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An Assessment of Ecosystem Services Provided by Public Street Trees in Bangkok, Thailand

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Natthanij Soonsawad

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ABSTRACT OF THE DISSERTATION

An Assessment of Ecosystem Services Provided by Public Street Trees
of Bangkok, Thailand

by

Natthanij Soonsawad

Doctor of Philosophy, Graduate Program in Environmental Sciences
University of California, Riverside, December 2014
Professor Roberto Sanchez-Rodriguez, Chairperson

This study focuses on the analysis of ecosystem services provided by green spaces in Bangkok, Thailand, as a potential tool to address urban and environmental problems there. The analyses are divided into two parts for achieving two objectives, 1) estimating the magnitude of ecosystem services provided by public street trees, and 2) examining the relationship between stable isotopic data of tree leaves and the environmental quality of Bangkok's streets. The findings could be used to identify tree management issues and tree species with high potential to mitigate environmental problems through enhancement of the ecosystem service provision. A combination of field inventories, interviews with related stakeholders, stable isotopic analyses, remote sensing, geographic information, and computational models were used in this dissertation.

For objective 1, the results indicate that citywide public street trees can provide environmental services, including reducing about sixty-five tons of air pollutants per

year; reducing 2.11 million m^3 of storm water runoff per year; reducing 13,000 tons of CO_2 per year; saving 8.29 million kWh of electricity per year; and storing 70,000 tons of carbon throughout the trees' lifetime. The total annual monetary benefit of these services is about $4.34 million. Interviews with public officials indicate that they have a moderate understanding of the ecosystem services provided by street trees. Major challenges in tree management are lack of personnel, conflicts with street vendors, sidewalk damage, and overhead wire problems. According to the opinions of street vendors, Bangkok Metropolitan Administration (BMA) should increase tree maintenance to reduce damage risks, and to improve tree health conditions.

Regarding the objective 2, the findings from studying the relationship of stable isotopic compositions of nitrogen in tree leaves, and factors such as air quality parameters could be useful in tracing air pollution levels, as well as determining which tree species can absorb high amounts of air pollutants. Tree species recommendations based on the two objective findings are: for reduced planting spaces (minimum width 1.2m), trees in the genus *Lagerstroemia* are highly recommended. For medium and broad sidewalk plantings (minimum width 1.8m), yellow poinciana (*Peltophorum pterocarpum*) and tamarind (*Tamarindus indica*) are the recommended species.

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Chapter 1

Introduction

1.1 Urban ecosystem and urbanization

Ecosystem services (ES) are the benefits people obtain from the ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; non-material benefits such as spiritual, recreational, educational, and cultural benefits; and supporting services such as nutrient cycling and soil formation (Millennium Ecosystem Assessment 2003). During the last decades, urban areas have become major centers of environmental disturbances and, at the same time, providers of public goods and services (Young 2010). Those two roles have been a relevant source of environmental change at local and global scales during the last decades, and the urban ecological footprint is expected to increase during this century (Grimm et al. 2008a). Therefore, a better understanding of the linkages between urbanization processes, socioeconomic factors, and ecosystems functions or services is needed to estimate more accurately current and expected impacts of urban growth on human well-being (Dobbs et al. 2011; Bastian et al. 2012); as well as to promote the design of sustainable cities (Lehman 2007). This is particularly important in developing countries where rapid and unbalanced urbanization often occurs.

Urban ecosystems develop in areas in which human population and built infrastructure concentrate (Pickett et al. 2001). Unlike other habitats, cities are sites of heavy resource consumption, and major sources of waste and environmental degradation (UK National Ecosystem Assessment 2011). Given the accelerated urban growth, the flows of energy and materials through the urban systems are expected to increase significantly during the next decades (Decker et al. 2000).

It took all of history until 1960 for the world urban population to reach 1 billion, but only twenty-six additional years to reach the 2 billion mark. The trend is expected to continue during this century, and some estimates indicate that the urban population will reach 6 billion during the next decades (Seto et al. 2010). According to estimates from the United Nations Population Division, two-thirds of the population in developing countries will be in urban areas by 2050, which is a substantial change from historical urbanization patterns. The total urban population in those countries was estimated to be 1.97 billion people in the year 2000, and is projected to increase to almost 4 billion people by 2030, and 5.26 billion people by 2050 (Montgomery 2008). Urban growth will be particularly intense in Asia, Africa, and South America, while urban population in high-income countries is expected to decline (Seto et al. 2010).

Rapid unsustainable growth is one of the two major threats to ecosystem services (Daily et al. 1997). Urbanization has driven environmental changes by increasing the demand of resources for human consumption, altering land use and land cover types, impacting hydrological systems, altering micro- and macro-climates, and reducing biodiversity habitats (Grimm et al. 2008a). Those changes influence ecosystem functions and ecosystem service provisions (Millennium Ecosystem Assessment 2005; Grimm et al. 2008b and Oudenhoven et al. 2012).

In this context, the challenge is to figure out how to efficiently implement urban growth patterns that are beneficial for society and the environment during the twenty-first century. An important step in that direction is to change the dominant perspective that urbanization is only detrimental to the environment for a more balanced approach that considers that well-planned cities can contribute to mitigate sustainability challenges (Grimm et al. 2008; Seto et al. 2010; Foley et al. 2005; Millennium Ecosystem Assessment 2005; Young 2010; and Dobb et al. 2011).

Urbanization constitutes a significant factor of cultural change, with an enormous influence on the configuration of social beliefs, economic growth, social organization, and well-being levels (Newman 1999; Martine et al. 2007; UK National Ecosystem Assessment 2011). Cities also play a key role in delivering public goods and services that positively affect ecosystems' health (Young 2010).

Policymakers, public officials, and citizens should acknowledge the importance of an urban ecosystem services provision as a mechanism to address environmental problems in the cities. That would not only help to avoid the loss of some of those services, but also to promote their maintenance, conservation, and development (Daily 2000; Costanza et al. 2006; Salzman et al. 2001). Failure to account for an ecosystem services provision in urban development plans could contribute to more environmental degradation and lower ecosystem resilience to natural and anthropogenic hazards (Bastian et al. 2012; Pickett et al. 2001).

In this regard, urban forests can play a significant role in improving environmental health, increasing community attractiveness and livability, as well as helping to balance economic growth with environmental quality and social well-being in metropolitan areas (Vargas et al. 2008; UK National Ecosystem Assessment 2011). For example, urban trees can aid in mitigating urban heat island effects, reducing summer heating costs, sequestering carbon, intercepting airborne pollutants, and reducing storm water runoff problems (Irani and Galwin 2003). Unfortunately, green spaces in metropolitan areas have been reduced at a rapid rate in developing countries with the consequent decline in the provision of ecosystem services (Kong and Nakagoshi 2005; Pham and Nakagoshi 2007; and Byomkesh et al. 2012).

To shed some light on the importance of urban forests, in this dissertation I estimate the magnitude and monetary benefits of ecosystem services provided by publicly maintained street trees; investigate social aspects of tree management; survey the perceptions of government officials and street vendors in the city with regard to the services provided by street trees; and map the distribution of green spaces across the metropolitan area of Bangkok, Thailand. The methods used to carry out the research were: fieldwork data collection on the status and characteristics of street trees; interviews and questionnaires with relevant agents; computational analysis of the collected data; and classification and analysis of remotely sensed imagery. Lastly, some recommendations are proposed based upon the findings with the aim of implementing a sustainable urban forest management program in Bangkok.

1.2 Conceptual framework in the studies of ecosystem services and their valuation

Although research on ecosystem services has been substantial during recent years, studies on how social processes can help to effectively manage ecosystem services have been limited (Cowling et al. 2008). Since human activities that impact local and global ecosystems are strongly influenced by the way society is configured at a particular location and time, the need for interdisciplinary and collaborative approaches are required to understand and tackle anthropogenic environmental degradation (Nissani 1997). A coupled human-environment system, or human ecology, conceptual framework is necessary for interdisciplinary research in this area (Marten 2001; and Turner II et al. 2003). Such a framework can be used to assess the vulnerability of people, places, and ecosystems in the face of environmental, socio-demographic and technological changes, and to investigate mechanisms to improve the human use of the common-pool of natural resources, their allocation, and access (Turner II et al. 2003; Prickett et al. 2001; Alberti et al. 2003; and Raven et al. 2010).

Additionally, some authors use resilience concepts to study how the socio-ecological system has the ability to absorb shocks or disturbances, self-organize, and adapt to emerging circumstances (Folke 2006; Carpenter et al. 2009; and Fisher et al. 2013). According to this approach, adaptive management is a useful tool for building resilience in systems that face high levels of uncertainty (Folke et al. 2002). This framework relaxes the conventional assumption that biological uncertainties are small, and that the human-environment system seeks stable and productive equilibrium in the use of resource stocks. The approach can be used to identify mechanisms or to design policies aimed at reducing risks and uncertainties through learning and adaptive attitudes development (Walter 1986).

Some of the commonly used methods to assess the qualitative or quantitative status of ecosystem services and observed trends include analysis of remotely sensed data, geographic information systems, inventories, ecological models, participatory approaches, and expert opinions (Ranganathan et al. 2008). The spatial scale of such assessments ranges from small communities to global studies. For instance, Constanza et al. (1997) grouped the Earth's ecosystem services into 17 categories, and evaluated their market and non-market values through the estimation of the willingness to pay individuals for such services.

According to Daily (2000), to describe and better manage the provision of ecosystem services, four elements should be considered: 1) identification of relevant ecosystem services; 2) quantitative and qualitative characterization of such services; 3) definition of the desired mix of services provisioning, and development of institutional safeguards to protect such assets; and 4) monitoring or evaluation of the implemented provisioning schemes. It is also recommended, after setting priorities and acquiring information on the status of the target ecosystem, to map out the distribution of the service providers and their associated threats to estimate potential impacts of changes in socio-demographic, institutional, and ecological factors.

Another comprehensive study of ecosystem services provided to human society was implemented in the Millennium Ecosystem Assessment (MA) (2005). According to the MA, to sustain, recover, or increase the delivery of such services, we must identify and understand their direct drivers, such as climate change, as well as the indirect factors that influence the quantity or quality of their provision, such as migration from rural to urban areas or macroeconomic policies (Millennium Ecosystem Assessment 2005). The linkages between the ecosystem, human well-being, and drivers of changes that affect an ecosystem services provision are presented in Figure 1.

The MA also recognizes that the actions that people take to improve ecosystem health are motivated not only from a concern for human well-being, but also from considerations about the intrinsic value of species and ecosystems. When key actors (e.g., government officials, or NGOs) recognize the value of the ecosystem services, they are more likely to support policies to increase the benefits market and non-market values received from such services, for instance, incentives for sustainable land management practices (Oudenhoven et al. 2012; MA 2005; and Mooney et al. 2004).

A combination of the aforementioned conceptual framework is used in this dissertation to study how green spaces, which are a relevant sub-habitat in the urban ecosystem, can provide solutions to environmental problems observed in the city of Bangkok.

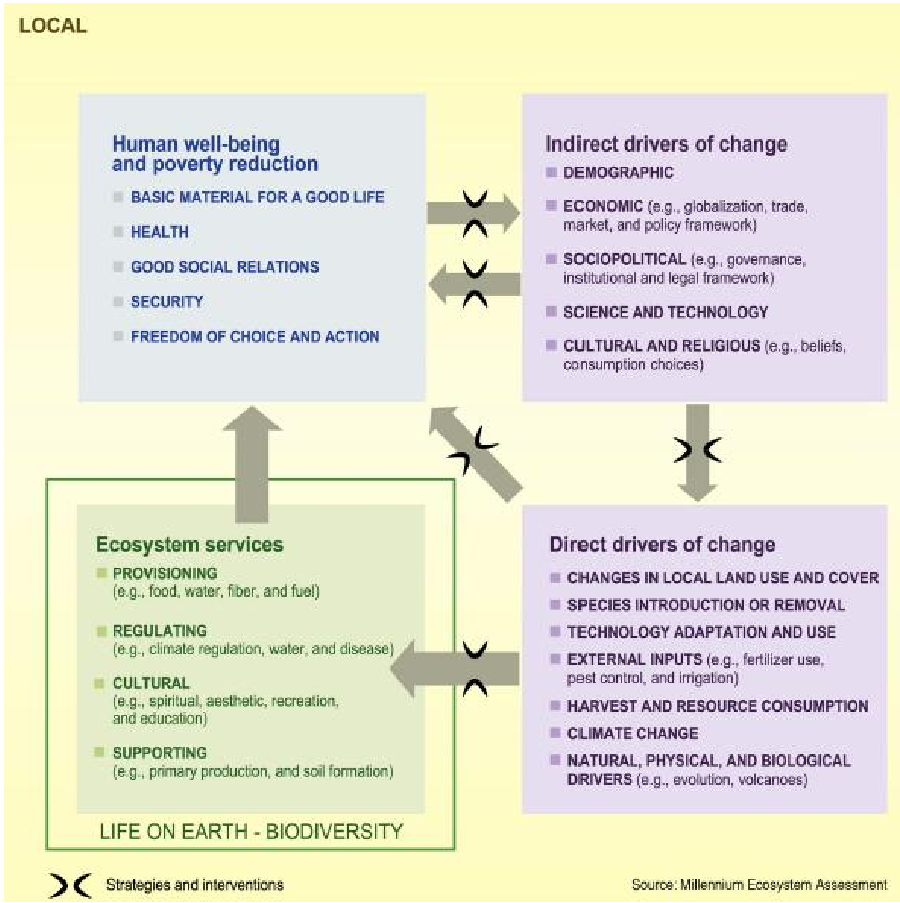

Figure 1 The Millennium Ecosystem Services Assessment Framework

1.3 Urban green spaces as providers of ecosystem services

Green spaces are areas that are partially or completely covered with grass, shrubs, trees, or other vegetation. Trees are a better option for planting than shrubs or other types of plants due to their low maintenance, long lifespan, and higher tolerance to climatic disturbances (Forest Research Center 2004; and Hostetler and Escobedo 2010). In urban areas with land degradation and environmental hot spots, ecosystem services can help mitigate such problems. Additionally, those services can enhance human well-being by reducing health hazards and improving livelihood security (Daily 1997; Millennium Ecosystem Assessment 2003; and Carpenter et al. 2009).

