International Journal of Agricultural Technology 2016 Vol. 12(3):395-413
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Diversity, Prevalence and Environmental Benefits of Street Trees in Nakhon Si Thammarat province, Thailand

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Choothong, S., Qin, H. and Soonsawad, N. (2016). Diversity, prevalence and environmental benefits of street tree in Nakhon Si Thammarat, Thailand. International Journal of Agricultural Technology 12(3):395-413.

Abstract Street trees provide a wide range of ecosystem services to cities including improving environmental quality, and socio-economic benefits. Despite their immense importance, there is a limited number of research in terms of diversity and ecosystem services of street trees in Thailand. This research is subjected to diversity, prevalence and environmental benefits of street trees in the district highway of Nakhon Si Thammarat province, southern Thailand. The systematic sampling inventory was conducted on 38 routes of the highway in early 2015. With about 3,000 trees sampled, they are composed of 83 species in 31 families. The five most abundant species are: *Cassis fistula* (13.51%); *Acacia mangium* (13.27%); *Senna siamea* (11.61%); *Tamarindus indica* (8.25%); and *Lagerstroemia floribunda* (8.14%). Using the i-Tree Streets model in calculating tree environmental benefits based on the trees's size and species, the total monetary value of those environmental benefits provided by these street trees is approximately $12 million per year. On average, the value that the city can save is about $40 per tree per year. The first three species that provided the greatest annual value (in the unit of $ per tree per year) are; *Ficus religiosa* (110); *Tamarindus indica* (100), *Senna siamea* (90); on the other hand, *Delonix regia* provided the lowest annual value of about $3 per tree. The Department of Highway could improve the city environmental quality and economy by selecting tree species with great environmental benefits as well as increasing tree diversity and abundance by planting or replanting more native species such as *Tamarindus indica* and *Senna siamea* on the highway.

Keywords: Street trees. Diversity. Environmental benefit. i-Tree Street model. Thailand

Introduction

Street tree is one of the most important aspects of the urban forestry and aesthetics of cities. Roadway greenscaping gives people to their first impression when they come through (Jacobs, 1993). Green landscaping supports the conservation of biodiversity in urban areas (Kummerling and Muller, 2012). Planting more trees can help increasing the quality of urban landscapes (Franco *et al*., 2003, Guthrie and Shackleton, 2006), by regulating microclimate

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(Kursten, 2000); increasing the CO2 sequestration (Merry *et al*, 2013); reducing surface water runoff (Stringer and Ennos, 2013, A.L. Soares *et al*, 2011, Wolch *et al*, 2014, Zhang and Liu, 2010); conserving energy (McPherson and Rowntree, 1993); supporting biodiversity (Burkman and Gardiner, 2014); and providing wildlife habitats (Ivanko, 2001, William, 2003). Enhancement of tree diversity plays an important role in forest management, by preventing native species lost from disturbance pollutions (Zhang and Jim, 2014).

One of the modern concepts of tree landscaping in the cities was originally derived from the United States. It started with Boston's Emerald Necklace through the planning of the Boston Park System created by Frederick Law Olmsted, during the late 19th century (J.G. Fabos, 2004). The early inventory of street trees in between year 1982-1985 in terms of the diversity in the U.S. cities showed that there were between 100 to 200 tree species (Nowak, 1993), and the mean number of street tree species for 22 U.S. cities was 53 (McPherson and Rowntree, 1989). In Bangalore, street tree diversity inventory in the Metropolitan Chennai city indicated that there were 45 species from 42 genera and 21 families (Muthulingamand and Sekar, 2012). Of the three cities in South Africa: Tzaneen, Bela Bela and Zeerust, the prevalence, density, and diversity of trees were the lowest in the informal areas (Shackleton *et. al*, 2014). There were 1,485 trees in total comprising of 61 species of which majority (56%) were alien species from the Eastern Cape of South Africa (Chitepo and Shacketon, 2011).

There are several aspects to be considered in managing street trees in a way that they can efficiently provide ecosystem services to cities. In order to improve urban environmental quality, environmental criteria in selecting trees should be significantly taken into account of forest managers. In addition, indigenous tree species and trees with slow growth rates are recommended to be planted in order to establish tree communities in the cities (Zhang and Dai, 2011, Lacy and Shacketon, 2014). Besides, the safety street, which is a natural concept, is applied to the urban areas by planting native species along the roads (Viles and Rosier, 2001, Wei and Hong, 2011, McPherson *et al.*, 2008).

