LINEAR MIXTURE MODELLING APPLIED TO IKONOS DATA FOR MANGROVE MAPPING

Kasturi Devi Kanniah[1], Ng Su Wai, Alvin Lau Meng Shin and Abd. Wahid Rasib
Department of Remote Sensing, Faculty of Geoinformation Science & Engineering
University Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
Email:kasturi@fksg.utm.my/kdkan1@student.monash.edu

Abstract

Mixed pixels problem in remotely sensed satellite data often results in poor classification accuracy. However, high spatial resolution sensors such as IKONOS and QuickBird, are expected to classify mangrove species more accurately than conventional coarse spatial resolution satellite images. Nevertheless, conventional classification technique such as maximum likelihood could not improve the classification accuracy when such high-resolution images are applied. In order to improve the classification accuracy Linear Mixture Model (LMM) was applied in this study to classify the mangrove forest at Sungai Belungkor, Johor, Malaysia. High spatial resolution satellite imagery (IKONOS) was used to map three different mangrove species in the area. The application of LMM to mangrove classification involved image preprocessing, endmember selection, inversion of LMM and finally the accuracy assessment. Accuracy assessment was carried out between the fraction of pixels estimated from LMM and the fraction measured in the field. The results of accuracy assessment gave a correlation coefficient value of ~0.8 for endmember bakau minyak and ~0.6 for bakau kurap and "others" type of mangrove species. An error image was also created to compare the best fitting spectrum produced by the inversion of LMM to the original observed spectrum where the maximum RMS error was only 5%. The accuracy of LMM was also assessed based on a generalized area based confusion matrix. Areas that were correctly classified according to reference data and classified data were 63 % and 73%, for bakau minyak, 62 % and 60% for bakau kurap and 58% and 52% for "others" type of mangrove respectively. These accuracies obtained from LMM were higher in comparison to the classification results derived from maximum likelihood with the inclusion of texture information or minimum distance to mean classifier.

Keywords: Mangrove species, IKONOS, Linear Mixture Model, area based confusion matrix.

Introduction

Previous studies indicate that accurate discrimination among mangrove species was not possible with conventional (coarse spatial/spectral) resolution data, but was possible using aerial photographs (Sulong et al., 2002, Kairo et al, 2002 and Verheyden et al., 2002) or images from airborne sensors such as CASI (Green et al., 1998), MASTER (Alvin and Mazlan, 2003) and AVIRIS (Vaiphasa and Ongsomwang, 2004). The finer the spatial and spectral resolution of satellite images, more accurate the mangrove species classification results would be. The recent availability of images from high spatial resolution satellite sensors like IKONOS and Quickbird enable the mapping of land covers more accurately and they can also substitute the higher cost of airborne images.

There have been several studies using IKONOS imageries for classifying different land cover types. A comparative study was made by Wang et al., 2004 using IKONOS and QuickBird images for mapping mangrove species on the Carribbean coast of Panama in terms of their spectral statistic, textural information and classification accuracy using maximum likelihood classifier (with inclusion of panchromatic band and also the inclusion of first and second order texture information extracted from the panchromatic band).

Franklin et al., 2001 (in Wang et al., 2004) found that second order texture values extracted from a panchromatic IKONOS image effectively increased separability among nine Douglas Fir forest age groups. Another study was conducted by Mumby and Edwards (2002) to compare an IKONOS image with other remote sensing images like Landsat TM, SPOT, CASI etc. and they found that the fine spatial resolution image of IKONOS could achieve a better thematic accuracy in mapping marine environments.

With the invention of high spatial resolution sensors such as IKONOS and QuickBird, it is expected that more detailed discrimination between mangroves community can be achieved. Nevertheless, the classification accuracy does not increase with the increasing spatial resolution due to the mixed pixel phenomenon (Hsieh et al., 2001). Mixed pixels may cover a region containing different classes of ground cover of varying proportions, and therefore alter the traditional image classification approach which assigns a particular class of ground cover to each pixel.

Problems associated with the mixed pixel phenomenon have promoted a new approach to unmix the spectral characteristics of the mixed pixel. The success of Linear Mixture Model (LMM) in various disciplines seems to meet

[1] currently at Monash University, Australia, undertaking her PhD.

such a requirement (Abdul Shakoor, 2003, Cherchali and Flouzat, 1994, Roberts et al., 1998, Shimazaki and Tateishi 2001 and Zhu and Tateishi, 2001). The contribution of each pixel is assigned in proportion to the percentage area each ground cover class occupies in that mixed pixel (Boardman, 1989). Such an approach is called spectral unmixing which assigns more than one class label to an individual mixed pixel (Keshava and Mustard, 2002).

