

## Developing Diameter at Breast Height (DBH) and a Height Estimation Model from Remotely Sensed Data

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### ABSTRACT

While most recent investigation in satellite-based remotely sensed data has concentrated upon the biophysical characteristics of overstory vegetation for large area, little attention has been given to the reflectance contribution of their associated understory, versus overstory plantation reflectance to the recorded pixel value. In this research, shrubs and herbs were considered as consistent backgrounds which have an inverse effect, in contrast to plantation overstory, to the recorded pixel value in terms of their surface-exposure to satellite sensors. Given the fact that planted tree crown closure is correlated with their height and diameter at breast height (DBH) in the early stages of the plantation, it is expected that a relationship exists between tree canopy closure, height, DBH and their associated reflectance values. The proposed concept was tested in a case study for a Jack Pine (*pinus banksina*) plantation using Landsat Thematic Mapper (T. M.). The crown width height, and DBH of planted trees were measured in an area of 30m X 30m, for every 2-year age interval from 1 to 21 years. Other understory natural regeneration within a 2m radius was recorded. Crown closure, mean height, and DBH of each plot (with shrub and herb understory of more than 60%) were plotted against their associated Digital Numbers (DN(s)) for 6 T. M. bands (1, 2, 3, 4, 5 and 7). The visible region of the spectrum (bands 1, 2 and 3) showed a narrow range of reflectance and was not suitable for this purpose. Band 4 revealed a greater range of DN(s) than bands 1, 2 and 3. A strong inverse linear relationship between DN(s) and their associated canopy closure, height, and DBH were found in band 5 as  $r^2 = 0.863, 0.941, 0.873$  respectively. Band 7 showed a stronger relationship with canopy closure ( $r^2 = 0.81$ ) than did the other T. M. bands (except band 5). Overall, the results of this study have shown the importance of T. M. band 5 for estimating DBH and the height of plantations based on the contrast between reflectance of the overstory and understory.

**Keywords:** Canopy closure, DBH, DN(s), Height, Satellite data, T. M. bands.

### INTRUDUCION

Over the last 50 years, forest managers have greatly expanded plantations of desired species in an attempt to assure an adequate level of wood supply.

Effective plantation management requires more frequent assessment of the divergence between expected and actual plantation development. Although some DBH and height vs. age ground data models have been developed to forecast the plantation height and DBH, an implicit assumption of these models is that a plantation will grow exactly as

forecasted whereas, during the planning period, the actual plantation growth may vary. These changes may be caused by disease, fire, windthrow, silvicultural treatments or competition from other invading species etc. To know how the plantations are actually performing in terms of growth and yield, it is essential to provide a better method of monitoring these changes. A monitoring system based on remotely sensed data from satellites has the potential to address this problem. Satellite imagery provides information over a large geographic area in a relatively short time cycle, and at a low cost on a regu-

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lar basis as opposed to the high cost of ground-based observations.

Young plantations are typically manifested in smaller sized trees, lower height and DBH, and incomplete crown closure, compared to the older plantations. Tree height, DBH and crown closure increase with age. As the tree crowns expand, they provide a greater light intercepting and reflecting surface. Full interception occurs when the crowns of all trees touch each other. It is commonly observed that an inverse relationship exists between the tree canopy and their associated understory ground coverage (i.e. snow, shrub and herbs etc.) in terms of their surface exposure. The contribution of the understory coverage reflectance versus the overstory canopy reflectance to the recorded pixel value depends on the proportion of their surface area that is exposed to the satellite sensors. That is, an increase in the surface area of understory coverage exposed to the satellite sensors dramatically alters the recorded pixel values (Gemmell, 1995; Lekie *et al.*, 1992; Spanner *et al.*, 1990; Stenback *et al.*, 1990). Since crown is correlated with tree height and DBH in the early stages of the plantation (Honer, 1972; Danson, 1989; Oladi, 1997), it is hypothesized that: (i) the reflectance values, recorded by sensors, for a given tree species is a function of the exposed crown projection area (i.e. canopy closure) regardless of their age and density. Consequently, the reflectance values of overstory planted trees vary with respect to the increase of understory canopy closure based on the reflectance contrast between these two layers, and (ii) a quantitative relationship exists between tree canopy closure, height and DBH, as measured on the ground, and reflectance values as estimated from the satellite imagery. Consequently, remotely sensed data could be used to determine plantation canopy closure, height, and DBH. A fundamental question may be raised here as to whether the concept is applicable to plantations with varying densities. It is obvious that, for a given plantation age, the higher the density (stem/ha) the sooner the canopy closes. Yet, initial plantation density is gen-

