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Airborne Hyperspectral Sensor for Individual Species Counting and Mapping of Karas (*Aquilaria malaccensis)* in Bukit Nanas F.R, Malaysia

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Abstract: Karas (*Aquilaria malaccensis)* is well known for producing gaharu, a fragrant material which is extremely valuable for cosmetic products manufacturing. Due to its un-permitted harvesting, there is an alarming depletion in the natural forests, which requires some forms of quick monitoring in near real time. A study on the spatial distribution of Karas trees in Bukit Nanas F.R., Federal Territory (FT) was therefore conducted to identify, quantify and map its geospatial distribution using an airborne hyperspectral sensor. Using a Sobel filter and Spectral Angle Mapper (SAM) processing techniques, a digital geospatial distribution map with an accuracy of 89.47% showing 38 individual Karas trees was developed. This study demonstrated that individual Karas trees can be easily counted and mapped with an airborne hyperspectral sensor which may lead to possible estimation of gaharu production for its future sustainable management and conservation efforts in FT, Malaysia.

Key words: Airborne hyperspectral sensor · Karas (*Aquilaria malaccensis)* · Individual tree · Mapping · Precision inventory · Conservation

INTRODUCTION

The tropical rainforest of Malaysia can be considered as one of the richest and most complex ecosystems in the world. It is regarded as an excellent heritage of floral genetic sources, of 14,500 species of flowering plants, with 9,000 species found in Peninsular Malaysia alone. There are also 3,000 tree species, 1,000 orchid species and 300 palm species, 60 species of bamboo and herbs, 500 species of ferns and 24 species of conifers [1]. Malaysia's forests are a major contributor to Malaysia's industrial development process and will be especially important within the context of 'Vision 2020,' which is designed to propel Malaysia into the digital age and position it as a hub for high-technology businesses in Southeast Asia.

Forest harvesting for timber and sapwood, especially gaharu, in Malaysia has a long history. Local people of the interiors in P. Malaysia, Sabah and Sarawak traditionally collect gaharu as a supplement to their income. In recent years, owing to the all-purpose characteristic and especially the yield of gaharu, the high demand for Karas species has led to excessive harvesting. In addition, this species of tree has been included in 'The World List of Threatened Trees' [2]. Global demand for gaharu is currently reported to exceed the available supply and this has led to the large increase in its price. In 2004, the price of super quality gaharu wood or chips was in the range of RM4,000 to RM6,000 per kilogram. In 2007, the price for good grade B and above gaharu has been doubled [3]. Since the issuing of Cites export permits began for the substance in 2002, the highest exported volumes were 357 tons in 2003 and 200 tons in 2007 [2]. The high demand for this fragrant resin has led to injudicious and rampant felling of trees deep in the forests. As a result, there has been a great loss in terms of taxes to the country and a big loss to the rainforest biodiversity as well.

Thus, identification, counting and mapping of Karas trees is demanded by the Peninsular Malaysia Forestry Department Headquarters for future sustainable management and conservation of the species stands of Karas trees in Bukit Nanas F.R. This is a good starting point where the geospatial information will be used for developing a more sustainable Karas management program, which is essential in determining the course of

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2action necessary to meet its conservation goals. The use of remote sensing for forestry mapping has expanded tremendously in recent years due to the availability of high spatial resolution imager such as the airborne hyperspectral sensor. This technology has been used to predict *Aquilaria* spp. distribution in P. Malaysia [4]. Therefore, the objective of this study is to identify, quantify and map Karas tree spatial distribution in the Bukit Nanas F.R using an AISA airborne hyperspectral sensor.

METHODS AND MATERIALS

Description of Study Area: The study was conducted in the Bukit Nanas Forest Reserve (F.R), the oldest permanent forest reserve and believed to be over 3 million years old. It is geographically located at latitude (3.1518°) 3° 9' 6" North of the Equator and longitude (101.7022°) 101° 42' 7" East of the Prime Meridian on the map of Kuala Lumpur, Peninsular Malaysia (Figure 1). From the survey of virgin jungle reserves in Peninsular Malaysia carried out by [5], Bukit Nanas F.R was recognized as one of the protected areas in World Heritage Program where its IUCN Management Category is classified as 'Ia' (Strict Nature Reserve). The Biogiographical Province of Bukit Nanas F.R is 4.07.01 which is 'Malayan Rainforest' and its land tenure belongs to the state. Besides that, BKFR is lowland dipterocarp forest which possesses a humid tropical climate. The most frequent emergent species are *Shorea bracteolata*, *Dipterocarpus baudii* and *Dyera costulata.* The area is important for ecological and botanical studies [5]. The yearly precipitation form is 2,266 mm [6].