Green spaces in public open areas, and in privately owned areas can have a marked effect on improving the quality of the urban environment, enhancing biodiversity indicators, and increasing the provision of ecosystem services in the cities (Givoni 1991). Green spaces play important roles in providing not only environmental benefits, such as air filtering, flood control, noise control, carbon dioxide sequestration, or sewage treatment, but they also provide indirect advantages, such as economic, recreational, and cultural benefits to urban dwellers by improving public health and safety (Bolund and Hunhammer 1999; Brack 2002; Givoni 1991; and McPherson et al. 2011). It is beneficial for city planners to study changes in green spaces, and to manage them appropriately so that they are sufficient in size, diversity, and distribution to support a wide variety of ecosystem services for both wildlife and human populations (European Environment Agency 2010; Zhou and Wang 2011). A classification that can be helpful in keeping track of the ecosystem services dynamics can be found in the MA, which groups those services into provisioning, regulating, and supporting categories, with an additional class to account for cultural services that can be obtained from urban green spaces. The next subsections present a description of the MA categorization.

1.3.1 Regulation of local and global climate through carbon dioxide sequestering

Urban green spaces can cool down the temperature in cities and reduce energy consumption for heating and air conditioning through shading, evapotranspiration, reduction of the cooling effects of winds, and by decreasing the range of temperature variations during the summer and winter seasons (Bolund and Hunhammar 1999). Givoni (1991) asserts that plant species selection and their distribution around buildings can affect the sun and wind exposure to the buildings, as well as to improve indoor comfort and energy usage for heating and cooling.

A significant number of studies have documented how urban vegetation contributes to the reduction of heat island effects in many urban areas around the world (Bowler et al. 2010). The distribution of pervious and impervious surfaces in urban areas should be implemented to achieve comfort levels, depending on the area's climate. For instance, Myint et al. (2010) identified that a small area of impervious cover in a desert region, such as the Phoenix metropolitan area in Arizona, can increase the maximum air temperature despite the presence of abundant vegetation around the area. Bowler et al. (2010) found that urban parks can cool downtown areas and cities during the summer months by approximately 0.94ºC during the day. Additionally, a study of the monetary benefits provided by evergreen and deciduous trees in Canberra, Australia, estimated that the value of energy savings from Canberra urban forests was more than $1 million per year (Brack 2002).

On the other hand, urban vegetation can help in mitigating global climate problems. As plants sequester carbon dioxide for use in the photosynthetic process, enhancement of green spaces can reduce CO_2 emissions generated in city areas. It is worth noting that a study by Hostetler et al. (2010) indicates that highly maintained lawns and trees sequester much less CO_2 than more natural areas with little maintenance. A study of the role of urban trees in Brooklyn, Washington, D.C., and Baltimore reveals that 610,000 trees with a canopy covering around 11.4% of the city area can store approximately 172,000 metric tons of carbon, at an estimated value of $3.5 million. The study indicates that management strategies can help to improve air quality and increase carbon sequestration from urban trees (Nowak et al. 2002).

1.3.2 Regulation of air quality

Vegetation can also improve air quality by filtering and reducing air pollutants and particulates, such as nitrogen dioxide, sulfur dioxide, ground-level ozone, total suspended particles (TSP), and particulate matter 10 microns or less in size. Such pollutants have been known to cause asthma and other respiratory diseases (American Forests 2002; Shan et al. 2007). Gaseous air pollution can be removed through plant uptake via leaf stomata, or via plant surface, but plants can also intercept airborne particles. The intercepted particles are re-suspended into the atmosphere, washed off by rain, or dropped to the ground with leaf and twig fall (Nowak et al. 2006a). Trees have a higher filtering capacity than bushes or grasslands because they have more leaf area and taller stems (Givoni 1991). As each type of tree has different characteristics and adaptation levels to different climates, tree selection is a key to successfully improving the urban green infrastructure (Thaiutsa et al 2008). For example, a study by the American Forests (2002) estimated that the urban forest in Charlottesville, Virginia, could remove approximately 88.6 million pounds of O_3, PM10, NO_2, and SO_2 per year. The economic value of such airborne pollution removal is estimated to be $218 million per year.

1.3.3 Provision of water drainage systems

Green spaces also contribute to reduce floods and to mitigate the reduction of groundwater tables generated by the presence of impervious surfaces and high extraction rates of water. For instance, in Stockholm, Sweden, vegetation was used to improve rainwater drainage, which helped to reduce substantially maintenance costs of storm water drainage systems (Bolund and Hunhammar 1999). With regard to flood protection, a study in Germany by Silva et al. (2006) used a plant-based surface system (PBSS) approach to increase the capacity of impervious urban surfaces to reduce runoff volumes, for example, along railway tracks. Bryant (2006) shows that green spaces that are configured as drainage networks can be used also as a conservation tool to buffer surface water and protect riparian species from the influences of adjacent developed landscapes.

1.3.4 Provision of sewage treatment

Wetlands can assimilate a large amount of nutrients, such as nitrogen and phosphorous, thereby reducing sewage treatment costs. They also can reduce eutrophication from nutrient discharge (Bolund and Hunhammar 1999). Vymazal et al. (2007) showed that vegetation can remove nitrogen and phosphorus from inflow loading. Additionally, constructed wetlands have the ability to remove metals, which is particularly important in urban areas with high concentrations of industrial facilities.

Given the wide spectrum of nutrient removal capacities from different species, various types of constructed wetlands could be combined to exploit the specific advantages of the different wetland configurations. For example, in Argentina a constructed wetland was built to treat wastewater containing metals (Cr, Ni, Zn), and nutrients from a tool factory. The results revealed that the wetland efficiently decreased the average concentrations of metals and most nutrients in water.

1.3.5 Provision of recreational and cultural values

In terms of recreational and cultural values, green spaces such as parks and playgrounds can provide aesthetic benefits and fulfill a variety of social and psychological needs of the residents. For example, those places can be used for social meetings, recreational activities with kids, walks to reduce stress, etc. Since green spaces help to increase the physical and psychological well-being and, hence, the quality of life of urban citizens, those spaces are highly valued ecosystem services in Stockholm, Sweden (Bolund and Hunhammar 1999). Parks may also help in creating a "community feeling" in neighborhoods. The socio-cultural functions of urban parks can be especially important in lower-income areas, as they can provide residents opportunities for recreation and entertainment (Givoni 1991). There are also other benefits from green spaces that can be identified in many cities around the world, such as providing food production areas, buffering noise pollution, improving health conditions, and providing public safety.

1.4 Ecosystem services in urban areas of developing countries

Problems in urban areas of developing countries extend from poverty to industrial pollution (Steffen et al. 2005). Seeking alternatives to address some of the major environmental and social challenges in those regions, including reducing the consumption of energy, non-renewable materials, and pollution emissions requires the inclusion of sustainability principles within the urban design, and management processes to orient the driving processes of formal and informal urban growth towards adequate levels of ecosystem services across the cities (Millennium Ecosystem Assessment 2005; and Lehman 2007).

Ecosystem services provided by urban trees and lower vegetation are promoted and used in developing countries in different parts of the world. Many cities in Latin America, such as Mexico City; Santiago, Chile; and Sao Paolo, Brazil, have integrated trees and other urban vegetation in their programs, policies, and projects aimed at improving environmental conditions (Escobedo et al. 2008). In Africa, trees have been used to control erosion in Nampula City, Mozambique (Carter 1993), and their capacity to sequester CO_2 was assessed in Tshwane, South Africa (Stoffberg 2010). As for some Asian cities, in Guangzhou and Beijing, China, and Kathmandu, Nepal, urban trees and vegetation were used as alternative ameliorative methods for removing some air pollutants, regulating microclimates, as watershed catchment covers, and as recreational facilities for urban dwellers (Carter 1993; Jim and Chen 2008).

1.5 Background of Bangkok's urban forest conditions and policies

As mentioned before, green spaces are important resources that can provide environmental, social and economic services that are especially important in urban areas. Although Bangkok, Thailand, has several policies related to green space enhancement, both from the city government and NGOs, rapid and unbalanced urban expansion makes the city a hotspot of environmental degradation. In this regard, green spaces, especially trees, can help to mitigate environmental problems, and to improve the quality of life of the city's residents. Bangkok has increased its park area over time. In 2000 Bangkok had about 19 square miles of public parks, or 1.2% of the total land area (Thaiutsa et al. 2008); while in 2012, that area expanded to about 26 square miles (BMA 2012). On the other hand, the number of trees in the city was estimated to be around 200,000 in the year 2000 (Thaiutsa et al. 2008).

Two main issues motivate this study. Firstly, new urban infrastructure construction (e.g., condominiums, roads, housing estates, and sky trains) has affected the density and connectivity of green spaces, including street trees, as the city is continuously expanding. As most of the areas in Bangkok are developed lands, street trees are needed to provide ecosystem services to reduce the impacts from environmental problems. Unfortunately, a major overhaul of the maintenance activities for public street trees is necessary to improve their health, and to reduce affectations to the electricity distribution network, problems with streets vendors, as well as damages to private properties. Secondly, trees provide more environmental benefits and require less maintenance than shrubs or other types of green spaces. Although there was a complete street tree inventory of Bangkok in 2000, there is no study that quantifies or values the provision of ecosystem by trees in the city to date. It is hoped that the information generated from this study can be beneficial to policymakers in the implementation of sustainable city planning and development, as well as in the selection of trees that could provide higher environmental and economic benefits.

Relevant guidelines and policies on street tree enhancement in Bangkok are derived mainly from three documents: “The Master Plan of Bangkok Green Area,” the “Sustainable Measures to Enhance and Manage Green Spaces in the Communities,” and the “Action Plan on Global Warming Mitigation.” The Master Plan aims to increase the density of green spaces to meet the World Health Organization standard of 9 m^2 of green space per capita (Thaiutsa et al. 2008), especially in the form of parks or other types of publicly accessible green spaces for recreation (e.g., street tree gardens, or riverside gardens). Such a plan also provides the action and implementation directives for the city government or Bangkok’s Metropolitan Administration (BMA), and offers guidelines on how to develop more green spaces. For example, it suggests that the BMA request assistance from the business sector, governmental agencies, schools or temples to increase the number of green spaces on their properties, such as areas between buildings or street setbacks (Forest Research Center 2003). The second document provides guidelines for implementing laws and economic instruments to maintain or enhance green spaces in certain zones of the city, criteria to select appropriate tree species for planting on the streets, as well as listing examples from cities in other countries of practices that could be replicated in Bangkok (Forest Research Center 2004). The action plan on Global Warming Mitigation 2007-2012 is focused on expanding the green space surface by planting more trees. It planned to double the number of trees in public areas by the end of 2012, and had plans for creating new public parks, increasing green space per capita, and providing incentives to enhance privately own green spaces (Bangkok Metropolitan Administration 2007). Unfortunately, to date there is no information on the result of the activities implemented under that plan.

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Chapter 2

Research design

2.1 Study site: Bangkok Metropolitan Area, Thailand

Bangkok, the capital of Thailand, covers an area of 1,569 km^2. It is located between latitude 13°45′8″N and longitude 100°29′38″E in the central region of the country. According to the 2010 census, Bangkok has a high population density of about 5,260 persons per km^2, which represents a considerable increase from the estimates generated by the 2000 census data that showed a population density of around 4,050 persons per km^2 in the city. The 2010 census also estimated that Bangkok's population was around 8.25 million people, which represents about 12.6% of the country's population (National Statistical Office of Thailand 2010). That number increases to more than 10 million city dwellers, if estimates of unregistered population are included (Thaiutsa et al. 2008).

The city, which is located in a tropical monsoon-influenced climate, presents significant environmental issues, such as urban heat island (UHI) problems, land subsidence, and relatively high concentrations of air pollutants. Also, the city is located in a flood-prone area, as evidenced by the major flood of 2011, which severely impacted the city and the economy of the entire country.

Two major air pollutants in Bangkok are particulate matter with a diameter of 10 microns or less (PM10), and total suspended solids (TSP). High levels of PM10, which are commonly observed near roadsides, are mainly generated from the rising number of vehicles in the city. Additionally, ground-level ozone (O_3) problems have been detected in residential areas located away from major highways (Bangkok Metropolitan Administration 2007). Ozone pollution levels have been observed to increase under the presence of UHI problems, climate variability, and global warming dynamics (Bangkok Metropolitan administration, Green Leaf Foundation, and United Nations Environment Programme 2009).

