Annals of Tropical Research 29(1): 9-20 (2007)

Using FCD Mapper Software and Landsat Images to Assess Forest Canopy Density in Landscapes in Australia and the Philippines

Jack Baynes

School of Natural and Rural Systems Management,
The University of Queensland, Gatton, 4343 Australia
and Queensland Department of Primary Industries and Fisheries,
Gympie 4570, Australia

ABSTRACT

Using Landsat imagery, forest canopy density (FCD) estimated with the FCD Mapper®, was correlated with predominant height (PDH, measured as the average height of the tallest 50 trees per hectare) for 20 field plots measured in native forest at Noosa Heads, south-east Queensland, Australia. A corresponding image was used to calculate FCD in Leyte Island, the Philippines and was validated on the ground for accuracy. The FCD Mapper was produced for the International Tropical Timber Organisation and estimates FCD as an index of canopy density using reflectance characteristics of Landsat Enhanced Thematic (ETM) Mapper images. The FCD 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 and forest. At Noosa, a positive strong nonlinear relationship (r^2 = 0.86) was found between FCD and PDH for 15 field plots with variable PDH but complete canopy closure. An additional five field plots were measured in forest with a broken canopy and the software assessed these plots as having a much lower FCD than forest with canopy closure. FCD estimates for forest and agricultural land in the island of Leyte and subsequent field validation showed that at appropriate settings, the FCD Mapper differentiated between tropical rainforest and banana or coconut plantation. These findings suggest that in forests with a closed canopy this remote sensing technique has promise for forest inventory and productivity assessment. The findings also suggest that the software has promise for discriminating between native forest with a complete canopy and forest which has a broken canopy, such as coconut or banana plantation.

Keywords: forest assessment, remote sensing, geographic information system

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 in 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 assist decision-making concerning 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 software which can be applied to forest structure change detection (Franklin *et al.* 2002).

A large number of past investigations have correlated digital data provided by the Landsat Enhanced Thematic Mapper (ETM) with forest parameters such as leaf area index (LAI[1]) or the more easily measured variables including stand stocking, basal area[2] or predominant height. The process of correlating satellite digital data with LAI or other forest parameters requires access to image processing or Geographic Information System (GIS) software, an understanding of the theory of remote sensing and expertise in bio-physical modelling. However, in developing countries, appropriate software and trained personnel are often not available. Hence, the FCD Mapper has been designed to provide foresters with a GIS which can be used by semi-experts to process satellite images into maps of forest density. In principle, use of the FCD Mapper eliminates the need to undertake much of the usual field validation process which is necessary with conventional remote sensing technology. The FCD Mapper was produced by the Japan Overseas Forestry Consultants Association (JOFCA) for the International Tropical Timber Organisation (ITTO). The latest version of the FCD Mapper, version 2, was revised in 2003 and one of its current uses is for the development of a forest resources monitoring system in the Philippines.

The FCD Mapper is a computer software package which has been designed to be compatible with Microsoft Windows based personal computers. It combines the reflectance characteristics of Landsat ETM bands 1 to 7 for vegetation and bare soil to calculate FCD. Forest with a high FCD is fully stocked, has complete canopy closure, a high basal area and a high PDH. Lower FCD percentages are calculated in situations where the forest is poorly stocked, has incomplete canopy closure and low basal area or PDH.

ETM images are processed with a semi-expert system where the operator makes key decisions concerning the classification of images into bare soil, grass and forest. The end result is a new image, an FCD map, which shows the FCD for each pixel as a percentage of canopy density, from 0 to 100% (JOFCA 1999). In that FCD is not

---

[1] For broadleaf canopies, LAI is the one-sided green leaf area per unit ground area.
[2] Basal area is the area (in m^2/ha) of the trees in a stand, measured at 1.3 m above ground level.

precisely defined in the user guide and is not directly correlated with any parameter of canopy density, it should be considered as an 'undefined' index of canopy or forest density. For forests with a closed canopy, PDH is widely used as a parameter of forest growth and development. Therefore if the FCD Mapper can be validated as providing a reliable estimate of PDH in closed canopy situations, the software may be useful for forest inventory and productivity assessment. Also, image processing software which is sensitive to breaks in forest canopies would be useful to distinguish between logged and unlogged forest. Monitoring of land which is deforested and replaced with other crops such as coconut or banana plantations would also be assisted if the software could discriminate between native forest and plantations.