Bukit Nanas F.R, formerly known as Bucket Weld F.R., was gazetted in 1906. It was also gazetted as a Wildlife Reserve and Bird Sanctuary in 1934 and in 1950 a pristine section of about five hectares was gazetted as a Virgin Jungle Reserve. Bukit Nanas F. R. is a 10.5 ha inner city slice of tropical rainforest at the base of one of Kuala Lumpur's most prominent landmarks, the 421m high Kuala Lumpur Tower, which is also the fifth tallest telecommunications tower in the world, built in the 1990s. Bukit Nanas F.R celebrated its Centennial Anniversary in 2006. As the only remaining tropical rainforest in the heart of the city of Kuala Lumpur, it is considered the 'Green Lung' of Kuala Lumpur and it helps to cleanse the air of its surrounding environment by acting as a purifier for dust and toxic pollutants. The rich variety of flora that flourishes within the forest includes rare herbs, creepers, ferns, climbers, Palmae species, giant bamboo grasses and

Fig. 1: A map of P.Malaysia showing the location of Bukit Nanas F.R

other indigenous plants. It has also become the natural habitat for colourful butterflies, insects, monkeys, squirrels and exotic birds.

Equipments and Software: The AISA airborne hyperspectral sensor was used in this study for the airborne data acquisition. It is operated by Faculty of Forestry's Tropical Airborne Forest Observatory (TropAIR) for application development in Karas mapping and inventory in Bukit Nanas F.R. It comprises four parts, namely the hyperspectral sensor front-end head, a miniature GPS/INS sensor (for precise positioning), data acquisition unit and post-processing (Caligeo software). It is quick to install and remove from any aircraft and provides timely, accurate and reliable information. The features of the AISA airborne hyperspectral sensor includes 'on demand' data collection, very high spatial and spectral resolutions, near real-time processing of images, airborne DGPS navigation of imagery (no ground control points required), first generation geo-referenced images and radiometrically and geometrically corrected 'GIS ready data'. It is small, light, portable and easy to handle with a total weight of 15 kg. Thus, it can be easily installed on any fixed-wing aircraft. The sensor is suitable for collecting data within a spectral range of 430 to 1100 nm and has 288 spectral channels. For this study, the configuration is set to 20 operational spectral bands with an aircraft speed of 120 knots, 1,000 m altitude to produce a 1 m spatial resolution.

ENVI 4.2 software was used in the digital image processing and visualizing of the airborne data. It is a wizard-based spectral tool with automated map composition and 3-D terrain capabilities. Image processing was performed using its classification and post-classification routines, registration and geo-referencing tools, mosaicking tools and integrated GIS and vector processing capabilities. ENVI 4.2 automatically identified tie points between two images for pixel-by-pixel analysis and classification with its geospatial statistics tools.

METHODOLOGY

The image of this study was acquired using an AISA hyperspectral sensor on March 2007 at the altitude of 1,000 m above sea level with a spatial resolution of 1 m^2. The entire image capturing process was conducted by Tropical Forest Airbone Observatory (TropAIR), Lebuh Silikon, UPM. The raw data was pre-processed on-board using Caligeo software, which is a plug-in of the latest ENVI 4.2, to reduce the unwanted effects, especially to correct for sensor- and platform- specific radiometric and geometric distortions of data.

Image enhancement, which included contrast enhancement and band combination, was performed to enhance the clarity of the image in order to obtain a more accurate classification of Karas. Contrast enhancement was conducted to expand the original brightness of the image while band combination enabled images to be recorded and displayed in colour or black and white. Supervised image classification was later used to classify the image into predetermined species classes using the spectra from the Regions of Interest (ROIs) and to extract the quantitative information from remote sensed image data. A minimum distance algorithm was used to perform classification; it uses the mean vectors of each extracted spectra and calculates the Euclidean distance from each unknown pixel to the mean vector for each class. All pixels are classified to the nearest class unless a standard deviation or distance threshold is specified, in which case some pixels may be unclassified if they do not meet the selected criteria. The minimum distance algorithm was selected to perform classification on the image because it can produce the most reasonable classification among other supervised classification algorithms. In addition, it is also mathematically simple and computationally efficient in that a large area can be classified within a short period of time. Sieving and clumping techniques were conducted after supervised classification. The function of sieving is to remove the isolated classified pixels in classification images using blob grouping. The sieve classes method look at the neighboring 4 or 8 pixels to determine whether that pixel is grouped with pixels of the same class. When pixels were removed from a class using sieving, black pixels, which are unclassified, were left. Classified images usually faced some problems such as the lack of spatial coherency like speckle or holes in the classified areas. Low pass filtering was later used to smooth these images, but the class information was contaminated by adjacent class codes. The selected classes were clumped together by first performing a dilate operation and then an erode operation on the classified image using a kernel of the size specified in the parameters dialogue. Ground verification was performed to verify and match the Karas trees identified from the image versus the field spectra archived data. It was executed by taking the exact GPS location of the Karas trees on the ground to assess the mapping accuracy of the individual Karas trees identified from the image spectra. The data was collected in the form of latitude and longitude of the position of the Karas trees in Bukit Nanas F.R using a handheld GPS. After the data was verified, an accuracy assessment was conducted based on the ground truth to determine the degree of mapping confidence achieved. The formula for calculating the accuracy can be given as:

$$\text{Accuracy (\%)} = 100\% - \text{Error (\%)}$$

$$= 100\% - \frac{\text{No. of Misclassified Karas}}{\text{Total No.of Karas}} \times 100\%$$

The outcome of this study is the development of a thematic map showing the spatial distribution of Karas in Bukit Nanas F.R based on airborne sensing techniques. Once the individual trees of Karas can be easily located and mapped in an acceptable precision, a tree-tagging map of Karas can be then further developed showing precisely their specific locations in the study area. This information will definitely assist in the development of a management and conservation plan for future sustainable development to avoid the alarming depletion of the Karas population in the Federal Territory of Kuala Lumpur.

RESULTS AND DISCUSSION

In this study, bands 12, 16, 20 (RGB) with a linear stretch to all three were selected as the best combination. At the same time, this band combination was adopted for further analysis in the image classification since it provides a well-enhanced colour composite image with respect to the forest cover [7], [8] and [9]. Meanwhile,

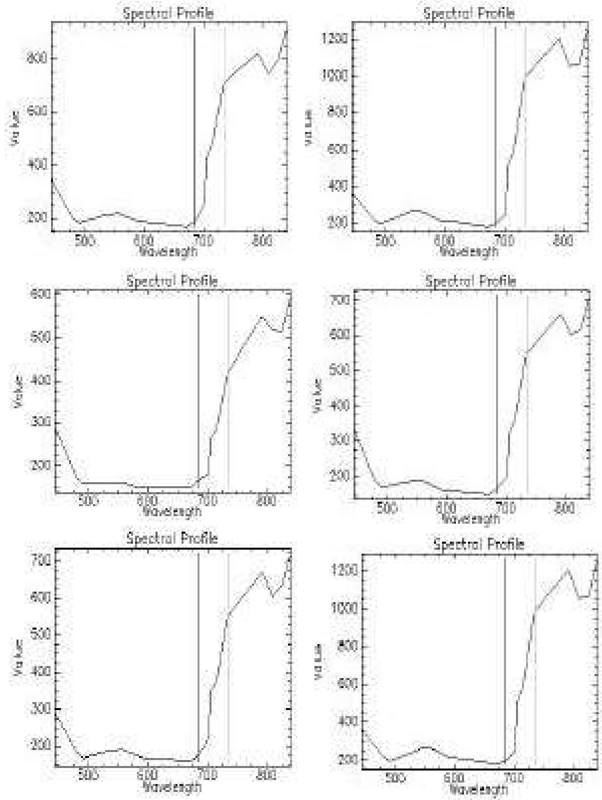

Fig. 2: Some selected sample-image spectral profiles developed for Karas trees of varying ages found in Bukit Nanas F.R

Sobel filter 3 x 3 was found to be the most appropriate for visual interpretation of Karas on the image. A similar filter was also reported best for other applications such as mapping power transmission lines and search-and-rescue for missing aircraft [8], [10], [11]. On the other hand, the end member spectra of Karas used by SAM were obtained from the archived spectral library using a handheld spectroradiometer. The image spectra of Karas obtained from the airborne data is shown in Figure 2.

The 0.15 radian used in this study was the most suitable and selected to classify and extract the individual Karas trees from the forest. Pixels with an angle larger than this value were not classified. By referring to the image, features such as the forest gap and other tree species can be easily differentiated from the Karas trees. The precise location of Karas trees is difficult to identify since they are too scattered and not grouped together. Therefore, the post classification, which was composed of clumping and sieving techniques, was required to minimize this positioning issue. Table 1 shows the GPS locations of Karas trees identified from the image and verified on the ground by the field survey team.