Regarding the urban heat island problem, a study by Taniguchi (2006) of meteorological data collected during a 50-year interval, found that the magnitude of surface warming, evaluated from subsurface temperatures in Bangkok, was 1.7^{o}C. According to that study, the magnitude of the surface warming has been higher in the center of the city than in the 25 suburban areas of Bangkok. Another study of UHI effects in Bangkok, implemented by Hung et al. (2006), identified a daytime UHI intensity of 8^{o}C, and a nighttime UHI intensity of 3^{o}C in February 2002. These figures are relatively high in contrast with the results estimated in two other cities – Manila and Ho Chi Minh City – located in similar climate conditions.

Due to the presence of a thick, soft clay layer on the ground surface, and land subsidence problems, Bangkok is very prone to flooding events. Land subsidence is mainly a result of over-extraction of groundwater resources, and by the lack of land use zoning regulations to manage construction projects around the city. The suburbs, located in the southeast, southwest, and eastern regions of the city, have experienced land subsidence at a rate of 20 to 30mm per year (Phien-wej, Giao, and Nutalaya 2006). On the other hand, increases in impervious surfaces associated with the rapid urbanization observed in recent decades, have exacerbated the effects of heavy rains on flooding events and their intensity (Bangkok Metropolitan Administration et al. 2009).

2.2 Objectives

Given the potential relevance of green spaces to mitigate some of the current urban challenges in Bangkok, this research is focused on the following two objectives:

1) To quantify and value-relevant ecosystem services provided by street trees in the city, and to assess the potential use of public street trees to increase ecosystem services provision.

2) To study the relationship between stable isotopic data of tree leaves and the environmental quality of Bangkok's streets to determine the best tree species for mitigating air pollution and to improve the estimation of the benefits from air pollution reduction.

2.3 Methodological framework

The stated objectives are the basis of the analyses presented in chapters 3 and 4 of this dissertation. The outcomes are expected to provide relevant information to support policy recommendations on tree species selections that can help to increase the provision of ecosystem services while reducing maintenance costs, and to provide evidence of the monetary benefits of ecosystem services from street trees to promote more planting investments.

2.3.1 Assessing the potential use of public street trees to provide ecosystem services

There are several types of approaches to quantify and value the provision of ecosystem services that depend on the spatial scale of the analysis (e.g., from a city to a small community or a public park). Some commonly used tools in ecosystem services assessments are analysis of remotely sensed data, geographic information systems (GIS), inventories, ecological models, participatory approaches, and expert opinions (Ranganathan et al. 2008). To generate useful information to effectively manage and safeguard the provision of ecosystem services, biophysical, economic, and social aspects should be considered in the analysis (Cowling et al. 2008; de Groot et al. 2010; and Van Oudenhoven et al. 2012). I incorporated factors from those three aspects within the study of ecosystem services provided by public street trees in Bangkok, Thailand.

Biophysical/ecological assessment

To assess environmental benefits provided by the street trees of Bangkok in this study, I used the i-Tree Streets software application. In the first stage, I used high-resolution satellite imagery, vector data representing the street network in the city, and Google Earth imagery to estimate the total number of trees in the city. In the second stage, I inventoried species and the morphological characteristics of 2,500 randomly selected street trees in Bangkok. The collected information was incorporated into the i-Tree Street model to estimate the quantity and quality of the ecosystem services provided by street trees in the study area. To improve the i-Tree estimates, adjustment factors were used to control for climatic and environmental differences observed between the reference city and Bangkok.

Biophysical assessments can provide useful information to orient planning and protection strategies aimed at enhancing the quality and magnitude of ecosystem services generated within a particular region. Such assessments typically include mapping the distribution of the ecosystem services, their flows and spatial linkages, and the effects that anthropogenic and natural disturbances exert on the observed dynamics (Cowling et al. 2008). For example, Ward and Johnson (2007) use geospatial tools for mapping, analyzing, and reporting urban forest information. In addition, there are computational models specifically developed to calculate the ecological benefits provided by urban green spaces. One example is BUGS (benefits of urban green space), which has been used in several European cities to evaluate the benefits provided by urban green spaces (De Ridder et al. 2004). InVEST is a tool that allows the mapping and valuation of the provision of ecosystem services, based on spatially explicit data (Tallis et al. 2011). Another modeling software to study the benefits of urban forests that has been used in several metropolitan areas around the world is the i-Tree suite developed by the USDA Forest Service (American Forests 2012). The suite contains an application called i-Tree Streets that is specifically designed to estimate environmental and aesthetic benefits of urban street trees. Specifically, i-Tree Streets estimates energy savings, air pollution reduction, carbon dioxide sequestration, carbon storage, storm water runoff reduction, and aesthetic values through the analysis of field data on the health and development conditions of representative trees across the city's road network.

The modeling software is based on tree growth and benefit parameters associated with predominant urban tree species identified in sixteen cities located in the same number of climate zones. That feature allows users to select a reference city that approximates the climate and environmental conditions of their study areas (McPherson 2010). Analyses based on i-Tree have been implemented in American cities, such as Los Angeles, California, and St. Paul, Minnesota (E. G. McPherson et al. 2011; and Jorgensen 2010), as well as globally in regions that include Lisbon, Portugal; Shenyang, China; and Toronto, Canada (Soares et al. 2011; Ning, Wei and Xingyuan 2011; Millward and Sabir 2011).

Economic valuation

The i-Tree Streets application was also used to calculate the monetary benefits of environmental services of street trees, including air pollution reduction, storm water runoff reduction, energy saving, and carbon sequestration. The economic benefit outputs from the model will be adjusted to the Bangkok context using the GDP per capita of Bangkok.

In general, the economic techniques used for non-market valuation of urban forests are hedonic price, travel cost, contingent valuation, and tree valuation (Gregory McPherson 1992; Donovan and Butry 2010). Monetary benefits can be assessed directly or as avoided costs. The avoided cost method has been used to measure the benefits of urban forests since the loss of ecosystem services involved the economic costs such as avoidance of heating and cooling, and avoidance of sewage treatment capacity due to reduced runoff (Gregory McPherson 1992; Escobedo et al. 2008; Gómez-Baggethun and Barton 2013). The i-Tree suite model uses avoided cost in assessing the economic value of ecosystem services of urban forests (American Forests; Gómez-Baggethun and Barton 2013).

Social assessment

In this study, I developed questionnaires and interviewed twenty-five district public officials of Bangkok in charge of tree management about issues related to maintenance, species selection, and their perception of ecosystem services provided by street trees. Furthermore, I interviewed about 190 street vendors in commercial areas of Bangkok about their opinions on tree planting and maintenance, including recommendations for urban forest management, and their perceptions of street tree ecosystem services.

To effectively impact local policies to achieve sustainability, land use planning should engage the community through a participatory approach to balance ecosystem service potentials and social demands (Valencia-Sandoval, Flanders, and Kozak 2010). Thus, social assessment is important and should provide knowledge on roles, needs, values, and perception of stakeholders, including individuals and organizations in the study areas (Cowling et al. 2008; and de Groot et al. 2010). The important aspects include social capital of management organizations, preferences, and incentives for behavioral change (Cowling et al. 2008). In addition to the physical conditions and urban form that influence urban trees, the study of policy factors, including regulation and strategies in management, can also affect urban forest structure and canopy cover (Heynen and Lindsey 2003; Conway and Urbani 2007).

The study of social aspects on ecosystem services can be undertaken through interviews and questionnaires. For example, interview surveys were used to determine municipal urban forest management in Santiago, Chile (Escobedo et al. 2006). A similar study was conducted to assess the value and quality of street trees planted in various areas of old Klang town, Selangor, Malaysia. Interviews and questionnaires targeted toward local authorities, the public, and related stakeholders were used to determine problems and conflicts in management. Researchers presented potential solutions for overcoming some of the town's issues (Kadir and Othman 2012).

2.3.2 Studying to examine the relationship of $\delta^{15}N$ and $\delta^{13}C$ of urban street tree leaves and environmental quality variables

This study investigated the variation in nitrogen and carbon isotope abundances or isotopic signatures ($\delta^{15}N$ and $\delta^{13}C$) in different species of Bangkok's street trees in six land use zones. The relationships of the trees' leaves with regard to nitrogen and carbon isotopic composition and air quality parameters, including NO_2, PM 10, ground level ozone, SO_2, VOC, and traffic volume were analyzed using principal component analysis (PCA). PCA is suitable for studying the relationship of several variables, as it reduces the dimensions of datasets. The benefit of this research is identification of tree species that absorb the most air pollutants, and to promote planting of the respective species on streets with poor air quality. In addition, the isotope compositions from some tree species can possibly be indicators of environmental pollution.

Stable isotopes in ecosystem analysis

The measurement of stable isotopes is used widely in ecosystem analysis because it helps us to understand element cycles and can be tracers (sinks-sources) of molecules of interest (Peterson and Fry 1987; Miljević and Golobocanin 2007). Stable isotope ratios can also be used as indicators of pollution impacts (Hofmann et al. 1997; Stewart et al. 2002; Savard 2010; and Thomas et al. 2013) or to study physiological processes of plants (Marshall, Brooks, and Lajtha 2007), and biogeochemical processes (Fox and Papanicolaou 2007; Werner et al. 2012). The change in isotopic compositions of materials can be detected by mass spectrometers (Peterson and Fry 1987). The mass spectrometer can create spectral information of components and can be combined with specialized instruments. For instance, isotope ratio mass spectrometry (IRMS) measures natural isotopic compositions as it chemically differentiates identical compounds based on their isotope content (Rodrigues et al. 2013).

The street tree leaves were used in this study in the measurement of isotopic signatures. The collected leaves were air-dried and oven-dried to remove the humidity at 60°C for 24 hours. The dried leaves were ground and weighted for about 2mg. Each sample was placed in a tin capsule before being analyzed for $\delta^{15}N$ and $\delta^{13}C$ by IRMS. The measurements of $\delta^{15}N$ and $\delta^{13}C$ of the tree leaf samples were carried out through the elemental analyzer, one of the inlets in IRMS. $\delta^{15}N$ and $\delta^{13}C$ were calculated according to the equations:

$$\delta^{15}N\ (‰) = \{(R_{sample}/R_{standard}) - 1\}\ {*}1000 \qquad (1)$$

$$\delta^{13}C\ (‰) = \{(R_{sample}/R_{standard}) - 1\}\ {*}1000 \qquad (2)$$

where R is the ratio of $^{15}N/^{14}N$ and $^{13}C/^{12}C$, respectively. These values were measures of the amounts of heavy and light isotopes in a sample. Increases in δ values indicated increases in the heavy isotope content and a reciprocal decrease in the light isotope contents (Peterson and Fry 1987; Heaton 1986). The δ values of each of the standards have been defined as 0‰. $\delta^{15}N$ and $\delta^{13}C$, and these values were measured relative to the equivalent nitrogen gas and VPDB (Vienna-PDB) standard, respectively (Kendall and Caldwell 1998).

Principal component analysis (PCA)

PCA is a useful statistical technique used in analyzing data, especially for identifying patterns in data of high dimension and finding the similarities and differences of data. Thus, the major advantage of the PCA is obtaining the reduced dimensions of data, as shown in some of its applications; for example, image compression or face recognition (Smith 2002). As PCA can reduce multiple dimensions of data to a new set of variables, called principle components, it gives a linear combination of the original set of data.

PCA is generally written as:

$$PC_i = l_{1i}X_1 + l_{2i}X_2 + \ldots + l_{ni}X_n \quad (3)$$

where PC_i is the order of principal component and l_{ni} is the loading (correlation) of the observed variable X_n (Ul-Saufie et al. 2013).

PCA has been used in different fields. In environmental sciences, PCA was employed to determine the possible major sources of air pollution in eight air quality monitoring stations in Malaysia. The findings from this analysis showed that the emission sources were motor vehicles, aircraft, industries, and highly populated areas (Dominick et al. 2012). PCA also was used to improve prediction of PM10 concentration in Negeri Sembilan, Malaysia, when it is combined with multiple linear regression (MLR) and feed-forward back propagation (FFBP). The finding showed the three principal components from seven variables related in PM10 variability (Ul-Saufie et al. 2013).

In this study, the mature tree leaves were randomly sampled using about three to five leaves per tree, per species for further $\delta^{15}N$ and $\delta^{13}C$ analysis. The sampling sites were stratified into six major land use zones: 1) agricultural zone (AZ); 2) low-density residential zone (LDRZ); 3) high-density residential zone (HDRZ); 4) commercial zone (CZ); 5) Thai identity and cultural conservation (ICZ); and 6) industrial zone (IZ).

PCA was carried out using XLSTAT, the extension in Excel, on twenty-five variables of dataset, including isotopic signature of carbon and nitrogen, air quality, environmental benefit, and other related variables. Correlations between variables, eigenvalue, percent variability of each factor, correlation between factors, and variables were obtained from the analysis.

2.4 References

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Chapter 3

Assessment of ecosystem services provided by public street trees in Bangkok, Thailand

Abstract

Knowledge of environmental, economic, and social benefits provided by urban green spaces, as well as current and potential threats to such provisions, is essential to achieve sustainable management of urban areas. This study estimates the magnitude and value of ecosystem services provided by publicly maintained street trees in Bangkok, Thailand, considering the three above-mentioned aspects. The studies are divided into three parts: 1) environmental service estimation; 2) monetary valuation of those services; and 3) studies on the perceptions of two groups of urban actors, namely district agricultural officers (forest managers) and street vendors, with respect to the ecosystem services provided by street trees. The results include a comparison of the differential capacity of street tree species, in terms of ecosystem services provision and maintenance requirements, recommendations for species selection, and recommendations from urban forest managers and street users to improve tree planting and maintenance activities.

