	2
	Mixed mangrove	√		√	
Paloh	*Avicennia–Sonneratia*	√	3	—	1
	Rhizophora	√		—	
	Mixed mangrove	√		√	
Batu Tampin	Mixed mangrove	√	1	—	—
Kemasik	*Avicennia–Sonneratia*	√	3	—	1
	Nypa	√		—	
	Mixed mangrove	√		√	
Kijal	*Nypa*	√	2	—	—
	Mixed mangrove	√		—	
Penunjuk	*Excoecaria*	√	2	—	1
	Mixed mangrove	√		√	
Cukai	*Rhizophora*	√	3	—	3
	Bruguiera–Rhizophora	√		√	
	Avicennia–Sonneratia	—		√	
	Mixed mangrove	√		√	
Kemaman	*Avicennia–Sonneratia*	√	12	√	7
	Avicennia–Bruguiera	√		—	
	Bruguiera	√		—	
	Bruguiera–Rhizophora	√		√	
	Young *Rhizophora*	√		—	
	Mature *Rhizophora*	√		—	
	Rhizophora	√		—	
	Ceriops	√		√	
	Kandelia	√		—	
	Lumnitzera	√		√	
	Mixed mangrove	√		√	
	Dryland mangrove	√		√	
	Nypa	—		√	
Total mangrove forest types identified			14		7

The map of mangrove forests for the district of Kemaman was available since 1973, but was based upon topographic maps of scale 1 : 63 360. This map indicates only the location and boundary of the mangrove forest reserves. Later, when the topographic maps of scale 1 : 50 000 were available, the mangrove forest maps were updated and converted to the new scale. The new maps did not show the forest types or zones because no study on the mapping of mangrove forest types was carried out at that time. Thus, the previous maps only showed boundaries for mangrove forest reserves. The Forestry Department of Terengganu then added additional information on the boundary concerning forest compartments upon completion of ground survey, for management purposes.

An early study in classifying the mangrove forest types in the district of Kemaman was performed by Sulong (1990) using 1 : 40 000 aerial photographs taken in 1983. However, the study only concentrated on the southern portion of the Kemaman