However, to date very few studies have examined the suitability of IKONOS images for mapping mangrove species (Wang et al, 2004) and none use LMM for mangrove mapping. Therefore, in this study, we attempted to map mangrove forest species using LMM.

Study area

The study area, Sungai Belungkor is located at the Southeastern edge of Johor river in Kota Tinggi District, Johor, Malaysia (Figure 1). It has been a reserved mangrove forest since 1930 has a total area of 1606 hectare. It is categorized as estuarine and highly disturbed mangrove. High species diversities of mangrove plants exist around the river (Christensen and Olsen, 1999). However, *rhizophora apiculata* (bakau minyak) and *rhizophora muscronata* (bakau kurap) are the dominant commercial mangrove species in this area besides other minor species such as nyireh bunga (xylocarpus granatum), berus (bruguiera cylindrica), lenggedai (bruguiera parvifloara), tumu (bruguiera gymnorrhiza), api-api putih (avicennia alba), tengar (ceriops tagal) and chinggam (scyphiphora hydrophyllcea) (Field visit and personal communication with forest rangers).

This area was particularly selected for this study because it is one of the mangrove areas in Johor that has never been studied using remote sensing techniques and little data are available on its forest composition due to its inaccessibility (personal communication). In addition, this area exhibits a high rate of mixture among various mangrove species that will certainly impose problems when classifying with per pixel classification techniques.

Figure 1. Study area at Sungai Belungkor mangrove forest, Johor, Malaysia. Polygon on the IKONOS image represents the mangrove boundary that was redrawn from the topographic map of Kota Tinggi district (map title: Pengerang, scale 1:50 000, map sheet number: 4651, year: 1996).

Data and methodology

Satellite data

The IKONOS imagery used in this study was acquired on the 16th March 2001 at 11:24 am local time (03:24 GMT time). The image was captured at 96.7 degrees sun azimuth angle and 62.8 degrees sun elevation angle. The cloud cover in this image is approximately 14% of the scene.

Three mangrove forest species, namely bakau minyak, bakau kurap and *"others,"* were selected to be classified in this study. The class *'others'* includes seven species (mentioned above) identified in the field. This is because, according to Johor Forestry Department, only bakau minyak and bakau kurap are the dominant commercial species in Sungai Belungkor, whilst the other species are considered minority and have no significant commercial value. Besides that only these two species and nyireh bunga could be differentiated spectrally in the IKONOS image (see Figure 2). Therefore we combined all other species as 'others'.

Field data

DGPS (Differential Global Positioning System) was used to obtain precise geographical locations in the field. The coordinates were mainly used to create Ground Control Points (GCP) in order to geo-register the satellite image accurately. Thirty sample plots with 4m x 4m spatial resolution that are identical to the size of IKONOS image (4 m) in size were established to estimate the mangrove species fraction on the ground with the aid of the DGPS. The fractions were measured based on the mangrove trees canopy or crown size. Fifty percent of the samples (15 points) were used for endmember determination and the rest of the points were used as checkpoints to assess the accuracy between the image derived and field measured fractions of the three mangrove species.

In addition, a portable spectroradiometer (model FieldSpec® Pro FR) that operates between spectral range of 350 - 1000 nm with 10 nm spectral resolution was used to build a spectral library of the mangrove species found in the study area. The spectral reflectances of all the species measured in the field were further re-sampled to suit the spectral bands of the IKONOS imagery (Figure 2). Image end-members or pure pixels were obtained by locating pixels in the scene with the maximum abundance of the physical end-members they represent. The image and the field-measured spectral library were input into ENVI 3.6 image processing software to compute fraction values for each end-members.

