USING FCD MAPPER SOFTWARE AND LANDSAT IMAGES TO DETECT BREAKS IN FOREST CANOPIES IN LANDSCAPES IN AUSTRALIA AND THE PHILIPPINES[1]

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Using Landsat imagery, forest canopy density (FCD), estimated with the FCD Mapper (Mapper), was correlated with stand height for 20 field plots, measured in native forest at Noosa Heads, south-east Queensland, Australia. Another image was used to calculate FCD in Leyte Island in the Philippines and was ground-truthed for accuracy. The Mapper was produced for the International Tropical Timber Organisation and is available on a CD ROM. It estimates FCD as an index of canopy density using reflectance characteristics of Landsat Enhanced Thematic Mapper images. The Mapper is a 'semi expert' computer program which uses interactive screens to allow the operator to make decisions concerning the classification of land into bare soil, grass or forest. At Noosa a strong, positive, nonlinear relationship (R^2 = 0.86) was found between FCD and stand height for 15 field plots in a range of native forest of variable stand height but complete canopy closure. An additional five field plots were measured in forest with a broken canopy and these plots were assessed as having a much lower FCD than forest with canopy closure. FCD was also calculated for forest and agricultural land on the island of Leyte and ground-truthing showed that at appropriate settings, the Mapper differentiated between tropical rain forest and banana or coconut plantations. These findings suggest that this remote sensing technique has potential for change detection in logged-over forests which are redeveloping a canopy, or in separating forests, which has a broken canopy, such as coconut plantations, from native forest. Since there is a continuing loss of natural forest to agriculture in the region, the Mapper may be a useful tool for the detection of illegal logging or the conversion of land from natural forest to agriculture.

INTRODUCTION

There is a continuing need to assess the condition and health of tropical forests because rural poverty is closely associated with forest decline in tropical countries (Krishnaswamy 1999). Inefficient monitoring of logging activities is a contributing factor to the high degree of unsustainable forest management in the tropics (Blaser and Douglas 2000). Therefore, one of the aims of research programs which are designed to achieve forest sustainability, is to measure the impact of logging on forest structure and to assess subsequent regeneration (Peralta and Baldiviezo 2003). However, there is a paucity of remote sensing tools which can be applied to forest structure change detection (Franklin *et al.* 2002).

Some recent investigations have correlated remotely sensed digital data with forest parameters such as leaf area index (LAI), or more easily measured variables including stand

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stocking, basal area and predominant height. The process of correlating satellite digital data with LAI or other forest parameters requires access to Geographic Information System (GIS) software, an understanding of the theory of remote sensing and expertise in bio-physical modelling. To overcome these difficulties, the FCD Mapper (JOFCA 2003) has been designed to provide foresters with a Microsoft Windows compatible GIS which can be used by semi-experts to process satellite images into maps of forest density. The Mapper is produced by the Japan Overseas Forestry Consultants Association (JOFCA) for the International Tropical Timber Organisation (ITTO). The latest version of the Mapper, version 2 was revised as part of ITTO project PD 13/97 Rev. 1 (F) in 2003. It is available from ITTO on a CD-ROM.

In principle, the calculation of forest canopy density should eliminate the need to undertake much of the usual ground-truthing process which is necessary with conventional remote sensing technology. Although the Mapper has been tested in broad leaved deciduous and evergreen forests to differentiate grassland from forest, version 2 of the Mapper has not been tested in eucalypt forest to compare the FCD of closed canopy forest with that of forest with a broken canopy. Also, it has not been used to differentiate between native forest and coconut or banana plantation in tropical areas. Therefore, the objective of the study reported here was to compare the FCD of forest with a closed canopy with the FCD of forest with a broken canopy. This was undertaken to assess the influence of breaks in the canopy on the calculation of FCD. Depending on the results of the first objective, a second objective was to attempt to differentiate between native forest and coconut or banana plantation on the island of Leyte.

In following sections of this paper, the operation of the Mapper and the procedures for undertaking an analysis of two widely differing vegetated landscapes is described. The usefulness of the Mapper to discriminate between forest types and its ability to detect forests with a broken canopy is discussed.

Background to the Operation of the FCD Mapper

The theory and operation of the Mapper are described fully in the FCD Mapper User's Guide Ver. 1.1 (JOFCA 1999), the FCD Mapper User Guide Ver. 2 (JOFCA 2003) and Baynes (2004). The Mapper uses Landsat ETM bands 1 to 7 as its data source. The FCD of a study area is computed using four main indices: a vegetation index (VI), a bare soil index (BI), a Shadow Index (SI) and a Thermal Index (TI). These four indices are calculated as new images from the raw ETM bands. From these images, the program calculates a vegetation density (VD), which includes grassland and forest but excludes bare soil. Grassland is then separated from forest using a scaled shadow index (SSI) and finally a forest canopy density is calculated for each pixel of forested land.

