Relationship Between Above Ground Live Biomass and Satellite Image Spectral Responses (Landsat ETM+) of *Pinus caribaea* Morelet at Lower Hantana Region in Sri Lanka

A.R. Gunawardena, S.P. Nissanka[1], N.D.K. Dayawansa [2]

Postgraduate Insitute of Agriculture
University of Peradeniya
Peradeniya, Sri Lanka

ABSTRACT. *Terrestrial carbon sequestration in woody biomass has received attention as a promising adaptation mechanism in mitigating global warming. Developing countries could trade these sequestered carbon with developed countries. To facilitate this type of projects, precise quantification of sequestered carbon in vegetations is essential. Though, many attempts have already been made to estimate vegetation biomass, no precise prediction models are developed for tropical ecosystems. Therefore, this study was initiated to develop carbon sequestration models using satellite image spectral response techniques for Pinus caribaea Morelet plantation at mid-country Wet zone of Sri Lanka.*

Using Landsat ETM+ image, pine plantations at the Hantana region were categorized in to three spectral strata. Six to nine plots (30 m × 30 m) were demarcated from each stratum to estimate biomass. Plant height and diameter at breast height (DBH) of individual trees inside the plot were measured. Three vegetation indices, Normalized Difference Vegetation Index (NDVI), Ratio Vegetation Index (RVI) and Difference Vegetation Index (DVI)) were developed for research site using Landsat ETM+ satellite image and correlated with the estimated biomass.

Results showed that the vegetation index of NDVI derived from satellite images was significantly correlated with calculated above ground biomass of P. caribaea than RVI and DVI. However, other two vegetation indices could also be used as precise carbon sequestration models to predict above ground biomass for P. caribaea.

INTRODUCTION

Over the years, tropical ecosystems became one of the major global crises due to continuous, indiscriminate, unprecedented and extensive deforestation all over the world. Loss of biodiversity, land degradation and global environmental changes are the major effects of deforestation. In addition, forest fragmentation and habitat degradation have further aggravated the impact on wildlife habitats, watersheds and hydrological cycle. The world is aware that carbon dioxide *(CO_2)* emissions particularly those from fossil fuel burning and deforestation are increasing and causing global warming (NASA, 2001).

---

[1] Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka.

[2] Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka.

However, terrestrial carbon sequestration in above ground woody biomass has received attention as a promising course in an immediate attempt to mitigate global warming. Among the carbon sequestration techniques identified, sequestration through vegetation plays a significant role. Green plants through photosynthesis fix atmospheric CO_2 back to biomass. In this manner, plantation forests are playing a major role to carbon stocking while reducing the global warming.

Biomass estimates provide means of calculating the amount of carbon dioxide that could be removed/fixed from the atmosphere by re-growing vegetation. There are many attempts made to estimate vegetation biomass, such as the use of existing forest inventory, which is the key method. Many researchers have developed various methods for the quantification of sequestered carbon. Traditional inventory of forest parameters based on fieldworks is often difficult, costly and time consuming to conduct in large areas. Remote sensing may be the only feasible way to acquire forest stand parameter information at a reasonable cost with acceptable accuracy. Advanced new remote sensing techniques such as, multi-sensor data fusion, increase spatial and spectral resolution and integration with Geographical Information Systems (GIS) make remotely sensed data, the primary source for many forestry applications. Among them, extraction of forest stands parameters through correlation or regression analysis to examine relationship between spectral response and structural factors of forest such as basal area, biomass, crown closer and vegetation density (Namayanga, 2002), hold more promise.

Remotely sensed data are comprehensive responses of the vegetation stand structure, vegetation density and vegetation species composition. Different forest stand structures have different reflectance and texture patterns in various wavelengths. Therefore, much more remote sensing research focused on the extraction of forest stand parameters through correlation or regression analysis to examine relationship between spectral response and structural factors of forests (Dengsheng *et al.*, 2004) are needed. The objective of this study was to identify the relationship between above ground live biomass of *Pinus caribaea* Morelet in Hantana foothills by using spectral responses of Landsat ETM+ satellite images.