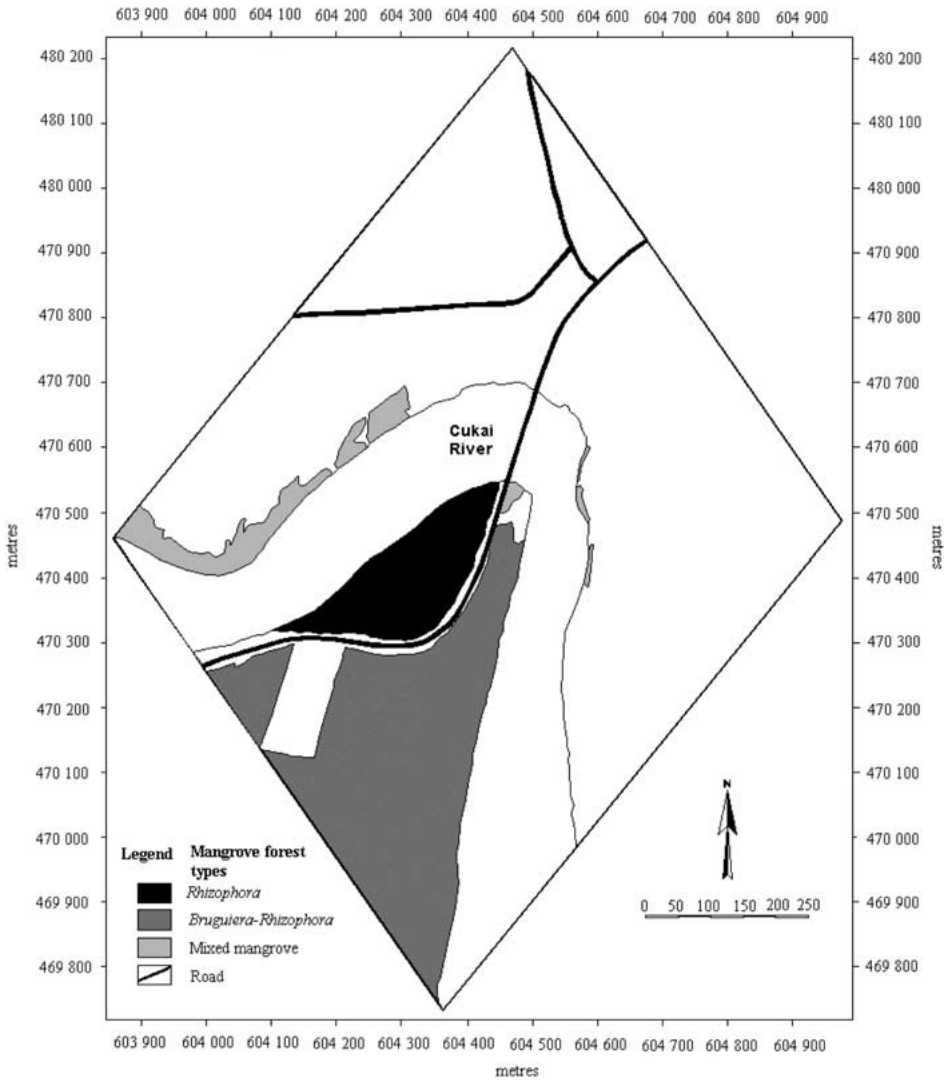

Figure 2. Map of the mangrove forest types along Cukai river determined using aerial photographs.

mangrove forest along Cukai and Kemaman rivers and revealed that the total extent of mangrove were about 901 ha. The result of this study was integrated with SPOT Imagery and used to map the sensitivity index (ESI) of the Cukai to Penor coastline (Nasiman and Sulong, 1988). In the ESI project, the mangrove forests were classified as the most sensitive areas with an ESI value of 10. This study, however, did not attempt to classify mangroves according to vegetation zones. Thus, this study is the first attempt to map the mangrove forest types for the whole district of Kemaman using aerial photographs and Landsat TM imagery.

The mangrove community in the study area is composed of 14 mangrove forest types: *Avicennia–Sonneratia*, *Avicennia–Bruguiera*, *Bruguiera–Rhizophora*,