erally known and, as such, the concept can be applied to different plantation densities.

The proposed method was tested in a case study on a Jack Pine plantation between 1 to 21 years of age, with shrubs and herbs as understory coverage, using T.M. data.

## Background

Most forest attributes such as age class, species composition, Leaf Area Index (LAI), mean height, basal area, mean DBH, timber volume and so on. Over very large areas have been investigated by many researchers using remotely-sensed data. The correlation between the reflectance values in various T.M. bands and forest at different developmental stages is well known from the early plantation development stage (Coleman *et al.*, 1990; Fiorella and Ripple, 1993) to the older forest stands (Poso *et al.*, 1987; Cohen and Spies, 1992). Pierce *et al.* (1992) and Franklin *et al.* (1992) used T.M. data to separate different forest cover types. They found that this sensor is able to provide adequate information to differentiate forest species. Stenback *et al.* (1990) used T.M. imagery to detect the presence or absence of understory vegetation for three different overstory canopy closure categories at less than 30%, 30% to 70% and more than 70% in northern California. They found a classification accuracy of 55 to 69 percent for understory presence and recommended that stands with homogeneous understory such as plantation could provide a better result. Gemmell (1995) investigated the utility of Landsat T.M. data to estimate coniferous timber volume for a mountainous mixed-conifer species. He used both forest polygons and ground data to estimate timber volumes and reported that sampling T.M. imagery in small areas (0.25 ha) was unsuitable for specifying the relationship between T.M. data and the forest information. A classification accuracy of 78% for the forest polygon inventory was found. In addition, height and density were correlated with T.M. band 5 reflectance (DN(s) values) at  $r^2$

= 0.86 and 0.96 respectively. He found that the utility of T.M. data to predict timber volume was dependent upon the homogeneity of forest stand. He noted that contrasting background has the effect of increasing the DN(s) range in T.M. band 5 for volumes less than  $400\text{-m}^3\text{ha}^{-1}$  and thus has the potential to discriminate between stands of different volumes.

From the background review, it can be concluded that most forest attributes have been studied by many investigators. However, the biophysical bases by which the forest attributes could be estimated are not well directed. Furthermore, previous studies have not made actual ground measurements of overstory and understory properties to develop or demonstrate a method for constructing DBH and height estimation models using remotely sensed data. Therefore, the biophysical bases and quantitative correlation between crown closure, tree height, DBH, understory vegetation and overstory planted tree, and their associated remotely sensed data in the plantation are the main objectives of this study.

## MATERIALS AND METHODS

The study area is a portion of the Moncton forest area on freehold land in the eastern part of Fredericton, New Brunswick Province, Canada. The region is covered with various types of plantations including Jack Pine, White Spruce, Red Spruce and Black Spruce.

The Landsat T. M. imagery was obtained simultaneously with ground data collection in June, 1997. The study site lies within the first and second quadrant of the T.M. scene identified in the Landsat Worldwide Reference System (WRS) as path 11 rows 27. A good cloud-free imagery for the study area were chosen based on examination of the quick look Landsat 5 imagery obtained from RADARSAT International from early April to late June, 1997. The quality of the image in terms of noise, missing lines, etc. was examined through displaying the image on the

monitor. There was no noise and no line missing in the chosen image.