3.1 Introduction

Developing countries in which rapid urbanization often occurs, commonly experience substantial reductions in green spaces and a corresponding decrease in ecosystem services provisions (Kong and Nakagoshi 2006; Uy and Nakagoshi 2007; Byomkesh, Nakagoshi, and Dewan 2012). It is particularly useful for city planners to have timely access to accurate information on the dynamics of health and distribution parameters of urban green spaces, and of their drivers of change. Such information is essential to manage the size, diversity, and distribution of green areas to enhance their ability to support the variety of ecosystem services delivered to both wildlife and human populations (European Environment Agency 2010; Zhou and Wang 2011). Unfortunately, there is still work to be done to improve the awareness of urban development officials about the relevance of ecosystem services obtained from urban forests, even in developed areas. For example, one study in Finland found that two-thirds of planning professionals are not familiar with the ecosystem services concept (Niemelä et al. 2010).

For tree management to be a sustainable source of ecosystem services, urban forest managers should select the appropriate species, considering not only aesthetic aspects and the expected environmental benefits, but also the conditions in the planting area (Zipperer 2008). Adequate execution of the selection of tree species can also help to reduce potential conflicts with urban dwellers affected by green space enhancement activities (Kadir and Othman 2012). Additionally, knowledge and understanding of how to maintain healthy trees, and collaboration initiatives between managers and users to maintain urban forests are important (Dwyer et al. 2000).

Although a complete street tree inventory was implemented in Bangkok in 2000, to date, there are no studies that quantify the ecosystem services provided by trees in that city. This chapter attempts to cover that information vacuum by assessing the use of public street trees as a mechanism to create a sustainable urban ecosystem in Bangkok. To that end, the chapter is integrated by three sections: estimation of the environmental services and their monetary benefit generated by public street trees; assessment of policies, challenges, and perceptions by city public officials with respect to street tree management; and assessment of the awareness and opinions of street vendors with respect to ecosystem services and management of urban trees. It is hoped that the policy implication from this study will be beneficial to encourage and orient sustainable management practices, and selection of tree species with a potential to increase the environmental quality and the flow of economic benefits from green assets, as well as to address identified issues faced by affected city dwellers.

3.2 Environmental and economic benefit assessment of public street trees

This assessment of ecosystem services from public street trees was conducted using four methods: 1) an analysis of remotely sensed data, 2) geographic information system, 3) a field inventory, and 4) a computational modeling. The steps followed to conduct this study are: pre-sampling, field inventory, reference city selection, quantification and valuation of ecosystem services using i-Tree Streets software, and corrections to the results to make them more specific to Bangkok's environmental and climate context. Those steps are described in the following subsections.

3.2.1 Methodology

Pre-sampling

The pre-sampling step was implemented to estimate the number of street trees in each land-use zone in Bangkok as a prerequisite to the field inventory. The Bangkok area was categorized into five zones, namely agricultural, low-density residential, medium-density residential, high-density residential, and the commercial and Thai identity and cultural conservation zone. Random sampling was conducted to select 3% of the street segments located within each zone in the city (i-Tree 2011). To quantify numbers of trees in those randomly selected segments, Google Earth was synchronized with the vector data of the street network using ArcGIS. Trees in each sampled segment were counted to generate sample estimates that could be used to approximate the number of trees in the whole city. Figure 1 shows the randomly selected street segments in the high-density residential zone, and an example of a street-view image from Google Earth corresponding to one of those selected random segments automatically displayed after synchronizing ArcGIS with the Google Earth engine. The numbers of public street trees sampled in each zone were then calculated according to the proportion of the street length present in each zone with respect to the city road network.

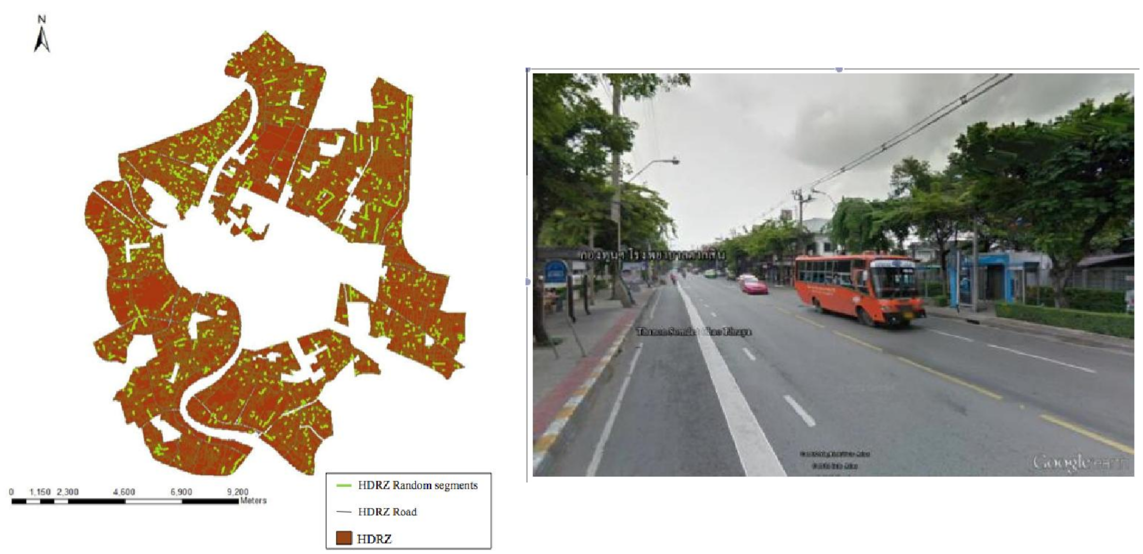

Figure 1 Randomly selected segments created in ArcGIS (left), and one example of a sampled street segment in Google Earth Street View (right) synchronized by Arc2Earth

Tree inventory

During the summer of 2012, a random sample of 50 street segments (each was 240 meters in length) in Bangkok was selected to conduct an inventory of 2,548 public street trees. In each segment, I collected data on tree species, diameter at breast height (DBH), crown width, crown height, tree height, foliage and wood conditions, conflicts with utility wires, and pavement damages.

Reference city selection

The selection of a reference city is needed before calculating tree environmental benefits as the i-Tree Streets model was developed using tree growth and geographic data from sixteen United States cities representative of a similar number of climatic regions. The selection of a reference is based on similarities, in term of species composition, heating degree-day, cooling degree-day, and annual precipitation (McPherson 2010). Based on the above-mentioned criteria, Bangkok's reference city is Honolulu, Hawaii, which is representative of cities in tropical climatic zones. However, given that Honolulu has highly different precipitation rates, from Bangkok, it was necessary to implement adjustment procedures to the estimated environmental benefits. Such adjustments are described later in this chapter.

Analysis of environmental benefits of street trees

The amount of environmental benefits that cities will gain from street trees depends on the number of trees, species, and age composition. This amount reflects the monetary benefits that cities can save through time. Data collected from the field were manually input into the i-Tree Streets model to perform the analysis.

Air pollution removal is calculated from the sum of reductions of air pollutants (O_3, NO_2, SO_2, PM10) deposited on tree leaf surfaces, as well as the amount of reduced emissions of NO_2, SO_2, PM10, and VOCs from reduced electricity use. The pollutant flux (F, in g/m^2) can be estimated as $F = V_d * C$ where V_d (in m/s) is the deposition velocity and C (in g/m^3) is the pollutant concentration (Nowak, Crane, and Stevens 2006).

The rainfall interception by tree leaf and stem surface is calculated by the summation of canopy surface water storage and evaporation from tree canopy surfaces (Xiao et al. 1998). To calculate canopy surface storage, the model also requires tree architecture information (such as dimension and leaf surface areas) and meteorological data (such as precipitation, air temperature, relative humidity), as input parameters (Xiao and McPherson 2002).

Reductions in CO_2 are estimated from the summation of trees' direct sequestration of CO_2 and avoided power plant emission (from reduction of electricity usage from air conditioners), subtracted from maintenance emission. In addition, as trees sequester CO_2, they accumulate it as woody biomass as they grow over time. This refers to carbon storage (McPherson 1998), which is calculated over the tree's lifetime, or about 40 years.

3.2.1.5 Adjustment of environmental benefit and economic values

As Bangkok has different weather (especially precipitation), environmental quality, and income levels with respect to Honolulu, the adjustment of the estimates of environmental and monetary benefits of street trees derived from i-Tree Streets modeling is necessary. For adjusting the environmental benefit values, data collected from Bangkok, including precipitation, air quality, and emission from electricity generation, corresponding to the year of data collection (2012), were compared with the Honolulu data used in the i-Tree Street model. Regarding the adjustment of the monetary benefits of the environmental services, the model estimates are adjusted using the GDP per capita of Bangkok and Honolulu as a basis to generate the adjustment factor (Robinson 2007).

3.2.2 Results

Resource structural analysis

Street tree population is estimated around 180,000 trees, with a standard error of 13,000 trees. The most dominant species is narra (*Pterocarpus indicus*), accounting for 24% of the population (43,000 trees ±8000), followed by crapemyrtle trees (*Lagerstroemia* spp.) with about 15%. Table 1 shows the species that contribute more than 1% to the composition of the tree population. The complete list of species and number estimation is presented in appendix 1-A.

Regarding the tree health status, the majority of public street trees (about 80%) have good wood conditions. Nevertheless, the data indicates that *Tabebuia rosea*, and Kamani or *Calophyllum inophyllum* have the highest proportions of poor and dying wood conditions. About 44% of street trees have good foliage conditions, but it was detected that around 50% of the trees of the species *Swietenia macrophylla*. *T. rosea* have a high proportion of poor and dying leaves. Complete information on wood and leaf condition of trees by species is listed in Appendix 1-B and 1-C respectively.

Table 1 Species distribution of Bangkok public street trees

Species	Tree count	Standard error	Percent
Pterocarpus indicus	43,004	±8347	23.81
Lagerstroemia spp.	26,246	±5277	14.53
Cassia fistula	20,209	±9752	11.19
Broadleaf Evergreen Medium Other	13,556	±4699	7.51
Broadleaf Evergreen Small Other	10,652	±3938	5.90
Polyalthia longifolia	10,368	±8105	5.74
Tabebuia rosea	9,144	±2680	5.06
Mimusops elengi	8,297	±4315	4.59
Swietenia macrophylla	8,091	±4580	4.48
Peltophorum pterocarpum	7,773	±5,411	4.30
Tabebuia aurea	6,958	±3,888	3.85
Canophyllum inophyllum	3,624	±3600	2.01
Tamarindus indica	3,404	±2150	1.88
Elaeis sp.	2,008	±1165	1.11
OTHER SPECIES	7,279		4.03
Total	180,613	±13,475	100

The importance value (IV) is determined by the average of the percentage of the number of trees, the percentage of total leaf area, and the percentage of canopy cover. The most abundant tree species, *P. indicus,* has the highest IV (26) followed by *Lagerstroemia* spp. (14), golden showers or *Cassia fistula* (9), and yellow poinciana or *Peltophorum pterocarpum* (9). The estimated citywide canopy cover of public street trees is about 7 km^2, accounting for about 0.45% of Bangkok land area (1,569 km^2). The importance values by tree species including % of total leaf area and canopy cover are in Appendix 1-D.

With regard to the tree age distribution, represented by DBH, about 53% of street trees have DBH between 15 and 30cm. There are about 30% of small trees, falling into the 0 to 15cm diameter range. These groups require special attention from the city. Among all the street tree species, golden shower (*C. fistula*) and Spanish cherry (*Mimusops elengi*) make up a relatively high proportion of small trees (75% and 60% respectively).

There are also conflict issues from sidewalk damages and overhead utility wires caused by street trees. Species that cause sidewalk lifting and cracking problems (heaves greater than 1.5 inches) with around 30% of their population are *Ficus religiosa* and *Ficus benjamina.* Appendix 1-E shows the information on the proportion of sidewalk damage of each species. Most of the street tree species generate conflicts with overhead utility wires because the street sidewalks of Bangkok are narrow, and most utility wires are above ground. In the collected data, the species that does not affect utility wires is *P. longifolia,* because it has a narrow canopy of about 1 m^2. The information on the proportion of utility wire conflicts per species is in Appendix 1-F.

Environmental service and economic benefit analyses

The adjustment factors for environmental services of Bangkok were computed and used in adjusting the results from i-Tree Street model (Table 2). For adjustment factors of monetary benefits of environmental services, Bangkok GDP per capita in 2010 of $28,000 (Mckinsey & Company 2014) was divided by the Honolulu GDP per capita of 2010 of $48,169 (Knoema 2014), making the adjustment factor equal to 0.5813.