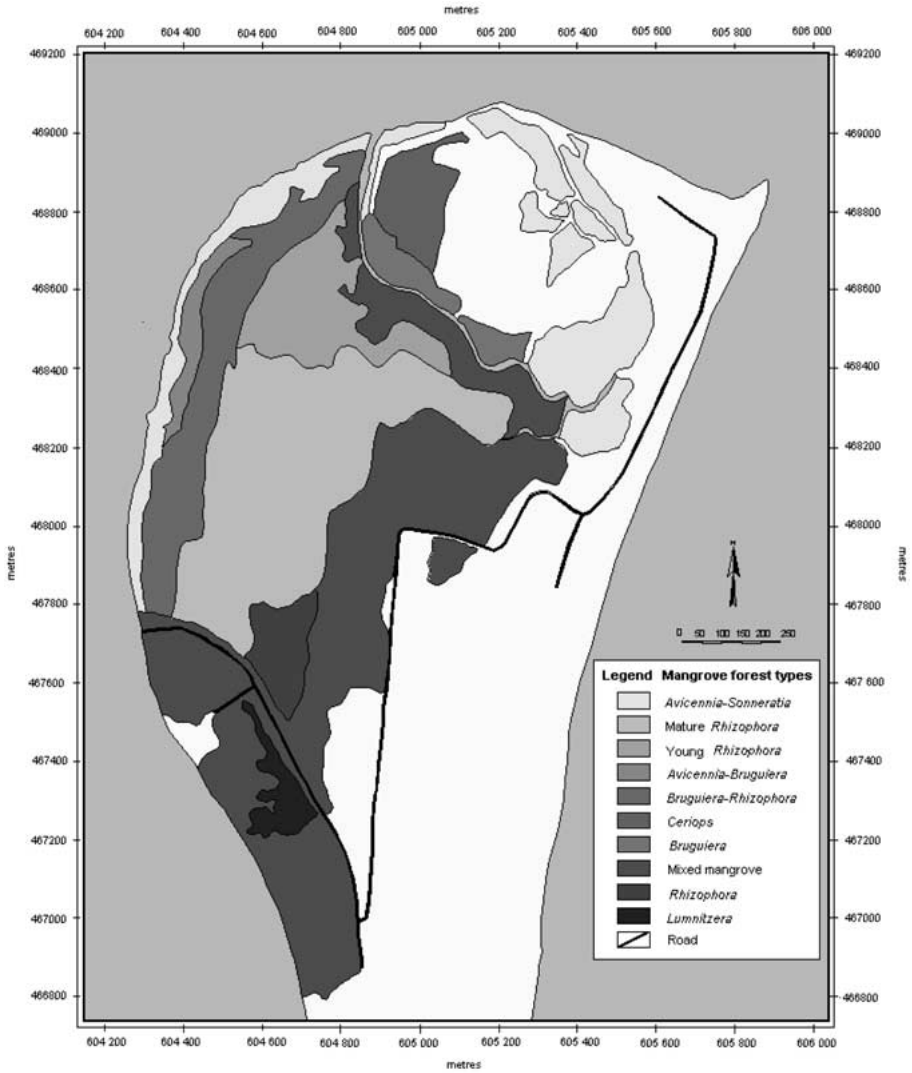

Figure 3. Map of the mangrove forest types along Kemaman river determined using aerial photographs.

Bruguiera, young *Rhizophora*, mature *Rhizophora*, *Rhizophora*, *Ceriops*, *Kandelia*, *Lumnitzera*, *Excoecaria*, *Nypa*, mixed mangrove and dryland mangroves. The present study was able to classify more mangrove forest types because there were more diverse species and forest types in the district of Kemaman. Other studies using various scales of aerial photographs are briefly described below for comparison. Earlier, Chai (1982) differentiated eight forest types in Sarawak using 1 : 10 000 scale aerial photographs (*Sonneratia alba* J. Smith, *S. caseoloaris* (L.) Engler, *Avicennia* spp., *Rhizophora mucronata* Lamk, *R. apiculata* Bl., *Bruguiera parviflora* Wight & Arnold Ex. Griffith, *B. gymnorrhiza* (L.) Lamk and *Rhizophora–Bruguiera*). Using aerial photograph of scale 1 : 40 000 Sulong

and Ismail (1990) were only able to differentiate three forest types in Kemaman (*Avicennia–Sonneratia*, *Rhizophora* and mixed mangrove). Similarly, Stellingwerf (1966) who used 1 : 40 000 aerial photographs were able to delineate the mangrove forest in Suriname into four forest types i.e. *Avicennia–Sonneratia, Rhizophora,* mixed mangrove and a freshwater-swamp. While Remeijn (1975) also differentiated them in Suriname into four forest types using aerial photographs of similar scale; *Avicennia–Sonneratia, Rhizophora–Bruguiera, Nypa* and ecotonic forest. Using aerial photographs of scale 1 : 25 000, Hamilton and Snedaker (1984) were able to classify the mangrove forest in Venezuela into three mangrove forest types: *Avicennia, Rhizophora* and marshland. Table III is a summary of the above studies on mangrove forest types mapping by aerial photo-interpretation.

It is clear that mangrove forests can be classified into several different forest types using different scales of aerial photographs and that the different scales can be used for different purposes. However, it seems that the 1 : 5000 aerial photographs give the best accuracy concerning tree aggregation for the purpose of forest types determination. Larger scale aerial photographs will reduce the accuracy of aggregation but will provide details of individual trees. It also seems that the black and white aerial photograph techniques are still practical in identifying and delineating mangrove forest types, particularly for the east coast mangroves where their occurrence are small in size and fragmented in nature.