Table 1: The GPS coordinates of Karas trees identified, mapped and verified by the field survey team

Tree No.	Latitude	Longitude
1	3° 9' 21.41"	101° 42' 11.26"
2	3° 9' 20.96"	101° 42' 10.36"
3	3° 9' 20.79"	101° 42' 11.68"
4	3° 9' 20.54"	101° 42' 10.26"
5	3° 9' 20.76"	101° 42' 8.74"
6	3° 9' 20.63"	101° 42' 11.62"
7	3° 9' 19.40"	101° 42' 7.67"
8	3° 9' 18.92"	101° 42' 7.50"
9	3° 9' 15.99"	101° 42' 6.23"
10	3° 9' 21.02"	101° 42' 11.52"
11	3° 9' 17.07"	101° 42' 6.33"
12	3° 9' 17.94"	101° 42' 7.08"
13	3° 9' 15.05"	101° 42' 7.14"
14	3° 9' 20.21"	101° 42' 9.81"
15	3° 9' 14.92"	101° 42' 6.23"
16	3° 9' 14.81"	101° 42' 8.56"
17	3° 9' 15.11"	101° 42' 8.98"
18	3° 9' 19.33"	101° 42' 9.84"
19	3° 9' 16.15"	101° 42' 8.50"
20	3° 9' 16.05"	101° 42' 8.95"
21	3° 9' 15.95"	101° 42' 9.92"
22	3° 9' 16.73"	101° 42' 9.41"
23	3° 9' 17.15"	101° 42' 10.06"
24	3° 9' 17.39"	101° 42' 6.43"
25	3° 9' 17.67"	101° 42' 9.73"
26	3° 9' 19.92"	101° 42' 9.61"
27	3° 9' 20.05"	101° 42' 9.97"
28	3° 9' 18.23"	101° 42' 9.77"
29	3° 9' 19.20"	101° 42' 10.77"
30	3° 9' 19.79"	101° 42' 10.06"
31	3° 9' 19.95"	101° 42' 10.58"
32	3° 9' 19.01"	101° 42' 9.45"
33	3° 9' 14.89"	101° 42' 5.84"
34	3° 9' 17.06"	101° 42' 7.63"
35	3° 9' 15.31"	101° 42' 6.33"
36	3° 9' 17.23"	101° 42' 17.31"
37	3° 9' 15.05"	101° 42' 6.17"
38	3° 9' 8.50"	101° 42' 6.92"

From a total number of 38 trees identified from the imagery, 34 Karas trees were ground verified and confirmed correct by the field survey team with the mapping accuracy of 89.47 %. Some selected samples of Karas found in Bukit Nanas F.R are shown in Figure 3.

The spatial distribution of Karas in Bukit Nanas F.R. is represented by the yellow areas in Figure 4. With this geospatial thematic map, a tree-tagging map specifically

Fig. 3: Some selected sampled trees of Karas found on the ground as identified and mapped from the AISA airborne hyperspctral sensor

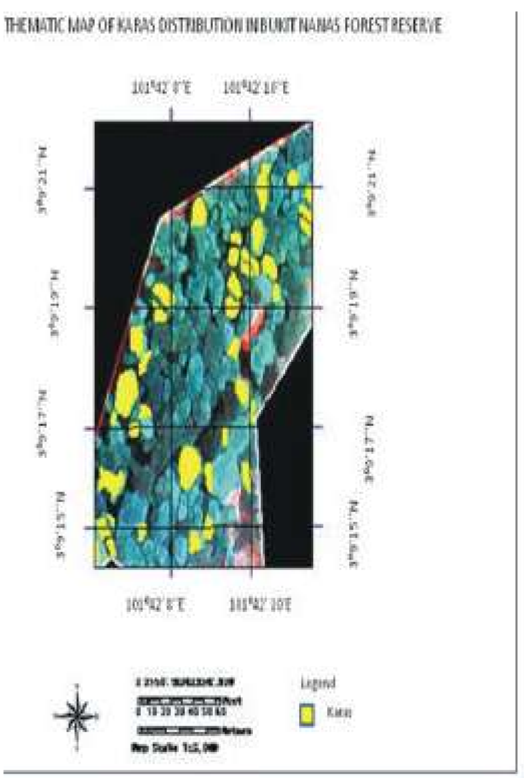

Fig. 4: A TropAIRMap™ product showing Karas distribution in Bukit Nanas F.R of Federal Territory, Kuala Lumpur.

for Karas can be further developed. The production of gaharu can be easily estimated if one knows the production of gaharu from one tree. This geospatial map is also useful to gather the actual number of Karas left behind in the whole forest of Federal Territory (FT) Kuala Lumpur if the airborne flight mission covers the whole FT airspace in the future.

CONCLUSIONS

It can be concluded that an airborne hyperspectral sensor is capable of identifying 38 individual Karas trees in the study plot of 4.5 ha in Bukit Nanas Forest Reserve where 34 Karas trees were correctly identified and mapped from the sensor. The other four trees were misclassified due to the poor GPS positioning during field checks with an overall mapping accuracy of 89.47%. Further research should be conducted on the hyperspectral image processing techniques to improve the mapping accuracy of Karas with more ground sampling work using a differential GPS to be done in the near future. More studies on Karas spatial mapping should be focussed in the other State and Permanent Reserve Forests of the Federal Territory since this species has been considered as endangered species.

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