Table 2 Adjustment factors for Bangkok environmental and weather data, based on Honolulu data

Parameter	**Precipi-tation[1] (mm/y)**		**Air pollution concentration[2] (mg/m^3)**								**% Emission from electricity generation[3]**					
			SO_2		NO_2		O_3		PM10		CO_2		NO_x		SO_2	
	H	B	H	B	H	B	H	B	H	B	H	B	H	B	H	B
Yearly average value	392	1497	0.1	0.05	0.08	0.22	0.13	0.23	0.07	0.11	99.11	99.35	0.25	0.22	0.64	0.43
Adjustment factor		3.82		0.48		2.8		1.81		1.54		1.01		0.7		0.22

H = Honolulu, B = Bangkok
Sources of yearly average values:
1. McPherson (2010); Thai Meteorological Department
2. Environmental Protection Agency (2005); Pollution Control Department
3. Vargas et al. (2008); Electricity Generating Authority of Thailand (2006)

The adjusted values of environmental services and monetary benefits of environmental services are listed in Tables 3 and 4, respectively. The reduction in electricity consumption is approximately 8.3 million kWh per year. The total air pollution reduction is about 65 tons per year (combining air pollutant deposition of NO_2, SO_2, O_3, PM10, and avoided emission from electricity generation CO_2, SO_2, NO_2, VOC subtracted, with biological VOC emitted by trees). The annual rainfall interception or storm water runoff reduction is about 2.1 million m^3. The net CO_2 reduction from avoided emission from electricity generation and CO_2 sequestration is about 13,000 tons per year.

For the monetary benefits, the city can obtain about $140,000 per year from the air pollution reduction; $3.24 million per year from storm water runoff reduction; $56,000 per year for CO_2 reduction; and $900,000 per year from electricity saving. The total monetary benefits of all mentioned environmental services that public street trees of Bangkok can provide is approximately $4.34 million per year. For the carbon stage value over the trees' lifetime, or about 40 years, it is about \$295,000, but this value is not included in the total value per year. The first three common species that provide the greatest annual monetary benefit per tree are *P. pterocarpum*, *T. indica*, and *P. indicus*. On the other hand, *C. inophyllum, P. longifolia,* and *Elaeis* sp. provide the least annual benefit.

The full findings of environmental services and monetary benefits, including annual energy saving, CO_2 reduction, air pollution reduction, storm water runoff reduction, and carbon storage for 40 years, or the tree lifetime, are in the Appendix 1-G, 1-H, 1-I, 1-J, and 1-K respectively.

3.2.3 Discussion

The total street tree population of about 180,000 in this study is about 10% lower than the number in the complete inventory in 2000, which was nearly 200,000 (Thaiutsa et al. 2008). Population of *P. indicus*, is about half of the number in 2000. In contrast, the *Cassia fistula* population in this study has increased about 40% from the inventory taken in 2000. This may be a change in species selection in planting new trees with conspicuous flowers. The population of *T. rosea* in 2012 is about 25% lower than that of 2000, because the city is no longer planting them due to sidewalk damage (Thaiutsa et al. 2008). The city should set the priority to immediately maintain species that are relatively young, especially *C. fistula* and *M. elengi,* as well as trees with poor leaf and wood conditions.

Table 3 Adjusted environmental services of public street trees of Bangkok

Species	Energy saving (kWh)	CO_2 reduction (kg)	Air pollution reduction (kg)	Storm water runoff reduction (m^3)
	Environmental services			
Pterocarpus indicus	1,955,194	3,587,564	22,950	562,039
Lagerstroemia spp.	1,194,833	2,015,527	10,211	257,619
Cassia fistula	599,528	1,037,372	5,504	145,408
Broadleaf Evergreen Medium Other	724,417	1,009,569	4,639	199,587
Broadleaf Evergreen Small Other	346,083	558,173	2,712	90,516
Polyalthia longifolia	84,972	222,817	976	29,058
Tabebuia rosea	412,278	540,918	2,761	91,402
Mimusops elengi	300,389	428,253	2,676	79,952
Swietenia macrophylla	238,139	367,915	2,295	49,394
Peltophorum pterocarpum	1,070,361	1,297,678	3,248	262,656
Tabebuia aurea	159,306	293,820	1,034	35,397
Canophyllum inophyllum	27,806	55,376	-124	7,756
Tamarindus indica	409,722	495,958	1,200	107,009
Broadleaf Deciduous Medium Other	151,667	246,027	1,362	33,935
Elaeis sp.	54,139	56,698	164	11,709
Other species	569,444	734,161	3,708	149,376
Total	8,298,278	12,947,824	65,316	2,112,814

Table 4 Adjusted monetary benefits of environmental services provided by public street trees of Bangkok

Species	Energy saving	CO_2 reduction	Air pollution reduction	Storm water runoff reduction	Total benefit	% Total benefit	Benefit per tree ($/tree)
	Monetary benefit ($)						
Pterocarpus indicus	213,116	15,427	41,749	863,065	1,133,357	26.11	26.35
Lagerstroemia spp.	130,237	8,667	18,434	395,599	552,937	12.74	21.07
Cassia fistula	65,349	4,461	9,996	223,289	303,094	6.98	15.00
Broadleaf Evergreen Medium Other	78,961	4,341	8,389	306,485	398,177	9.17	29.37
Broadleaf Evergreen Small Other	37,723	2,400	5,620	138,995	184,738	4.26	17.34
Polyalthia longifolia	9,262	958	1,778	44,621	56,620	1.30	5.46
Tabebuia rosea	44,938	2,326	6,138	140,356	193,758	4.46	21.19
Mimusops elengi	32,742	1,841	4,883	122,775	162,242	3.74	19.55
Swietenia macrophylla	25,957	1,582	4,162	75,849	107,550	2.48	13.29
Peltophorum pterocarpum	116,669	5,580	13,210	403,334	538,794	12.41	69.32
Tabebuia aurea	17,364	1,263	2,325	54,356	75,309	1.73	10.82
Canophyllum inophyllum	3,031	238	170	11,910	15,350	0.35	4.24
Tamarindus indica	44,660	2,133	5,180	164,323	216,296	4.98	63.54
Broadleaf Deciduous Medium Other	16,532	1,058	2,472	52,110	72,172	1.66	28.72
Elaeis sp.	5,901	244	668	17,980	24,793	0.57	12.35
Other species	62,069	3,157	10,950	229,382	305,791	7.11	64.16
Total	904,512	55,676	136,127	3,244,430	4,340,745	100.00	24.03

Regarding utility wire problems, there are some alternative ways to avoid this conflict: planting trees with a narrow canopy, selecting trees with appropriate height, and planning for underground wires. Firstly, planting trees with a narrow canopy, such as the cemetery tree (*P. longifolia*), is a suitable solution for narrow streets. Also, this species is known to alleviate noise from street traffic (Kaviya, Santhanalakshmi, and Viswanathan 2011). With the medium height, and well-defined and rounded-shaped canopy, *M. elengi* may be appropriate for Bangkok streets, as it does not cause much conflict with overhead utility wires, according to this inventory. Furthermore, having underground wires along the streets could help avoid this conflict in the long term.

For other tree species, *F. religiosa* and *F. benjamina* are among the greatest environmental service providers, but they have a relatively high risk of causing sidewalk damage. Thus, they should be planted in the median strips instead of along sidewalks. Alternatively, installation of vertical root barriers during the planting process can help leading roots to grow to a deeper level (Smiley 2008). The species *P. pterocarpum* provides relatively high environmental services and can enhance soil fertility under the tree canopy (Virginia 1986). In contrast, *C. inophyllum* are not recommended, except for the areas requiring salt-tolerant species, as they provide relatively low environmental services.

Table 5 shows the comparison of inventories of public street trees in five cities, including Bangkok, Thailand; New York City; Lisbon, Portugal; San Francisco, and Davis, California. Bangkok has the lowest street tree density and street tree per capita. Also, the percent of total canopy cover of public street trees over Bangkok's city area is relatively low when compared with New York (3.7%) and Davis (5%). Through various methods, such as conducting tree inventories (American Public Works Association), finding more spaces to plant (Wu, Xiao, and McPherson 2008), as well as educating residents on the ecosystem services (Niemelä et al. 2010), street trees can be well maintained, or increased, and can improve quality of life in the city.

Table 5 Comparison of urban public maintained street tree analyses

Inventory year	City	% canopy cover	Number of trees	Areas (km^2)	Street tree density (trees/ km^2)	Street tree per capita
2012	Bangkok, Thailand	0.45	180,613	1,569	115	0.03
2007	New York, USA[1]	3.70	592,000	1,214	488	0.07
2006	Lisbon, Portugal[2]	N/A	41,247	85	486	0.16
2003	San Francisco, USA[3]	0.36	98,534	601	164	0.13
2001	Davis, USA[4,5]	5.00	23,810	25	972	0.40

Sources: 1. Peper et al. (2007); 2. Soares et al. (2011); 3. Maco and McPherson (2003) ; 4. Maco and McPherson (2002); 5. Maco and McPherson (2003)

Calculating environmental services using the i-Tree Streets, the model input can be identified with different types of errors, including sampling error, formulaic error, price error, temporal and spatial error (McPherson 2010). For the sampling aspect, this study may have errors, in terms of the total tree number, as I conducted the sample inventory. However, I followed the method used in sampling urban trees (Jaenson et al. 1992), which suggested to sample about 2,300 trees in the city, and I conducted the pre-sampling to estimate the number of trees of each zone prior to conducting the field inventory. The difference in tree species composition between Honolulu and Bangkok can also cause errors. For non-matching species, I selected the most similar species or groups, using the method recommended by the model developer. Despite some errors, this study could be used to reflect the environmental services trees can provide, and to be an initial guide in selecting trees to plant to increase environmental services, prioritize the maintenance tasks, and promote the investment in tree planting and maintenance in the city.

3.3 Social assessment of public street trees: Policies, challenges and perceptions on ecosystem services of public officials

3.3.1 Methodology

This study investigates policy issues and challenges with respect to street tree planting and maintenance in Bangkok, Thailand, and evaluates the perceptions held by public officials on the ecosystem services provided by street trees. In 2012, I interviewed twenty-five district agricultural officers in twenty-five districts of Bangkok[1] and constructed a perception index to measure their level of understanding of ecosystem services from street trees. The officers were questioned about their perception, using a scale from 1 to 7. A score of 7 was given to a well-informed response, and a value of 1 was given to a highly superficial response. Additionally, the officers were asked to elaborate on three aspects of tree benefits, issues that they encountered in street tree management including planting, maintenance, and their recommendations for future policies. The questionnaire used in this study is in Appendix 2.

[1] There are total of 50 districts in the city of Bangkok. Each has agricultural officials responsible for tree management. 50% of them were surveyed, accounting for areas that cover 65% of the city.

3.3.2 Results

Challenges in street tree management

Major challenges in management include the lack of personnel to provide adequate maintenance, issues in tree health and maintenance, and the conflicts that occur through arbitrary tree removal and damages. There are also resident complaints from damages by street trees.

More than 50% of the districts face insufficient labor for the maintenance of trees. An insufficient budget and the untrained crews are raised as management problems, as well. There are also mismanagement issues. For example, only top-down management approaches exist in some districts, resulting in a failure by supervisors to listen to subordinates' concerns or problems they have encountered.

The health of trees brings other challenges, although most districts (84%) have a higher proportion of healthy trees than unhealthy trees. The causes of unhealthy trees include pests, brittle branches, eroded roots, root interference with underground pipelines, or intolerance in younger trees. Also, some trees are extremely old and are deteriorating as a result of natural aging. The major problem of the most dominant species, *P. indicus,* in the city is that it is prone to the stem borers, *Aristobia horridula*, a type of beetle. Additionally, the position of water pipelines, poor soil quality, and shallow soil layers in some planting strips impede the root growth underground. Some districts have insufficient water sources, resulting in unhealthy trees.

Regarding conflicts, 80% of districts have experienced conflicts with street vendors (both mobile and fixed vendors), as some vendors illegally cut or damage trees at nighttime, or they indirectly damage them through the uses of equipment storages or food waste disposals. Furthermore, another source of conflict includes damage to property. About 70% of districts experienced complaints filed by residents, due to property and car damages. In most cases, the districts compromise and provide compensation. The species that cause the most damages to properties through broken-off branches are *P. indicus*, *Delonix regia*, *T. rosea,* and *P. pterocarpum.*

Perception on ecosystem services provided by street trees

The results using the perception index indicates that the interviewed public officials understand fairly well *the social benefits* of trees (scored 5.46 out of 7), but have a relatively low level of understanding and gave the least information on *the economic benefits* (scored 3.00 out of 7). For economic benefits, about 20% of officers recognized that tree branches from pruning could be used as fertilizers. For environmental services, most of the public officials (92%) mentioned they were aware that trees help reduce air pollution, but they did not elaborate in any further detail. The most common social benefit mentioned during the interviews was the provision of recreational amenities, followed by provision of shade for pedestrians (about 67% and 54%, respectively). The scores and the response information provided by public officials are listed in Table 6 and 7, respectively.

The recommended tree species identified in the interviews included those requiring low maintenance, having evergreen foliage, and appropriate canopy density, such as *Swietenia macrophylla*. Trees with hairy leaf surfaces were also highly recommended, as this allows for the interception of particulate matter in the air, such as the leaves of the genus *Lagerstroemia*. Two district officers recommended food-bearing street trees, such as *Dolichandrone serrulata, Azadirachta indica* (Neem tree), and *Seanna siamea* (Kassod Tree).