3.2. Terrestrial characteristics of mangrove forest types

The mangrove forests types identified in this study are typical up of the dominant species of exclusive and non-exclusive mangroves from the 10 major mangrove vegetation families: Rhizophoraceae, Avicenniaceae, Fabaceae, Meliaceae, Sonneratiaceae, Combretaceae, Euphorbiaceae, Arecaceae, Moraceae and Rutaceae. The detailed terrestrial characteristics of each mangrove forest types are listed below.

3.2.1. The Avicennia–Sonneratia *forest*

This zone is where the mangrove first develops on bare surface and the species are therefore the initial colonisers. The forest is located at the waterfront where

TABLE III. Summary of mangrove forest types mapped by aerial photo-interpretation.

Authors	Year	Scale of aerial photograph	Results
Stellingwerf	1966	1 : 40 000	4 forest types
Forestry Department	1972	1 : 40 000	1 forest type
Remeijn	1975	1 : 40 000	4 forest types
Forestry Department	1982	1 : 40 000	1 forest type
Chai	1982	1 : 10 000	8 forest types
Hamilton and Snedaker	1984	1 : 25 000	3 forest types
Sulong and Ismail	1990	1 : 40 000	3 forest types
Tarmizi et al.	1998	1 : 5000	10 forest types
Sulong et al.	2000	1 : 20 000	9 forest types
Present study	2000	1 : 5000	14 forest types

the muddy substrate is soft and deep. This mangrove forest area in preferred by *Avicennia alba* Blume while on the firmer soil further inland it supports *A. marina* (Forsk.) Vierh and *A. lanata* Ridley. Along estuaries and rivers, *Sonneratia alba* and *S. caseolaris* were found to grow gregariously but never extensively.

3.2.2. The Avicennia–Bruguiera *forest*

This mangrove forest type mainly consists of *Avicennia* and *Bruguiera* species such as *Avicennia alba, A. lanata, Bruguiera cylindrica* (L.) Blume and *B. parviflora*. Other species such as *A. marina, B. sexangula* (Lour.) Poir and *B. gymnorrhiza* are scarcely scattered in this forest type. This forest grows as a narrow strip on silt and mud along the banks near the river mouth.

3.2.3. The Bruguiera *forest*

The dominant exclusive species of mangrove trees found here are *Bruguiera cylindrica*, *B. gymnorrhiza*, *B. sexangula* and *B. parviflora*. *Avicennia* species such as *Avicennia alba* and *A. lanata* are also found scattered in this mangrove forest type. It is normally found as narrow strips on the clay soil type near the river mouths and riverbanks.

3.2.4. The Bruguiera–Rhizophora *forest*

Bruguiera cylindrica, *B. parviflora*, *B. gymnorrhiza* and *Rhizophora apiculata* are the dominant species in this area. However, *R. apiculata* occupied approximately 50% of the area. This forest type is found normally close to the riverbanks whose substrate is of the muddy and clayey soil type. This forest type was found closest to young and mature *Rhizophora* forests.

3.2.5. The young Rhizophora *forest*

In this forest type, the sapling trees and seedlings of *Rhizophora apiculata* species dominate and form an extensive pure stand. The height of this stand is shorter compared to the mature *R. apiculata* trees. A few scattered *Bruguiera cylindrica* and *B. parviflora* were also noted in this forest. This forest type occurs on the higher area of the riverbanks where the soil is clayey and sometimes mixed with sand.

3.2.6. The mature Rhizophora *forest*

The mature *Rhizophora apiculata* is the dominant species in this area with a few occurrences of *R. mucronata*. The soil of this mangrove forest type is usually drier than the young *Rhizophora* forest type and is usually inundated by the normal flood tides.

