ESTIMATING BIOMASS IN MANAGED URBAN GREENERY AREAS USING CANOPY COVER PERCENTAGES DERIVED FROM NDVI

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ABSTRACT: Biomass estimation with remote sensing methods is greatly challenged in urban areas due to highly heterogenic structure of urban vegetation and large amount of man-made objects. In this paper we present a method to estimate the amount of biomass in large metropolitan areas using land use polygon based canopy cover percentages derived from a 10 m resolution SPOT 5 HRG image. The study area covered all managed greenery areas (i.e. park, recreational and commercial/institutional land use) in Singapore encompassing over 42 000 ha. In addition to the SPOT data, seven 0.5 m resolution GeoEye images and 26 field sample plots were used. The results showed a strong correlation (r = 0.83) between canopy cover percentages derived from the very high resolution satellite imagery using manual delineation and the percentages of areas in the SPOT image with NDVI values above 0.57 after grass areas had been masked out of the NDVI map. Subsequently, a correlation of r = 0.61 was found between canopy cover percentages and biomass in the sample plots. Thereby, a biomass estimation procedure for managed urban greenery environment was developed based on canopy cover percentages within land use polygons. The method not only allows estimation of the current biomass in urban greenery areas but also enables monitoring of biomass changes. With this method, the total biomass in urban greenery areas of Singapore (excluding road side trees, undeveloped and nature reserve areas in the island) was estimated to be around 1.7 Mt, equalling to 40 t/ha or about a third of a typical biomass of young secondary forests. These figures reveal the high amount of biomass found urban areas of Singapore and illustrate the potential of biomass accumulation in urbanised environment.

1. INTRODUCTION

With the proportion of the world's population living in urban areas projected to reach 70% by 2050 (United Nations 2008) and urbanised land use rapidly expanding, the study and quantification of urban ecosystem services has started to receive increasing attention in recent years (van Delm and Gulinck 2009). An urban ecosystem service that has particularly received much attention is the carbon storage potential of biomass in urban green spaces since carbon capture and storage is identified as an important component of climate change mitigation policies. Recent studies have suggested that even though carbon storage in urban areas is small compared to the emissions they produce per unit area, nonetheless, the size of urban carbon storage appears to be substantial. Indeed, studies indicated that residential zones in urban areas may have even greater carbon storage than agriculture land due to higher productivity in urban vegetation (Nowak and Crane 2002, Davies et al. in press).

The most common method for estimating urban biomass is based on field data collection of vegetation parameters (species, girth width, height etc.) in different land cover/land use type by random sampling and deriving biomass from allometric equations. Such methods however suffer from being extremely labour expensive and time consuming. Remote sensing methods that are used for biomass estimation in forests are unsuitable in an urban environment as satellite data that are commonly used for such purposes such as those acquire from Satellite pour l'Observation de la Terre (SPOT) and Landsat lack the necessary spatial detail to effectively detect urban greenery which are characterised by extreme heterogeneity and fragmentation. The new generation of very high resolution (VHR) satellites (such as GeoEye and Worldview) are capable of producing satellite imageries that rivals the spatial detail provided by aerial images and are able to detect the highly heterogenic and fine structure of urban vegetation. Indeed such data have already been exploited for quantitative and qualitative analysis of urban green (Nichol and Lee 2005). However VHR data do not provide the spatial coverage of satellites such as SPOT 5 and is cost prohibitive for city scale mapping.

In this study we investigate the potential of using cheaper and more readily available high resolution satellite data from SPOT 5 to estimate vegetation biomass in an urban environment. With the help of 26 field sample plots and seven GeoEye images we develop a NDVI based model to estimate tree cover percentage and subsequently biomass in managed urban areas using only SPOT 5 HRG (High Resolution Geometric) sensor images.