There has been a number of research in several cities in the United States that worked on analyzing benefits of street trees using the i-Tree Streets such as Chicago (McPherson, 1997), Modesto (McPherson, 1999), Eugene; Newark, and Los Angeles (McPherson and Rowntree, 1993). In addition, outside the United States, there are some studies that i-Tree Streets were used in calculating urban tree benefits. For example, in Lisbon, Portugal, street trees provided value of $8.4 million annually from environmental and esthetic benefits with an average of $204 per tree (A.L. Soares *et al.*, 2010); while in Bangkok, Thailand, the total annual monetary value of environmental benefits (not including aesthetic value) is about $4.34 million with an average of $24 per tree (Soonsawad, 2014).

For Thailand, there is a limited literature on urban greening including street trees and their environmental benefits in Thailand (Chudchawan, 2005, Thaisuita *et al*., 2008, Kjelgren *et al.*, 2011, Soonsawood, 2014). The purpose of this research is to update the city street tree inventory in terms of abundance and diversity on 988 kilometers of 38 street segments of Nakhon Si Thammarat district highway. The study objectives were: (1) to determine diversity and prevalence, hazard, health and status of street trees; and (2) to assess annual environmental benefits including reductions in carbon dioxide, air pollution, stormwater runoff, and saving energy; and monetary value of these environmental benefits.

Materials and methods

Study site

Nakhon Si Thammarat is a province in Southern Thailand, known as a famous old town of Buddhism. It is located at 8° 25′ 7″ N, 99° 57′ 49″ E covering the area of 9,942 km2 (Fig.1). With tropical monsoon climate, the weather is warm to hot throughout the year. An annual average temperatures is 27.7° C and annual rainfall is 2,496.5 mm.

Field survey

A field study of street trees was conducted in two months of January and February 2015. The inventory of 38 route's street trees was carried out on the district highway with the distance of 988 km. Samples of random selecting road was located by the general traffic on the left hand side in each 200 meters per plot. All trees' diameters at breast height (DBH) were measured at a height of 1.40 m. Other parameters collected include tree species, crown diameter, height, hazard, and health of trees. The i-Tree Streets model was employed to calculate environmental benefits annually provided by trees. Moreover, Shannon diversity index, importance value, canopy cover from all species of street trees were computed (Barbour *et al*., 1987).

Reference city selection

As climatic conditions define tree species composition and growth in different parts of the world, the selection of a reference city is necesary before estimating trees environmental benefits using the i-Trees Streets model. The i-Tree Streets model was developed, using tree growth and geographic data from sixteen U.S. cities, which represent sixteen climatic zones. Species compositions, heating degree-day, cooling degree-day, and annual precipitation are four criteria used in selecting a reference city (McPherson, 2010). Based on those criteria, Honolulu, Hawaii, has the most similar characteristics as of Nakhon Si Thammarat. Therefore, it is selected as a reference city. However, Honolulu has much less rainfall than in Nakhon Si Thammarat. For this reason, it is needed to adjust the estimated environmental benefits directly derived from the model. Such adjustments are described as detailed below (Soonsawad, 2014).

Analysis of environmental benefits of street trees

How much environmental benefit that the cities will gain from street trees depends on the number of trees, tree species, and ages of trees. Environmental benefit values will reflect monetary values that cities can save. Data collected from the field were put into the i-Tree Streets model to calculate environmental benefits including energy saving, air pollution removal, stormwater runoff reduction, carbon dioxide reduction, and carbon storage.

Adjustment of environmental benefit

Not only that Nakhon Si Thammarat has the different precipitation rates from Honolulu, its environmental quality, and income levels are also different. Regarding to this, the output from the model including the estimates of environmental benefits of street trees and monetary value of those benefits was adjusted. Adjustment factors used in calculating proper environmental benefits were computed based on environmental parameters' data of Honolulu and Nakhon Si Thammarat's data; i.e. precipitation, air quality, and emission from electricity generation (Table 1).