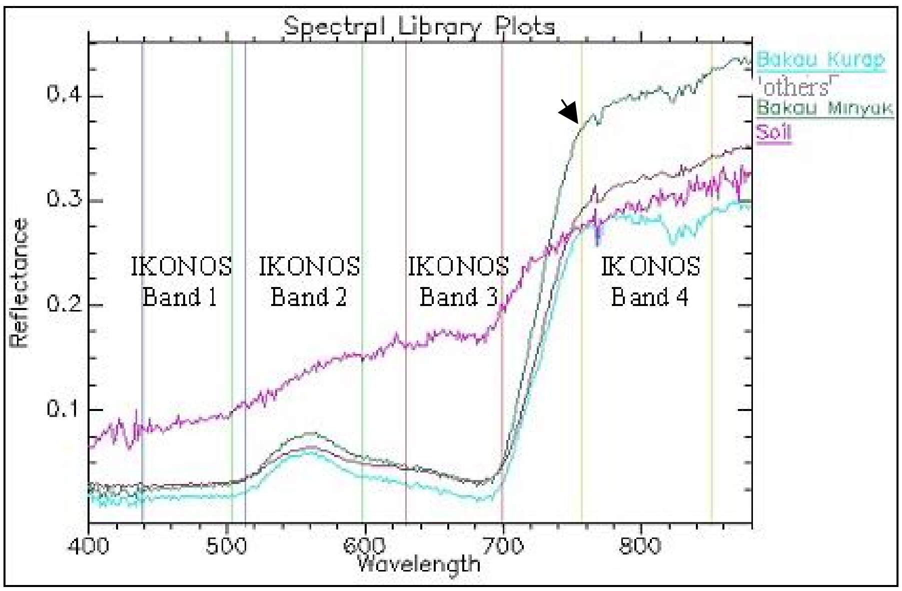


Figure 2. Spectral library for end-members bakau minyak, bakau kurap and 'others' from spectroradiometer readings. The four surface features can be separated in bands 4 and 2. However, in bands 1 and 3, bakau kurap can easily be differentiated from the other two species, but it is spectrally inseparable for bakau minyak and nyireh /'others'. Broadly speaking, these mangrove species are spectrally distinct in the wavelength covered by IKONOS images.

Methodology

The methods adopted in this study are illustrated in Figure 3. The IKONOS imagery was first corrected atmospherically and geometrically. Sub-setting and masking of water bodies and clouds were done to ensure only extent of mangrove forest would be further processed. Then, the raw digital number values were converted into reflectance values. Subsequently, LMM was applied by (i) selecting endmembers, (ii) inverting the LMM to estimate the fractional abundances of each mixed pixel from its spectrum and the end member spectra and (iii) assessing the accuracy of the image derived fraction values. Accuracy assessments were performed using (i) regression analysis between image derived and field measured fraction values, (ii) error image to compare the best fitting spectrum produced by the inversion of LMM and (iii) area based confusion matrix. The software used to carry out this study was ENVI 3.6 for satellite image processing and Microsoft Excel for statistical analysis.

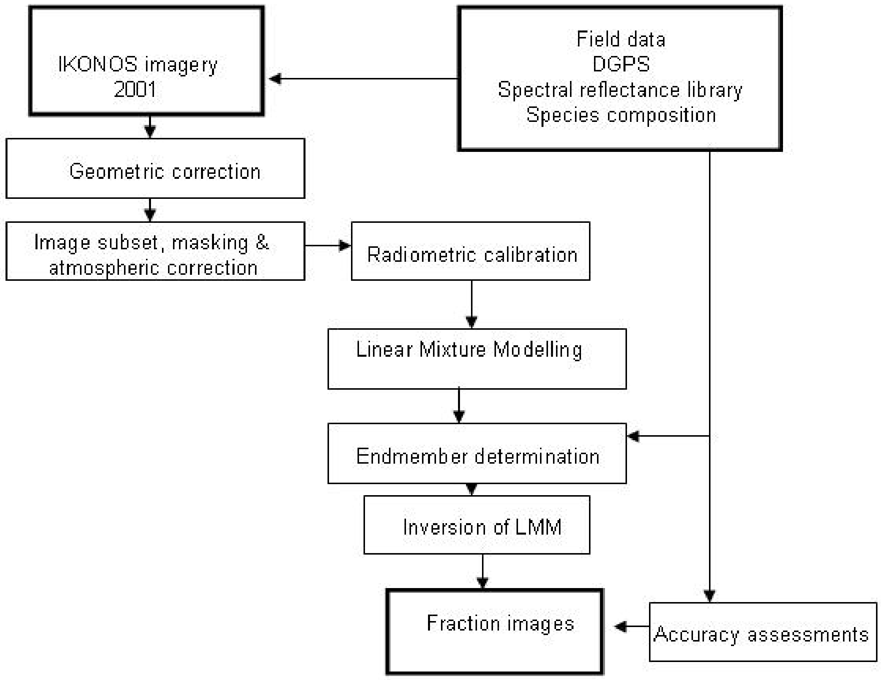


Figure 3. The methods adopted to classify mangrove species at Sungai Belungkor mangrove forest.

