Article

Ecological structure of a tropical urban forest in Bang Kachao peninsula, Bangkok

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Abstract: Rapid urbanization has changed the structure and function of natural ecosystems, especially the floodplain ecosystems in SE Asia. This paper describes the ecological structure of vegetation stands and the usefulness of satellite images to characterize a disturbed tropical urban forest located in the lower floodplain of the Chao Phraya River, Thailand. Nine representative plots were established in Bang Kachao peninsula in 4 tropical urban forest types: rehabilitation forest, home-garden agroforestry, mangrove and park. The correlation between NDVI and LAI obtained from satellite images and plant structure from field surveys were analyzed. The NDVI had the highest relationship with stand factors for the number of families, number of species, Shannon-Weiner's diversity index and total basal area. The LAI had the highest correlation with total basal area, number of canopy layers, stand density and canopy density. Linear regression predicted the correlation between NDVI and LAI with stand factors as show above. The trend in NDVI and LAI reflected the urban forest type, being high in rehabilitation and mangrove forests, moderate in home-gardens and low in parks. Future urban planning of the Bang Kachao peninsula should focus on rehabilitation to increase the biodiversity and complexity of the urban forest.

Keywords: LAI; NVDI; stand structure; urban forest; Thailand

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1. Introduction

Urban green space provides multiple benefits and these can be categorized as ecological, social and economic in attribute. Rapid urbanization has a significant negative impact on urban green spaces and the ecosystem services they provide [1]. One important aspect of a city's functioning lies with its urban forest. The structure of urban green space is an important variable that influences urban ecosystem function and affects urban inhabitants. Characterizing the structure of the urban forest requires knowledge of tree density, tree size, tree location and spatial arrangement of forest in urban areas. The management of composition and structure of urban forests are the keys to successfully improving urban green infrastructure and human well-being. Information from tree inventories regarding species performance and native habitat can suggest general guidelines for appropriate species selection and management practices [2]. Unlike in more temperate parts of the

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Peer-reviewed version available at Forests 2018, 9, 36; doi:10.3390/f9010036

world, there is a lack of urban forest research in tropical, less urbanized, and less economically developed regions such as in parts of SE Asia [1, 3].

Bang Kachao peninsula is a large (ca. 1,891 ha) urban green space, located in the lowland of the Chao Phraya watershed in central Thailand, between Bangkok and Samut Prakan provinces. The Chao Phraya river basin is the largest watershed area in Thailand and is an important tropical floodplain area for conservation of freshwater swamp and tropical moist broadleaf forests in the Indo-Malay Ecoregion. An important period in the history of Bang Kachao was between the years 1982 to 1987 when H.M. King Bhumibol Adulyadej viewed the oasis from an airplane and recommended that the green area should be saved as Bangkok's green lung, protecting the citizens of Bangkok from industrial pollution generated to the south in Samut Prakan province. Pressures of urbanization and industrialization from Bangkok Metropolitan and Samut Prakan provinces have affected and changed some of the land use in Bang Kachao peninsular from green space as home-gardens and swamps to urban use such as residential, official and industrial areas [4]. For several reasons, it would be a tragedy for Bangkok and the entire metropolitan region if this "green lung" were to be sacrificed for more concrete and asphalt. The area not only offers a welcome, nearby retreat for nature-minded weekenders, but also plays an important role in the city's eco- and climate control systems, and could be instrumental to the city government's climate change mitigation and adaptation strategies. This means that both the pressure and the stakes are high. To enhance the functional green space, the Royal Forest Department has been undertaking restoration using enrichment planting on ca. 10% of the peninsula.

Whilst there has been some research on plant species [5] and biodiversity [6] in Bang Kachao, the database and in-depth information on the structure and function of green space is still limited. This constrains the future intensive management of urban green space in the Bang Kachao peninsula. Using representative vegetation plots, the main objective of this research is to determine the usefulness of satellite images to characterize the tropical urban forest. The results will be used to guide the future research and use of remote sensing approaches for urban forest restoration and management in Thailand.