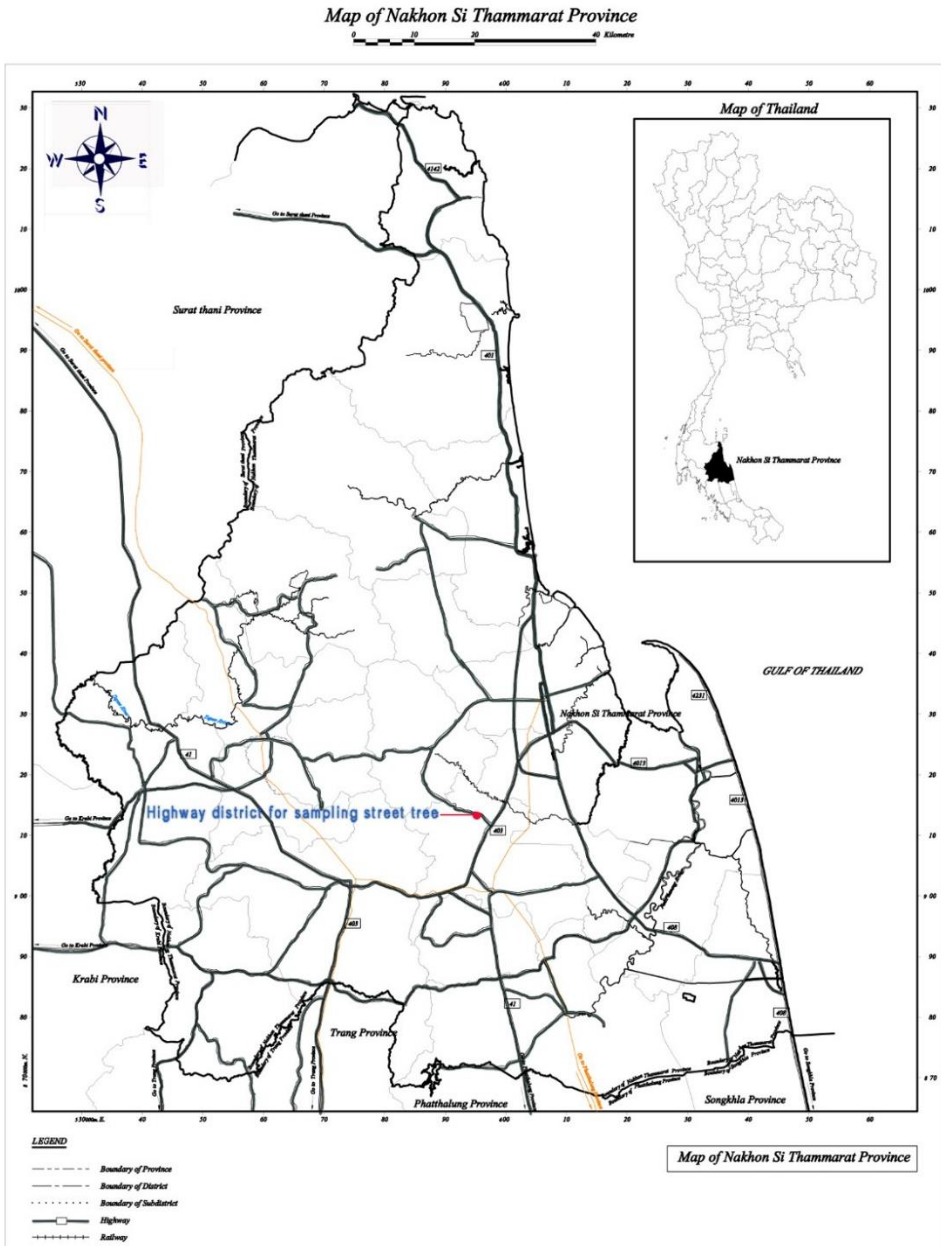

Figure 1. Street tree random selecting Nakhon Si Thammarat district highway

Tabel 1. Adjustment factors for Nakhon Si Thammarat environmental benefits and weather data, based on Honolulu data

Adjustment	Air pollution concentration[1] (mg/m^3)				% Emission from electricity generation[2]			Precipitation[3]
factor indicator	SO_2	NO_2	O_3	PM10	CO_2	NO_2	SO_2	(mm/y)
H	0.1	0.08	0.13	0.07	99.11	0.25	0.64	392
NST	0.048	0.007	0.025	0.1126	99.35	0.22	0.43	2,496
Adjustment factor	0.48	0.09	0.19	1.61	1	0.88	0.67	6.37

H=Honolulu, NST= Nakhon Si Thammarat
Sources of yearly average values:
1. Environmental Protection Agency, 2014 (data from Soonsawad, 2014); Pollution Control Department
2. Vargas *et al*, 2008; Electricity Generating Authority of Thailand 2006 (data from Soonsawad, 2014)
3. McPherson, 2010; Thai Meteorological Department

Results

Diversity and prevalence of street tree

Species diversity

The systematic sampling inventory of 2,947 street trees on Nakhon Si Thammarat district highway, were from 83 species, 69 genera and 31 families in 38 routes. Table 2 shows the abundance and species composition of street trees. The five most abundant are; 1) *Cassis fistula* (13.51%); 2) *Acacia mangium* (13.27%); 3) *Senna siamea* (11.61%); 4) *Tamarindus indica* (8.25%); and 5) *Lagerstroemia floribunda* (8.14%).