Linear Mixture Modelling

Linear mixture modelling is an image classification technique to map the relative abundance of surface materials present within a pixel. When the size of a pixel is larger than the size of the object being sensed, more than one object will be included in the pixel and hence mixed pixels are generated. This problem is obvious in areas with heterogeneous surfaces. In this study, we assume the mixture of more than one feature within a pixel is linear. Linear mixture modelling assumes that the signal received at the satellite sensor depends on the proportion of individual surface components such as soil, water and vegetation present in a particular pixel and on the mixing process (Abdul Shakoor, 2003).

Mathematically, LMM can be modelled using the "Eq (1)" given by Abdul Shakoor (2003).

$$b_i = \Sigma a_{ei} x_i + \varepsilon_I \quad (1)$$

where;

b_i = reflectance of mixed pixel spectra in band i

a_{ei} = reflectance of the surface component e in band i

x_i = proportion of pixel area covered by the e ground cover type

ε_I = residual error

In this study, the proportion images were derived by performing the following procedures:

(i) Determination of end-members- is a technique used to find the number of spectrally distinct surface materials/endmembers that occupy in the image. The theoretical limit to the number of end-members is equal to the number of spectral channels plus one. However, the number of end-members is far fewer in practical owing to the spectral information being redundancy for some spectral bands (Keshava and Mustard, 2002). So, in this study we used three end-members (*bakau minyak , bakau kurap, and 'others').* These three species were found to be abundant in the study area (Field visit and personal communication with forest rangers). One extra class i.e. soil, was also chosen since it is necessary to include classes that are not useful to the user in order to meet the closed-world assumptions (Lewis and Brown, 2001). Interactive end-member determination technique (Plaza et al., 2002) was used in this study to obtain endmembers. The spectra of the three mangrove species and soil endmember were derived from field measurements using the spectro-radiometer as described in the methodology section.

(ii) Inversion of the LMM was done to estimate the fractional abundances of each mixed pixel from its spectrum and the end-member spectra. It is done by inverting the linear mixing equation (equation 1) through a least square regression technique. In this study, we used the singular value decomposition technique (Boardman 1989) to unmix the mixed pixels into images giving abundance values ranging from 0 to 1.

During the unmixing process, a unit sum constraint was applied by adding weighting factors in order to decrease the contributions of the smallest singular values. Different weight (0-10) was applied to find out the best solution to the unmixing result. The best result obtained when:

i. the fraction values for each end-members fall between 0.0 to 1.0
ii. the sum of all end-members fraction is equal or less than one for a pixel
iii. the RMS error is between 0.00-0.05.

The generalized area-based confusion matrix technique was adopted from Lewis and Brown (2001) to describe errors in the estimation of classes' areas. This matrix allows the accuracy of maps generated using area estimation models to be assessed quantitatively just like the assessment of traditional classification techniques. The confusion matrix for the data produced by LMM (area estimation model) was derived using "Eq. (2)" (Lewis and Brown 2001).

$$\mathbf{C} = \mathbf{T}^T\mathbf{Y} = \begin{bmatrix} \sum_{k=1}^{m} t_{k1}y_{k1} & \sum_{k=1}^{m} t_{k1}y_{k2} & \cdots & \sum_{k=1}^{m} t_{k1}y_{kc} \\ \sum_{k=1}^{m} t_{k2}y_{k1} & \sum_{k=1}^{m} t_{k2}y_{k2} & & \sum_{k=1}^{m} t_{k2}y_{kc} \\ \vdots & & \ddots & \vdots \\ \sum_{k=1}^{m} t_{kc}y_{k1} & \sum_{k=1}^{m} t_{kc}y_{k2} & \cdots & \sum_{k=1}^{m} t_{kc}y_{kc} \end{bmatrix} \begin{bmatrix} \sum_{k=1}^{m} t_{k1} \\ \sum_{k=1}^{m} t_{k2} \\ \vdots \\ \sum_{k=1}^{m} t_{kc} \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} \sum_{k=1}^{m} y_{k1} & \sum_{k=1}^{m} y_{k2} & \cdots & \sum_{k=1}^{m} y_{kc} \end{bmatrix}$$

$$\mathbf{T} = \begin{bmatrix} \mathbf{t}_1 \\ \mathbf{t}_2 \\ \vdots \\ \mathbf{t}_m \end{bmatrix} = \begin{bmatrix} t_{11} & t_{12} & \cdots & t_{1c} \\ t_{21} & t_{22} & & t_{2c} \\ \vdots & & \ddots & \vdots \\ t_{m1} & t_{m2} & \cdots & t_{mc} \end{bmatrix}$$