2. MATERIALS AND METHODS

2.1. Study Area and Field Sampling Method

The study area for the research covered all managed greenery areas in Singapore encompassing some 42 000 ha in total. 26 sampling plots (20 m radius circular plot) which typify the various types of managed greenery found in urban Singapore were selected across the island for field biomass measurements. These greenery types vary from fields with short grass cover, public parks and gardens with dense tree planting to residential areas with sparser planting of vegetation. Within each plot, the girth and species for all trees above 5 cm dbh were recorded and their biomass calculated using a biomass allometric equation developed by Chave et al. (2005):

$$AGB = \rho \times \exp(-1.499 + 2.148 \ln(D) + 0.207 (\ln(D))^2 - 0.0281 (\ln(D))^3) \quad (1)$$

Where ρ is the wood density (oven dry mass divided by green volume) (g/cm^3) of the tree species and D is the DBH (cm) of the tree. Wood density values were obtained from the Global Wood Density Database collated by Zanne et al. (2009), the largest wood density database to date.

2.2 Preprocessing of the SPOT 5 Data

Two multispectral optical images from SPOT 5 acquired on 14 April 2010 and 20 May 2010 were used in this study. The SPOT 5 imagery have a spatial resolution of 10 m and comprises of four wavelength bands; green (Band 1; 0.50 – 0.59 µm), red (Band 2; 0.61 – 0.68 µm), near infra-red (Band 3; 0.79 – 0.89 µm) and shortwave infra-red (Band 4; 1.58 – 1.75 µm). The raw digital numbers (DN) from both images were first converted to top of the atmosphere (TOA) and then corrected for Rayleigh scattering and molecular absorption using routines in the 6S package (Vermote et al. 1997), assuming a standard tropical atmosphere with considerations of the spectral response of each spectral band of the sensor. The images were than merged and resampled using the nearest neighbour method to form a single cloud-free image over the study area. NDVI was calculated as:

$$\text{NDVI} = (\text{Band 3} - \text{Band 2} / \text{Band 3} + \text{Band 2}) \quad (2)$$

2.3 Derivation of Biomass Estimation Model

A huge component of biomass in urban greenery is found in trees compared to herbaceous vegetation. As larger tree canopy area is usually associated with taller trees and larger trunk diameter size, the total area of tree canopy in an urban environment may be related to its biomass. Medium resolution satellites such as SPOT 5 with a spatial resolution of 10 m are unable to effectively extract tree canopy cover data as frequently many features are contained within each pixel in the satellite imagery, resulting in the so called “mixed pixel” problem. GeoEye imagery on the other hand, with their sub-metre resolution does not face such problems and is ideally suited for measuring the tree canopy area of urban greenery environment using manual delineation.

The tree canopy cover for 26 sampling plots were delineated manually on seven VHR GeoEye images using digitising tools in a GIS software package. After which, total tree canopy cover were measured as percentage area within each plot. The strength of the linear relationship between tree canopy area and field measured biomass were tested using the Pearson’s correlation coefficient. In addition, by using biomass as a dependent variable and tree canopy area as the independent variable, an empirical relationship between the two variables was also established using a linear regression model.

However, the manual delineation of canopy cover is an extremely time consuming and laborious process. VHR imagery are also comparatively expensive compared to medium resolution satellite imageries and as many such images are likely to be needed to sufficiently cover a whole city, the cost of purchasing the data may be too cost prohibitive. While it is difficult to extract tree canopy cover data from SPOT 5 imageries directly, the Normalized Difference Vegetation Index (NDVI), a commonly used vegetation index for quantifying vegetation cover was tested as a proxy indicator for tree canopy cover. An analysis was conducted to investigate the range of values for which NDVI best relates to tree canopy cover by comparing them to the tree canopy percentage area that are measured from GeoEye imageries for 21 polygons (selected by random sampling) as defined by a land use GIS dataset. In order to ensure that only NDVI values that reflect tree canopy cover were compared to the manually delineated tree cover area, grass areas as defined by a simple classification procedure were masked out.