Table 2. Tree species composition of the street tree population of Nakhon Si Thammarat, Thailand

Scientific Name	Family	Frequency	Percent (%)	Canopy Cover (m²)	Importance Value	Shannon-Wiener diversity	Provenance
Cassis fistula	FABACEAE	398	13.51	19,054	10.54	0.117	South Asia
Acacia mangium	FABACEAE	391	13.27	20,276	12.26	0.116	Australia
Senna siamea	FABACEAE	342	11.61	10,357	7.19	0.109	Southeast Asia
Tamarindus indica	LEGUMINOSAE	243	8.25	46,549	15.63	0.089	Africa
Lagerstroemia floribunda	LYTHRACEAE	240	8.14	9,328	4.87	0.089	Southeast Asia
Samanea saman	LEGUMINOSAE	166	5.63	36,419	10.49	0.070	South America
Lagerstroemia speciosa	LYTHRACEAE	144	4.89	20,898	7.20	0.064	Southeast Asia
Terminalia catappa	COMBRETAEAE	116	3.94	14,160	4.62	0.055	Asia
Alstonia scholaris	APOCYNACEAE	107	3.63	7,642	2.86	0.052	Asia
Pterocarpus indicus	FABACEAE	95	3.22	3,681	2.31	0.048	Southeast Asia
Delonix regia	LEGUMINOSAE	67	2.27	154	0.84	0.037	Africa
Acacia auriculiformis	FABACEAE	54	1.83	7,012	2.52	0.032	Australia
Casuarina equisetifolia	CASUARINACEAE	52	1.76	6,701	2.45	0.031	Southeast Asia, Australia
Mangifera indica	ANACARDIACEAE	43	1.46	2,051	1.30	0.027	South Asia
Swietenia macrophylla	MELIACEAE	41	1.39	1,648	0.98	0.026	South America
Lagerstroemia loudonii	LYTHRACEAE	38	1.29	4,496	1.64	0.024	Southeast Asia
Leucaena leucocephala	LEGUMINOSAE	31	1.05	820	0.60	0.021	Central America
Other species	-	374	12.72	24,542	11.7	0.329	-
Total		2,947	100	235,788	100	1.34	

DBH Distribution, height and crown dimeter of street trees

For the most ten observed dominant species, the majority of street trees (40%) in Nakorn Si Thammarat are in 15.2-30.5 cm-DBH class, followed by 30.5-45.7 cm (31.08 %), and 40.7-61 cm (11.85 %), (Figure 2). According to the table below, about 70% of *Cassis fistula*, the most dominant species, have DBH in between 15.2-30.5 cm.

Among the tree communities of the ten most dominant species, most trees (58%) are in small sizes with the height less than 6 m while about 38% have the height ranges between 6-12 m. More than half of *Cassis fistula*, *Acacia mangium*, and *Senna siamea* population are at the height between 6-12 m, whereas the height of majority of *Tamarindus indica* is between 0-6 m (Figure 3). The most frequently observed crown dimeter class among the ten most dominant species is 0-6 m (97%). The highest street trees in highway road is *Senna siamea*, about 14% absent in 6-12 m of crown dimeter (Figure 4).