MATERIALS AND METHODS

Data, materials and other information

The primary data used in the study was Landsat ETM+ image acquired in 2000. Digital Elevation Model (DEM) was derived from SRTM (90 m resolutions) data and site verification was done using the 1: 50,000 scaled topographic maps. To demarcate plots and geo-rectification of satellite images, Trimble GeoXT differential Global Positioning System (GPS) was used. Base station data were also used for differential corrections of GPS coordinates to achieve a high accuracy of locations.

Research site

P. caribaea plantation forest of the University of Peradeniya is located in the foothills of the Hantana mountain range which lies at an altitude between 1000 and 1500 m at msl and between 7^0 13′ 00″ N & 7^0 16′ 00″ N and 80^0 36′ 00″ E & 80^0 38′ 00″ E geographical coordinates. Figure 1 shows the location of the research site.

Image processing and selection of sample locations

Geometrical rectification and radiometric and atmospheric correction of remotely sensed data are required for many applications. The importance of accurate geometric correction is obvious due to the image data that are often related to the ground truth data (Lu *et al.,* 2004). Acquired image was geometrically rectified into UTM (Universal Transverse Mercator) projection and datum WGS 84 (zone 44) using ground control points obtained through GPS together with 1: 50,000 topographic maps. All images that were collected had good quality and were free of clouds.

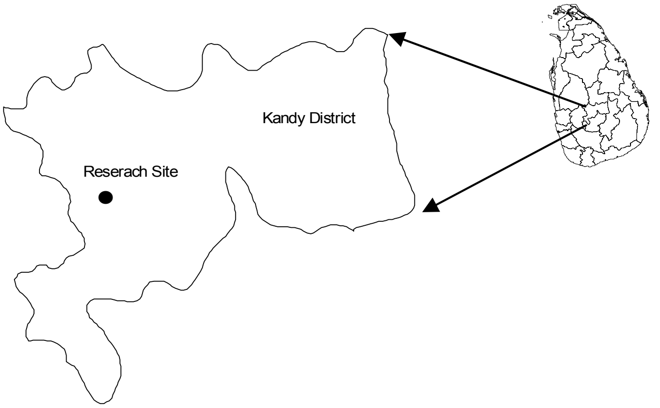


Fig. 1. Location map of the study area.

Site stratification

False color composite (FCC) technique was used for initial stratification of Landsat ETM+ satellite image (6 bands) with 4:5:3 band combination. The image was subjected to unsupervised classification to obtain 10 different classes.

Initial field survey was conducted to collect GPS locations to identify different vegetation types including pine, grassland, natural vegetation and settlements in research area. Collected GPS locations were subjected to differential correction and overlaid with unsupervised images. Afterwards, raster images were converted to vector format and different vegetation layers (strata) were created. Using the ground truth information and visual interpretation, “Class 1” layer was identified as pine plantation. To identify variability within the pine stratum, same procedure of unsupervised classification was followed and pine plantation was stratified in to 3 different classes.

Development of vegetation indices

After geometric rectification, 3 vegetation indices were developed and calculated for Landsat ETM+ image (Table 1) using an appropriate software (ERDAS imagine). Among those indices, Normalized Difference Vegetation Index (NDVI) is the most widely used index for biomass calculation and has extensively used to monitor vegetation (Panda, 2005). Difference Vegetation Index (DVI) shows the reflectance value difference of Near Infrared (NIR) and red bands also widely used to monitor crop growth conditions (Ritchie, 2003). Ratio Vegetation Index (RVI) is commonly used for differentiating geological materials and vegetation (Jensen, 2004).

Table 1. Selected vegetation indices applied for the research to estimate above ground biomass of *Pinus caribaea* Morelet.