### Satellite Image Processing and Stratification

The Landsat T.M. image that was acquired for this study has already been atmospherically corrected. In order to geometrically correct the image and register it to the coordinates of the NB stereographic projection system (NBSPS), the following steps were performed.

To minimize the effects of systematic and nonsystematic errors, geometric correction was applied to the imagery. In order to correct the geometric distortion of the Landsat T.M. scene of June 1997, Image to Vector Ground Control Points collection (GCTV) was used. For a rough registration of the image, four initial Ground Control Points (GCPs) were selected. The Image and vector file were displayed in full resolution and 28 GCP(s) including such features as road junctions, sharp road bends, railway crossings and objects with sharp shapes such as clear-cut areas were collected.

The use of all 28 points resulted in a RMSE (Root Mean Square Error) of 0.97 pixel size. In order to obtain this result, several polynomial equations were applied. This was done through frequent deletion and/or addition of GCP(s) before running the model. Thirteen of the worst GCP(s) had to be dropped from the third order polynomial transformation to achieve a final RMSE error of 0.26 T.M. pixel sizes.

Due to a rather smooth topography in the study area the elevation effect on reflectance was neglected. Since the goal of this study was pixel-wise data collection, the nearest neighboring resampling method was applied for image registration, to preserve original DN values.

### Determining the Best Sample Plot Size

Landsat measurement units (pixels) are lar-



ger than the size of individual tree crowns, but are smaller than the size of forest stands. Therefore, characteristics of forest cover can not be estimated accurately based on stand level and/or individual tree crown data. Using this information, this study employed pixel-based (30m X 30m) data collection in homogeneous plantation stands. This plot size is the primary measurement unit of Landsat T.M. imagery. All necessary ground data were collected within this sample size.

Previous works on forest attribute estimation using remotely sensed data have been undertaken on a large area with a wide range of green vegetation (Oladi, 1997). However, some authors recommended grouping the sample plots with respect to their species structure categories and spatial boundaries provide a better determination of the relationship between forest attributes and the T.M. imagery (Gemmell 1995 and Franklin 1986). This is because forest cover polygons are often not homogeneous in terms of biophysical characteristics of the forest, which determine their associated stand reflectance. Grouping forest attributes in homogeneous classes, thus, enables us to determine a better relationship between these attributes and reflectance values (Oladi, 1997).

With all this information in perspective, this study focused on the pixel based data collection in homogeneous plantation stands. Using the aerial photographs covering this area, selected plantation stands were stratified into units of homogeneous height, crown closure, and density. Plots were identified in Jack pine plantations at 2-year intervals. It was assumed that the growth of planted trees at any given age and stand conditions are relatively similar.

### Plot Identification on the Maps

In a preliminary test inquiring into the feasibility of this research, there was the general problem of finding the area corresponding to individual pixel (Oladi, 1997). Other researchers (Jaakola *et al.*, 1998; Coppin, 1991) also noted this problem. The reason

behind this problem is that researchers typically utilize roads, river tie points (junctions) and/or other natural phenomena visible both on map and in satellite imagery to match field plots and the corresponding pixels. However, roads and other natural phenomena generally do not bound pixel matrices. Instead, imagery pixels are arranged in a matrix, which has to be registered to a coordinate system (usually UTM). The coordinate system takes no account of roads or other natural phenomena. To resolve this problem of discrepancy, the following procedure was developed: start points of plots within stands were determined in relation to road junctions. Once the start point of each plot was assigned, its direction (angle) with respect to the UTM coordinate system was determined on a 1:12 500-scale map, thereby providing compass bearings for fieldwork. This procedure enabled an accurate identification of ground sample plots to their corresponding imagery pixels.