Although the FCD Mapper has been tested in broad-leaved deciduous and evergreen forests, version 2 of the FCD Mapper has not been tested in eucalypt forest with a closed canopy but variable canopy height. While it has been used to distinguish grassland from forest in tropical forests, it has not been used to differentiate between native forest with a complete canopy and coconut plantation with a broken canopy in tropical areas. Therefore, the objective of the study was to assess the correlation of FCD with PDH in mature forest with closed canopies, over a wide PDH range. A subsequent objective was to assess the influence of breaks in the canopy (and subsequent increase in the proportion of sunlit ground) on the calculation of FCD. A final objective was to differentiate between native forest and coconut/banana plantation in the island of Leyte, the Philippines.

BACKGROUND TO THE OPERATION OF THE FCD MAPPER

The theory and operation of the FCD Mapper are described fully in the FCD Mapper User Guide, Version 1.1 (JOFCA 1999) and the FCD Mapper User Guide, Version 2 (JOFCA 2003). 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 indices, 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 program 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 positive relationship with the quantity of vegetation, i.e. it increases from bare soil to grassland to forest. The BI increases as the proportion of bare soil increases with increasing site aridity and consequent exposure of the soil. The high negative correlation between 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 relatively low 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, e.g. bare soil, vegetation. For each classification, the computer screen shows a histogram of the digital reflectance of the image and the operator moves the cursor bar to set threshold levels of the index (Figure 1). 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.

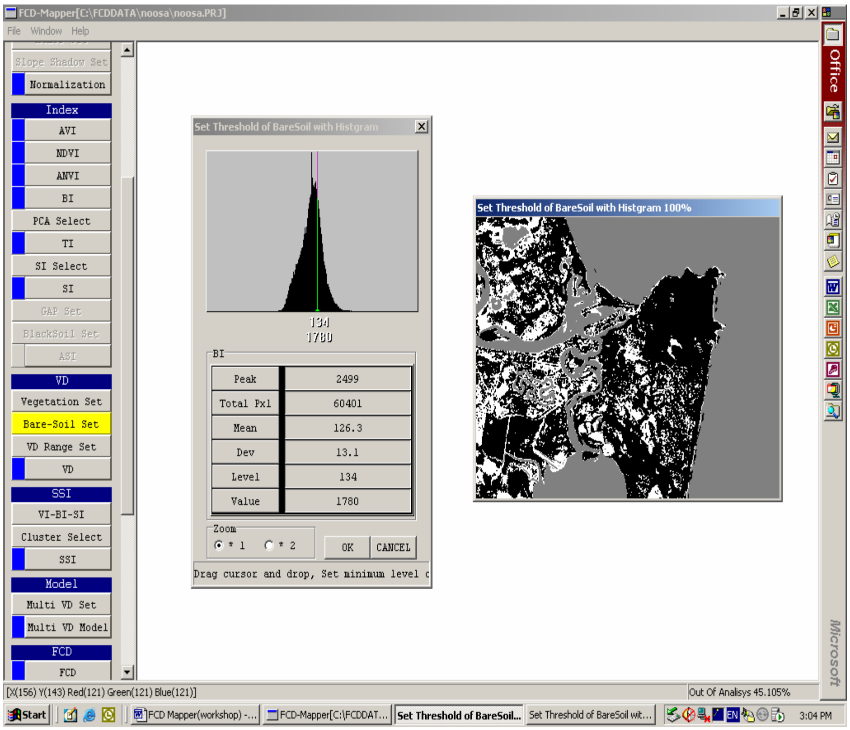

Figure 1. Screen window of the BI dialogue box of the FCD Mapper, showing the cursor bar of the bare soil index histogram set at the level which differentiates bare soil (white) from ground with a vegetative cover (black)

RESEARCH METHOD

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

In contrast, the second study site, the island of Leyte, is situated approximately at 10^o N and 125^o E and is hot and wet with no distinctive wet or dry season and with an average annual rainfall (at Baybay in the middle of the island on the western coast) of 2600 mm. The main areas of the island of interest for this investigation are the forests and agricultural fields on the western side of the island, to the north of Baybay.

Vegetation Cover in the Study Sites

For the purposes of remote sensing, vegetation over the main study area consists of native forest which is affected by exposure to wind from the sea. Native vegetation is dominated by mixed stands of Eucalyptus and Corymbia species. The coastal sands are phosphorus deficient and at its poorest level, tree cover is reduced to scattered mature trees and bushes, principally scribbly gum (*Eucalyptus signata*) with a height of less than 15 m. On slightly more fertile or wetter areas bloodwood (*Corymbia intermedia*) and other eucalypt species form a forest cover with a canopy height of up to approximately 30 m though as low as 4 m where 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 was 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 low site infertility.