The Mapper calculates these indices and integrates them into an FCD (as an index from 0 to 100) for each pixel of the final FCD image. As described in the manual, the underlying principle for each of the four main indices is that the VI has a negative relationship with the quantity of vegetation, i.e. it decreases from bare soil to grass land to forest. The BI increases as the proportion of bare soil increases with increasing site aridity and consequent exposure of the soil. The high reciprocity of bare soil status and vegetation status is combined using the VI and the BI to assess land cover as a continuum ranging from dense forest to exposed soil. The SI increases as forest density increases and this index is used to separate grassland from forest. The TI is less inside the canopy of a forest due to blocking and absorption of the sun's rays and because of the cooling effect of evaporation from leaves. The TI is therefore used to further differentiate bare soil from grassland and forest. As each index is computed, the operator is required to visually classify the study area into mutually exclusive categories, for example, bare soil or vegetation. For each classification, the computer screen shows a histogram of the digital reflectance of the image and the operator sets threshold levels of the index (Figure 1) by clicking on the cursor bar with the computer mouse and moving the bar. This operation presupposes that the operator has some knowledge of the vegetative cover of the area and that classification errors will be picked up in subsequent field checking. FCD statistics for particular areas of the image may be calculated and the FCD map may be exported as a bitmap.

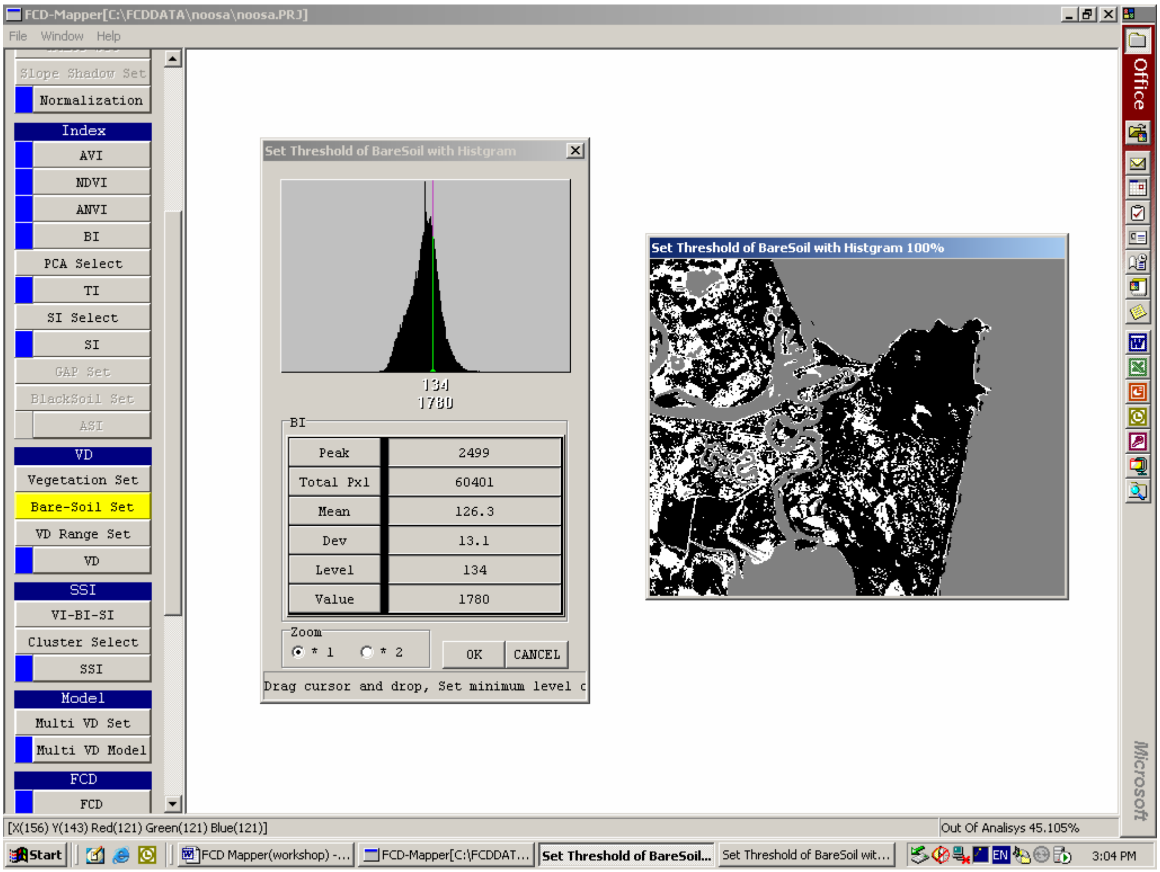

Figure 1. Screen window of the BI dialogue box of the FCD Mapper, showing the cursor bar of the bare soil index histogram set at the level which differentiates bare soil from ground with a vegetative cover