3.2.7. The Rhizophora *forest*

The dominant species in this forest type is the young and mature *Rhizophora apiculata* with scattered occurrences of *Bruguiera cylindrica*, *B. parviflora* and *B. gymnorrhiza*.

3.2.8. The Ceriops *forest*
The dominant mangrove species here is *Ceriops decandra* (Griff.) Ding Hou and this type of forest is usually found as pure stands near the mouth of the river on sandy to muddy soil.

3.2.9. The Kandelia *forest*
This forest type is dominated by the exclusive mangrove species of *Kandelia candel* (L.) Druce. *K. candel* usually grows as pure stand on muddy soil within estuaries and not far from the river mouth.

3.2.10. The Lumnitzera *forest*
The exclusive mangrove species *Lumnitzera littorea* (Jack) Voigt is dominant in this mangrove forest type. A few scattered patches of *L. racemosa* Willd are also sometimes found here. It is found growing on muddy and sandy soil near the river mouth.

3.2.11. The Excoecaria *forest*
The exclusive mangrove species *Excoecaria agallocha* L. is found dominant in this mangrove forest type. Other species such as *Xylocarpus moluccensis* (Lamk.) Roem is also found scattered in this forest. *E. agallocha* grows sporadically on drier soil. This tree inhabits the landward edge of mangrove forests and can often be found at or just above the high tide mark.

3.2.12. The mixed mangrove forest
The common exclusive species found in this forest type are *Rhizophora* species, *Bruguiera* species, *Avicennia* species, *Lumnitzera* species, *Nypa fructicans* (Thunb.) Wurmb. and *Xylocarpus granatum* König. This forest type is distributed further inland growing mainly on clayey and sandy soils.

3.2.13. The Nypa *forest*
The *Nypa fruticans* palm is the dominant species found in this mangrove forest type. Stands of *N. fruticans* are commonly found occurring along the banks of most rivers where the salinity of the water is low. This forest also extends several kilometres inland. The palm generally grows gregariously, interspersed with *Avicennia* species and *Sonneratia* species near the river mouth and with *Rhizophora* species and *Bruguiera* species on soft mud further inland.

3.2.14. The dryland mangrove forest
Dryland mangroves denote the final stage of forest succession and represent the transition into inland forests. They are often found towards the landward side of mainland mangrove or in the interior of island mangroves. They are normally found on higher grounds and are, therefore, inundated by the higher spring tides. The common tree species in this forest type are the exclusive mangrove species of *Xylocarpus moluccensis* and *Intsia bijuga* (Colebr.) Kuntze and non-exclusive mangrove

species of *Oncosperma tigillarium* (Jack) Ridley, *Euodia roxburghiana* Benth. ex Hook F. (= *Euodia Lunu-ankenda* (Gaertn.) Merr.), and *Ficus microcarpa* L.F. with a few occurrences of palms.

Overall, during our ground truthing of the mangroves of Kemaman, we observed that the mangrove forest in the Kemaman district contained 29 species of exclusive mangrove (Mohd Lokman and Sulong, 2001). This equals to 76% of the total exclusive species reported to occur in Malaysia by Japar (1994) who reported the existence of a total of 38 exclusive mangroves for Malaysia.

3.3. Digital image analysis

In order to map the areas of mangrove forest, which were not covered by the black and white aerial photographs, the Landsat TM imagery was used. Two classification techniques (unsupervised and supervised) were performed on eight subsets (eight rivers) of Landsat TM imagery in the district of Kemaman using PCI EASI/PACE version 6.2 digital image processing software. Sixteen clusters were used to extract all the classes for unsupervised classification. The unsupervised classification maps were used as reference material during field survey to determine the information of spectral classes. The information from the field survey was used to select training sites for classes of mangrove forests by supervised classification techniques.