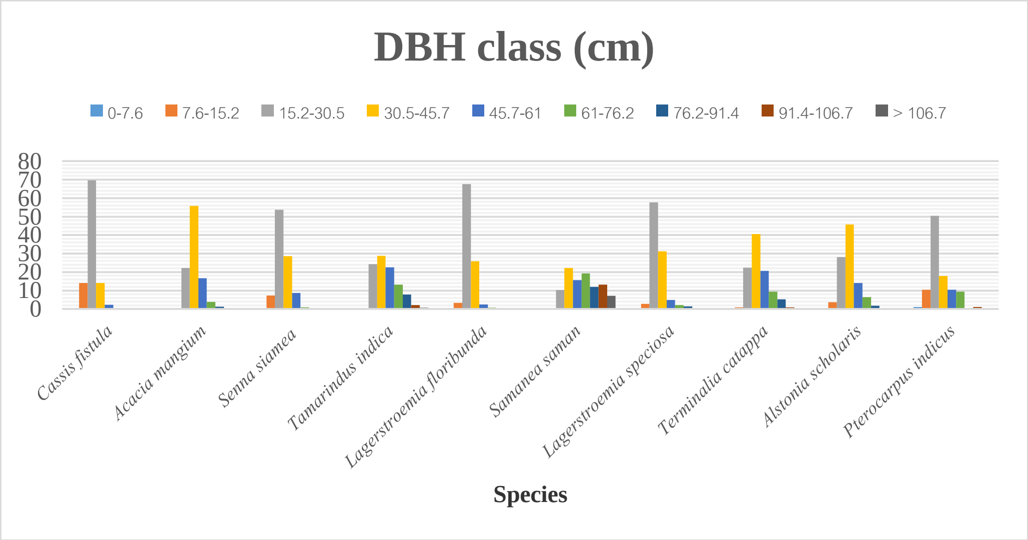

Figure 2. DBH class distribution of the ten most dominant tree spec

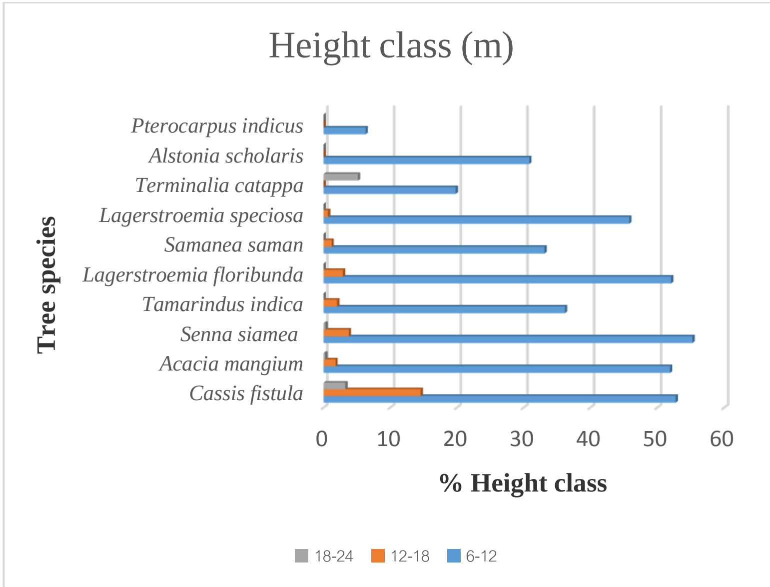

Figure 3. Height class distribution of the ten most dominant tree species

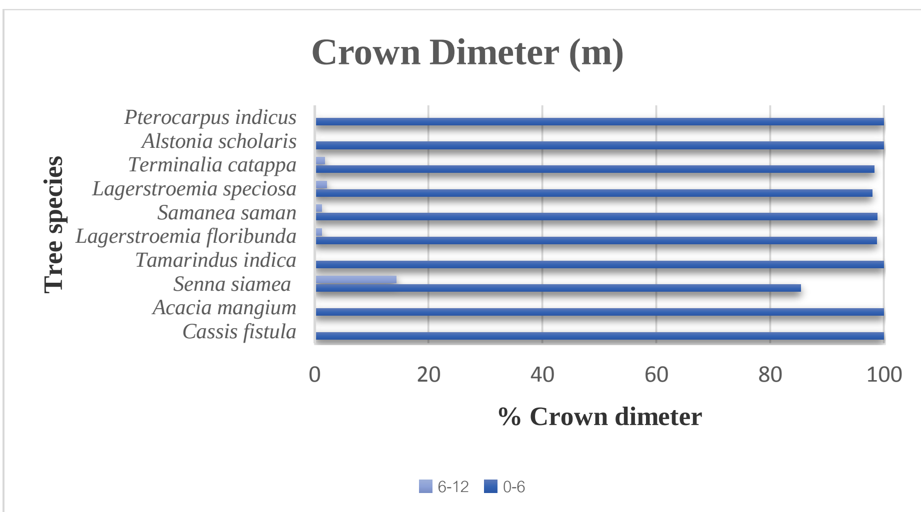

Figure 4. Crown dimeter distribution of the ten most dominant tree species

Hazards and hazard rating of street trees on the highway

The most frequent hazards among the ten most abundant species are excessive end weight (31.13%), poor taper (26.30%), and co-dominants (19.85%), respectively (Figure 5). About 48% of the trees have medium hazard rating, while about 28% have low rating (Figure 6). The health of foliage color and density of trees leaf in each plot revealed some inappropriate growing up such as having yellow or red color and dry leaf more than 50% of the shade and branches of street trees. This may be due to the infestation of the parasitic plants or insects and low pruning. Nevrtheless, some appear in good conditions having green color and high leaf density.