2. Materials and Methods

The study was undertaken in Bang Kachao peninsula, Phra Pradaeng District, Samut Prakan province, Thailand between 13°39'16 "to 13°42'5 "N and 100°32'36 "to 100°35'28 "E. The peninsula is composed of 6 sub-districts: Song Khanong, Bang Krasop, Bang Ko Bua, Bang Kachao, Bang Nam Phueng and Bang Yo. The total area is about 1,891 ha of which around 10 percent is being rehabilitated and managed for conservation by the Royal Forest Department (RFD). The topography is a sediment flood plain, approximately 1 m above mean sea level, surrounded by 15 km length of the Chao Phraya river that flows south into the Gulf of Thailand (Figure 1). The peninsula contains 14 canals which are connected to each other and lead out to the Chao Phraya river. The connection with the ocean creates a unique brackish water wetland in which a total of 675 flora and fauna species occur in swamp forest, mangrove forest and agricultural land classified as home garden [4, 6]. The inter-annual variation in climate is influenced by the tropical monsoon system where average daily high temperature remains relatively constant over the year, fluctuating within a range of 31-35 °C. Like many tropical cities in the latitudinal belt between 15 and 25 °C, Bang Kachao peninsula has a 6-month monsoonal wet season from May through October that ameliorates the heat. November-April is the dry season with the cooler months being November-January. Based on a 7-year (2008-2014) climate data from the nearby Bangna weather station of the Thai Meteorological Department, the average annual rainfall is 1,365 mm over 120 wet days, with the heaviest rainfall generally in

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September as a result of low pressure systems and typhoons in the South China Sea . The annual mean, maximum, and minimum air temperatures are 28.8, 32.7, and 24.1 °C, respectively [4].

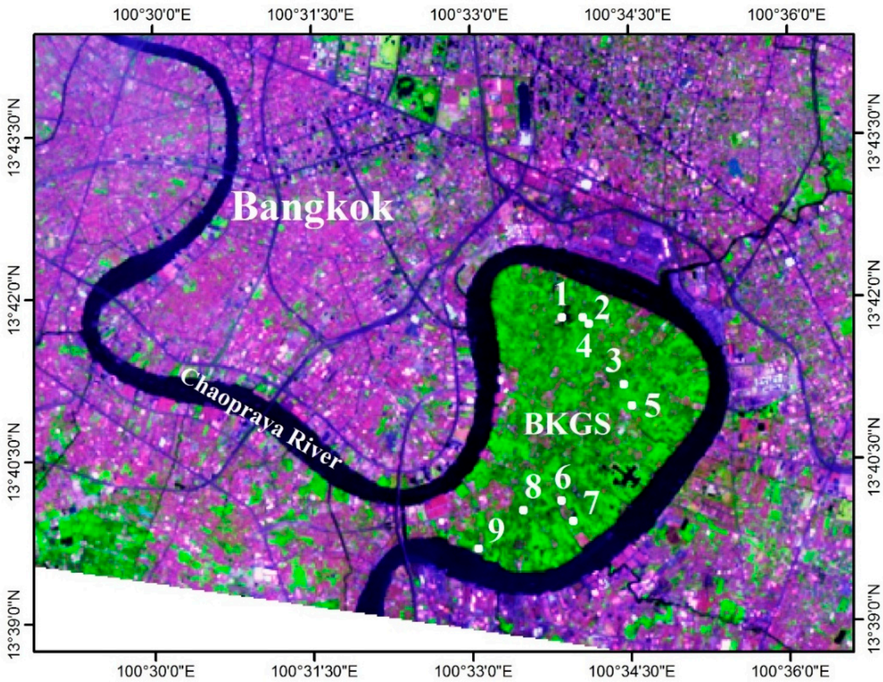

Figure 1. Satellite LANDSAT 7 false color image of Bangkok and Chaopraya River showing location of the Bang Kachao Green Space (BKGS), 25 April 2012.

Landsat 7 ETM+ three-band RGB imagery at 30 m² pixel resolution was acquired for 25 April 2012 and aerial photography with a scale of 1:4,000 were used to identify urban forest types as rehabilitation forest, mangrove forest, home garden and parks. The urban forest in Bang Kachao peninsular comprised 919 ha or 59.7%, home-garden agroforestry 459 ha or 29.8%, and mangrove forest 39 ha or 2.5% as a strip along the canals and bordering the Chao Phraya River. The two parks, Sri Nakhon Khuean Khan Park and Botanical Garden in Bang Kachao sub-district, and Chalerm Phra Kiat the King Bhumibhol 80 Phansa Park in Song Khanong sub-district comprised 1.9% of the total area (29.5 ha). The rehabilitation forest was distributed in the conservation area managing by the RFD.