Results of the supervised classification showed that there were only six rivers in the district of Kemaman that have mangrove forests. The mangrove areas identified were found along the river mouths and riverbanks of Kertih, Paloh, Kemasik, Penunjuk, Cukai and Kemaman rivers. The result of the supervised classification for Cukai River (Figure 4) is produced as an example while Figure 5 is the digital mangrove forest type map for the Cukai River. The seven mangrove forest types delineated using this technique are: *Avicennia–Sonneratia, Bruguiera–Rhizophora, Ceriops, Lumnitzera, Nypa,* mixed mangrove and dryland forest. The detailed mangrove forest types for each river are shown in Table II.

In certain area, different result for identification and classification of mangrove forest types were obtained because different approach between remote sensing and aerial photograph techniques were applied. Remote sensing was based on spectral reflectance values compared to aerial photograph, which reflected by its tone and texture. It is also probably due to the spatial resolution of Landsat TM (30 m) and scale of aerial photograph (1 : 5000). The classification of mangrove forest types for Sungai Cukai was an example of this problem. The *Bruguiera–Rhizophora* forest type that was classified using remote sensing technique can be differentiated as *Rhizophora* and *Bruguiera–Rhizophora* types using aerial photograph technique.

Although digital image processing was able to classify mangrove forest types in a shorter time, it lacked details compared to aerial photo-interpretation that allowed us to distinguish 14 mangrove forest types. Although photo-interpretation of the area was not simultaneously done for the area, our observation during ground truthing revealed that a few more classes could have been identified if aerial photographs of 1 : 5000 scale of the area were available for analyses. As such the