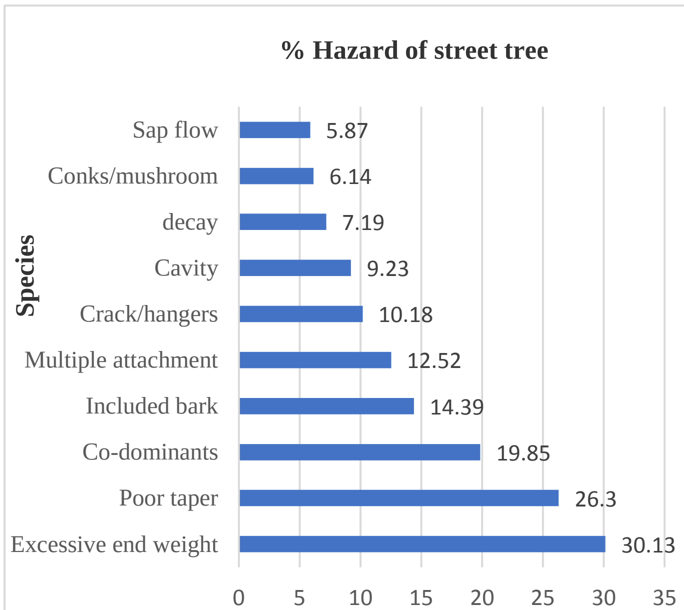

Figure 5. Percentage of hazard of street trees

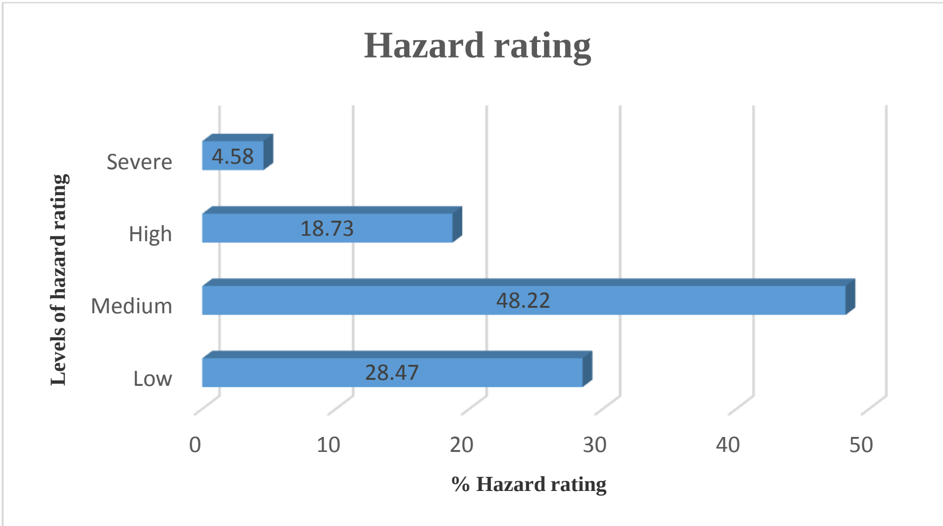

Figure 6. Percentage of hazard rating of street trees

Environmental benefits of street tree

From the sampling inventory on 38 routes along the distance of approximately 1000-kilometer highway district roads, the estimated total street trees in Nakorn Si Thammarate is about 294,700 trees with the standard error of about 10% (29,470 trees). They were planted with the spacing distance about 6-10 m.

Energy savings

Trees can provide direct shading; thereby reducing energy used from air conditioners and reducing climate impact for the cities. In this study, street trees can reduce electricity consumption by approximately 27,810 MWh per year accounting for about $3.4 million of electricity saving per year. The top five species that benefit the city in energy saving are: *Tamarindus indica* (5,630 MWh per year, $687,100 per year), followed *by Samanea saman* (3,190 MWh per year, $389,400 per year); *Acacia mangium* (2,900 MWh per year, $353,200 per year); broadleaf evergreen large Others (2.560 MWh per year, $312,700 per year), and *Cassis fistula* (2.530 MWh per year, $309,100 per year) respectively (Table 3, Table 4).

Atmospheric carbon dioxide reduction

The carbon dioxide reduction from the emission from electricity generation and carbon dioxide sequestration is 333,844 tons per year, accounting for about $2.4 million per year. The top five street tree species that can help reduce carbon dioxide the most are; *Tamarindus indica* (67,324 tons per year, $485,000 per year); followed by *Samanea saman* (50,294 tons per year, $362,300 per year); *Acacia mangium* (43,256 tons per year, $311,600 per year); broadleaf evergreen large others (29,584 tons per year, $213,100 per year); and *Cassis fistula* (20,400 tons per year, $146,900 per year). (Table 3, Table 4).