Index and Bands	Name	Formula
DVI	Difference Vegetation Index	NIR-Red
RVI	Ratio Vegetation Index	NIR/Red
NDVI	Normalize Difference Vegetation Index	[(NIR – Red) / (NIR + Red)]

Plots

Stratified random sampling technique was used to select plots. According to the three strata identified from the classified images, plots were placed within each stratum. Size of the plot (30 m × 30 m) was pre-defined to match one pixel of Landsat ETM+ image. Plots were demarcated using the differential GPS with accuracy of less than one meter. A total of 23 field plots were used to measure and estimate the parameters.

Variables measured in the field

To estimate biomass content and derive satellite images, following information were collected in each plot.

- GPS coordinate: Center of the plot X and Y coordinates were taken using high accuracy differential GPS (sub meter accuracy level).
- Diameter at Breast Height (DBH): DBH tape was used to measure the diameter of the trees at the height of 1.3 m from the ground of the trees, which are above 10cm DBH.
- Heights of the trees were taken using the clinometer and measuring tape.
- Canopy cover m^2/plot: Wide-angle digital photographs of the tree canopy were taken for each subplot and canopy cover was calculated using computation.

Measurement of live biomass

The carbon stocks of trees were estimated through the field inventory in which all trees in the sample plots above a minimum diameter of 10 cm were measured. Biomass and carbon stock were estimated from DBH and of total height using locally relevant allometric equations. Empirical data confirm that highly significant biomass regression equations can be developed with DBH as single independent variable (Brown *at al.*, 2004). However, this study used DBH and total height for the estimation of above ground biomass and following equation was used to measure biomass of *P. caribaea.*

$$\text{Biomass (kg)} = -\,3.843 + 1.035\,(d^2\,h)$$

(George *at al.,* 2004)

Where;

d is the diameter at breast height
h is the total height of the tree

Integrated of field data with image spectral responses

Sampled plots have accurate coordinates derived from high accuracy GPS device and were located on geometrically rectified, stratified Landsat ETM+ image during the field work. These plot data (forest stand parameters) were linked with individual bands of both images and other vegetation indices extracted from spectral responses. Forest stand parameters such as above ground biomass (AGB) and canopy cover, from each site were associated with spectral response using multiple regression analysis (SAS software) to explore the relationship between forest parameters and image indices.

RESULTS AND DISCUSSION

Image stratification

Landsat ETM+ image was generalized in to 10 different classes using unsupervised classification and it aggregates the details for each classes. This procedure helps to eliminate pixels with zero values and to gather similar pixels (Fig. 2). Initial ground truth locations of pine plantation perfectly fitted with class number 1 and its area is 198.96 ha. The extracted class 1 layer is displayed in Figure 3. However, signature graphs of above unsupervised 10 class image and spectral values of different Landsat ETM + images were (Table 2) also used to further verify the pine plantation. According to the graphs, *P. caribaea* spectral response signature curve is different from other 9 classes with R^2 value of 0.9034 (Fig. 4). Further classification of class 1 layer was necessary to identify the variation within the pine plantation.

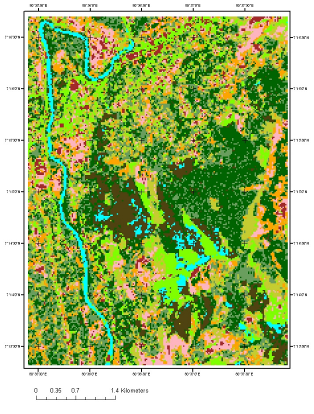


Fig. 2. Unsupervised 10 classes image.

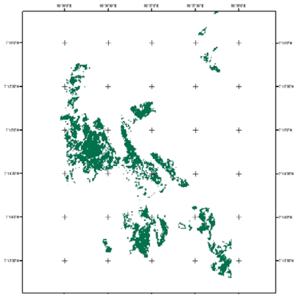


Fig. 3. Extracted area of *Pinus caribaea* Morelet from unsupervised 10 classes image.

This stratification generalizes the pine plantation into 3 different strata according to the variation of plant density and canopy cover (Fig. 5).