### Ground Data Collection

To obtain as much accuracy as possible, the selected stands were verified by field surveys. Cross-sectional Approach Modeling Data Collection (i.e. data were taken from 2-year age classes intervals from 1 to 21) were used to construct crown closure, height and DBH estimation models. A total plantation area of 800 ha was chosen within the 300 km<sup>2</sup> of satellite coverage. Sampling intensity was a minimum of 10 plots for every 2-year interval. A sample plot encompassed an area of 90m X 90m which was subdivided into 9 square subplots. Each subplot measured an area of 30m X 30 m of the size of a T.M. pixel. Because a good road network existed within the plantation sites, the junctions of roads were chosen for plot establishments. A common problem in assessing plantation performance using remotely sensed data is the invasion of other vegetation along the edges of the roads, particularly light demanding species. These invading species depress (disturb) the planta-

tion and thus confound its expected reflectance. To avoid the effect of this influence, plots were chosen 60 meters from the roads depending on the extent of encroachment of the invading species and the proximity of the first pixel to the road junction. A handheld compass was used to establish the subplots, which were demarcated with strings. Trees at the corners of each subplot were marked with red ribbons and were labeled with the plot and subplot numbers. This enabled us to make random checks over the field crews so as to minimize measurement errors. In each subplot, the crown width, height, and DBH of the planted trees were measured. The sampling procedure was to measure one planted tree and skip three. In each subplot, generally, 17 trees were measured. In addition, any natural regeneration and dominant understory vegetation within a 2m radius around the trees were recorded. All the ground- sample plots were marked on the plantation map. To find the pixels which correspond with the sample plots on the map, the digital file of these maps (vector file) was overlaid on the image and then all the associated pixels of these sample plots were marked on the image. The DN(s) of them were extracted in six bands, separately.

## RESULTS AND DISCUSSION

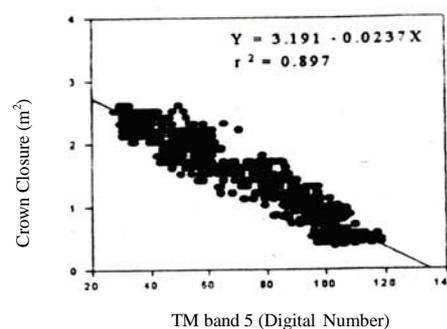
The mean crown closure for each subplot (30m X 30m) was calculated from crown widths which were derived from field survey, in plots with shrub and herb understory of more than 60%. The DN(s) in T.M. bands 1,2,3,4,5 and 7 were extracted for plantation ages of 1, 3, 5, 9, 11, 13, 15, 17, 19 and 21 years. For each age class, 90 subplots were selected (a total 900). The extracted DN(s) were plotted against their associated crown closure.

The visible region of the spectrum (0.4 to 0.7  $\mu\text{m}$ ; T.M. bands 1, 2, and 3) showed a narrower range of reflectance due to the higher absorption of the plant leaves, where the energy is required for photosynthesis, than the near and middle-infrared (T.M.

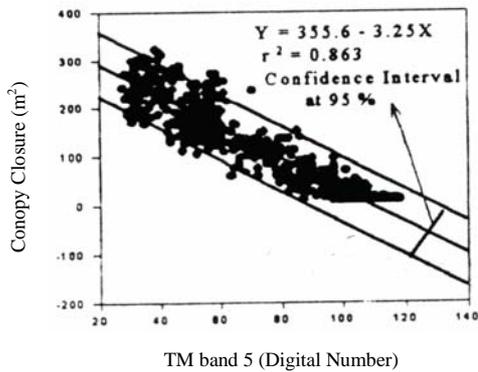
bands 4, 5, and 7). Thus, this region of the spectrum may not be suitable for estimating canopy closure, DBH and height, using contrast reflectance between the overstory and the understory shrubs and herbs. T.M. band 4 was less sensitive to background reflectance than T.M. band 5 and the latter had a greater dynamic range of DN(s). Although band 4 revealed a greater range of DN(s) than bands 1, 2 and 3, it is characterized by low absorption, high scattering radiation on intercellular walls of leaf tissue and other microscopic interface and high transmittance. As a result, healthy green vegetation generally reflects 40 to 50% of the incident near-infrared radiation energy (Oladi, 1997).

