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Carbon Sequestration Estimation of Urban Trees in Parks and Streets of Bangkok Metropolitan, Thailand

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ABSTRACT

The study estimated the averaged greenhouse gas (GHG) absorption factor of trees planted in urban area in Bangkok using survey data in urban parks and on roadsides to estimate the GHG absorption effect of urban greening. A dataset of tree species in four parks (2,621 trees) and in main/sub-main streets (200,388 trees) in Bangkok surveyed in 2003, 2011, and 2012 were used. The biomass for each species was calculated using allometric equations by parks and streets and conversion factors from the literature to estimate whole tree dry weight biomass and carbon. Allometric equations were sourced from "GlobAllomeTree" (FAO, online) and IPCC (2003). Tree ages were assumed to be the year difference between the surveyed year and the year of park establishment. Annual carbon absorption of trees in four parks ranged between 0.001 and 0.026 tonnes carbon (tC)/tree/year with a weighted average of 0.009 tC/tree/year. Street trees absorbed 0.002–0.015 tC/tree annually with an average of 0.012 tC/tree/year. The results of the present study were within the range of the default values of the IPCC of 0.0033–0.0142 tC/tree annually. It is expected that the results in this study can be applied for evaluation of the urban greening effect in Bangkok and other cities in Thailand and ASEAN countries, as the results the urban greening for mitigation are further promoted.

Keywords: carbon sequestration, absorption factor, urban park, street tree, urban greening

INTRODUCTION

The IPCC Fifth Assessment Report (2014) indicated that "human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases driven largely by economic and population growth are the highest in history, and recent climate changes have had widesp read impacts on human and natural systems.(IPCC, 2014).

In the Copenhagen Accord at COP15, it was confirmed that the global temperature increase needs to be limited to within 2°C compared with the pre-industrial level in order to avoid dangerous anthropogenic interference with climate systems (UNFCCC, 2010). The greenhouse gas (GHG) emissions in the world need to be reduced by 50% by 2050 compared with 1990 in order to keep the global temperature within the desired limit. GHG emissions from Asian countries account for almost half of the global GHG emissions by 2050 in the business-as-usual (BAU) case. Low-carbon society development in the Asian area is urgent in order to achieve the target of global climate (Matsuoka *et al*., 2013).

JICA (Japan International Cooperation Agency) has started a technical cooperation project in order to formulate Bangkok Master Plan on Climate Change during 2013-2023, which includes five sectors-transport, energy, waste and wastewater, green urban planning, and adaptation planning-and to enhance institutional capacity further for increasing the preparedness for implementing the Master Plan in cooperation with the BMA (Bangkok Metropolitan Agency). In the green urban planning sector, the averaged GHG absorption factor of trees planted in the BMA is required in order to estimate the GHG absorption effect of urban greening activities in Bangkok such as urban park construction and tree planting along road sides.

Few GHG absorption factors for urban trees are available. Most studies have been conducted in the United States (Nowak, 1994; Nowak and Crane, 2002; Escobedo *et al.*, 2010). Default values referred to in IPCC Good Practice Guidance for LULUCF (2003) are from studies in North America (IPCC, 2003), while the study in Japan conducted by Ministry of Environment (2014) also provided GHG absorption factors of urban trees based on trees in the temperate and the subarctic zone. GHG absorption factors of urban trees in the tropical zone are limited to date. Most studies in Thailand have provided the GHG absorption factor of trees in forested areas; for example Nualngam and Wachrinrat (2002) reported GHG absorption factors of several fast-growing trees in forested areas. It is known to be inappropriate to apply the results of trees grown in forested areas to estimate a single tree in an urban area. To assess the potential of urban trees in Bangkok in reducing atmospheric CO_2, it is therefore necessary to study the GHG absorption factor of urban trees in Bangkok a city located in the tropics.