3. RESULTS AND DISCUSSION

2.2 Correlation between Tree Canopy Area and Biomass

Our analysis started with the evaluation of correlation between tree canopy cover and biomass in the 26 sample plots. A Pearson correlation coefficient of 0.61 was achieved between tree canopy area and field biomass which indicates a reasonable linear relationship between the two parameters in managed urban areas of Singapore. Figure 1 presents the scatter plot for the relationship and Equation 3 gives the relationship expressed in a linear regression model.

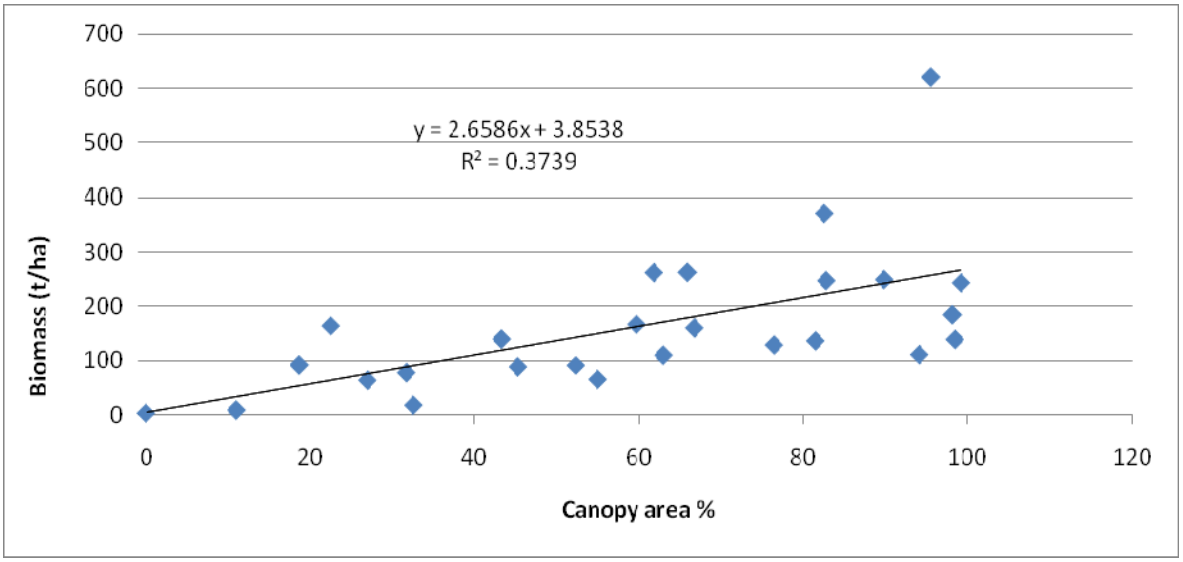

Figure 1. Correlation between biomass and tree canopy cover percentage in field sample plots.

$$\text{Biomass (t/ha)} = 3.854 + 2.6586 * (\text{Canopy cover \%}) \quad (3)$$

This indicates that with the above model it is possible to estimate biomass for managed urban greenery areas provided the canopy percentage of the area is known.

2.3 Derivation of Canopy Cover from SPOT 5 Imagery

The above analysis revealed that it is possible to derive reasonably reliable biomass estimates for urban greenery areas if the tree canopy cover percentage of the area in question is known. Subsequently we tested the correlation between canopy cover percentages and a range of NDVI values in the 21 test polygons. The results revealed that the percentage of areas having NDVI values of 0.57 and above within the 21 test polygons best correlates to the measured canopy cover percentages in the same polygons. An r value of 0.83 was achieved indicating a very strong linear relationship. The relationship is presented by a scatter plot in Figure 2.