Location of the Noosa and Leyte Study Areas

The main study site is situated at the resort town of Noosa Heads in subtropical southeast Queensland. The long-term average rainfall at the nearby Toolara Forest Station (26^{o} 05$'$S, 152^{o} 50$'$E) is 1275 mm and as is typical for coastal subtropical regions, more than two thirds of this falls in the period October-March.

In contrast, the second study site, the island of Leyte, is situated approximately at 10^{o} N, 125^{o} E and is characterised by coastal plains with mountains in the interior. The island is traversed by the central cordillera mountains extending from north to south with peaks ranging 700 m to 1000 m in height. The climate is hot and wet, and there is generally no distinctive wet or dry season. The western side of the island is drier than the eastern side with average rainfall at Baybay (midway between the north and south extremities of the island on the western coast) of 2600 mm (SLE 2001). The main areas of the island which are of interest to this investigation are the forests and agricultural fields on the western side of the island, to the north of Baybay.

Vegetation of the Noosa and Leyte Study Areas

For the purposes of remote sensing, vegetation of the Noosa study area consists of native forest which is affected by exposure to winds from the sea. Native vegetation is dominated by mixed stands of Eucalyptus and Corymbia species. The coastal sands are phosphorus deficient and tree cover is reduced to scattered mature trees and bushes in some locations, principally scribbly gum (*Eucalyptus signata* F. Muell) with a height of less than 15 m. On slightly more fertile or wetter areas, bloodwood (*Corymbia intermedia* (R.T. Baker, K.D. Hill and L.A.S. Johnson) and other eucalypt species form a forest cover with a canopy height of up to approximately 30 m and as low as 4 m where it is exposed to coastal winds. On wet, sheltered and more fertile coastal sands, rainforest grows as a number of overstorey and understorey species including trees, vines, palms and ferns. The principal feature of the Noosa Heads headland which is of interest to this investigation, is that the forest maintains more or less complete canopy closure even though canopy height decreases with increased exposure. The exception to this situation is the scribbly gum forest which has a broken canopy due to the low soil fertility of the site.

Vegetation in the Leyte study area is characterised by intensive agriculture (principally rice) on the flat coastal plains. These fields are broken up by coconut plantations, some of which have an understorey of other crops and would be imaged by the Landsat sensor as dense vegetation. On the hills and mountains, the native forest is fragmented by coconut and banana plantations. Most of the original forest has been logged and valley floors, particularly, have little original vegetation. To the east of Leyte State University (20 km north of Baybay), a nature reserve contains vegetated hill slopes leading to mountains covered in rainforest. Trees in the rainforest have a height of less than 35 m in most cases, much less than the rainforest of Noosa. This lower height is anecdotally attributed to typhoon damage. Coconut plantations on the slopes of the hills often have less understorey than on the coastline and this makes them visually different from the remnant native vegetation.

Characteristics of the Landsat Images

Landsat 7 ETM images of the study sites, taken on 16 September 2000 (Noosa) and 14 January 2004 (Leyte) were obtained for bands 1-7. The images had been radiometrically and geometrically corrected to remove detector to detector and band to band brightness variations and image distortions. The original ETM thermal image was supplied with a pixel size of 50 m, this image was converted to pixels of 25 m using the EXPAND utility of the GIS ‘Idrisi’. All images were then exported to the Mapper as TIFF files and subset images of Noosa Heads and Leyte Island used as the data source.

The different vegetation patterns of the two areas were visually evident from an inspection of the different image bands. The Leyte image had a much higher green reflectance than the Noosa image reflecting the tropical nature of the vegetation. Band 4 (near infra-red) was not useful in discriminating vegetation patterns on the Noosa image, but clearly differentiated forest and agricultural land in the Leyte image. Band 5 (middle infra-red), which is absorbed by water, showed clear differentiation between grassland and forest in the Noosa image, but this differentiation was less clear in the wetter Leyte environment. In the Leyte image, some of the open fields are irrigated and thus have much lower band 5 reflectance than open fields at Noosa.