Satellite metadata were used to analyze NDVI (Normalized Difference Vegetation Index) and LAI (Leaf Area Index). The NDVI is one of the most commonly used vegetation indices from remote sensing images for calculating biomass, because the chlorophyll of vegetation tends to have high absorption in the Red band and relatively high reflectance in the Near Infrared band (NIR) (https://earthexplorer.usgs.gov). We used the Landsat 7 ETM+ satellite image data to analyze NDVI (Figure 2) by equation (1). The NDVI for each plot was determined by summing the number of pixels.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

Based on NDVI, the fractional vegetation cover (FVC_{NDVI} in Equation 2) as used by [7-8] was derived with equation (2):

$$FVC_{NDVI} = \frac{NDVI - NDVI_s}{NDVI_v - NDVI_s} \quad (2)$$

where, $NDVI_s$ represents the NDVI values for bare soil while $NDVI_v$ characterizes the NDVI values at full vegetation cover in respective images. The FVC was calculated to avoid mixed signals in satellite data. For this determination, NDVI was scaled between lowest $NDVI_s$ (bare soil) and highest $NDVI_v$ (dense vegetation) to calculate fractional vegetation cover (Equation 2). For this model, $NDVI_s$ and $NDVI_v$ were selected through histogram evaluation. Subsequently, LAI was calculated through a given logarithmic relation (Equation 3) between respective FVC_{NDVI} and LAI:

$$LAI_{NDVI} = \frac{-\log(1 - FVC_{NDVI})}{k(\theta)} \tag{3}$$

where, $k(\theta)$ is the light extinction coefficient for a specified solar zenith angle. The solar zenith angle (θ) depends on terrain geometry, solar declination, solar elevation angle, latitudinal location and day of the year [9]. The light extinction coefficient is a measure of attenuation of radiation in the canopy.

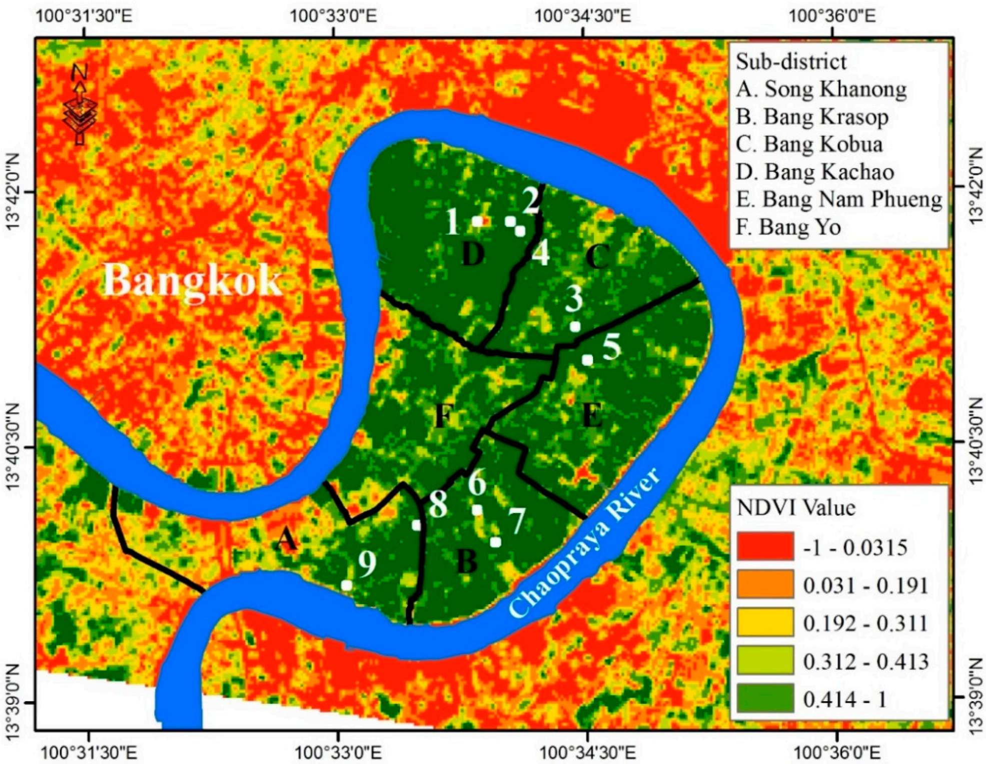

Figure 2. NDVI classification image. Boundaries of the 6 sub-districts are shown. The numbers are the locations of the 9 research plots.

Nine 50 x 50 m plots were randomly established in Bang Kachao Green Space (Figure 2) in February 2012 as follows: 4 plots in rehabilitation forest, 1 plot in mangrove forest, 2 plots in home-gardens and 2 plots in parks (Figure 2). The four plots of rehabilitation forest were plot 1, 2, 3 and 6. The positions of each plot were obtained by using a global positioning system device (GPS Garmin Oregon 550, Olathe, Kansas, USA).

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A census of all living trees with diameter at breast height (DBH) >4.5 cm was conducted. Tree height was measured with a VERTEX Laser VL400, DBH was measured with a diameter tape, canopy diameter was measured with a tape in 2 directions (N-S and E-W axes) for each tree and the number of canopy layers was recorded using profile diagrams [10]. All trees were identified to species by collecting leaf specimens for comparison with standard specimens in the herbarium at the Department of National Parks, Wildlife and Plant Conservation. The nomenclature followed of the Flora of Thailand [11]. Collected data were used to calculate stand structural characteristics of the representative Bang Kachao Green Space.