Vegetation in the Leyte study area is characterised by intensive agriculture (mainly 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 in particular have little original vegetation. To the east of Leyte State University (adjacent to Baybay), a nature reserve contains vegetated hill slopes leading to mountains covered with 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 attributed to typhoon damage. Coconut plantations on hill slopes often have less understorey than on the coastline and this makes them visually different from remnant native vegetation.

Landsat Images

Landsat 7 ETM images of the study site, taken on 16 September 2000 (Noosa) and 14 January (Leyte) were obtained for reflectance bands 1-7, i.e. the visible blue, green, red, near infrared bands, two middle infrared bands and the thermal band. The images had been radiometrically and geometrically corrected to remove detector-to-detector and band-to-band brightness variations and image distortions. As 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 bands 3 (visible red), 4 (near infrared) and 5 (middle infrared). The Leyte image had a much higher green reflectance than the Noosa image reflecting the tropical nature of the vegetation. Band 4 was not useful in discriminating vegetation patterns on the Noosa image, but clearly differentiated forest and agricultural land in the Leyte image. Band 5, which is absorbed by water, showed clear grassland versus forest differentiation in the Noosa image but this differentiation was much 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 through frost or dryness and contrast well against perennial vegetation. For the Noosa image, no rain had fallen in the previous 14 days with the last rainfall being only 1.2 mm, as recorded at the Toolara Forest Station. The image of Leyte was one of the 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 the Image in the Noosa Study Area

The Noosa study area was processed first and the results were used to guide the processing of the Leyte image. The Landsat image was loaded into the Mapper and processed as per the instructions in the user guide. Four reference positions were chosen to assist classification of the study area, namely dry sand dune vegetation in association with scribbly gum (scribbly gum), poor quality bloodwood forest which was exposed to sea winds (exposed bloodwood), medium quality bloodwood forest (sheltered bloodwood) and a rainforest/eucalypt association (rainforest).

Processing was undertaken to the stage of calculating the initial FCD map. To assist interpretation of the results of the FCD map, the bare soil index (BI), shadow index (SI), thermal index (TI) and the normalised difference vegetation index (NDVI) were calculated for the three reference positions with a closed canopy, i.e. the exposed bloodwood, the sheltered bloodwood and the rainforest. From a field inspection, five positions were chosen across the range of each land-cover type and the reflectance of a

2x2 pixel matrix was recorded for each position. Reflectance values were obtained from each image using the interactive query function of the Mapper and a mean reflectance of the 20 pixels calculated for each index. In addition, a mean reflectance of 20 pixels, selected as described above, was calculated for the three closed canopy landcovers for bands 1 to 5 using the interactive query function in Idrisi.

Plot Selection

In order to check the accuracy of the FCD classification, 20 field plots of 0.1 ha were measured for PDH, stocking and basal area. Five plots each were measured in scribbly gum, exposed poor quality bloodwood forest, sheltered bloodwood forest and rainforest. Plot positions were located on the FCD image and the coordinates were transferred to a hand-held Global Positioning System (GPS)[3] receiver for location in the field.

Processing of the Image in the Leyte Study Area

Five ground-truthing sites were chosen in the central west of the island, namely rice paddy, banana and coconut plantation, 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. For each site, the height of the forest cover, the presence of secondary vegetation layers and the amount of sunlight penetrating the canopy were noted.

RESULTS

In the Noosa study area, 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 trees/ha for the rainforest and scribbly gum and 340 and 430 trees/ha for the sheltered bloodwood and exposed bloodwood, respectively. All trees and palms over 15 cm diameter were measured and the lower stocking of the rainforest and scribbly gum plots 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 comprised some trees which consist of multiple stems growing from one lignotuber and these were counted as separate trees. Mean basal area was highest for the rainforest (17.3 m^2/ha) and sheltered bloodwood (17.2 m^2/ha) and 12.9 and 10.3 m^2/ha for the exposed bloodwood and scribbly gum. Mean FCD was 78, 72, 45 and 43 for the rainforest, sheltered bloodwood, exposed bloodwood and scribbly gum, respectively (Table 1).

---

[3] A global positioning system receiver is a radionavigation instrument which receives signals from satellites, enabling its position on the earth to be fixed.

Table 1. Mean PDH, stocking, basal area and FCD for five plots each in rainforest, sheltered bloodwood, exposed bloodwood and scribbly gum forest at Noosa Heads, south-east Queensland

Forest type	PDH (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 PDH and FCD for the 15 field plots in forest with a closed canopy (Figure 2).