Air quality improvement

The total air pollution reduction is about 5.6 tons per year (combining air pollutant deposition of NO_2, SO_2, O_3, PM10, and avoided the emission from electricity generation CO_2, SO_2, NO_2, VOC subtracted with biological VOC emitted by trees). This accounts for the monetary value about $746,500 per year. The top five street trees species that provide the most contribution in the annual air pollution reductions, ranked from the highest to the least are; *Samanea saman* (286 kg), followed by *Acacia mangium* (224 kg), *Cassis fistula* (197 kg), *Terminalia catappa* (111 kg), and broadleaf evergreen large others (98 kg per year). *Terminalia catappa* shows the most money saving for the city relating to air pollution, i.e. about $131,900 per year, followed by *Samanea saman* $115,600 per year, *Cassis fistula* $90,600 per year. In contrast, *Casuarina equisetifolia* is the only one species that negatively impacted the air quality in city. Biological VOC emitted by this tree is greater than the combined pollutant reduction for about 408 kg per year (Table 3, Table 4).

Storm water runoff reduction

The annual water runoff reduction or rainfall interception by Nakorn Si Thammarat's street trees is about 12,346,334 m^3 per year, providing saving to the city $5.12 million per year from damage costs. The top five street trees species that can help reduce storm water runoff are: *Tamarindus indica* (2,572,206 m^3 per year, $ 1.06 million per year); followed by *Samanea saman* (1,549,184 m^3 per year, $642,600 per year); *Acacia mangium* (1,445,353 m^3 per year, $599,300 per year); broadleaf evergreen large others (258,622 m^3 per year, 473,400 per year) and *Cassis fistula* (952,315 m^3 per year, $395,000 per year) (Table 3, Table 4).

Table 3. Adjustment of environmental benefits of top ten of street tree

Environmental benefits per year	*Cassis fistula*	*Acacia mangium*	*Senna siamea*	*Tamarindus indica*	*Lagerstroemia floribunda*	*Lagerstroemia speciosa*	*Samanea saman*	*Broadleaf Evergreen Large Other*	*Terminalia catappa*	*Pterocarpus indicus*	Citywide total
Energy saving(MWh)	2,530	2,900	1,360	5,630	1,080	1,270	3,190	2,560	1,240	670	**27,810**
CO2 reduction(tons)	20,400	43,256	11,345	67,324	7,356	14,506	50,294	29,585	14,237	7,187	**333,844**
Air pollution reduction(kg)	198	224	83	43	88	98	286	26	111	60	**5,613**
Storm water runoff Reduction (tons)	952,315	1,445,353	591,136	394,940	2,572,206	486,668	1,549,184	1,141,504	588,588	320,411	**12,346,334**

Table 4. Adjusted monetary vulues of environmental benefits by public street trees

Environmental benefits ($)	*Cassis fistula*	*Acacia mangium*	*Senna siamea*	*Tamarindus indica*	*Lagerstroemia floribunda*	*Lagerstroemia speciosa*	*Samanea saman*	*Broadleaf Evergreen Large Other*	*Terminalia catappa*	*Pterocarpus indicus*	Citywide total
Energy saving	309,100	353,200	165,900	687,100	132,000	155,400	389,400	312,700	151,700	81,800	3,393,100
CO2 reduction	146,900	311,600	81,700	485,000	53,000	104,500	362,300	213,100	102,500	51,800	2,404,700
Air pollution reduction	79,000	90,600	40,500	131,900	35,300	38,700	115,600	60,500	45,000	24,300	746,500
Storm water runoff Reduction	395,000	599,300	245,300	1,066,700	163,700	201,800	642,600	473,400	244,200	132,900	5,120,100
Total benefits	930,000	1,354,700	533,400	2,270,700	384,000	500,400	1,409,900	1,059,700	543,400	290,800	11,664,400
% Total benefits	7.97	11.61	4.57	19.47	3.29	4.29	12.09	9.08	4.66	2.49	100
Benefits per trees ($/trees)	23.37	34.65	15.2	97.56	16	27.5	90.95	80.9	45.67	30.61	39.57