The following were calculated for each plot:

- For stem density (SD), the number of trees (N) per unit are (N/ha) was counted;
- The basal area (BA) as (m^2/ha), defined as the ratio of the cross-section area of all trees in the sampling plot to the plot ground area; and
- Canopy Cover (CC), define as a typically, the value used in diameter crown width modeling efforts has been the arithmetic mean of two (or occasionally more) crown width measurements[12-13]. This value has no mathematically intrinsic relationship, however, to crowns that are not round. If the true shape of a crown with differing width measurements is assumed to be an ellipse, Canopy Cover (CC) is calculated using the equation (4).

$$\mathrm{CC}\ (\mathrm{m}^2) = A = \pi(X)(\mathrm{Y}) \quad (4)$$

where, CC is projected crown area, X and Y are the major and minor radii of the ellipse.

- Canopy density (CD): the CD refers to the proportion of an area in the field/ground that is covered by the crown of trees and is expressed in percentage of the total area. This research calculated CD from a profile diagram of each 50 x50 m plot using QGIS software to reference scale with Cartesian coordinates.
- Importance value index (IVI) for each plant species in the plot was calculated by summing up the relative percentages of basal area, density, and frequency [14].
- Shannon-Wiener index (H’) was calculated as a measure of tree species diversity in each forest community [15].

Matrix correlation was used to analyze the correlation between plant factors from satellite data (NDVI and LAI) and plant factors obtained from ground survey for the nine plots. Where the correlation was significant, linear regression analysis of the relation between the dependent variable Y and the explanatory variables Xi was used as in equation (5):

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + e \quad (5)$$

where, β_0 is the intercept, β the regression coefficient of the ith independent variable, n the total number of independent variables, and e a random error term that represents the unexplained variation in the dependant variable. The coefficients are typically estimated with the least squares approach, in which the error term e is minimized.

3. Results

3.1. Urban forest structure and biodiversity

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The ecological structure and biodiversity of the tropical urban forests in Bang Kachao peninsula differed across the 9 plots (Figure 3). The rehabilitation forest contained trees (includes palms and *Musa* spp) from 10-17 families and 15-25 species. The rehabilitation forest had 5 habitats: moist

Figure 3. Appearance of vegetation from the ground of study plots in Bang Kachao Green Space. Plot descriptors are given in Table 1. Plots 1 (a), 2 (b), 3 (c) and 6 (f) were rehabilitation forest, plots 4 (d) and 8 (h) were home-garden agroforestry, plot 5 (e) was mangrove forest, plot 7 (g) was in Chalerm Phra Kiat the King Bhumibhol 80 Phansa Park and plot 9 (i) was in Sri Nakhon Khuean Khan Park and Botanical Garden.

evergreen forest (*Caryota bacsonensis*), dry evergreen forest (*Cassia siamea*), beach forest (*Cerbera odollam*, *Hibiscus tiliaceus*, *Terminalia catappa*), freshwater swamp forest (*Streblus asper*), and abandoned orchard (*Cocos nucifera*, *Pithecellobium dulce*). The home-garden agroforestry plots had 8-15 families and 11-17 species. The representative plots of home-garden agroforestry in Bang Kachao peninsula showed that the traditional farmers planted mixed species on mounds separated by water-filled channels. Planting of commercial fruit species (*Areca catechu*, *Artocarpus heterophyllus*, *Cocos nucifera*, *Mangifera indica*, and *Musa* spp.) and native tree species (*Cerbera odollam*, *Streblus asper*, and *Terminalia catappa*) resulted in multiple canopy layers. The mangrove plot 5 comprised 11 families and 15 species. The park plots had the lowest biodiversity with 2-8 families and 2-13 species. Most of tree species in the park plots were native tree species (*Antidesma ghaesembilla*, *Cerbera odollam*, *Peltophorum dasyrachis* and *Terminalia catappa*). Shannon-Weiner's H index was used to compare the

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relative abundance and evenness of the biodiversity across the plots (Table 1). The index was very low (0.43) for plot 9 reflecting the dominance of one species, the coconut palm. Indices for all the other plots lay in the range 1.39 to 2.58. Plot 6 had the highest H index.

Table 1. Stand characteristics for Bang Kachao Green Space study plots.