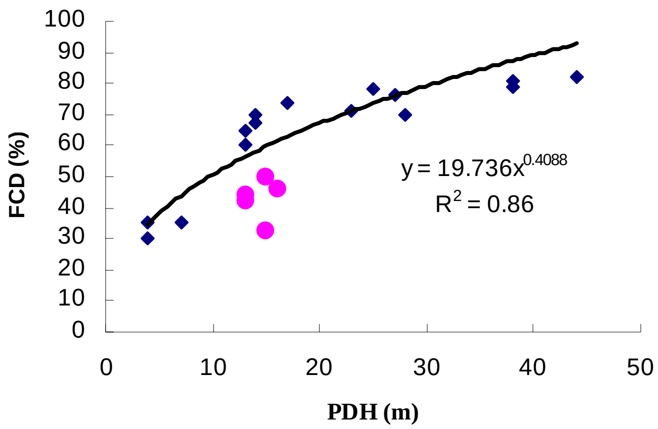

Figure 2. Relationship between PDH and FCD for 15 field plots (diamonds) in native forest of closed canopy but variable height. Also shown are five scribbly gum field plots (balls) in forest where the canopy is broken and more of the ground is exposed to sunlight.

Calculation of BI, SI, TI and VI Indices

BI, SI, TI and the VI for the exposed bloodwood, sheltered bloodwood and rainforest are shown in Table 2. SI increased from 161 for the exposed bloodwood, to

167 for the sheltered bloodwood and 173 for the rainforest, consistent with the proportion of sunlit ground in these land types. TI declined from 63 for the exposed forest to 54 for the sheltered bloodwood forest and 51 for the rainforest consistent as a result of lower temperatures underneath the deeper canopies. However, there were no clear trends in the BI and the VI.

Reflectance values for bands 1 to 5 for the three forest types are shown in Table 3. As expected, digital reflectance declines with increasing canopy height for bands 1, 2, 3 and 5. The reflectance of band 4 shows no relationship with canopy height.

Table 2. Bare soil index, shadow index, thermal index and vegetation index, calculated as the mean of 20 pixels over three different land covers at Noosa Heads, south-east Queensland

	Bare Soil Index	Shadow Index	Thermal Index	Vegetation Index
Exposed bloodwood	113	161	63	152
Sheltered bloodwood	95	167	54	179
Rainforest	106	173	51	150

Table 3. Mean reflectance of 20 pixels each for TM bands 1 to 5 in the exposed bloodwood, sheltered bloodwood and rainforest reference sites at Noosa Heads, south-east Queensland.

	Band 1	Band 2	Band 3	Band 4	Band 5
Exposed bloodwood	67	86	80	184	105
Sheltered bloodwood	50	68	55	205	88
Rainforest	31	43	31	163	60

Leyte Study Area

The broad-scale classification of Leyte island into FCD percentages was as expected, i.e. 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 estimated FCD of some of these small forested areas was probably lower than it should be. In addition, some of the native forest areas are very steep and sheltered and the FCD Mapper classified them as shadow with a consequent FCD of zero. A qualitative description of the vegetation on the field validated areas is provided in Table 4.

Table 4. Approximate FCD for several types of vegetation in Leyte

Site	Vegetation type	Predominant height	Presence of secondary layers	FCD
Rice paddy	Wet green grass		None	0
Banana plantation and coconut plantation	Broadleaf plantation interspersed with grass	6 m (banana) to 15 m (coconut)	Grass	0-20
Small forest plot amongst paddy field	Forest plantation	Variable approx 15 m	Sometimes dense secondary layer	50
Casuarina plantation	Forest plantation	Approx 25 m	Grass	55
Native forest	Rainforest	>30 m	Multi-layered	Variable 40–90

DISCUSSION AND CONCLUSION

The high correlation of FCD with PDH at Noosa Heads indicated that the FCD Mapper may be useful to distinguish between forests at different stages of development provided canopy closure is maintained. The FCD Mapper was originally developed as a tool to assess the regrowth of a forest canopy in logged-over tropical forest (Rikimaru *et al.* 1999) and these results support the aims of the software developers. 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. However, 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 shown by the field plots of this investigation. This may be explained by the inconsistent relationship of near infrared (band 4) reflectance with PDH in these images. Visual inspection of bands 1 to 5 in the original images of the region showed a consistent negative relationship between PDH and reflectance for bands 1, 2, 3 and 5 and this supports the results reported in table 4. The original image of band 4 showed no consistent relationship of digital reflectance with PDH for the Noosa image.