Discussion

There are five most dominant species of street trees in Nakhon Si Thammarat that make up greater than 54% of the total population. This observation is similar to that of Hong Kong, where the most five common species constituted over 50% of the total population (Jim, 1994). The prevalence observations of street trees are varied by ctities around the world. In Bangkok, only one dominant species; *Pterocarpus indicus* constituted over 40% of the tree population (Thaiutsa *et al*, 2008); in Hefei, China; top five of street trees constituted of more than 80% (Ying *et al*., 2011); in Syracuse, United Stated, the most three common species constituted of 70% (Sanders, 1981); in Chicago, United Stated, the four dominant species comprise 70% of the entire population (McPherson *et al*, 1997). In Lisbon, Portugal, street tree community was dominated by *Celtis australis* L., *Tillia* spp., and *Jacaranda mimosifolia* D. which together counted 40% of tree population (Soares *et al*., 2010). In contrast, in Bangalore, India, the four most commomly found species; *Albizia saman*, *Peltophorum pterocarpum*, *Spathodea campanulata*, and *Pongamia pinnata*, while *Albizia saman* is common species that was found less than 10% of the population (Nagendra and Gopal, 2010).

The diversity of street trees in Nakorn Si Thammarat is relatively moderate (83 species from 31 familites) when compared with other Asian cities in the tropical zone. In Kuala Lumpur, there are 35 species in 16 families of street trees (Sreetheran *et al*., 2011); Hefei, China has 22 species from 16 families (Ying *et al*., 2011). In contrast with the highly populated cities like Bangalore, there are 108 species from 33 families (Nagendra and Gopal, 2010) and Bangkok of 127 species in 36 families (Thaiutsa *et al*., 2008). For the U.S., the average number of street tree species of 22 cities is 53 from studied in 1982-1985 (McPherson and Rowntree, 1989).

Developed by USDA Forest Service, the i-Tree Streets model has been used in many parts of the world for calculating street trees' environmental and esthetic benefits and the monetary values of those benefits. For example, in Davis, the monetary value of both types of benefits is approximately $1.2 million per year (Maco and McPherson, 2003). For two observations in China cities; in Habin city, that value is about $4.5 million per year (Zhou and He, 2012) while in Hefei is about $8.5 million per year (Ma *et al*., 2011). In Thailand, there are two studies on investigating environmental benefits of street trees; however, only monetary value of only environmental benefits of street trees was observed (not including esthetic benefits). This study is the second reserach after Soonsaward's (2014) observing Bangkok's street trees. Due to the higher number of street trees, while in Nakorn Si Thammarat's value of street trees’ environemental benefits is about $11.64 million per year, the value in Bangkok is about $4.34 million per year (Soonsawad, 2014).

Conclusions

This study of street trees on Nakhon Si Thammarat highway includes aspects of diversity, prevalence and environmental benefit provision. The approximated number of the street trees is 300,000 from 83 species, 69 genera, and 31 families. While *Cassis fistula* is the most dominant species, *Ficus religiosa* provides the greatest annual environment benefit per tree ($113). However, *Tamarindus indica* and *Samanea saman* are highly recommended to be planted due to lower requirements in planting space, and relatively high environmental benefits ($98 and $91 per tree per year respectively). The most common problems found in this inventories are branches having excessive of end’s weight and poor tapers. This may be due to a lack of regular maintenance, especially in *Acacia mangium*. The Department of Highway can improve the health of the street trees by implementing a management plan to maintain the original street trees based on the considerations of road safety and pleasant environment.

Street trees in the district highways can greatly help to improve environmental quality in the city. For energy, they can help to save approximately 27,810 MWh per year from the reduction in electricity consumption. Regarding CO_2 reduction, it is about 333,844 tons per year. Moreover, the net air pollution reduction is about 5.6 tons per year. The annual rainfall interception or stormwater runoff reduction is approximately 12.34 million m^3 per year. These combined are accounted for approximately $11.64 million per year or about $40 per tree per year. It is obvious that the i-Tree Streets model is useful for calculating environment benefits produced by street tree community. Thus, it could be used as a tool to implement studies on this type of projects in other cities.

The Highway Department can improve the long-term sustainability of these street trees by selecting to plant native species with the ability to provide high environment benefits (Helfand *et al.*, 2006). Moreover, the agency should implement regular maintenance and monitoring activity to ensure the healthy existing trees and safety street trees. The future research is to work on the cost benefit analyses of street trees in order to study their net benefits.

Acknowledgement

Our thanks to Department of Highway in Thailand and Horticulture and Landscape Architecture school at Southwest University, Chongqing, China.

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(Received: 16 March, accepted: 16 April 2016)