Green space type/	Rehabilitation forest				Home-garden		Mangrove	Park	
Plot number	1	2	3	6	4	8	5	7	9
Number of families	10	15	13	17	15	8	11	8	2
Number of species	15	23	19	25	17	11	15	13	2
Plot density (trees/ha)	1,268	988	716	892	820	980	840	360	104
Average DBH (cm)	12.9	13.3	13.2	9.7	11.8	9.6	12.9	8.2	24.7
Average height (m)	8.4	8.2	8.5	6.7	5.1	6.6	7.6	5	7.5
Total basal area (m^2/ha)	22.8	18.6	14.6	10.1	12.5	9.6	13.2	2.3	5.2
Canopy density (%)	91.8	67.2	82.4	38.2	57.5	69	91.8	19.6	25
Number of canopy layers	4	3	3	2	3	3	3	2	1
Mean crown cover area (m^2/tree)	24.3	19.3	24.9	15.1	11.4	13.6	30.4	9.9	22.6
Shannon-Wiener's H	1.78	2.39	2.12	2.59	1.57	1.39	1.88	1.86	0.43

Stand density, DBH, total stem basal area and canopy density varied with urban forest types and plots. Stand density ranged from 104 to 1,268 trees/ha with an average for the nine plots of 774 trees/ha. Plot density was high in the rehabilitation forest (716-1,268 trees/ha), medium in the home-garden and mangrove forest (820-980 trees/ha) and low in the park (104-360 trees/ha) (Table 1). The DBH ranged from a mean/plot of 8.2 to 24.7 cm. However, more than 50% of trees had diameters <10 cm (data not shown). Trees with diameters >40 cm in diameter were mostly *Antidesma ghaesembilla*, *Cocos nucifera*, *Erythrina fusca*, *Peltophorum dasyrachis* and *Sonneratia caseolaris*. The total stem basal area ranged from 22.8 m^2/ha in plot 1 to 2.3 m^2/ha in plot 7. The stem basal area ranged from 10.1 to 22.8 m^2/ha in the rehabilitation forest, was 13.2 m^2/ha in the mangrove forest plot, 12.5 and 9.6 m^2/ ha in the home-garden agroforestry plots and only 2.3 and 5.2 m^2/ha in the park plots. The canopy density of crown cover varied across plots and urban forest types. The value of canopy density for the rehabilitation and mangrove forest plots ranged from 38.2 to 91.8% with the highest canopy densities in plots 1 and 5. The home-garden agroforestry plots had intermediate canopy density and the lowest density was in the park plots (Table 1). Also, the canopy layers varied with urban forest types and plots, ranging from 1 to 4 canopy layers. There were multiple canopy layers in the rehabilitation and mangrove forest and the least number of layers in park plots.

Over 80% of trees were less than 10 m in height. Trees >15 m in height were mostly *Cassia siamea*, *Cocos nucifera*, *Ficus* spp., *Sonnerratia caseolaris*, *Streblus asper* and *Terminalia catappa*. The tallest trees were *Sonneratia caseolaris* and *Ficus* sp. with 25.0 and 22.5 m in maximum height, respectively.

The IVI of the top-five species in each plot suggested the dominant species as show in Table 2. The dominant species of rehabilitation forest plot 1 were *Cocos nucifera*, *Streblus asper* and *Cassia siamea*; for plot 2 *Cocos nucifera*, *Cerbera odollam* and *Hibiscus tiliaceus*; for plot 3 *Cerbera odollam*, *Streblus asper* and *Erythrina fusca*; and for plot 6 *Cocos nucifera*, *Cerbera odollam* and *Pterocarpus indicus*. In the mangrove forest (plot 5), the dominant species were *Cerbera odollam*, *Sonneratia caseolaris* and *Hibiscus tiliaceus*. The dominant species of the home-garden agroforestry plot 4 were *Musa spp.*, *Cocos nucifera*

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and *Mangifera indica*; and for plot 8 *Streblus asper*, *Terminalia catappa* and *Cocos nucifera*. In parks, the dominant species in plot 7 were *Antidesma ghaesembilla*, *Cerbera odollam* and *Senna siamea*; and in plot 9 *Cocos nucifera* and *Peltophorum dasyrachis*.

Table 2. Importance value index for top-five main species in each plot.