Despite the fact that there are no campaigns currently promoting the ecosystem services provided by street trees, the majority of district officers felt that these would be important and should be implemented in the future, particularly to aid in selecting appropriate species for new planning projects, and to assist in their overall maintenance. However, they also recognized difficulties in reaching out to some groups, especially in residential zones, due to occasional unwillingness to be involved, as well as insufficient human resources to implement such campaigns.

Table 6 Score of public officials' understanding of ecosystem service benefits (1= providing superficial response, 7 = providing well-informed response)

	Number of public officials									
Score	1	2	3	4	5	6	7	Total score	Average score	Standard deviation
Economic benefits	11	0	3	3	2	5	0	72	3	2.09
Environmental services	0	0	5	6	3	3	7	121	5.04	1.57
Social benefits	0	0	3	3	3	10	5	131	5.46	1.32

Table 7 Perception of twenty-five agricultural officers on the ecosystem service benefits provided by street trees

Economic benefits	%	Environmental services	%	Social benefits	%
1. Reducing electricity costs from air conditioners	12.50	1. Reducing air pollution	91.67	1. Reducing crime	4.17
2. Helping to add value to the property	4.17	2. Reducing noise pollution	29.17	2. Improving physical health	25.00
3. Providing materials to be used in fertilizers (cut branches or fruits)	20.83	3. Reducing the temperature	33.33	3. Providing recreational space/meeting places	66.67
4. Providing materials for making furniture (dead trees)	12.50	4. Enhancing soil quality	4.17	4. Enhancing street safety for pedestrians	8.33
5. Saving money for food cost	4.17	5. Providing oxygen	25.00	5. Enhancing street safety for drivers	8.33
6. Providing jobs to people who grow trees	4.17	6. Reducing storm water runoff	12.50	6. Providing shade to pedestrians	54.17
7. Gaining carbon credits for tree-planting	4.17	7. Preventing soil erosion	4.17	7. Providing aesthetic value and relieves from stress	45.83
8. Providing materials for making charcoal (dead trees)	8.33	8. Sequestering CO_2	8.33	8. Providing food for community	8.33

3.3.3 Discussion

As the level of understanding of agricultural officers on average is not very high in this area of ecosystem services, especially economic benefits, it is crucial to promote educational policies to further their understanding of the variety of ecosystem services. That way they can promote the benefits of street trees and conservation of those services, as well as educating the residents.

The tree inventory, including species composition, maintenance needs, and safety risk levels are important so that forest managers can monitor trees for safety risks on a regular basis (American Public Works Association). For example, trees with well-balanced canopies will make the streets safe for pedestrians and drivers, as well as to avoid interfering with utility wires (Kadir and Othman 2012).

Moreover, the allocation of city resources for tree planting and maintenance should be defined through participatory mechanisms that involve the recommendations from those directly involved in tree management. It is necessary to develop an assessment of the available public space in the city to implement adequate planting strategies that improve city aesthetics.

3.4 Social assessment of public street trees: Awareness and opinions of street vendors on ecosystem services and tree management

3.4.1 Methodology

During the summer of 2012, I conducted interviews of 209 street vendors in Bangkok, Thailand (89 fixed vendors and 115 mobile vendors) on their awareness and opinions on street tree benefits and management, as well as recommendations for future policies. I randomly interviewed the vendors in eleven commercial zones of the city: 1. Silom; 2.Yaowarat; 3. Rama IV-Saun Lumpini; 4. Victory Monument; 5. Surasak-Patpong; 6. Siam Square; and 7. Klong Toey; 8. Petchburi (near Panthip Plaza); 9. Jatujak Weekend Market; 10. Prachasongkhro; and 11. Ngamwongwan-Paholyothin (Amornpan Intersection).

The awareness of people on the benefits of street trees is very critical in reducing the number of injured or dead trees, and will help to improve tree health and survival. I questioned the vendors about their awareness of the benefits of street trees, including regulating microclimates; reducing air pollution; and enhancing city aesthetics. The parks and public cleaning sections of most districts conduct maintenance twice a year (e.g., pruning and inventory). Out of total of 209 vendors, I filtered the findings from 167 vendors that have been in their current locations for more than two years. The questionnaire used in this study is in Appendix 3.

3.4.2 Results

Street tree population dynamics

About 54% of the vendors said that the street tree population where their businesses are located remain roughly the same over time. In the Ngamwongwan-Paholyothin zone (Amornpan Intersection), 65% of mobile vendors there said that they believe the street trees have decreased over time.

Impacts of street trees on the business

Findings from the questionnaires shows that about 8% of the vendors reported that having street trees negatively impact their businesses, as trees block the walkways and the view of their shops. They also said that the trees allow less space for their business, and damages from broken branches, untidy streets from fallen flowers/leaves, and bird droppings negatively affect their businesses. While most vendors (192 vendors, about 92%) do not feel that street trees negatively affect their business, sixteen of them (eleven mobile vendors and five fixed vendors) prefer not to have trees near their business, mostly due to limited space. They recommended to plant shrubs instead of trees, or trees that do not shed leaves or flowers.

The first three reasons vendors prefer to have trees near their businesses are the benefits of providing shade and cooling the air (69%), providing recreational and aesthetic values (7%), and reducing air pollution (3%). All mentioned reasons are listed in Table 8. For the species preference, *Cassia fistula* tree is most preferable (28%), followed by *Pterocarpus indicus* (22%). Some mobile vendors said they'd like the city to plant trees that bear edible fruits, such as jackfruits, and mangoes. The list of preferable plants is shown in Table 9.

Table 8 Reasons why the vendors want to have trees near their businesses

		Fixed vendors		Mobile vendors		Total	
	Reason	Number	%	Number	%	Number	%
1	Providing shades and cooling the air	59	62.77	86	74.78	145	69.38
2	Providing recreational benefit	4	4.26	4	3.48	8	3.83
3	Providing aesthetic value	3	3.19	4	3.48	7	3.35
4	Reducing air pollutants and increasing oxygen	4	4.26	2	1.74	6	2.87
5	Protecting from the rain	0	0.00	4	3.48	4	1.91
6	Reducing the wind speed	0	0.00	2	1.74	2	0.96
7	Reducing noise pollution	0	0.00	1	0.87	1	0.48
8	Bringing luck into life	0	0.00	1	0.87	1	0.48

Table 9 Plant species preference from street vendors

		Fixed vendors		Mobile vendors		Total	
	Plant name	Number	%	Number	%	Number	%
1	*Cassia fistula* (Golden shower)	32	67.74	26	22.61	58	27.75
2	*Pterocarpus indicus* (Narra)	18	38.11	27	23.48	45	21.53
3	Any trees	3	6.35	13	11.30	16	7.66
4	*Alstonia scholaris* (Blackboard tree)	5	10.59	9	7.83	14	6.70
5	*Lagerstroemia* spp. (Giant Crapemytles)	5	10.59	8	6.96	13	6.22
6	*Millingtonia hortensis* (Indian cork tree)	2	4.23	6	5.22	8	3.83
7	*Mimusops elengi* (Spanish cherry)	3	6.35	4	3.48	7	3.35
8	*Mangifera* spp. (Mango)	2	4.23	5	4.35	7	3.35
9	Shrubs	5	10.59	2	1.74	7	3.35
10	Trees that bear edible fruits	0	0.00	6	5.22	6	2.87
11	Trees with no conspicuous flowers	4	8.47	2	1.74	6	2.87
12	*Polyalthia longifolia* (Cemetery tree)	3	6.35	2	1.74	5	2.39
13	*Artocarpus heterophyllus* (Jackfruit)	1	2.12	4	3.48	5	2.39
14	Trees that are tolerant with strong branches	1	2.12	4	3.48	5	2.39
15	*Cananga odorata* (Cananga)	3	6.35	1	0.87	4	1.91
16	Palm	2	4.23	2	1.74	4	1.91
17	Trees with appropriate heights	0	0.00	3	2.61	3	1.44
18	Trees with lots of shade	1	2.12	2	1.74	3	1.44
19	*Michelia alba* (White Champaka)	1	2.12	1	0.87	2	0.96
20	*Senna siamea* (Kassod tree)	0	0.00	2	1.74	2	0.96
21	*Peltophorum pterocarpum* (Yellow flame tree)	0	0.00	2	1.74	2	0.96
22	*Tamarindus indica* (Tamarine)	0	0.00	2	1.74	2	0.96
23	Vines	1	2.12	1	0.87	2	0.96
24	Street garden	1	2.12	1	0.87	2	0.96
25	Trees that do not shed leaves	0	0.00	2	1.74	2	0.96

Awareness of street tree benefits

From the interview, more than 85% of both groups of street vendors are aware of the benefits of street trees. Among the three questions, the highest number of vendors (94%) know that trees can help regulate the negative impact of extreme weather, while the benefits of reducing air pollution are perceived the least (87%). Fixed vendors are more aware of tree benefits than the mobile vendors in all three questions, probably because they have higher incomes and a higher education, in general. This information is useful in identifying the target group for implementing educational activities in order to decrease conflicts generated by green space enhancement policy. The findings of vendor awareness are shown in Table 10.

Table 10 Awareness of street vendors on street tree benefits

10.1 Trees can help regulate the negative impact of extreme weather

	Fixed vendors		Mobile vendors		Total	
Answer	Number	%	Number	%	Number	%
No	1	1.06	11	9.57	12	5.74
Yes	93	98.94	104	90.43	197	94.26

11. 2 Trees con help reduce air pollution

	Fixed vendors		Mobile vendors		Total	
Answer	Number	%	Number	%	Number	%
No	5	5.32	23	20.18	28	13.46
Yes	89	94.68	91	79.82	180	86.54

11.3 Trees can improve the aesthetic of the city and attracts people to the streets

	Fixed vendors		Mobile vendors		Total	
Answer	Number	%	Number	%	Number	%
No	2	2	16	14.29	18	8.74
Yes	92	98	96	85.71	188	91.26

Opinions on green space enhancement policy and management

The interviewees were inquired about their opinions on the policy of increasing tree numbers in two locations of the city: 1) in the streets in which they are located, 2) in the streets of Bangkok, in general. The results indicate that 35% of the vendors disagree with tree plantings in the streets in which their businesses operate, especially in the three zones of Yaowarat, Surasak-Patpong, and Klong Toey. Some of their reasons are that trees reduce space for their businesses, and block the walkways. Other vendors indicated that there are already enough trees in their business area. Regarding the tree planting policy of Bangkok streets in general, more than 96% of both groups of vendors agree with this policy. The vendors' opinions about the BMA planting policy are shown in Table 11, and the list of reasons for not supporting this policy on the streets is shown in Table 12.

The interviewees were asked about their opinion of BMA's performance on tree planting and maintenance. The findings show that 44% of the vendors feel that BMA does a good job of tree planting and maintaining, while 34% of the vendors said that BMA performs poorly (Table 13). This information can help BMA analyze its performance, and take into consideration the recommendations by vendors for tree planting and maintenance. The recommendations are listed in Table 14. Regarding tree abundance, about 17% of vendors suggested the BMA should plant more trees, in general, and in the median strips. Vendors suggested trees with appropriate height and canopy be planted so they will not interfere with the utility wires. They also suggested planting species that provide the greatest environmental services, such as reducing air pollution and CO_2.

Table 11 Willingness to support the tree planting policy

11.1 On the street the vendors are currently located

Answer	Fixed vendors Number	%	Mobile Vendors Number	%	Total Number	%
No	35	37.23	38	33.33	73	35.10
Yes	59	62.77	76	66.67	135	64.90

11.2 On the streets of Bangkok as a whole

Answer	Fixed vendors Number	%	Mobile Vendors Number	%	Total Number	%
No	3	3.19	4	3.54	7	3.38
Yes	91	96.81	109	96.46	200	96.62

Table 12 Reason for not supporting the policy of planting trees on the streets where vendors are located

	Reasons	Fixed vendors Number	%	Mobile vendors Number	%	Total Number	%
1	Narrow streets & small space/less space for business	10	10.64	10	8.70	20	9.57
2	Trees are blocking the business and walkways	11	11.70	5	4.35	16	7.66
3	The street already has lots of trees	3	3.19	10	8.70	13	6.22
4	There is no more available space to plant	0	0.00	10	8.70	10	4.78
5	Conflicts with utility wires	1	1.06	3	2.61	4	1.91

Table 13 BMA performance in planting and maintaining street trees

		Fixed vendors		Mobile Vendors		Total	
Level	Quality of work	Number	%	Number	%	Number	%
1	BMA maintains trees regularly and sufficiently	42	44.68	49	43.36	91	43.96
2	BMA does the work sporadically	28	29.79	14	12.39	42	20.29
3	BMA does the work rarely and poorly	22	23.40	49	43.36	71	34.30
N/A	The vendor does not notice	2	2.13	1	0.88	3	1.45

As for the tree maintenance, the most frequent recommendation is that BMA should prune trees regularly for several reasons, but mainly for safety and aesthetic purposes. BMA should carry out maintenance tasks on a regular basis, including pruning, fertilizing, cultivating the existing trees, and replanting trees when the old trees die or are removed during construction. However, pruning too much canopy can expose the tree to too much sunlight and can lead to sunburn. Furthermore, the city should sufficiently and carefully water the trees. Furthermore, the city should sufficiently and carefully water the trees.

For tree management, in general, the vendors suggest that BMA should have strict measures for people that damage trees or remove trees without permission. In addition, BMA should raise awareness and promote involvement of vendors, such as giving away tree saplings. Also, some vendors suggested BMA should increase the number of trained crew members that maintain city trees, and put the utility wires underground.