Table 2. **Spectral reflectance (digital numbers) of "class1" which representing the *Pinus caribaea* Morelet in ETM+ image.**

Sensor	ETM+ Band	Spectral Reflectance Value (Digital Number)			
		Minimum	Maximum	Mean	SD
ETM+ Image	B1	62	86	72.3	4.5
	B2	42	68	51.4	4.6
	B3	29	71	41.4	6.1
	B4	8	67	43.6	12.5
	B5	1	56	33.4	10.2
	B7	1	51	20.5	6.6

Note: SD - Standard Deviation.

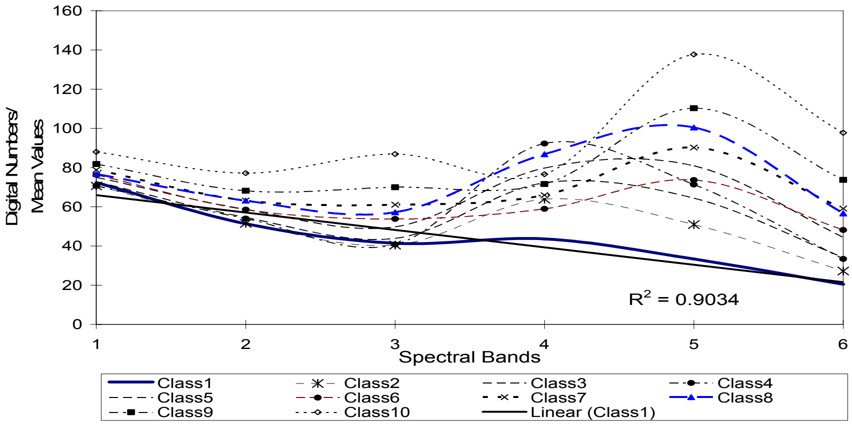


Fig. 4. **Spectral response graphs of unsupervised 10 class ETM+ images of the study area with 6 spectral bands (thick line shows the reflectance of Pinus layer).**

Estimation of forest stands parameters

According to the estimations, the highest estimated above ground live biomass content (54,137.50 kg) was recorded in plot number 1 of stratum 3 while the lowest (26,995.29 kg) was recorded in plot number 2 of stratum 1. The highest tree density of 268 (per plot) was observed in plot number 4 of stratum 3 and the lowest value was observed in plot number 7 of stratum 3. Average canopy cover percentage was in plot 4 of stratum 3. Amount of dry biomass content of *P. caribaea* observed is 231 mt/ha by Khadka (2005) with the biomass distribution percentage within the plants with 71.39% from stem, 7.04%

from branches and 2.78% from needles. The mean biomass production of the research site is 38,855.16 kg per plot of 30 m × 30m.

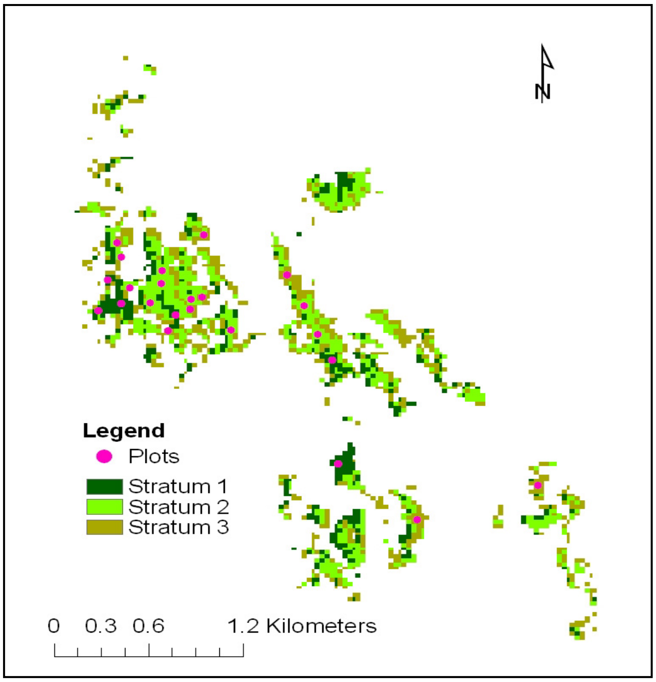


Fig. 5. Three different strata within the *Pinus caribaea* Morelet and locations of plots.