Near infrared wavelengths are strongly reflected by vegetation. Danson and Plummer (1995) found a strong negative relationship between near infra-red reflectance and forest stand parameters, but suggested that this could be caused by crown structural differences. Near infrared reflectance has also been found to show little or inconsistent variation under conditions of variable crown closure and the associated ratio of understorey to overstorey (Curren *et al.* 1992; Baynes and Dunn 1997). This would appear to be the case in this investigation as the mean band 4 reflectance is less (164) in the rainforest than in the bloodwood (184) and the sheltered bloodwood (205). A lower band 4 reflectance results in a lower VI and this in turn decreases the calculated vegetation density which the FCD Mapper software calculates from the first principal component of the VI and BI. FCD is subsequently reduced for this vegetation type. BI also increases as band 4 reflectance declines, again reducing FCD. Hence, unless band 4 displays a consistent trend with increasing vegetation density, it may not be possible to detect trends in PDH, in this case beyond an FCD of approximately 70. This corresponds to a PDH of approximately 20 m for the Noosa Heads area.

In this investigation, the FCD Mapper discriminated between scribbly gum forest with a broken canopy and low basal area and the three other forest types with a closed canopy, although no statistical analysis was undertaken. This supports the value of the FCD Mapper as a tool for change detection in forest canopies. However, the inconsistent reflectance characteristics of band 4 with forest of different canopy heights may lead to the misclassification of forest types. This suggests that it may be worthwhile to inspect the raw images before inputting them into the FCD Mapper. It also suggests that preliminary knowledge of the land covers likely to be encountered would be most useful, as well as post-assessment field validation.

In band 4, the Leyte image showed a negative relationship with vegetation height, opposite to the Noosa image. This does 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 more likely to have underplantings of vegetables and other palms, while the more remote coconut plantations have little understorey. In these tropical areas, the FCD Mapper would appear to be a useful aid to analysing deforestation or conversion from native forest to coconut or banana plantation but intensive field validation will still be required if large images are used. Although the FCD Mapper classifies vegetation in the same way over any spatial scale, changes in vegetation architecture may lead to misclassification over a range of vegetation types. This suggests that if a high degree of accuracy is required, as would be envisaged with time series comparisons, then the Mapper may be more useful in areas where the architecture of the vegetation is consistent.

REFERENCES

BAYNES, J. and DUNN, G.M. 1997. Estimating foliage surface area index in 8 year old stands of *Pinus elliottii* var. *elliotii x Pinus caribaea* var. *hondurensis* of variable quality. *Canadian Journal of Forest Research.* **27**: 1367–1375.

BLASER, J. and DOUGLAS, J. 2000. A future for forests? *Tropical Forest Update*. **10**: 9–14.

CURRAN, P.J. DUNGAN, J.L. and GHOLTZ, H.L. 1992. Seasonal LAI in slash pine estimated with Landsat TM. *Remote Sensing Environment*. **39**: 3–13.

DANSON, F.M. and PLUMMER, S.E. 1995. Red edge response to forest leaf area index. *International Journal of Remote Sensing*. **16**: 183–188.

FRANKLIN, S.E., LAVIGNE, M.B., WULDER, M.A. and McCAFFREY, T.M. 2002. Large-area forest structure change detection: An example. *Canadian Journal of Remote Sensing*. **28**: 588–592.

GROETSCHEL, A., AQUINO, R., BUCHHOLTZ, I., EUFRACIO-MAZIO, T., IBKENDANZ, A., SALES, N.A., SEVEN, J. and VICENTUAN, K.C. 2001. *Natural resource management strategies on Leyte Island, the Philippines.* Centre for Advanced Training in Rural Development. Margraf Verlag, Berlin.

JOFCA (JAPAN OVERSEAS FORESTRY CONSULTANTS ASSOCIATION) 1999. FCD-Mapper Ver. 1.1. *User Guide*. International Tropical Timber Organisation and Japan Overseas Forestry Consultants Association. Yokohama.

JOFCA (JAPAN OVERSEAS FORESTRY CONSULTANTS ASSOCIATION) 2003. FCD-Mapper Ver. 2. *User Guide*. International Tropical Timber Organisation and Japan Overseas Forestry Consultants Association. Yokohama, Japan.

KRISHNASWAMY, A. 1999. A Global Vision for Forests in the 21st Century. *Tropical Forest Update*. **9:** 7–9.

PERALTA, R. and BALDIVIEZO, J.P. 2003. The road to sustainability. *Tropical Forest Update*. **13**: 10–12.

RIKIMARU, A. MIYATAKE, S. and DUGAN, P. 1999. Sky is the limit for forest management tool. *Tropical Forest Update*. **9**: 6–8.