T is an $m \times c$ target matrix where the memberships in a target reference data (fraction values from the field) set containing m pixels and c

$$\mathbf{Y} = \begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_m \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1c} \\ y_{21} & y_{22} & & y_{2c} \\ \vdots & & \ddots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mc} \end{bmatrix}$$

The memberships assigned to the m pixels by the model can be presented in an $m \times c$ output matrix, **Y**.

Results and Discussions

The outputs of unmixing analysis are usually shown in proportion images for each of the surface components and root mean square images. They provide information on the relative abundances of surface components at every pixel and their distribution throughout the image. Dark colours correspond to high fractions and light colours to low fractions. The results of linear spectral unmixing for endmembers bakau minyak, bakau kurap, 'others' and soil are shown in Figure 4.

In the bakau minyak fraction image, the species has significantly higher values indicating their widespread concentration over most of the study area. Meanwhile, soil has very small fraction values in this image and this is prominent in the middle east of the image (shown by a box). Fraction image of bakau kurap reveals that high fraction values of this species occur in the centre of the study area in small patches. According to the image, the rest of the study area has close to zero fraction values for bakau kurap. As for the 'others' class of mangrove species, high fraction values of this species occur in the middle east, along the riversides in the west and south of the study area in small patches. Another endmember unmixed by the LMM method is the soil. In the soil fraction image, very high fraction values are found in the middle east of the study area.

The results of the unmixed endmembers in this study show that few pixels were misclassified. For endmember bakau kurap, misclassification occurred in the south east of the image where the fraction values are very low, whilst along the river sides, south west and west of the study area were accurately classified by the LMM. Endmember 'others' was misclassified as bakau minyak in the south and southeast of the study area and as bakau kurap in the lower western part of the study area. Soil was misclassified as bakau kurap, and ‘others’. Such misclassifications were also observed by Abdul Shakoor (2003) and Roberts et al (1998) even though the latter used hyperspectral airborne data and collceted more endmembers to unmix different types of vegetations, non photosynthetic surfaces and soil in southern California.