From previous experience in the Noosa region, September is ideally suited to the collection of remotely sensed data used to discriminate between vegetation types. This is because annual grasses have died off and contrast well against perennial vegetation. Image reflectance was not affected by surface water as no rain had fallen in the previous 14 days. In contrast, the image of Leyte was one of the very few cloud free images available. As rain frequently occurs as scattered storms over Leyte on any day, surface water is common, particularly in the low lying rice paddy fields.

Processing of Noosa and Leyte Study Area Images and Selection of Field Plots to Check FCD Classifications

The Landsat images were loaded into the Mapper and processed to the stage of calculating the initial FCD map as per the instruction manual for both the Noosa and Leyte study areas. In order to check the accuracy of the FCD classification in the Noosa study area, twenty 0.1 ha field plots were measured for stand height (measured as the average height of the 50 tallest trees per hectare), stocking (trees per hectare) and basal area (square meters per hectare of tree cross sectional area measured at 1.3 m above ground level). Five plots each were measured in scribbly gum, exposed low-quality bloodwood forest, sheltered bloodwood forest and rainforest. Plot positions were located on the FCD image and the coordinates transferred to a Global Positioning System for location in the field.

For the Leyte study area, three ground-truthing sites were chosen in the central west of the island, a small forest plot and rice paddy north of Ormoc, vegetation surrounding Lake Danao and a valley leading to Mt Panasugan at Leyte State University. In each case, the FCD map was visually correlated with the ground cover found at the site. On these sites, the height of the forest cover, the presence of secondary vegetation layers and the amount of sunlight penetrating the canopy were noted.

Results of Noosa Study Area Field Plot Measurements

Mean PDH was 34.0 m, 19.6 m, 8.2 m and 14.4 m for the rainforest, sheltered bloodwood, exposed bloodwood and scribbly gum, respectively (Table 1). Mean stocking was 160 stems per hectare (sph) for the rainforest and scribbly gum and 340 and 430 sph for the sheltered bloodwood and exposed bloodwood. All trees and palms over 15 cm diameter were measured. The lower stocking of the rainforest and scribbly gum was a consequence of fewer, larger trees in these plots, compared with a higher number of smaller diameter trees in the bloodwood plots. Also, the exposed bloodwood forest comprises some trees which consist of multiple stems growing from one lignotuber and these were counted as separate trees. Mean basal area was 17.3 m^2/ha for the rainforest, 17.2 m^2/ha for the sheltered bloodwood, 12.9 m^2/ha for the exposed bloodwood and 10.3 m^2/ha for the scribbly gum. Mean FCD was 78, 72, 45 and 43 for the rainforest, sheltered bloodwood, exposed bloodwood and scribbly gum, respectively (Table 1).

Table 1. Mean stand height, stocking, basal area and FCD for five plots each, in four forest types at Noosa, south-east Queensland

Forest type	Stand height (m)	Stocking	Basal area (m^2/ha)	FCD
Rainforest	34.0	160	17.3	78
Sheltered bloodwood	19.6	340	17.2	72
Exposed bloodwood	8.2	430	12.9	45
Scribbly gum	14.4	160	10.3	43

A strong non-linear relationship (R^2 = 0.86), best described by a power function, was observed between stand height and FCD for the 15 field plots in forest with a closed canopy (Figure 2).

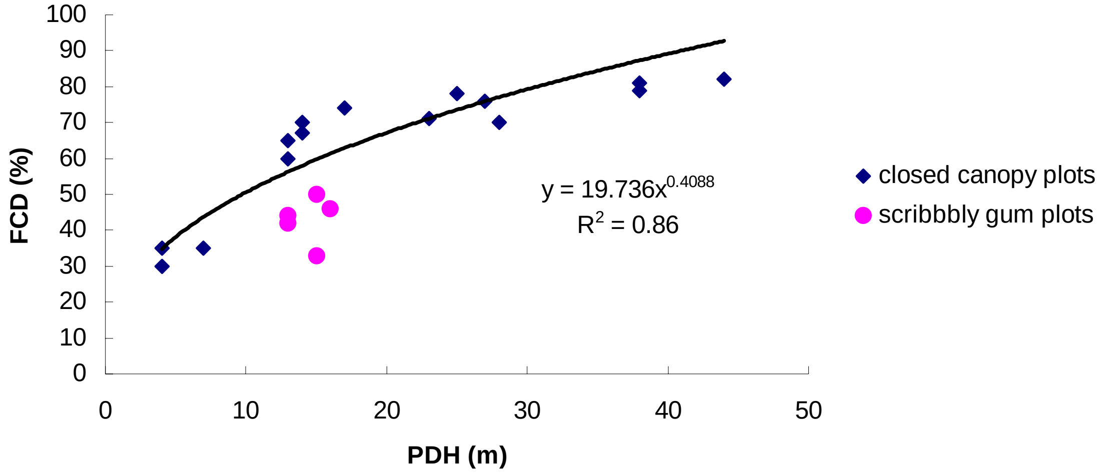

Figure 2. Relationship between stand height and FCD for 15 field plots in native forest of closed canopy but variable height[a]