3.4.3 Discussion

The opinions on tree selection and recommendations in tree planting and maintenance from street vendors are informative, as they directly receive the benefits from trees and observe related problems (e.g., broken branches, pests) every working day. For example, about 30% of street vendors said that BMA performs poorly on street tree management. In this regard, BMA should conduct an inventory and effectively maintain street trees on a regular basis, especially for trees that need immediate maintenance, to increase safety for pedestrians (Kadir and Othman 2012).

Regarding conflicts with residents, the interest of ecosystem services by stakeholders is useful in analyzing potential conflicts in management (Hein et al. 2006). Although most street vendors are aware of major benefits of street trees, some vendors consider having street trees in their areas as not preferable especially the mobile vendors. In this case, dialogue between managers and street vendors are important to facilitate adaptive management (Dwyer et al. 2000). This may reduce conflicts by identifying their main causes, and involving vendors in educational activities related to tree plantings (e.g., providing knowledge of the benefits of street trees on ecosystem services, organizing tree planting days, as well as taking care of trees nearby the vendor locations). In addition, BMA should consider allocating alternative areas for mobile vendors to prevent conflicts between BMA and the vendors, and lessen damages to street trees.

Table 14 Street vendors' recommendations to BMA on tree management

Recommendations	Fixed vendors Number	Fixed vendors %	Mobile vendors Number	Mobile vendors %	Total Number	Total %
Number of trees						
BMA should plant more trees on the median stripes	14	12.17	4	4.26	18	8.61
BMA should plant more trees in general	10	8.70	7	7.45	17	8.13
BMA should provide more parks or plant more trees in non-commercial areas	4	3.48	3	3.19	7	3.35
Tree planting-preferable types						
BMA should not plant shrubs or small plants due to high maintenance and intolerance	3	1.74	1	1.06	4	1.91
BMA should plant trees that have great environmental services	2	1.74	1	1.06	3	1.44
BMA should select species with low maintenance and strong roots	0	0.00	3	3.19	3	1.44
BMA should plant more trees that bear flowers esp. in downtown	0	0.00	3	3.19	3	1.44
BMA should plant appropriate sized trees in this zone (height and canopy shape)	2	1.74	1	1.06	3	1.44
BMA should plant evergreen trees with wide canopy to provide shade	3	2.61	0	0	3	1.44
BMA should plant more Bo trees as people do not cut down according to religion belief	1	0.87	0	0.00	1	0.48

Table 14 Street vendors' recommendations to BMA on tree management (continued)

Recommendations	Fixed vendors Number	Fixed vendors %	Mobile vendors Number	Mobile vendors %	Total Number	Total %
Tree maintaining						
BMA should prune trees regularly (for safety and esthetic purposes)	17	14.78	20	21.28	37	17.70
BMA should replant trees when the old trees die or are removed during construction	21	18.26	4	4.26	25	11.97
BMA should effectively and regularly maintain existing trees (pruning, fertilizing, cultivating, pest control)	11	9.57	7	7.45	18	8.62
BMA should sufficiently and carefully water the trees	9	7.83	2	2.13	11	5.26
BMA should not over-prune canopies, as they provide shade	2	1.74	3	3.19	5	2.39
BMA should carefully protect the newly planted trees from damages	1	0.87	4	4.26	5	2.39
BMA should sweep the fallen leaves regularly	3	2.61	0	0.00	3	1.44
Landscape and general management						
BMA should have strict measures for vendors that damage trees	1	0.87	4	4.26	5	2.39
BMA should raise awareness and promote involvement of vendors, such as giving away tree saplings	1	0.87	4	4.26	5	2.39
BMA should put utility wires underground	2	1.74	0	0	2	0.96
BMA should increase crews, esp. ones trained on tree pruning	1	0.87	1	1.06	2	0.96
BMA should broaden the pavement for more space in planting trees	1	0.87	0	0	1	0.48
BMA should not plant new trees right before water splash festival	0	0	1	1.06	1	0.48
BMA should allocate space for vendors in particular	1	0.87	0	0.00	1	0.48

3.5 Conclusions

The i-Tree Streets model calculation of Bangkok public street trees in 2012 reveals that trees can provide environmental services: sixty-five tons per year of total air pollution reduction; 8.3 million kWh per year of electricity consumption reduction; 2.1 million m^3 per year of storm water runoff reduction; 13,000 tons per year of net carbon dioxide reduction through avoided emission and tree sequestration; and 70,000 tons of total carbon stored in the trees' wood over their lifetime, or about 40 years. The total monetary benefit of these environmental services is approximately \$4.34 million per year. The carbon stage value over the trees' lifetime is about \$300,000, but this value is not included in the total value per year.

The study's finding of district public officials' lack of knowledge about the multiple benefits of street trees could be tackled by educational policies. The feedback from street vendors is also very helpful, as the city can evenly and regularly maintain and monitor its street trees to reduce damage risks, and promote tree health.

Urban forest managers should select the appropriate tree species, according to the site conditions and social contexts, environmental services (Zipperer 2008), and also consider that the benefits should outweigh management costs (McPherson 2003). One of the first criteria in selecting species to plant is to determine the spaces needed for different sizes of trees. Tree sizes can be categorized by canopy diameter, such as small trees (mature diameter 4.6m), medium trees (mature diameter 9.1m), and large trees (mature diameter 15.2m). These groups should have minimum width for planting, about 1.20m, 1.80m, and greater than 1.80m, respectively (Wu, Xiao, and McPherson 2008).

In this study, there are species that can be categorized in either medium or large size, depending on ages. Thus, I grouped them in one category. Table 15 summarizes the characteristics of common tree species of Bangkok, including major characteristics and drawbacks. This finding is based on the analyses from part 3.2 to 3.4, taking into consideration environmental services (using the same size of trees of different species as inputs into i-Tree model), sidewalk damages, and opinions from the tree management sector and street vendors.

For the small-sized trees, species in the genus *Lagerstroemia* appear to be good candidates for both achieving high environmental services, as well as having fewer problems in tree management and conflicts than other species. For medium and large-sized trees, *P. pterocarpum,* and *T. indica* are found to have beneficial characteristics in promoting high environmental services, and do not appear to have major maintenance problems.

In conclusion, the city should integrate the knowledge of all related aspects of street tree management. Perceptions and opinions of related stakeholders are helpful for the responsible agencies to understand problems and unseen issues. This would improve tree management tasks to facilitate tree provision of the ecosystem services and conservation, as well as determining the management needs in tree planting and maintenance.

Table 15 Bangkok tree species profile: A guide for tree selection in maximizing environmental services and opinions from stakeholders

Space Availability	**Species**	**Characteristics[1]**	**i-Tree Findings**			**Agricultural officer's interview**						**Street vendor interview**	
			Monetary benefit of environ. services ($/tree)	Environ service ranking	Sidewalk damage[2] (% of species)	Recommended species	Frequency	Major characteristics	Species with maintenance problems	Frequency	Maintenance problems	Preferred species	Frequency
Small space	*Delonix regia*	Deciduous, fast growth	23.21	1	0.00				✓	7	Brittle branches	✓	1
	Lagerstroemia spp.	Deciduous, slow growth	13.36	2	0.63	✓	8	Pubescent leaf surface, Tolerant				✓	8
	Millingtonia hortensis	Evergreen, very slow growth	10.55	3	4.25							✓	6
	Polyalthia longifolia	Evergreen, slow growth Dense but narraw canopy	3.21	4	0.00							✓	2
	Calophyllum inophyllum	Evergreen, very slow growth	2.48	5	0.00			Salt tolerant					

Table 15 Bangkok tree species profile: A guide for tree selection in maximizing environmental services and opinions from stakeholders (continued)

Space Availability	**Species**	**Characteristics**[1]	**i-Tree Findings**			**Agricultural officer's interview**						**Street vendor interview**	
			Monetary benefit of environ. services ($/tree)	Environ. service ranking	Sidewalk damage[2] (% of species)	Recommended species	Frequency	Major characteristics	Species with maintenance problems	Frequency	Maintenance problems	Preferred species	Frequency
Medium and large space	*Ficus benjamina*	Evergreen, very fast growth	96.62	1	28.65	For median strips							
	Peltophorum pterocarpum	Dense and large canopy	41.86	2	16.69	✓	1	Low pest risk	✓	2	Brittle branches; vulnerable young roots	✓	2
	Tamarindus indica	Evergreen, medium growth	37.91	3	2.12							✓	2
	Azadirachta indica	Facultative deciduous, slow growth	23.23	4	0.00	✓	1	Edible				✓	1
	Alstonia scholaris	Evergreen, medium growth	17.83	5	3.10	✓	1	Easy to prune; pretty canopy; tolerant	✓	3	Not tolerant; sidewalk damage	✓	9
	Ptherocarpus indicus	Facultative deciduous, fast growth	15.92	6	4.33	✓	3	Strong branch and root system; large canopy	✓	14	Prone to stem borers (*Aristobia horridula);* fragile branches	✓	28
	Tabebuia rosea	Deciduous, fast growth	13.21	7	7.97				✓	6	Brittle branches, eroded roots; sidewalk damage		

Table 15 Bangkok tree species profile: A guide for tree selection in maximizing environmental services and opinions from stakeholders (continued)

Space Availability	Species	Characteristics[1]	i-Tree Findings			Agricultural officer's interview						Street vendor interview	
			Monetary benefit of environ. services ($/tree)	Environ. service ranking	Sidewalk damage[2] (% of species)	Recommended species	Frequency	Major characteristics	Species with maintenance problems	Frequency	Maintenance problems	Preferred species	Frequency
Medium and large space	*Tabebuia rosea*	Deciduous, fast growth	13.21	7	7.97				✓	6	Brittle branches, eroded roots; roots penetrate upward causing the sidewalk damage		
	Mimusops elengi	Evergreen, medium growth	11.85	8	0.87	✓	2	Easy to prune; beautiful canopy				✓	4
	Cassia fistula	Deciduous, medium growth	9.30	9	1.87				✓	3	Prone to Aphids; not tolerant at the young age	✓	26
	Sweitenia macrophylla	Evergreen, medium growth	8.51	10	0.00	✓	6	Strong branch; easy to propagate; tolerant to flood; low pest risk; easy to prune				✓	1
	Tabebuia aurea	Deciduous, medium growth	6.80	11	5.59								

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Appendix 1-A

Thailand

Complete Population of Public Trees

13/9/2014

Species	0-7.6	7.6-15.2	15.2-30.5	30.5-45.7	45.7-61	61-76.2	76.2-91.4	91.4-106.7	> 106.7	Total Standard Error
				DBH Class (cm)						
Broadleaf Deciduous Large (BDL)										
Pterocarpus indicus	530	3,683	28,189	8,892	1,538	172	0	0	0	43,004 (±8,347)
Lagerstroemia speciosa	595	5,900	18,572	1,178	0	0	0	0	0	26,246 (±5,277)
Polyalthia longifolia	1,433	8,341	595	0	0	0	0	0	0	10,368 (±8,105)
Tabebuia species	0	144	3,649	4,289	839	223	0	0	0	9,144 (±2,680)
Terminalia catappa	0	0	72	121	145	121	0	0	0	459 (±284)
Samanea saman	0	0	0	0	81	0	72	0	0	153 (±108)
Total	**2,558**	**18,068**	**51,077**	**14,480**	**2,603**	**516**	**72**	**0**	**0**	**89,375 (±11,663)**
Broadleaf Deciduous Medium (BDM)										
Cassia fistula	1,963	13,069	4,867	310	0	0	0	0	0	20,209 (±9,752)
Broadleaf Deciduous Mediur	0	81	2,351	81	0	0	0	0	0	2,513 (±1,670)
Total	**1,963**	**13,150**	**7,218**	**391**	**0**	**0**	**0**	**0**	**0**	**22,722 (±9,894)**
Broadleaf Deciduous Small (BDS)										
Delonix regia	0	0	76	159	215	0	0	0	0	449 (±272)
Broadleaf Deciduous Small (	0	81	0	0	0	0	0	0	0	81 (±81)
Total	**0**	**81**	**76**	**159**	**215**	**0**	**0**	**0**	**0**	**530 (±284)**
Broadleaf Evergreen Large (BEL)										
Swietenia mahagoni	232	1,444	6,253	162	0	0	0	0	0	8,091 (±4,580)
Peltophorum pterocarpum	0	0	2,513	4,701	559	0	0	0	0	7,773 (±5,411)
Tabebuia aurea	0	1,043	5,596	319	0	0	0	0	0	6,958 (±3,888)
Tamarindus indica	217	733	1,083	722	433	72	144	0	0	3,404 (±2,150)
Artocarpus heterophyllus	0	228	72	289	217	72	0	0	0	877 (±717)
Mangifera indica	0	83	302	72	0	0	0	0	0	457 (±319)
Azadirachta indica	0	0	378	76	0	0	0	0	0	453 (±377)
Casuarina equisetifolia	83	83	83	76	0	0	0	0	0	325 (±259)
Ficus religiosa	0	0	0	72	0	0	72	0	72	217 (±110)
Ficus benjamina	0	0	0	121	0	0	0	48	0	169 (±120)
Acacia koa	0	0	83	83	0	0	0	0	0	166 (±165)
Averrhoa bilimbi	0	83	0	0	0	0	0	0	0	83 (±83)
Pithecellobium dulce	0	0	0	81	0	0	0	0	0	81 (±81)
Broadleaf Evergreen Large C	0	0	0	0	76	0	0	0	0	76 (±75)
Ficus benghalensis	0	72	0	0	0	0	0	0	0	72 (±72)
Total	**532**	**3,769**	**16,363**	**6,773**	**1,284**	**144**	**217**	**48**	**72**	**29,203 (±9,147)**
Broadleaf Evergreen Medium (BEM)										
Broadleaf Evergreen Mediun	81	613	10,511	2,200	76	76	0	0	0	13,556 (±4,699)
Mimusops caffra	680	4,149	2,241	1,011	217	0	0	0	0	8,297 (±4,315)
Calophyllum inophyllum	1,284	2,340	0	0	0	0	0	0	0	3,624 (±3,600)
Salix matsudana	0	0	72	0	0	0	0	0	0	72 (±72)
Moringa oleifera	0	0	72	0	0	0	0	0	0	72 (±72)
Total	**2,044**	**7,103**	**12,896**	**3,211**	**292**	**76**	**0**	**0**	**0**	**25,622 (±7,043)**
Broadleaf Evergreen Small (BES)										
Broadleaf Evergreen Small C	307	3,089	7,127	129	0	0	0	0	0	10,652 (±3,938)
Plumeria species	76	302	76	0	0	0	0	0	0	453 (±450)
Morinda citrifolia	0	48	0	0	0	0	0	0	0	48 (±48)
Total	**382**	**3,440**	**7,202**	**129**	**0**	**0**	**0**	**0**	**0**	**11,154 (±3,962)**
Palm Evergreen Medium (PEM)										
Palm species	0	0	144	702	1,162	0	0	0	0	2,008 (±1,165)
Total	**0**	**0**	**144**	**702**	**1,162**	**0**	**0**	**0**	**0**	**2,008 (±1,165)**
Grand Total	**7,479**	**45,611**	**94,977**	**25,845**	**5,556**	**736**	**289**	**48**	**72**	**180,613 (±13,475)**