This study aimed to estimate the carbon storage of trees in urban parks and streets of Bangkok using survey data in urban parks and from roadsides. The results can be used to estimate the GHG absorption effect of urban greening activities in the Bangkok Master Plan on Climate Change during 2013-2023 with more precision. It is also expected that the results from this study can be applied to estimate the amount of GHG absorption in urban greening in other cities in Thailand and ASEAN countries. Understanding the role of urban forests in carbon storage and sequestration will promote urban greening.

MATERIALS AND METHODS

Overall Flow for Estimating Annual Carbon Absorption

Average annual carbon absorption of urban trees in Bangkok was calculated following the flow diagram shown in Figure 1. Details of each stem are explained in the following section.

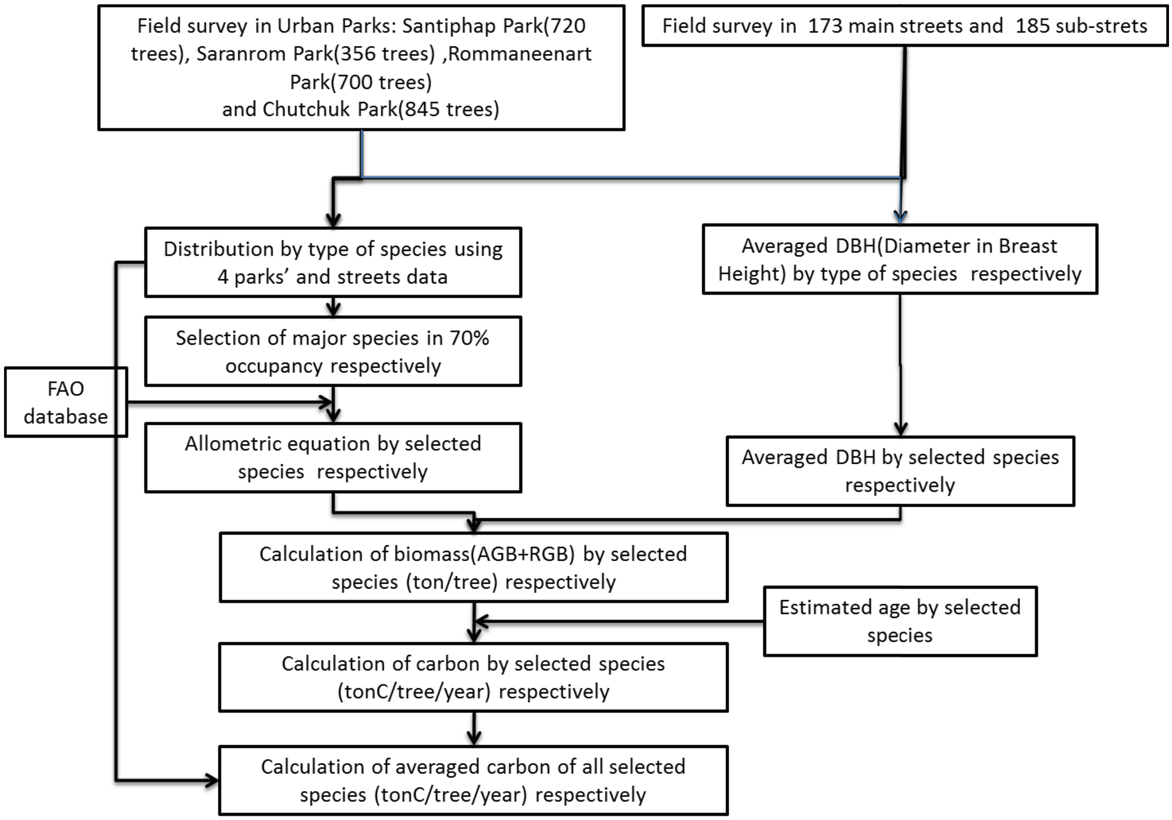

Figure 1 Flow for estimating annual carbon absorption of urban trees in Bangkok.