Pearson Correlation Coefficient values were obtained for the estimated and measured biomass contents. Above ground fresh biomass content is strongly correlated ($p < 0.0001$) with the basal area with R^2 value of 0.91. Tree density is also significantly correlated ($p<0.0471$) with biomass content with a R^2 value of 0.41. Probability value (0.0283) was observed between basal area and the tree density ($R^2 = 0.46$).

Spectral reflectance and vegetation index values of sampled plots

Using the vegetation indices of NDVI, RVI and DVI, each map was prepared and overlaid with respective plots (Figs 6, 7 and 8). The highest NDVI value was recorded in plot 4 of stratum 3 while the lowest was in plot 2 of stratum 1. Mean NDVI values of each stratum are 0.017, 0.201 and 0.218, respectively for strata 1, 2, and 3. The highest mean values were observed in high dense vegetation due to higher Leaf Area Index (LAI) (Jensen, 2004). Chen (1996) evaluated the spectral indices for boreal forests and concluded that NDVI was the best correlated index with LAI. Plot number 4 of stratum 3 shows the highest RVI value (1.6857) while the lowest (1.1395) is in plot 2 of the stratum 1. The RVI can enhance radiance difference between soil and vegetation while soil and geological materials exhibits similar ration near to one. Vegetation shows larger ratio value of two or more, the higher values indicate more luxuriant crop growth conditions (Panda, 2005).

Relationship between forest stand parameters and vegetation indices

All vegetation indices are significantly related to forest stands parameters. Table 3 summarizes the statistical significance between forest stand parameters and vegetation indices for the study area. Figure 9 shows the map of biomass content of the study area, which was developed using the estimated biomass values and NDVI. However, RVI and DVI are not significantly correlated with above ground live biomass content though they are statistical significant at 0.05 level. According to the results NDVI is significantly correlated (r = 0.51) with above ground live biomass content of *P. caribaea* than RVI (Fig. 10b) and DVI (Fig. 11a) at the level of 0.05. A strong relationship could not be established between canopy cover percentage and the biomass (Fig. 11b). Forest parameter measurements and vegetation index values for the sampled plots are presented in Table 4.

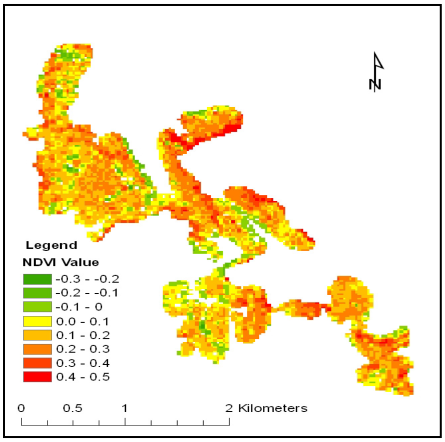


Fig. 6. NDVI map of the study area.

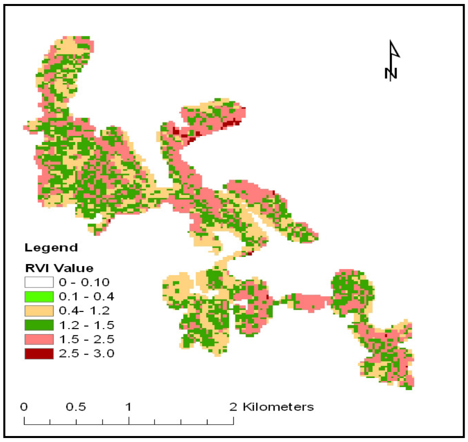


Fig. 7. RVI map of the study area.