Green space type/	Rehabilitation forest				Home-garden		Mangrove	Park	
Plot number	**1**	**2**	**3**	**6**	**4**	**8**	**5**	**7**	**9**
Antidesma ghaesembilla								112.6	
Areca catechu						23.5			
Artocarpus heterophyllus					11.3				
Caryota bacsonensis	21.8			23.6					
Cassia siamea	57.9								
Cerbera odollam		59.6	73.2	48.8	13.1		80.8	42.5	
Cocos nucifera	103.9	73.0	24.7	59.7	101.3	24.9			220.9
Erythrina fusca	16.0		43.4						
Hibiscus tiliaceus		30.8					37.9		
Leucaena leucocephala		21.1		20.7		22.7			
Mangifera indica					35.6				
Musa spp.					108.2				
Nypa fruticans							35.3		
Peltophorum dasyrachis									79.1
Pithecellobium dulce			24.1						
Pterocarpus indicus				27.1				39.6	
Senna siamea								40.4	
Sonneratia caseolaris							65.6		
Streblus asper	64.7		43.8			144.8			
Terminalia catappa		28.6				39.5	28.5	15.0	

3.2. NDVI and LAI

The NDVI in the rehabilitation forest (plots 1, 2, 3 and 6) ranged from 0.432 to 0.481 and the mangrove plot was 0.436 (Table 3). However, the NDVI of the home-garden plots were different from each other, being 0.170 and 0.422. The lowest NDVI occurred in the park plots. Similarly, the LAI was highest in the rehabilitation and mangrove plots but also in home-garden plot 4. The LAI of the park plots and home-garden plot 8 were lower (Table 3).

Table 3. NDVI and LAI values for Bang Kachao Green Space study plots.

Green space type/	Rehabilitation forest				Home-garden		Mangrove	Park	
Plot number	**1**	**2**	**3**	**6**	**4**	**8**	**5**	**7**	**9**
NDVI	0.481	0.471	0.466	0.432	0.422	0.170	0.436	0.228	0.156
LAI	4.933	3.641	3.692	3.421	3.597	2.369	3.717	2.583	2.155

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3.3. Relationship between NDVI and stand structure

The NDVI was high correlated with the number of families, number of species, Shannon-Weiner's diversity index and total basal area ($p<0.05$). However, NDVI was not correlated with stand density, DBH, height, canopy density, mean crown cover area per tree, and number of canopy layers. Linear regression was used to analyze all significant relationships between NDVI and stand factors. The measured stand structural factors were used as the dependent variable, and the NDVI factor from the remote sensing was used as the independent variable (Figure 4). The best linear equation between NDVI and plant factors was the number of families (R^2 = 0.634) and total basal area (R^2 = 0.623).