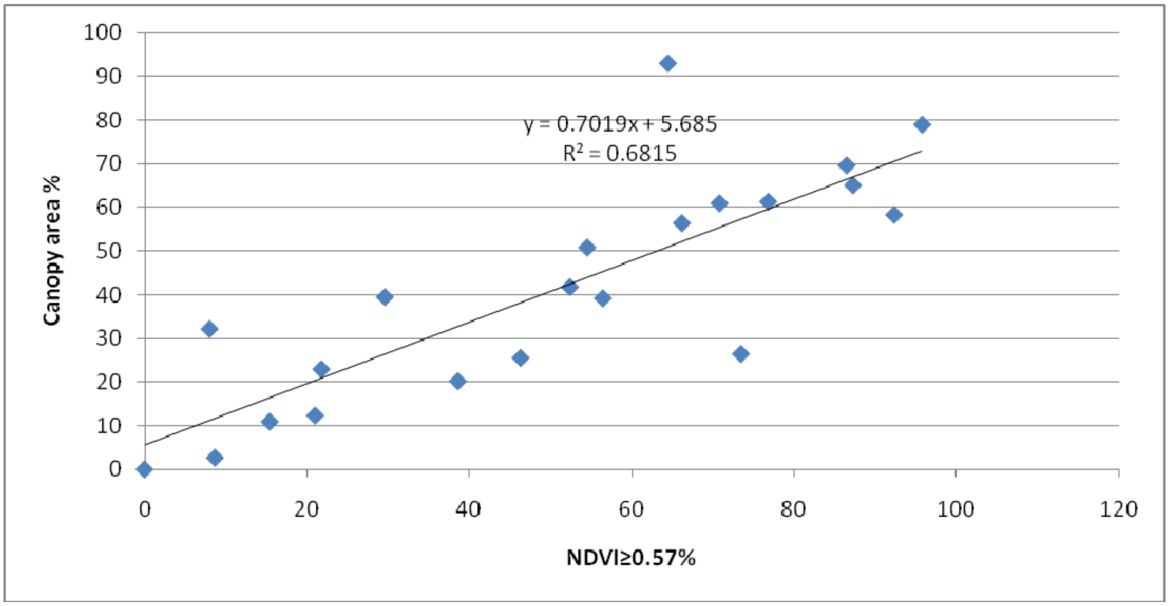

Figure 2. Correlation between canopy cover percentage and percentage of area with NDVI values above 0.57 within the 21 test polygons.

It is thus possible to estimate the percentage canopy area (within each land use polygon) in a managed greenery environment (e.g. parks, recreational, commercial/institutional land use etc.) from NDVI values derived from SPOT 5 imagery using the following regression model with high accuracy (Equation 4):

$$\text{Canopy cover \%} = 5.685 + 0.7019 * ((\text{NDVI} \geq 0.57)\%) \tag{4}$$

It is important to remember, however, that grassland areas need to have been masked out before calculating the percentage of areas having NDVI values larger than 0.57 within the interest polygons. These percentage values can then be used as an input for the biomass estimation model presented above to derive biomass estimates for interest polygons within urban greenery environment.

3. CONCLUSION

In this study we have described a simple approach to estimate biomass in urban greenery areas using SPOT 5 data and empirical models derived using information from field data and very high resolution imagery. Although these models that only need the SPOT 5 data to be executed were developed in Singapore, we believe that similar approach could be usable in managed greenery areas of other major urban centres as well.

Using the method developed in this study we estimated that the biomass of managed urban greenery areas in Singapore totals in 1.7 Mt or an average of 40 t/ha (excluding road side trees, undeveloped and nature reserve areas). This amount represents about 37% of all vegetation biomass in Singapore (unpublished data, CRISP). On a per hectare basis, the results of this study suggest that Singapore's built environment has about a third of the typical biomass of young secondary forests. Urbanisation is expected to continue at a fervent pace globally but as this study revealed, urban land use can contain significant amount of biomass. The method illustrated in this study would not only enable biomass estimation in an urban environment, but it would also allow for inexpensive and effective monitoring of biomass changes. This would allow policy makers and local authorities to better manage urban vegetation carbon stores and develop strategies and policies to increase the carbon content in urban areas and thereby offset a little the high carbon emissions from urban areas.

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