The canopy closure of each plot was calculated by multiplying the number of survived-planted trees to the crown closure projection area.

Figure 1 shows an inverse-linear relationship ( $r^2 = 0.897$ ) between DN(s) and their associated crown closure in band 5. Figures 1 and 2 represent scatter plots of the mean crown closure and canopy closure against their associated DN(s) in band 5, respectively. A comparison between Figure 1 and Figure 2 shows there is slightly lower correlation between canopy closure and DN(s) than the mean crown closure and DN(s) (0.897 and 0.863 respectively). These differences may be due to variation among the



**Figure 1.** Scatter plots and results of regressing mean crown closure on TM band 5. Each point represents the mean crown closure of a 30 m X 30 m ground plot.

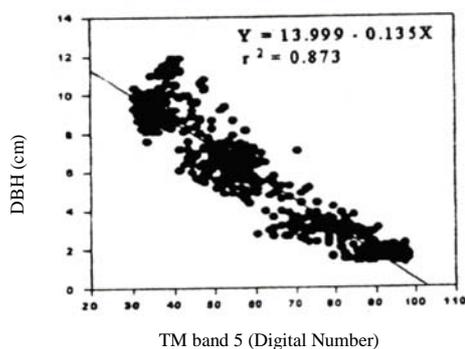


**Figure 2.** Scatter plots and result of regressing canopy closure on TM band 5 point represents the mean crown closure of a 30 m X 30 m ground plot.

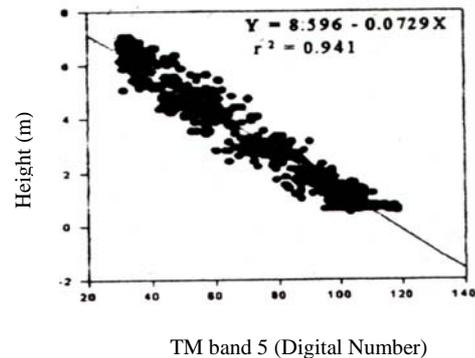
number of survived-planted trees in different plots.

Figure 3 gives the result of a linear correlation between DN(s) and mean height. There was a high inverse correlation between height and DN(s) in T.M. band 5 ( $r^2 = 0.941$ ).

Figure 4 presents an inverse correlation between DN(s) in band 5 and DBH ( $r^2 = 0.873$ ). DN(s) in T.M. band 5 have a higher correlation with the height than the DBH. This difference is consistent with the relationships between canopy closure where



**Figure 3.** Scatter plots and result of regressing height on TM band 5. Each point represents the mean height of a 30 m X 30 m ground plot.



**Figure 4.** Scatter plots and the result of regressing DBH of a 30 m X 30 m ground plot.

plotted against height and DBH ( $r^2 = 0.87$  and  $0.77$  respectively). T.M. band 7 showed a wider dynamic range of DN(s) than did bands 1, 2 or 3. There was a relatively strong inverse relationship between canopy closure and its associated DN(s) of band 7 up to 21 years of age ( $r^2=0.81$ ). Although T.M. band 7 showed a wider dynamic range of DN(s) than bands 1, 2 and 3, this dynamic range was less than in band 5.

## CONCLUSION

Previous work on the spectral reflectance contribution of understory, vegetation, versus overstory canopy closure reflectance to the recorded pixel values raised the fundamental question as to what extend for the satellite sensors are sensitive to contrast reflectance of the understory and the overstory. This study demonstrated that the T.M. imagery is a valuable data source for estimating canopy closure, height and DBH based upon the contrast reflectance between overstory canopy closure and understory.