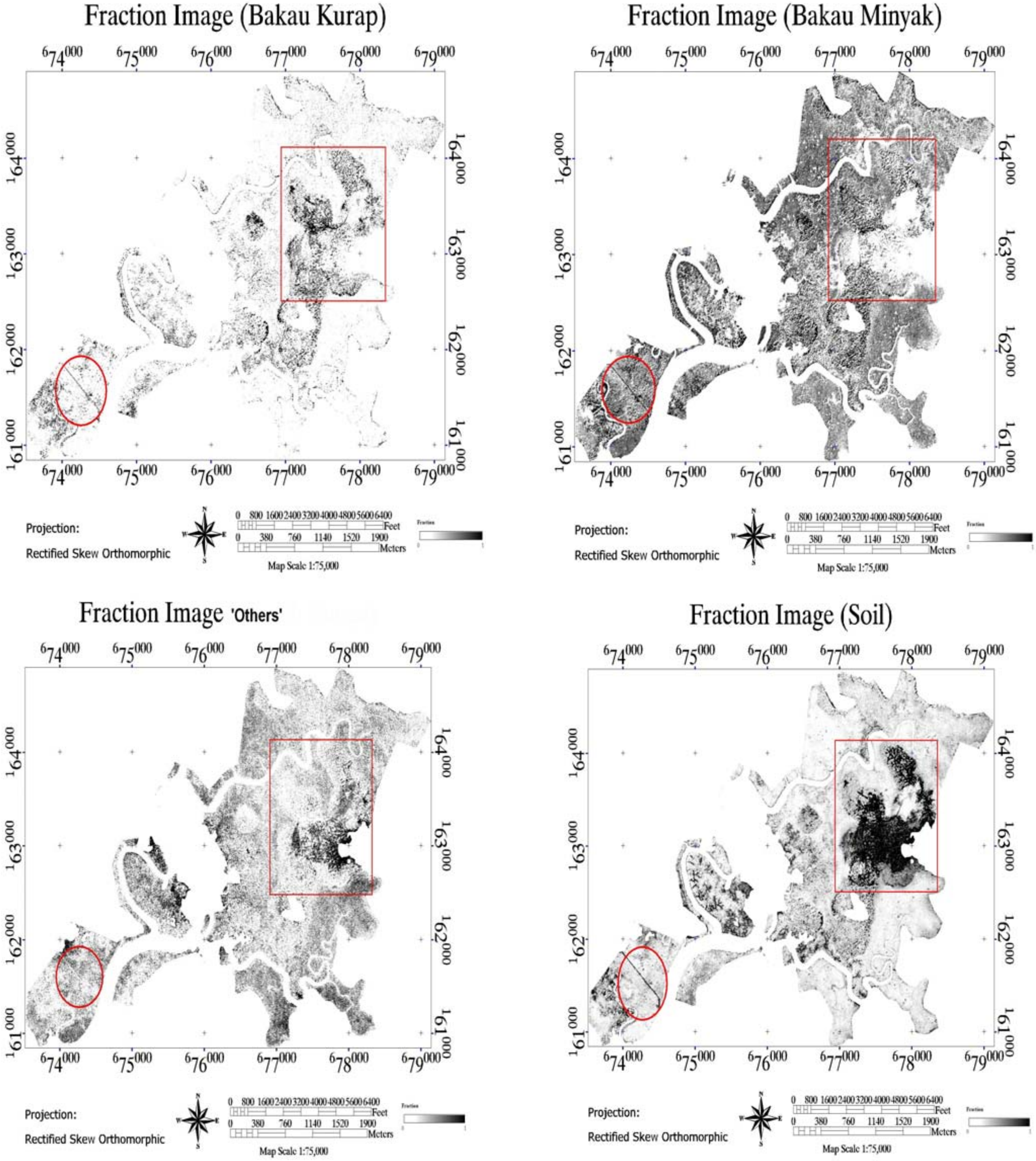
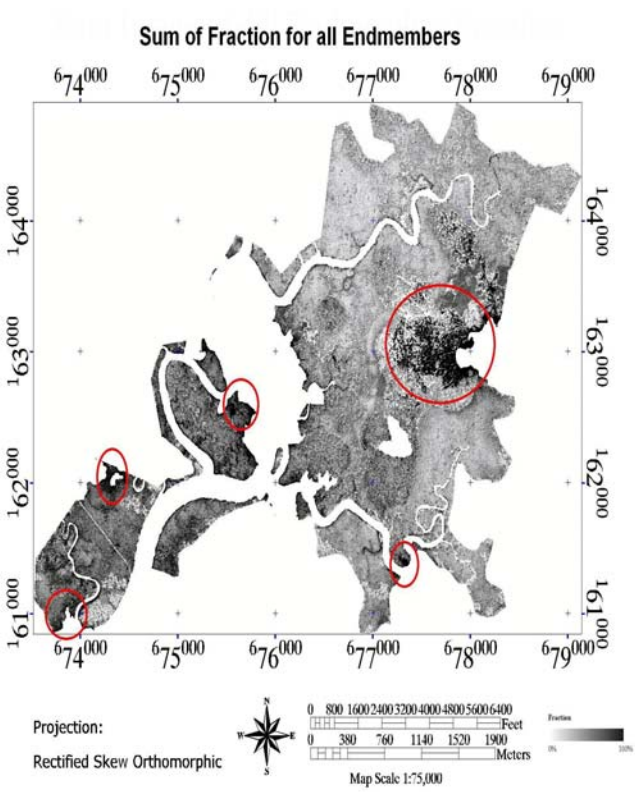


Figure 4. Results of the unmixing analysis for endmembers bakau minyak, bakau kurap, ‘others’ and soil. Fraction images are in grey scale where dark tones represent maximum fractional values and bright tones show lower fractional values.