Field Data

The Bangkok Metropolitan Administration (BMA) and the Department of Silviculture at Kasetsart University, Bangkok, Thailand have conducted a series of inventory surveys on trees grown on roadsides and in urban parks in Bangkok during 2000-2012. The data sources are shown in Table 1. Those field data were provided by BMA and Kasetsart University. The tree datasets were then classified by location and species. In total, 21 tree species comprising 70% of the trees planted in four different parks and 7 species comprising 70% of trees planted in main/sub-main streets in Bangkok were used for calculation of the annual carbon absorption per tree. Weighted average diameter at breast height (1.3 m) over bark (DBH) by species and location were used for the calculation.

Table 1 Source of field data used in the present study.

Location	Survey year	Number of trees	Source
Rommaneenart Park	2003	700	Forest Research Center (2004a)
Saranrom Park	2003	356	Forest Research Center (2004b)
Santiphap Park	2011	720	Sanpop (2011)
Chatuchak Park	2012	845	Kaewpakasit (2012)
Main- and sub-streets*	2000	200,388	Thaiutsa *et al.* (2008)

Note: *173 main streets and 185 sub-streets in Bangkok.

Biomass Equations

The biomass for each species in each location was calculated using allometric equations from the literature. Allometric equations were searched using "GlobAllomeTree" (FAO, online). Since only the DBH of the measured street trees was available as a parameter for biomass prediction, one-variable equations were chosen. Where several equations were found for a species, the allometric equations developed in similar climatic zones such as Southeast Asia were used as a priority. If no allometric equation could be found for an individual species, equations for same the genus or a given equation for tropical moist hardwoods in the IPCC Good Practice Guidance for LULUCF were used. Table 2 shows the biomass equations applied for the most common species found in urban parks and on roadsides in Bangkok which comprise 70% of the total trees. It was confirmed that all allometric equations can estimate total aboveground biomass including branches and leaves, except for two species, *Polyalthia longifolia* (Benth.) and *Acacia auriculiformis* A. Cunn. ex Benth. For those two species, 3.4 was used as the Biomass Expansion Factor to convert the trunk volume to total aboveground biomass (IPCC, 2003). Only the equation for *Polyalthia* species requires Wood Density (WD) and the value for the same genus (0.510 was used (IPCC, 2003). Aboveground biomass was converted to whole tree biomass based on a root-to-shoot ratio default value of 0.24 (IPCC, 2003). The Carbon Fraction (CF) to covert biomass to carbon weight was 0.47 (IPCC, 2003).

Table 2 Allometric equations used for biomass calculation of urban trees in Bangkok.