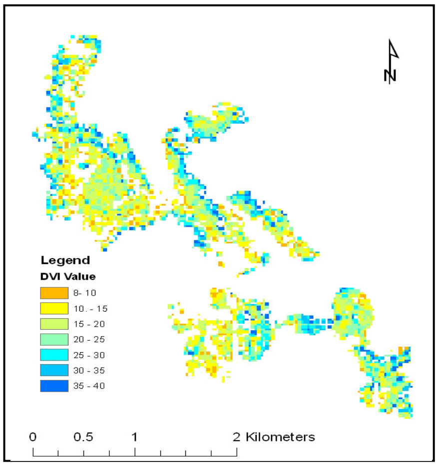


Fig. 8. DVI map of the study area.

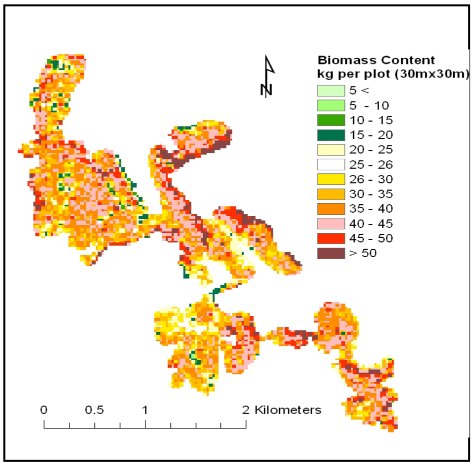


Fig. 9. Biomass map of the study area.

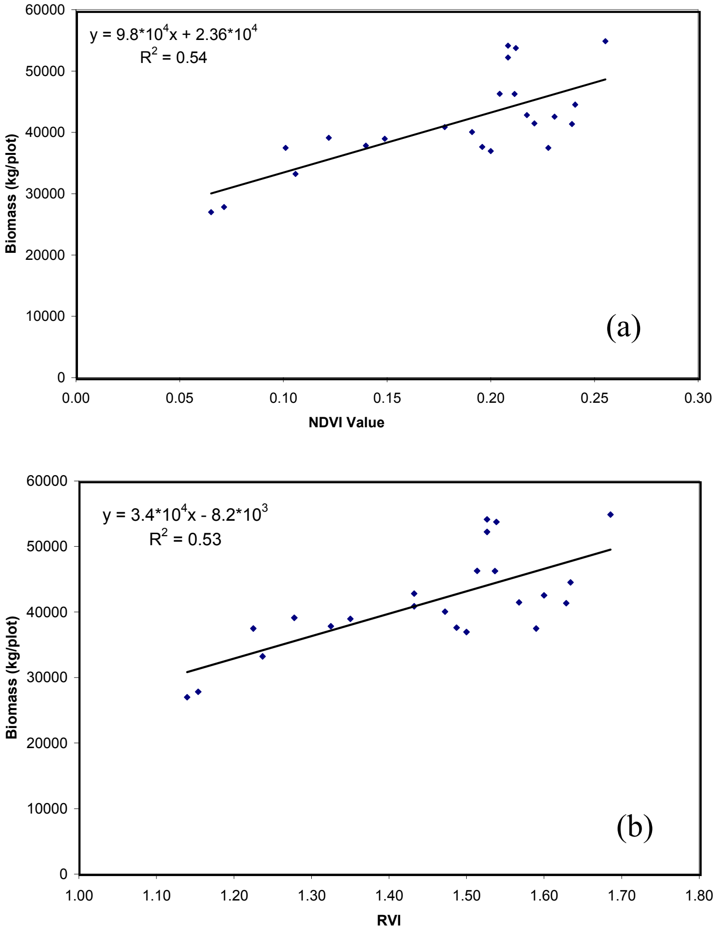
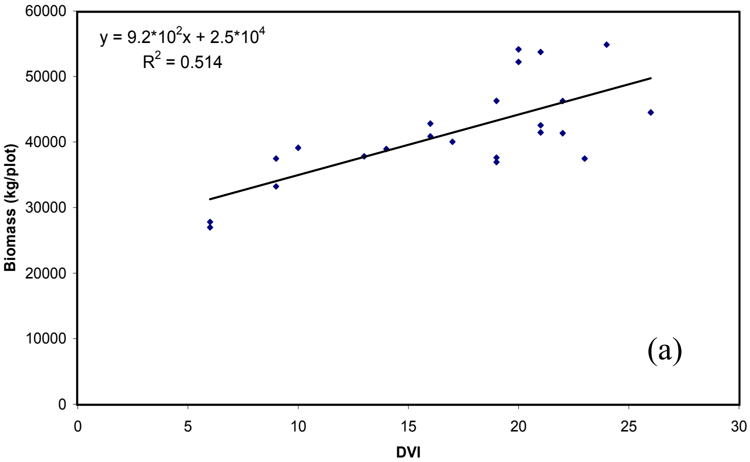