Besides misclassifications, the unmixed IKONOS imagery also showed false positive values (sum of fraction values within a pixel exceeded 1 or 100%) in some locations. As highlighted by the rectangles in all the four fraction images (Figure 4) and Figure 5, the fraction values in these areas show false positives. This endmember corresponds to soil where soil is misclassified as bakau kurap and others. Besides that, false positives were also found in areas marked by circles in Figure 5. However, when we checked on the original image, the dark straight line corresponded to a pathway.

The accuracy of the LMM produced fraction images were assessed through an error image (Figure 6) that was produced by comparing the best fitting spectrum generated by the inversion of the LMM to the original observed spectrum. This gives a pixel by pixel estimate for the accuracy of the inversion and the appropriateness of the chosen endmembers. The lower the RMS error, the inversion result would fit better the original observed digital numbers or reflectance values. The RMSE range for the LMM results is between 1 to 5 percent, which is very low. Highest accuracy was achieved for river side mangroves because more field data were collected from these areas. On the other hand, areas in the north and east of the study area, where no field data were obtained, showed low accuracy and this is represented by a darker tone. The inaccessibility to locations to the north of Sungai Belungkor inhibited the field survey at these locations.



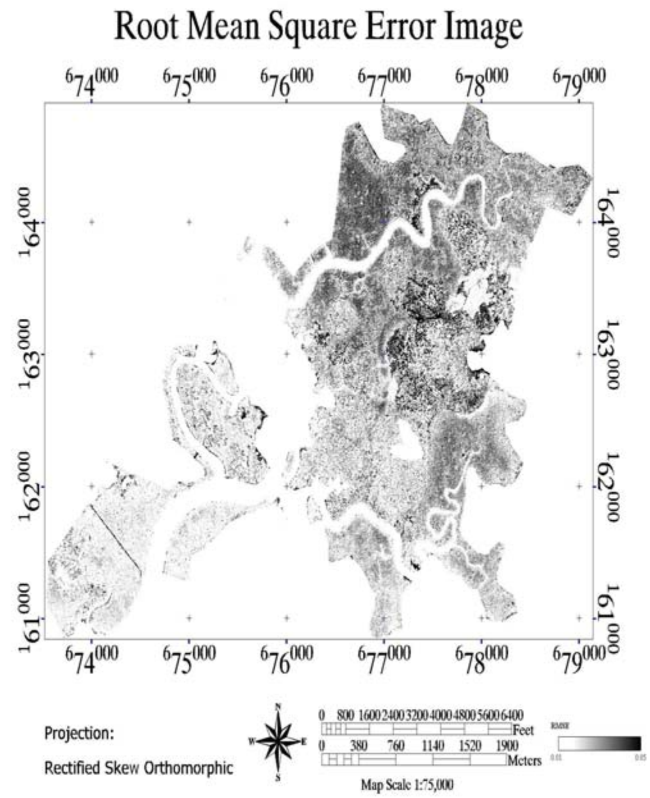


Figure 5. Sum of fraction values for all endmembers. Areas marked show sum of fraction values of more than 100% .
Figure 6. Root Mean Square Error (RMSE) image for LMM.

Furthermore accuracy assessment was also carried out by matching the fraction of endmembers derived from the unmixing process and the fraction values for each endmember measured in the field. Among the three mangrove species, bakau minyak yielded quite a good accuracy where the R^2 value was 0.78 and the RMS error was 13.38% (Figure 7). Meanwhile, the relationship between the fraction of bakau kurap and 'others' derived from the image and measured in the field yielded only a moderate accuracy with R^2 of 0.64 and 0.65 with RMS error of 21.32% and 14.3% respectively.

[1] currently at Monash University, Australia, undertaking her PhD.