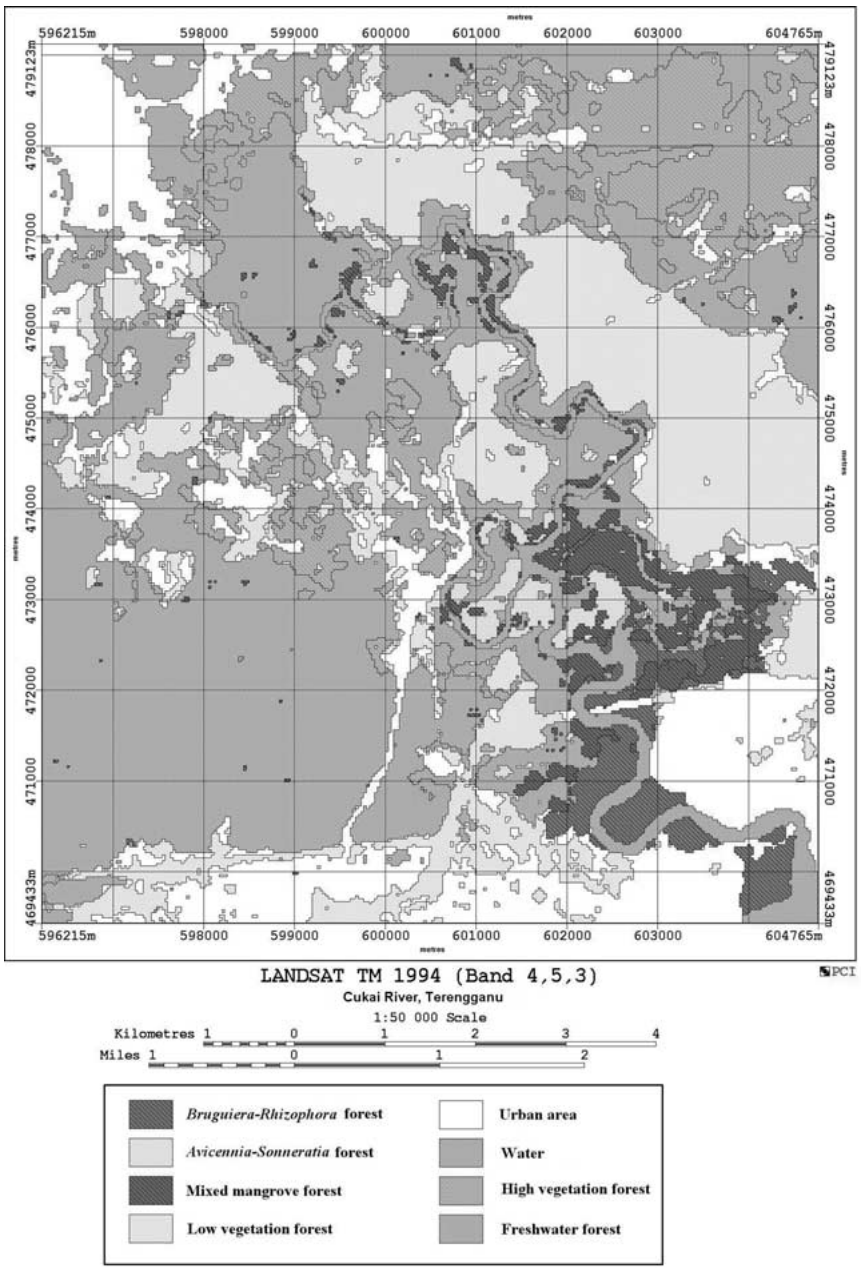

Figure 4. The supervised classification of the Landsat TM for Cukai river.

results from the supervised classification can be concluded not to be good enough for day-to-day management purposes. Additional complementary data by aerial photo-interpretation and ground sampling must be made available for the purpose.

Table IV lists similar studies done in Malaysia and in other parts of the world. From this table with respect to the number of classes or types of mangrove detected