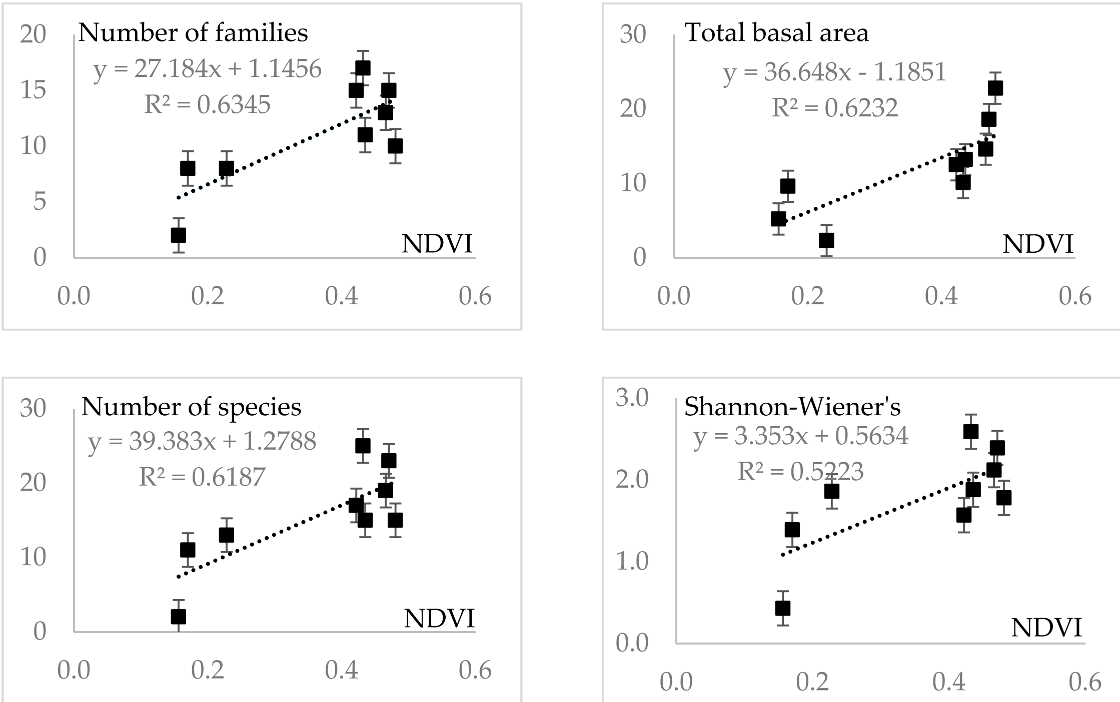
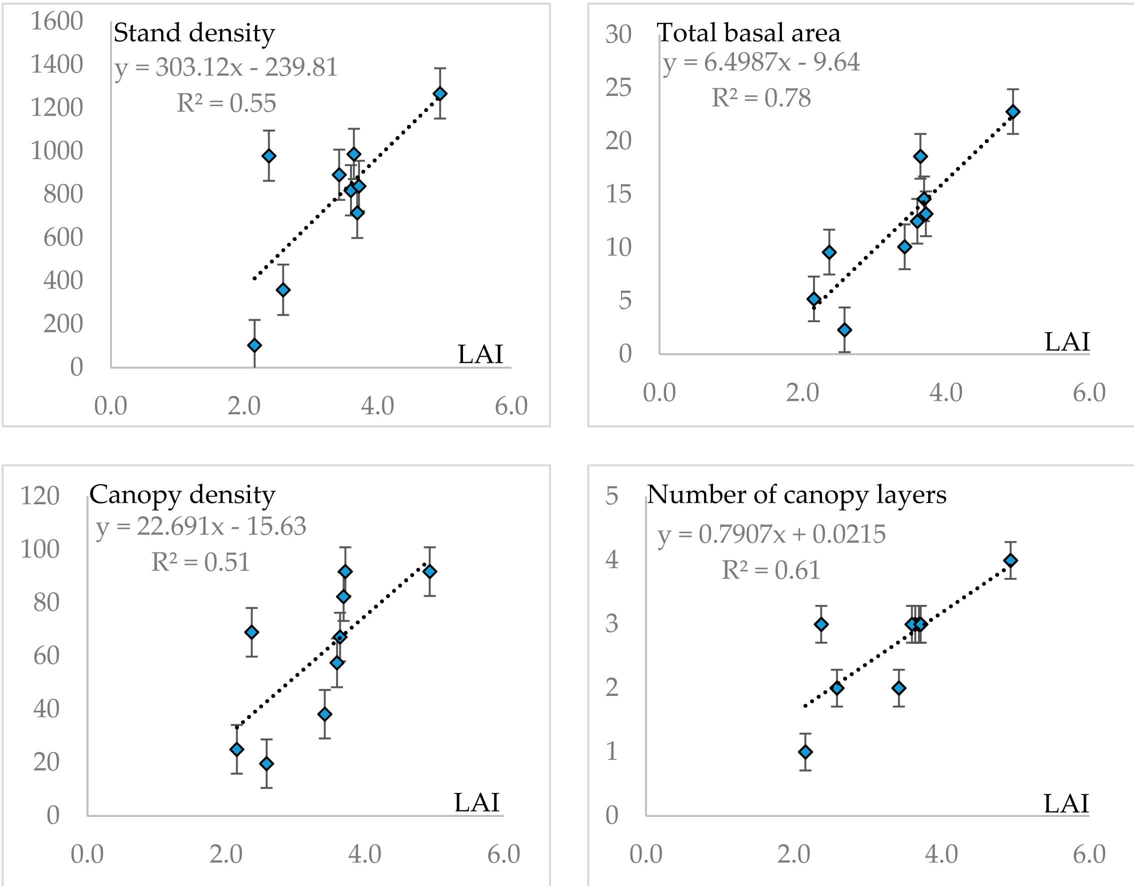


Figure 4. Linear regression between NDVI and number of families, number of species, total basal area and Shannon-Wiener's index.

3.4. Relationship between LAI and stand structure

The LAI was highly correlated with total basal area ($p<0.01$), followed by stand density, canopy density and number of canopy layers ($p<0.05$) (Figure 5). The best equation between LAI and plant factors was total basal area (R^2 = 0.78), followed by the number of canopy layers (R^2 = 0.61), stand density (R^2 = 0.55) and canopy density (R^2 = 0.51).



244 **Figure 5.** Linear regression between LAI and stand density, total basal area, canopy density and number
245 of canopy layers.

246 **4. Discussion**

247 The Bang Kachao peninsula contains a range of tropical urban forest types in an urban oasis
248 strongly affected by land use from local residents as well as by reforestation efforts in recent decades.
249 Regarding biodiversity, the research looked only at trees but included the coconut palm because of
250 its prominence and stature in the area. Overall, 52 tree species in 17 families were assessed across the
251 9 plots and the number of species ranged from 2 to 26 per plot. Tree biodiversity varied with NDVI,
252 with the most biodiversity in the rehabilitation and mangrove forest plots with high NDVI.
253 Biodiversity was moderate in the home-garden agroforestry plots and low in the park plots.