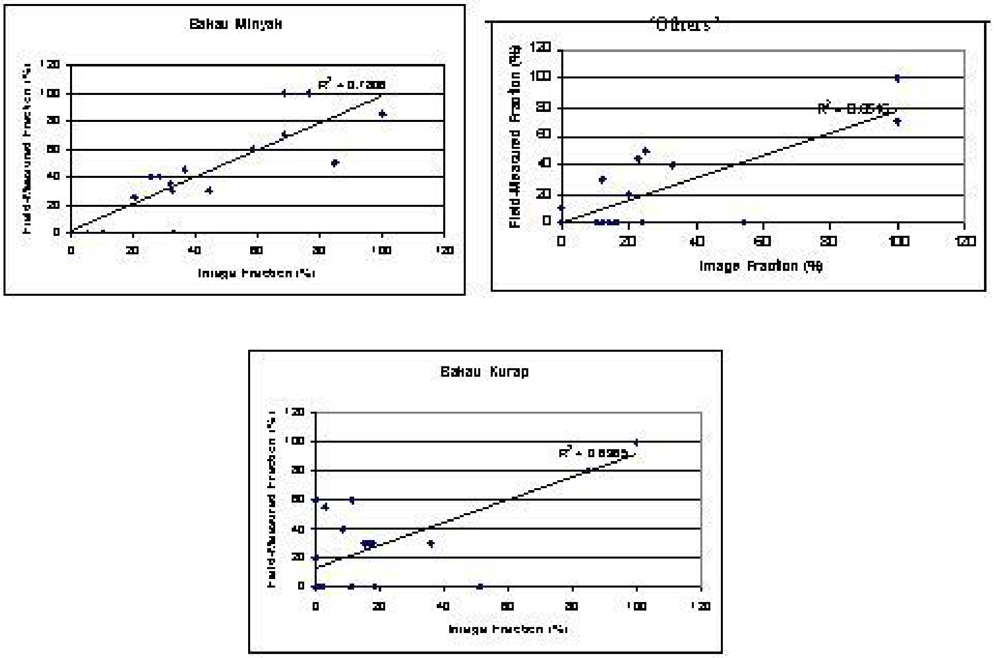


Figure 7. The relationship between the image derived fraction and field measured fraction values for bakau minyak, bakau kurap and 'others'. The strength of the relationships is represented by R^2.

The results of area based generalised confusion matrix is shown in Table 1. The results of LMM was compared with conventional per pixel classification techniques (not shown) like the maximum likelihood with IKONOS inclusion of texture information derived from IKONOS panchromatic band and minimum distance to mean (paper submitted to Applied GIS, Monash University Press).

Table 1. Summary of area-based confusion matrix for LMM, maximum likelihood and minimum distance to mean classification techniques.

Classification	Classes	Area that are correctly classified according to reference data (%)	Area that are correctly classified according to classified data (%)
LMM	Bakau minyak	63.42	73.24
	Bakau kurap	62.49	60.00
	Nyireh Bunga	57.85	52.45
Maximum Likelihood (inclusion of second order texture information)	Bakau minyak	62.00	46.50
	Bakau kurap	61.67	64.38
	Nyireh Bunga	57.53	52.50
Minimum Distance	Bakau minyak	53.33	40.00
	Bakau kurap	47.31	65.83
	Nyireh Bunga	57.53	35.00

Results of area based confusion matrix show that LMM outperformed the other two per-pixel classification techniques in the effort to classify bakau minyak, bakau kurap and nyireh bunga. Bakau minyak achieved the highest percentage of area correctly classified according to reference data (similar to the concept of producer accuracy in conventional confusion matrix) (63%) as well as classified data(user accuracy) (73%). This is because this species was unmixed more accurately than the other two species. Maximum likelihood classification (inclusion of second order texture information) is comparable to LMM in the percentage area that are correctly classified according to reference data

(62%), but poor in the percentage area that are correctly classified according to classified data for bakau minyak. For species bakau kurap both areas that are correctly classified according to reference data and classified data, are almost similar for both LMM and maximum likelihood techniques. Meanwhile, minimum distance classification was found to be the worst classifier in this study in mangrove forest classification.

Conclusions

This study used high spatial resolution satellite data to classify various mangrove species. The LMM produced distribution of fraction images revealing various mangrove species within 4 x 4 meter resolution in the study area. The proportion maps of forest species derived from the LMM of remotely sensed data can be utilized for forest management such as harvesting plan and ecological conservation when such images are combined with age or stand maps of forest species. In Sungai Belungkor mangrove forest, it was found that the LMM technique can produce reliable results for bakau minyak but only moderate results for endmember bakau kurap and 'others'. The reason for this could be the fewer number of input endmembers. Only 3 endmembers were selected in this study because of the spectral limitation of the IKONOS image that could not differentiate spectrally between different species. The results of unmixing might deteriorate if some endmembers are missing. Furthermore, the poor accessibility to some parts of the forest also imposed a problem in obtaining more representative samples from the study area. As a conclusion, knowledge of more end-members in the region and also the use of hyperspectral data with more spectral bands to discriminate various mangrove species and more representative samples would help enhance the results of LMM in this study.

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[1] currently at Monash University, Australia, undertaking her PhD.