Fig. 10. Relationship between estimated above ground live biomass content with NDVI (a) and RVI (b).

Table 3. Summary of stand parameters and vegetation indices for the three *Pinus caribaea* Morelet strata.

	NDVI	RVI	DVI
r value	0.5063	0.4885	0.4800
Statistical Significance (Pr)	0.0137	0.0180	0.0204
R^2 value	0.5390	0.5260	0.5145



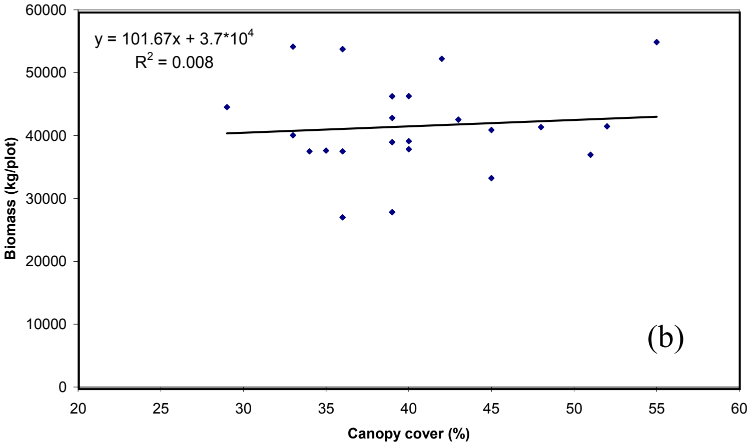


Fig. 11. Relationship between estimated above ground live biomass content with DVI (a) and plot canopy cover percentage (b).

Table 4. Forest parameter measurements and vegetation index values of sampled plots.

		Stand parameters				Vegetation index		
	Plot	Biomass (kg/plot)	Basal area (m^2/plot)	Tree density (trees/plot)	Canopy cover (%)	NDVI	RVI	DVI
Class 1	P1	37,485.47	41.94	181	36	0.10112	1.22500	9
	P2	26,995.29	42.09	189	36	0.06521	1.13953	6
	P3	27,818.09	26.70	162	39	0.07143	1.15385	6
	P4	39,119.10	46.09	165	40	0.12195	1.27780	10
	P5	33,230.92	40.65	173	45	0.10586	1.23684	9
	P6	40,877.52	44.95	182	45	0.17778	1.43243	16
Class 2	P1	37,829.32	51.79	252	40	0.13979	1.32500	13
	P2	52,215.98	59.35	198	42	0.20833	1.52632	20
	P3	38,953.05	50.20	216	39	0.14894	1.35000	14
	P4	41,352.23	54.73	180	48	0.23913	1.62857	22
	P5	42,550.72	46.48	218	43	0.23077	1.60000	21
	P6	36,938.72	34.60	178	51	0.20000	1.50000	19
	P7	41,466.30	54.69	159	52	0.22105	1.56757	21
	P8	42,807.27	48.79	181	39	0.21739	1.43243	16
	P9	46,276.98	27.67	163	40	0.20430	1.51350	19
Class3	P1	54,137.50	60.47	221	33	0.20833	1.52632	20
	P2	37,624.14	44.47	234	35	0.19588	1.48718	19
	P3	53,744.90	65.62	212	36	0.21212	1.53846	21
	P4	54,872.41	49.88	268	55	0.25532	1.68571	24
	P5	46,262.23	41.94	199	39	0.21154	1.53659	22
	P6	44,519.41	51.62	215	29	0.24074	1.63415	26
	P7	40,046.42	41.75	157	33	0.19101	1.47222	17
	P8	37,485.47	41.94	173	34	0.22772	1.58974	23