Species	Allometric equation	Component	References
Acacia auriculiformis A. Cunn. ex Benth	$Y=\exp[0.4515\cdot(\ln DBH)-0.4573\cdot(\ln DBH)^2]$	B, S, T	Jayaraman, *et al.* (1992)
Albizia saman (Jacq.) Merr.	$Y=0.1142\cdot DBH^{2.4451}$	B, Br, L, S, T	Hung *et al*. (2012)
Cassia fistula L.	$Y=0.1142\cdot DBH^{2.4451}$	B, Br, L, S, T	Hung *et al*. (2012)
Cerbera odollam Gaertn.	$Y=\exp[-2.289+2.649\cdot\ln(DBH)-0.021\cdot(\ln(DBH))^2]$	ABG	IPCC (2003)
Delonix regia (Bojer ex Hook.) Raf.	$Y=\exp[-2.289+2.649\cdot\ln(DBH)-0.021\cdot(\ln(DBH))^2]$	ABG	IPCC (2003)
Hopea odorata Roxb.	$Y=0.1277\cdot DBH^{2.3943}$	B, Br, L, S, T	Hung *et al*. (2012)
Lagerstroemia floribunda Jack	$Y= 0.1277\cdot DBH^{2.3943}$	B, Br, L, S, T	Hung *et al*. (2012)
Lagerstroemia loudonii Teijsm. & Binn	$Y= 0.1277\cdot DBH^{2.3943}$	B, Br, L, S, T	Hung *et al*. (2012)
Lagerstroemia speciosa (L.) Pers.	$Y= 0.1277\cdot DBH^{2.3943}$	B, Br, L, S, T	Hung *et al*. (2012)
Melaleuca bracteata L.	$Y=\exp[-2.289+2.649\cdot\ln(DBH)-0.021\cdot(\ln(DBH))^2]$	ABG	IPCC (2003)
Millingtonia hortensis L.f	$Y=\exp[-2.289+2.649\cdot\ln(DBH)-0.021\cdot(\ln(DBH))^2]$	ABG	IPCC (2003)
Mimusops elengi L.	$Y=\exp[-2.289+2.649\cdot\ln(DBH)-0.021\cdot(\ln(DBH))^2]$	ABG	IPCC (2003)
Peltophorum pterocarpum (DC.) Backer ex K. Heyne	$Y=0.1245\cdot DBH^{2.4163}$	B, Br, L, S, T	Hung *et al*. (2012)
Plumeria rubra L.	$Y=\exp[-2.289+2.649\cdot\ln(DBH)-0.021\cdot(\ln(DBH))^2]$	ABG	IPCC (2003)
Polyalthia longifolia (Benth.) Hook. f.	$Y=0.2270\cdot DBH^{2.3519}\cdot WD^{1.2211}$	B, S, T	Dung *et al*. (2012)
Pterocarpus indicus Willd.	$Y=0.1277\cdot DBH^{2.3943}$	B, Br, L, S, T	Hung *et al*. (2012)
Ptychosperma marcarthurii H.Wendl.	$Y=6.666+12.826\cdot(HT^{0.5})\cdot\ln(HT)$	ABG	IPCC (2003)
Sesbania grandiflora (L.) Desv.	$Y=\exp[-2.289+2.649\cdot\ln(DBH)-0.021\cdot(\ln(DBH))^2]$	ABG	IPCC (2003)
Swietenia macrophylla King	$Y=0.0018\cdot DBH^2-0.0807\cdot DBH+1.1748$	B, Br, L, T	Arreaga (2002)
Streblus asper Lour.	$Y=\exp[-2.289+2.649\cdot\ln(DBH)-0.021\cdot(\ln(DBH))^2]$	ABG	IPCC (2003)
Syzygium cumini (L.) Skeels	$Y=\exp[-2.289+2.649\cdot\ln(DBH)-0.021\cdot(\ln(DBH))^2]$	ABG	IPCC (2003)
Tabebuia argentea Britt.	$Y=\exp[-2.289+2.649\cdot\ln(DBH)-0.021\cdot(\ln(DBH))^2]$	ABG	IPCC (2003)
Tabebuia rosea (Bertol.) DC.	$Y=\exp[-2.289+2.649\cdot\ln(DBH)-0.021\cdot(\ln(DBH))^2]$	ABG	IPCC (2003)

Notes: ABG: Aboveground; B: Bark; Br: Branch; DBH: Diameter at breast height under bark; HT: Height; L: Leaves; S: Stump; T: Trunk under bark; WD: Wood density

Estimation of Annual Tree Growth and Carbon Absorption

Tree age is an important parameter in estimating mean annual growth. Unfortunately, no records were available on urban tree age planted in the Bangkok Metropolitan area. For trees grown in parks, tree age was therefore estimated using the difference between the surveyed year and year the park was established (Rommaneenart Park: 12 years, Santiphap Park: 14 years and Chatuchak Park: 33 years). Saranrom Park which was the former Royal Palace site, was established in 1874, but tree age was calculated by the difference between surveyed year and the year when management responsibility was transferred to the BMA (44 years) because most of trees were planted after BMA took full charge of the Palace and turned it into a Public Park.