254 Comparison of the diversity of trees between Bang Kachao Green Space in this research with
255 Bangkok, using [16], found that Bang Kachao (52 species) had more tree species than Bangkok (48
256 species). However, the number of tree species measured in the nine stands in this research was lower
257 than the 179 tree species reported previously [5] in Bang Kachao Green Space. Therefore, over half
258 the diversity of trees was not represented in the nine sites that were studied, indicating the need for
259 further investigation on microclimate and forest composition. [17] inventoried tree species in
260 Bangkok at Kasetsart University, in suburban community areas in Phatum Thani province and in
261 agricultural areas in Nakhon Phathom province located in the lower central plain of the Chao Phraya
262 River. They recorded 395 species of trees within 60 families. Furthermore, [18] observed home-garden
263 agroforestry in Nonthaburi province (suburban Bangkok) and found 58 species of trees.

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The most studied garden city in SE Asia is Singapore, a highly urbanized city with a population of 5 million people. Singapore has a rich natural heritage with more than 10 ecosystems and 2,145 vascular plants. The management of urban green space in Singapore is based on a network of parks and park connectors which permeate the island, allowing easy access to varied habitats rich in plant and animal life. It seems therefore that knowledge transfer from tropical Singapore may help to develop further intensive management in order to increase the biodiversity of trees in Bang Kachao Green Space in the future.

The average stand density of Bang Kachao Green space was 774 trees/ha, which was higher than in Bangkok with 27 trees/ha [16]. In Sakaerat Biosphere Reserve, Nakhon Rachasima Province, the dry evergreen forest (DEF) and dry dipterocarp forest (DDF) had 992 and 602 trees/ha, respectively [16]. The density of tropical rain forest in the south of Thailand was between 818 and 1,540 trees/ha [19]. Thus, the stand density in Bang Kachao Green Space was quite similar to the density in natural forests of Thailand, especially the DDF and DEF. In contrast, stand density in Bank Kachao Green Space was lower than home-garden agroforestry in Nonthaburi Province (6,877 trees/ha) [18]. It seems that species selection and intensive management are important in order to increase the density of forests in urban areas in the future.

The tree population of Bang Kachao Green Space was dominated by small diameter trees. The average tree DBH was 12.9 cm, with 70.6% of the population having a DBH less than 15 cm. This was similar to Bangkok with 69.6% of the urban forest cover consisting of small diameter trees less than 23 cm DBH [16]. In the home-garden agroforestry study in Nontaburi province, the tree DBH ranged from 10.5 to 15.5 cm [18]. The observed size class distributions are typical of natural forest regenerating from seed, with high stem counts in the small size class [20]. However, in the case of urban green space, it can also imply the lack of management or that the growth increment is very low.

NDVI was used in this study as a recognized indicator of the extent of vegetation greenness, implying some aspects of plot structure such as plot density, canopy cover and relative green biomass. This study showed that not all the plot factors selected in this study can be predicted by the NDVI from TM imagery. These results showed there were significant relationships between NDVI and some factors assessed in Bang Kachao Green Space. The number of families, total basal area, number of species, Shannon-Weiner's Index and LAI tend to increase with NDVI. Likewise, LAI was correlated with total basal area, stand density, canopy density and canopy layer. The linear regression model can be applied to estimate vegetation abundance within a pixel by assuming a linear relationship between a pixel's vegetation fraction (response variable) and the spectral bands of Landsat ETM+ (explanatory variables). Regression analysis has been applied between NDVI and known vegetation fractions to estimate fractional vegetation cover [8]. Although this approach can be reliable and efficient, vegetation estimates derived from spectral mixture modelling can be less sensitive due to background soil reflectance [21].

Remote sensing data utilized in the research was limited to the available satellite imagery. In recent years there has been considerable progress in developing high resolution multi- and hyper-spectral cameras that can be applied to drones as well as fixed-wing aircraft. These now can provide precise information on canopy condition as well as tree height classes. Bang Kachao Green Space would be an ideal place to evaluate this new technology as much ground-based data have already been collected. It would be interesting to undertake annual monitoring of canopy condition to obtain

Peer-reviewed version available at Forests 2018, 9, 36; doi:10.3390/f9010036

a better understanding of the rate of change, positive and negative, for management purposes into the future.

Acknowledgments: The Center for Advance Studies in Tropical Natural Resources, National Research University-Kasetsart University, Thailand (CASTNaR, NRU-KU) provided a PhD scholarship to the first author. field work; M.S. analyzed the field data; J.S. the satellite images; M.S. and B.D. wrote the paper.

Author Contributions: M.S., C.W., N.T. and B.D. conceived and designed the experiments; M.S. undertook the field work; M.S. analyzed the field data; J.S. analyzed the satellite images; M.S. and B.D. wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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