CONCLUSIONS

NDVI from Landsat ETM + is the best spectral data index which is significantly correlated with the above ground live biomass content ($y = 97952x + 23636$) of *P. caribaea*. However, these predicted biomass values are applicable for pine with age classes of 20 to 30 years growing in mid-country Wet zone region of Sri Lanka. Presence of canopy cover is one of the critical factors which affected the prediction of biomass through vegetation indices. When the biomass content is low and the canopy cover is high, these areas show higher predicted biomass content due to higher LAI.

REFERENCES

Brown, S., Shoch, D., Pearson, T. and Delaney. M. (2004). Methods for measuring and monitoring forestry carbon projects in California. Winrock International, for the California Energy Commission, PIER Energy related Environmental Research. 500-04-072F. pp. 15-17.

Densheng, Lu., Mausel, P., Brondizio, E. and Moran, E. (2004). Relationship between forest stand parameters and Landsat TM spectral response in the Brazilian Amazon Basin. Forest Ecology and Mgt. 157.

George.M., Koutsias, N., Makras, A. and Karteris, M. (2004). Forest parameters estimation in European Mediterranean landscape using Remote Sensing. J. Forest Sci. 50(4): 450-452.

Gong, P., Pu, R., Miller, J.R. (1995). Coniferous forest leaf area index estimation along the Oregon transact using compact airborne spectrographic imager data. Photogram Eng. Rem. Sens. 61: 1107-1117.

International Institute for Geo-Information Science and Earth Observation. (2004). Principles of remote sensing. Hengelosestraat 99, Enschede, The Netherlands.

Jensen, J.R. (2004). Remote Sensing of the Environment, an Earth Resource Perspective, Pearson Education (Singapore) Pvt. Ltd. pp. 333-378.

Khadka, P. (2005). Biomass production of *Pinus caribaea*. http//www.Literature.al/elib.

Lillesand, T.M., Kiefer, R.W. and Chipman, J.W. (2004). Remote Sensing and Image Interpretation (fifth edition), John Willey and Sons (ASIA) Pvt. Ltd., Singapore. pp. 17-20.

Ministry of Agriculture Land and Forestry, Sri Lanka. (1995). Sri Lanka forestry sector master plan.

Ministry of Environment and Natural resources. (2002). State of the Environment in Sri Lanka.

Namayanga, L.N. (2002). Estimating Terrestrial Carbon Sequestered in Above Ground Woody Biomass from Remotely Sensed Data, International Institute for Geo-information Science and Earth Observation, Netherlands. pp. 10-12.

NASA. (2001). NASA Facts Sheets [Online].

NASA http://pao.gsfc.nasa.gov/gsfc/service/gallery/fact_sheets/earthsci/warming.htm.

Negi, J.D.S. and Sharma, D.C. (1985). Biomass and nutrients distribution in age series of Eucalyptus hybrid plantation in Tamil Nadu District. Organic Matter 4: 1111-1122.

Panda, B.C. (2005). Remote Sensing Principles and Applications, Viva books Privet Limited, New Delhi. pp. 100-148.

Ritchie, G. (2003). Use of ground-based canopy reflectance to determine radiation capture, Nitrogen and water status, and final yield in wheat, unpublished M.Sc. Thesis, http://www.usu.edu/cpl/PDF/ritchie_thesis.pdf.

Tandon, V.N., Pande, M.C. and Sing, R. (1988). Biomass estimation and distribution of nutrients in five different aged Eucalyptus grandis plantations in Kerala state. Indian Forest. 114: 184-199.