For the street trees, information on tree age and diameter size was limited. Therefore, average annual carbon absorption of street trees was calculated using assumed values. For this study, the average annual carbon absorption of street trees was calculated assuming that tree age and average diameter size of each species were the same as for Rommaneenart Park except for *Tabebuia rosea*. Those assumed values were set based on three reasons. First, the tree age was assumed based on Thaiutsa *et al*. (2008) mentioning that the street trees in Bangkok likely had been planted during the 1980s and Thaiutsa *et al*. (2008) mentioning that most of trees were planted in the 1990s. Those reports suggested that the tree age of street trees at the survey year, 2000, was between 10-20 years. Second, the diameter of street trees was recorded by size categories such as small, medium, and large, of which most street trees were categorized in the medium size and this trend was similar to Rommaneenart Park. Finally, the species compositions of street trees and those in Rommaneenart Park were similar and this fact made it convenient to set an assumed value for the average diameter by species.

However, *Tabebuia rosea* was excluded because it is known that *Tabebuia rosea* has no longer been planted as a street tree (Thaiutsa *et al*., 2008). Although this species is commonly found along streets, it is not popular in the relatively new parks such as Rommaneenart Park and Santiphap Park, but it is found in old parks like Chatuchak Park and Saranrom Park. In general, selection of urban tree species changes with times and conditions. Accounting for this trend, we estimated the street tree age of *Tabebuia rosea* as 33 years which is the same age as the trees in Chatuchak Park.

Several species appear in different parks with different sizes which results in different annual carbon absorption factors. In order to estimate the average annual carbon absorption by parks, the weighted average was processed after annual carbon absorption was averaged having been weighted by species.

RESULTS AND DISCUSSION

In total, 152 tree species were recorded in four parks in the Bangkok Metropolitan area and the five most frequently appearing species constituted 42% of the trees listed (Figure 2). Along the main streets and sub-streets, 50 species were listed and the top five species accounted for 64% of all street trees (Figure 3). *Pterocarpus indicus* was the most common street tree species in Bangkok accounting for 42%. The DBH of the top 70% of species ranged between 7 and 45 cm for park trees, and 12 and 26 cm for street trees indicating that various sizes of trees existed in the parks in contrast to the streets where the tree sizes were relatively uniform.

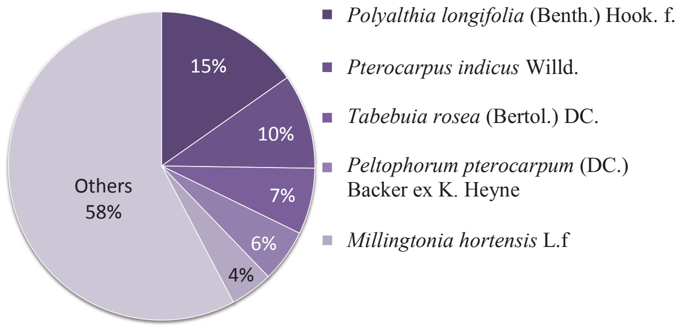

Figure 2 Composition of five major tree species found in four parks of Bangkok.

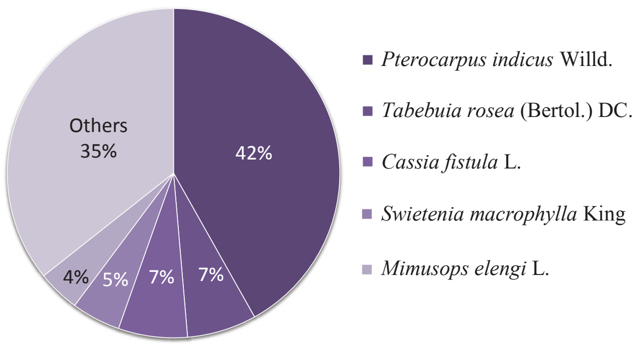

Figure 3 Composition of five major tree species found on the streets and sub-streets of Bangkok.