[a] Five field plots are also shown in scribbly gum forest where the canopy is broken and more of the ground is exposed to sunlight.

Correlation of FCD with Vegetation in the Leyte Study Area

A qualitative description of the vegetation and an approximate FCD for the ground-truthed areas is presented in Table 2. The broad classification of the island is as expected, zero or very low FCD on the coastal plains with increasing FCD on the hills. However, pixel contamination is a major problem in calculating the reflectance signature of small forest plots and consequently the FCD of some of these small forested areas have probably been reduced by the influence of pixels of rice paddy or grassland which have a low FCD. In addition, some of the native forest areas are steep and sheltered and the Mapper has classified these as shadow and these are not calculated as having a FCD.

Table 2. Approximate FCD for several types of vegetation in Leyte

Site description	Vegetation type	Stand height	Presence of secondary layers	FCD
Rice paddy	Wet green grass	Not applicable	None	0
Banana plantation and coconut plantation	Broadleaf plantation and grass	6 m approx	Grass	Typically 0-20
Small forest plot amongst paddy field	Forest plantation	Variable approx 15 m	Sometimes dense secondary layer	Typically < 50
Casuarina plantation	Forest plantation	Approx 25 m	Grass	Approx 55
Native forest	Rainforest	>30 m	Multilayered	Variable 40-90

DISCUSSION AND CONCLUSION

The high correlation of FCD with stand height at Noosa Heads indicates that the Mapper discriminates between forest types over a wide range of heights as long as canopy closure is maintained. The Mapper was originally developed as a tool to assess the regrowth of a forest canopy in logged-over tropical forest (Rikimaru *et al.* 1999). The low FCD of the scribbly gum plots is consistent with this aim, because the scribbly gum forest is structurally similar to a logged forest in which understorey species have started to regrow but in which the canopy is not fully established.

Foresters wishing to use FCD as an index of forest productivity would prefer a growth curve with greater variation of FCD with PDH than that found in the field plots of this investigation. This may be explained by the inconsistent relationship of band 4 (near infra-red) reflectance with stand height in these images. Visual inspection of bands 1 to 5 in the original images of the Noosa area reveals a consistent negative relationship between stand height and reflectance for bands 1, 2, 3 and 5. However, the original image of band 4 shows no consistent relationship of digital reflectance with stand height for the Noosa image.

Near infra-red wavelengths are strongly reflected by vegetation. Danson and Plummer (1995) found a strong negative relationship between near infra-red reflectance and stand parameters, but suggested that this could be caused by crown structural differences. Near infra-red reflectance has also been found to show little variation or inconsistent variation under conditions of variable crown closure and the associated ratio of understorey to overstorey (Curran *et al.* 1992, Baynes and Dunn 1997). This would appear to be the case in this investigation because band 4 reflectance is typically less in the rainforest than in the bloodwood forest and the sheltered bloodwood. FCD is consequently reduced for the rainforest compared to the other vegetation types. This suggests that it may be worthwhile to inspect the raw images before inputting them into the Mapper. It also suggests that preliminary knowledge of the land covers likely to be encountered would be most useful, as well as post assessment ground-truthing.

In the Leyte image, band 4 showed a negative relationship with vegetation height, opposite to the Noosa image. This did not affect the calculation of FCD. However, the slopes of Mt Panasugan are very broken and this may affect the calculation of FCD through varying degrees of scene shadow. Also, from observation, coconut plantations on the coastal strip are likely to have underplantings of vegetables and other palms, while the more remote coconut plantations have little understorey. In these tropical areas, the Mapper would appear to be a useful aid for analysing deforestation or conversion from native forest to coconut or banana plantation but as with the Noosa image, intensive ground-truthing is still required. Although the Mapper classifies vegetation in the same way over any spatial scale, changes in vegetation architecture may lead to misclassification over a range of vegetational types. This suggests that if a high degree of accuracy is required, as would be envisaged with time series comparisons, then the Mapper should be used over a spatial scale in which the vegetation architecture shows consistent variation.

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