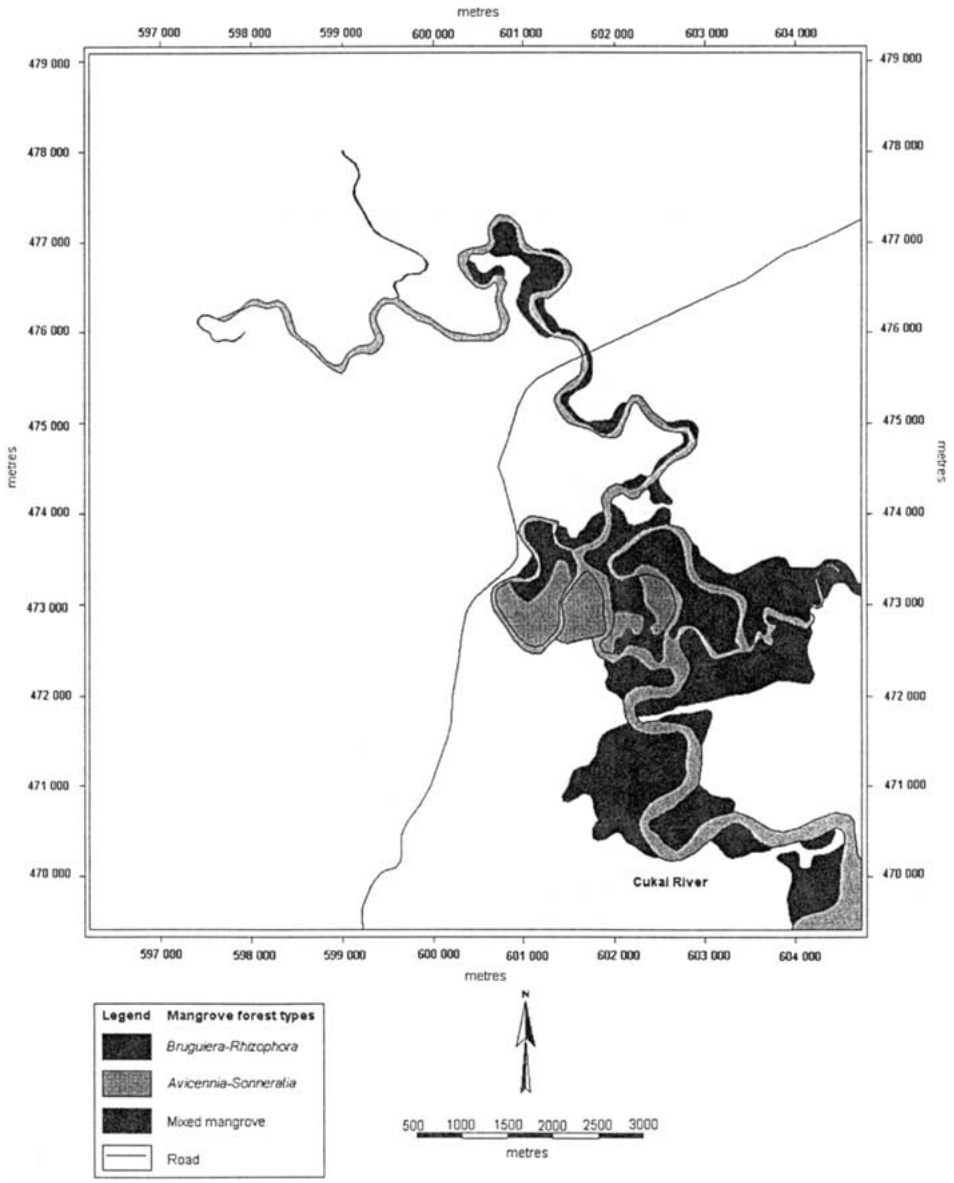

Figure 5. Digital map of mangrove forest types along Cukai river determined using Landsat TM imagery.

by digital image processing of Landsat TM imagery, it can be argued that the mangrove forests in the district of Kemaman have the highest number of forest types and may be one of the more diverse mangroves in Malaysia.

In this study, our results showed that classification of mangrove forest types using black and white aerial photographs with a scale 1 : 5000 was higher than Landsat TM imagery. Fourteen forest types were identified by aerial photo-interpretation

TABLE IV. Mangrove forest types mapped using satellite Landsat TM images.

	Author	Year	Location	Number of mangrove forest types
1	Sulong and Veddin	1999	Selangor, Malaysia	5
2	Shamsudin et al.	1999	Johor, Malaysia	5
3	Eong et al.	1992	Kedah, Malaysia	3
4	Sulong et al.	2001 Present study	Terengganu, Malaysia	7
5	Garcia et al.	1997	Mexico	2
6	Ramsey and Jensen	1996	Florida	3
7	Brondizio et al.	1996	Brazil	1
8	Long and Skewes	1996	Australia	1
9	Youssef and Saenger	1999	Australia	1
10	Green et al.	1998	Turks & Caicos Islands	1
11	Rasolofoharinoro et al.	1998	Madagascar	1
12	Chauvayd et al.	1998	French West Indies	1
13	Laba et al.	1997	Dominican Republic	1

compared to only seven forest types discriminated from digital image processing of Landsat TM imagery. The classification accuracy from aerial photograph is (91.2%) and from Landsat TM imagery (87.8%) respectively when both were evaluated against the result for ground truthing. Although, Landsat TM is useful as it covers a large area, but detailed information can only be provided by large-scale aerial photos, for the time being.

4. Conclusion

Based on the results of this study, it can be concluded that the Kemaman mangroves is one of the more diverse in Malaysia with 14 different classes of mangrove forest. As mangrove forests in the east coast region of Peninsula Malaysia are relatively scarce, steps must be taken to conserve them as Permanent Forest Reserves. The fringing and fragmented nature of the mangroves in Kemaman suggest that their role is more towards the physical aspect, that is shore protection as opposed to the more renown ecological role of the more extensive mangroves of the west coast of Peninsula Malaysia. Further, the 1 : 5000 scale black and white aerial photographs seems to be the largest that can provide tree aggregation information without giving individual tree detail. While imageries from Landsat TM are theoretically available every 26 days but good quality image with less than 20% cloud cover are only available approximately once a year. The classification accuracy from the satellite image is lesser than that of the 1 : 5000 aerial photographs.

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