By using biomass allometric equations, the DBH of trees, tree ages, and carbon fraction, the annual carbon absorption of each species was calculated. Table 3 shows the annual carbon absorption and its weighted average for the top 21 species which comprised 70% of the trees in four urban parks in Bangkok. The annual carbon absorption ranged between 0.001 and 0.026 tonnes C (tC)/tree/year with a weighted average of 0.009 tC/tree/year. *Delonix regia* (Hook.) Raf. had the highest average annual carbon absorption of 0.026 tC/tree/year followed by *Acacia auriculiformis* A. Cunn. ex Benth (0.025 tC/tree/year) and *Peltophorum pterocarpum* (0.021 tC/tree/year).

Table 3 Annual carbon absorption of major tree species found in four Bangkok urban parks.

Species	Number of trees	DBH (cm)	Carbon sequestration (tC/tree/year)	Weighted average carbon sequestration (tC/tree/year)
Polyalthia longifolia (Benth.) Hook. f.	401	8.5-12.0	0.002-0.006	0.001
Pterocarpus indicus Willd.	261	26.0-43.0	0.005-0.015	0.013
Tabebuia rosea (Bertol.) DC.	182	29.1-38.0	0.011-0.016	0.012
Peltophorum pterocarpum (DC.) Backer ex K. Heyne	146	27.0-41.0	0.013-0.035	0.021
Millingtonia hortensis L.f	118	16.0-25.0	0.002-0.017	0.009
Streblus asper Lour.	90	4.3-22.2	0.0013-0.005	0.005
Sesbania grandiflora (L.) Desv.	81	11.9	0.001	0.001
Mimusops elengi L.	61	13.0-72.0	0.004-0.076	0.010
Lagerstroemia speciosa (L.) Pers.	58	16.0-23.0	0.003-0.006	0.005
Albizia saman (Jacq.) Merr.	51	40.2	0.017	0.017
Cerbera odollam Gaertn.	46	18.3	0.003-0.008	0.006
Lagerstroemia floribunda Jack	44	9.0-21.0	0.001-0.003	0.003
Melaleuca bracteata L.	40	9.0-17.0	0.001-0.002	0.002
Lagerstroemia loudonii Teijsm. & Binn	36	13.4-26.0	0.003-0.005	0.005
Delonix regia (Hook.) Raf.	35	23.1-46.0	0.006-0.065	0.026
Ptychosperma marcarthurii H. Wendl.	34	7.7	0.003	0.003
Acacia auriculiformis A. Cunn. ex Benth	32	36.4	0.025	0.025
Plumeria rubra L.	32	13.0-15.0	0.002-0.004	0.003
Tabebuia argentea Britt.	32	14.0-24.1	0.0008-0.016	0.007
Syzygium cumini (L.) Skeels	30	7.0-20.4	0.0044-0.108	0.020
Hopea odorata Roxb.	26	8.3-38.0	0.0004-0.01	0.001
		Weighted average		0.009

Note: Height of 8.4 m used in the estimation of *Ptychosperma marcarthurii* H. Wendl.

Street trees had higher average annual carbon absorption compared to trees in urban parks with an average for the former of 0.012 tC/tree/year, ranging between 0.002 and 0.015 tC/tree/year. This appears reasonable because most of the planted roadside trees are fast-growing species, while there is more diversity in park trees. The details of carbon absorption of the top seven species which comprised 70% of trees along roadsides in Bangkok are shown in Table 4.

Table 4 Annual carbon absorption of major tree species found on the main streets and sub-streets of Bangkok.