In this initial investigation, canopy closure, height and DBH were successfully correlated with T.M. DN(s) and these attributes could, thus, be estimated from T.M. imagery. Due to the high absorption of the visible region of the spectrum (bands 1,2

and 3) by plant leaves, these bands showed a narrow range of DN(s). Therefore, these bands were unsuitable for this purpose because of their small DN(s) range. T.M. band 4 was less sensitive to background reflectance than T.M. band 5. T. M. band 5 had the greatest DN range of the T. M. bands. This band revealed a higher correlation with canopy closure, height and DBH ( $r^2 = 0.86, 0.94$  and  $87$  respectively) than T. M. band 4. T. M. band 7 showed a wider dynamic range of DN(s) than bands 1, 2 and 3, however this dynamic range was less than in band 5.

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## نوسعه یک مدل اندازه‌گیری قطر برابر سینه و ارتفاع با استفاده از داده‌های سنجش از راه دور

### ج. اولادی

#### چکیده

اکثر تحقیقات مبتنی بر داده‌های ماهواره‌ای در زمینه تعیین پارامترهای درختان جنگلی، که در سالهای اخیر به انجام رسیده‌اند، بر خصوصیات بیوفیزیکی اشکوب فوقانی پوشش گیاهی در مناطق وسیع متمرکز بوده‌اند لیکن، نسبت به نقش انعکاس اشکوب تحتانی در مقابل انعکاس اشکوب فوقانی در جنگلکاریها، در ثبت ارزش پیکسلی ماهواره‌ها، توجه چندانی اعمال نشده است. در این تحقیق بوته‌ها و علفهای کف جنگلکاریها، که انعکاس متفاوتی نسبت به پوشش اشکوب فوقانی دارند، به عنوان زمینه‌های ثابت در نظر گرفته شده‌اند. این تفاوت انعکاس متناسب با سطحی از کف جنگل است که در معرض دید سنجنده‌های ماهواره‌ها قرار میگیرند و به عنوان ارزشهای پیکسلی در آنها (Digital Number; DN) ثبت میشوند. با توجه به اینکه تاج پوشش درختان کاشته شده از یک سو با ارتفاع و قطر برابر سینه آنها در مراحل اولیه رشد و از سوی دیگر به ارزش پیکسلی ثبت شده در ماهواره‌ها بستگی دارند، انتظار می‌رود که بین ارزش پیکسلی ثبت شده در ماهواره‌ها و ارتفاع و قطر برابر سینه درختان ارتباطی وجود داشته باشد. در این تحقیق با استفاده از سنجنده TM (Thematic mapper-نقشه بردار مصنوعی) ماهواره لندست فرضیه فوق را در مورد کاج جک (Jack Pine) مورد آزمایش قرار دادیم. عرض تاج پوشش، ارتفاع و قطر برابر سینه درختان کاشته شده، در نمونه‌هایی به مساحت  $30 \times 30$  m (اندازه هر پیکسل سنجنده TM) از ۱ تا ۲۱ سال، با فاصله سنی ۲ سال، اندازه‌گیری گردیدند. تجدید حیات اشکوب تحتانی این جنگلکاریها تا شعاع دو متری اندازه‌گیری شد. بین ارزشهای پیکسلی باندهای ۴ و ۵ TM، بعنوان متغیر، و تاج پوشش، ارتفاع متوسط و قطر برابر سینه (هر نمونه با بیش از ۶۰٪ بوته و علفهای هرز در اشکوب تحتانی)، بعنوان تابع، ارتباط رگرسیونی برقرار گردید و بصورت نمودار ترسیم شد. در باند ۵، میان تاج پوشش، ارتفاع، قطر برابر سینه و DN رابطه خطی معکوسی وجود داشت که ضریب همبستگی آنها بترتیب بمقدار  $R=0.863, 941, 0.873$  بوده است.