Species	Number of trees	Average DBH (cm)	Average carbon absorption (tC/tree/year)
Pterocarpus indicus Willd.	79,365	26	0.0152
Tabebuia rosea (Bertol.) DC.	12,792	29	0.0106
Cassia fistula L.	22,731	20	0.0084
Swietenia macrophylla King	9,026	20	0.0136
Lagerstroemia speciosa (L.) Pers.	7,841	16	0.0047
Mimusops elengi L.	8,293	13	0.0038
Polyalthia longifolia Benth. & Hook.f.	5,829	12	0.0017
Weighted average			0.0120

The average annual carbon sequestration of urban trees in parks (0.009 tC/tree/year) and streets (0.012 tC/tree/year) estimated from the present study were within the range of the default values set by the IPCC Good Practice Guidance for LULUCF which indicates that an urban tree absorbs 0.0033-0.0142 tC/tree annually (IPCC, 2003). In general, rapidly growing trees generally sequester more CO_2 than slow-growing trees. Generally, trees selected for urban planting are fast-growing species which do not show much difference in carbon sequestration between temperate and tropical climate zones. However, the estimates given in the present study are based on several limitations which make it impossible to get a more precise estimate.

Field data in the present estimation were limited to four urban parks in which tree surveys had been conducted in 2003, 2011, and 2012. Considering only large urban parks with a minimum size of 4 ha in Bangkok, there are 26 with a total area of 2,860 ha, so the surveyed parks accounted only for 8% of the park area which is not sufficiently representative. A field survey of other urban parks should be conducted to increase the number of parks and to collect the most recent tree data. Moreover, the ages of trees for the estimation of their GHG absorption factor were estimated based on the difference between the construction year of the surveyed urban park and the implementation year of the data collection survey. Since there is no established methodology to estimate tree ages of tropical trees, it is therefore difficult to acquire accurate tree ages of existing trees in Bangkok. However, the relationship between the age of the tree and other parameters, including the DBH, can be constructed to improve the estimation. The measurement of the DBH by species of tree should be conducted in the same parks where the tree data were collected. Then, using the difference between the year of the previous data collection survey and the year of new measurement of the DBH, the difference in growth could be calculated precisely. Carbon sequestration can then be updated.

Allometric equations of trees in the present study were based on the allometric equation database of the Food and Agriculture Organization of the United Nations (FAO). Some tree species in Bangkok's urban parks are not in the FAO database. The allometric equations of tropical moist hardwoods described in IPCC Good Practice Guidance for LULUCF were therefore applied for those species. The development of allometric equations for some species in Bangkok's urban parks should be conducted to increase the accuracy of estimation of the GHG absorption factor. Generally, allometric equations developed for forest trees were used for the estimation of urban tree biomass. However, due to the regular trimming of urban trees to overcome their limited planting space, urban trees tend to have less aboveground biomass than those predicted by equations developed for natural forest. Nowak (1994) suggested a 20% biomass reduction for urban trees with a DBH greater than 30 cm. This suggested value has not been applied to the present study since only a few urban trees in Bangkok have reached the suggested size. Further studies on urban tropical species might be needed.

In the Urban Green Planning sector of the Bangkok Master Plan on Climate Change during 2013-2023, the tree data collection will be conducted in stages commencing with planting and then regularly after planting as a part of the MRV (monitoring, reporting, verifying) activity of urban parks construction and tree planting along roadsides. These collected tree data can be utilized to update the carbon absorption factor periodically.

CONCLUSION

Urban trees can play a significant role in reducing atmospheric CO_2 in urban areas. Unfortunately, quantification of tropical urban tree carbon sequestration is limited. This paper provides an estimation of carbon sequestration of urban trees grown in Bangkok based on the limited availability of measured field data. The estimated carbon sequestration for trees grown in some urban parks of Bangkok was 0.009 tC/tree/year, while for street trees it was 0.012 tC/tree/year. The results were within the range of the default values recommended by the IPCC. More field data are needed to improve the quality of the estimation. In the mean time, these figures, can be used for the calculation of carbon storage and sequestration of urban trees in Thailand and in other ASEAN countries.

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