Appendix 1-B

Thailand

Structural (Woody) Condition of All Trees by Species

13/9/2014

Species	Condition	Tree Count	Standard Error	% of Species	% of All Trees
Acacia koa	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	166	(±165)	100.00	.09
	Total	166	(±165)	100.00	.09
Artocarpus heterophyllus	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	372	(±298)	42.40	.21
	Good	505	(±428)	57.60	.28
	Total	877	(±717)	100.00	.49
Averrhoa bilimbi	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	83	(±83)	100.00	.05
	Good	0	(±0)	.00	.00
	Total	83	(±83)	100.00	.05
Azadirachta indica	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	453	(±377)	100.00	.25
	Total	453	(±377)	100.00	.25
Broadleaf Deciduous Medium Other	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	162	(±161)	6.45	.09
	Good	2,351	(±1,643)	93.55	1.30
	Total	2,513	(±1,670)	100.00	1.39
Broadleaf Deciduous Small Other	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	81	(±81)	100.00	.04
	Good	0	(±0)	.00	.00
	Total	81	(±81)	100.00	.04
Broadleaf Evergreen Large Other	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	76	(±75)	100.00	.04
	Total	76	(±75)	100.00	.04
Broadleaf Evergreen Medium Other	Dead or Dying	275	(±208)	2.03	.15
	Poor	97	(±96)	.71	.05
	Fair	2,647	(±1,111)	19.52	1.47
	Good	10,538	(±3,915)	77.73	5.83
	Total	13,556	(±4,699)	100.00	7.51
Broadleaf Evergreen Small Other	Dead or Dying	129	(±94)	1.22	.07
	Poor	81	(±81)	.76	.04
	Fair	3,254	(±1,253)	30.55	1.80
	Good	7,188	(±2,838)	67.48	3.98
	Total	10,652	(±3,938)	100.00	5.90
Calophyllum inophyllum	Dead or Dying	151	(±150)	4.17	.08
	Poor	0	(±0)	.00	.00
	Fair	982	(±975)	27.08	.54
	Good	2,492	(±2,475)	68.75	1.38
	Total	3,624	(±3,600)	100.00	2.01
Cassia fistula	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	3,319	(±2,094)	16.42	1.84
	Good	16,890	(±8,794)	83.58	9.35
	Total	20,209	(±9,752)	100.00	11.19

Structural (Woody) Condition of All Trees by Species

13/9/2014

Species	Condition	Tree Count	Standard Error	% of Species	% of All Trees
Casuarina equisetifolia	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	250	(±248)	76.78	.14
	Good	76	(±75)	23.22	.04
	Total	325	(±259)	100.00	.18
Delonix regia	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	449	(±272)	100.00	.25
	Total	449	(±272)	100.00	.25
Ficus benghalensis	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	72	(±72)	100.00	.04
	Total	72	(±72)	100.00	.04
Ficus benjamina	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	48	(±48)	28.65	.03
	Good	121	(±86)	71.35	.07
	Total	169	(±120)	100.00	.09
Ficus religiosa	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	217	(±110)	100.00	.12
	Total	217	(±110)	100.00	.12
Lagerstroemia speciosa	Dead or Dying	164	(±115)	.63	.09
	Poor	416	(±185)	1.59	.23
	Fair	4,423	(±2,045)	16.85	2.45
	Good	21,243	(±4,229)	80.94	11.76
	Total	26,246	(±5,277)	100.00	14.53
Mangifera indica	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	457	(±319)	100.00	.25
	Total	457	(±319)	100.00	.25
Mimusops caffra	Dead or Dying	72	(±72)	.87	.04
	Poor	0	(±0)	.00	.00
	Fair	292	(±170)	3.52	.16
	Good	7,933	(±4,214)	95.61	4.39
	Total	8,297	(±4,315)	100.00	4.59
Morinda citrifolia	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	48	(±48)	100.00	.03
	Total	48	(±48)	100.00	.03
Moringa oleifera	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	72	(±72)	100.00	.04
	Total	72	(±72)	100.00	.04
Palm species	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	2,008	(±1,165)	100.00	1.11
	Total	2,008	(±1,165)	100.00	1.11

Thailand

Structural (Woody) Condition of All Trees by Species

13/9/2014

Species	Condition	Tree Count	Standard Error	% of Species	% of All Trees
Peltophorum pterocarpum	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	7,773	(±5,411)	100.00	4.30
	Total	7,773	(±5,411)	100.00	4.30
Pithecellobium dulce	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	81	(±81)	100.00	.04
	Total	81	(±81)	100.00	.04
Plumeria species	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	453	(±450)	100.00	.25
	Total	453	(±450)	100.00	.25
Polyalthia longifolia	Dead or Dying	97	(±96)	.93	.05
	Poor	48	(±48)	.47	.03
	Fair	1,899	(±1,485)	18.31	1.05
	Good	8,325	(±7,174)	80.29	4.61
	Total	10,368	(±8,105)	100.00	5.74
Pterocarpus indicus	Dead or Dying	652	(±368)	1.52	.36
	Poor	413	(±236)	.96	.23
	Fair	7,735	(±2,254)	17.99	4.28
	Good	34,205	(±6,373)	79.54	18.94
	Total	43,004	(±8,347)	100.00	23.81
Salix matsudana	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	72	(±72)	100.00	.04
	Total	72	(±72)	100.00	.04
Samanea saman	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	153	(±108)	100.00	.08
	Total	153	(±108)	100.00	.08
Swietenia mahagoni	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	8,091	(±4,580)	100.00	4.48
	Total	8,091	(±4,580)	100.00	4.48
Tabebuia aurea	Dead or Dying	76	(±75)	1.09	.04
	Poor	81	(±81)	1.17	.04
	Fair	475	(±291)	6.83	.26
	Good	6,326	(±3,560)	90.92	3.50
	Total	6,958	(±3,888)	100.00	3.85
Tabebuia species	Dead or Dying	144	(±143)	1.58	.08
	Poor	289	(±219)	3.16	.16
	Fair	2,522	(±804)	27.58	1.40
	Good	6,189	(±2,209)	67.68	3.43
	Total	9,144	(±2,680)	100.00	5.06
Tamarindus indica	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	1,155	(±933)	33.93	.64
	Good	2,249	(±1,258)	66.07	1.25
	Total	3,404	(±2,150)	100.00	1.88

Thailand

Structural (Woody) Condition of All Trees by Species

13/9/2014

Species	Condition	Tree Count	Standard Error	% of Species	% of All Trees
Terminalia catappa	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	72	(±72)	15.74	.04
	Good	387	(±258)	84.26	.21
	Total	459	(±284)	100.00	.25

Appendix 1-C

Thailand

Functional (Foliage) Condition of All Trees by Species

13/9/2014

Species	Condition	Tree Count	Standard Error	% of Species	% of All Trees
Acacia koa	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	166	(±165)	100.00	.09
	Total	166	(±165)	100.00	.09
Artocarpus heterophyllus	Dead or Dying	0	(±0)	.00	.00
	Poor	144	(±143)	16.46	.08
	Fair	300	(±230)	34.17	.17
	Good	433	(±358)	49.37	.24
	Total	877	(±717)	100.00	.49
Averrhoa bilimbi	Dead or Dying	0	(±0)	.00	.00
	Poor	83	(±83)	100.00	.05
	Fair	0	(±0)	.00	.00
	Good	0	(±0)	.00	.00
	Total	83	(±83)	100.00	.05
Azadirachta indica	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	76	(±75)	16.67	.04
	Good	378	(±375)	83.33	.21
	Total	453	(±377)	100.00	.25
Broadleaf Deciduous Medium Other	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	2,026	(±1,232)	80.65	1.12
	Good	486	(±483)	19.35	.27
	Total	2,513	(±1,670)	100.00	1.39
Broadleaf Deciduous Small Other	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	81	(±81)	100.00	.04
	Good	0	(±0)	.00	.00
	Total	81	(±81)	100.00	.04
Broadleaf Evergreen Large Other	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	76	(±75)	100.00	.04
	Total	76	(±75)	100.00	.04
Broadleaf Evergreen Medium Other	Dead or Dying	441	(±266)	3.25	.24
	Poor	3,997	(±1,398)	29.48	2.21
	Fair	4,992	(±1,884)	36.82	2.76
	Good	4,127	(±1,690)	30.44	2.28
	Total	13,556	(±4,699)	100.00	7.51
Broadleaf Evergreen Small Other	Dead or Dying	211	(±120)	1.98	.12
	Poor	2,690	(±1,207)	25.25	1.49
	Fair	5,309	(±1,962)	49.84	2.94
	Good	2,443	(±1,059)	22.93	1.35
	Total	10,652	(±3,938)	100.00	5.90
Calophyllum inophyllum	Dead or Dying	151	(±150)	4.17	.08
	Poor	378	(±375)	10.42	.21
	Fair	1,736	(±1,725)	47.92	.96
	Good	1,359	(±1,350)	37.50	.75
	Total	3,624	(±3,600)	100.00	2.01
Cassia fistula	Dead or Dying	528	(±393)	2.62	.29
	Poor	5,134	(±2,740)	25.40	2.84
	Fair	10,658	(±6,130)	52.74	5.90
	Good	3,889	(±1,435)	19.24	2.15
	Total	20,209	(±9,752)	100.00	11.19

Functional (Foliage) Condition of All Trees by Species

13/9/2014

Species	Condition	Tree Count	Standard Error	% of Species	% of All Trees
Casuarina equisetifolia	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	166	(±165)	51.18	.09
	Good	159	(±112)	48.82	.09
	Total	325	(±259)	100.00	.18
Delonix regia	Dead or Dying	0	(±0)	.00	.00
	Poor	76	(±75)	16.81	.04
	Fair	242	(±182)	53.87	.13
	Good	132	(±96)	29.31	.07
	Total	449	(±272)	100.00	.25
Ficus benghalensis	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	72	(±72)	100.00	.04
	Total	72	(±72)	100.00	.04
Ficus benjamina	Dead or Dying	0	(±0)	.00	.00
	Poor	48	(±48)	28.65	.03
	Fair	0	(±0)	.00	.00
	Good	121	(±86)	71.35	.07
	Total	169	(±120)	100.00	.09
Ficus religiosa	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	72	(±72)	33.33	.04
	Good	144	(±96)	66.67	.08
	Total	217	(±110)	100.00	.12
Lagerstroemia speciosa	Dead or Dying	166	(±101)	.63	.09
	Poor	2,701	(±762)	10.29	1.50
	Fair	8,937	(±1,965)	34.05	4.95
	Good	14,441	(±3,243)	55.02	8.00
	Total	26,246	(±5,277)	100.00	14.53
Mangifera indica	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	76	(±75)	16.51	.04
	Good	382	(±250)	83.49	.21
	Total	457	(±319)	100.00	.25
Mimusops caffra	Dead or Dying	72	(±72)	.87	.04
	Poor	289	(±219)	3.48	.16
	Fair	2,137	(±1,132)	25.75	1.18
	Good	5,799	(±3,396)	69.90	3.21
	Total	8,297	(±4,315)	100.00	4.59
Morinda citrifolia	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	48	(±48)	100.00	.03
	Good	0	(±0)	.00	.00
	Total	48	(±48)	100.00	.03
Moringa oleifera	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	72	(±72)	100.00	.04
	Good	0	(±0)	.00	.00
	Total	72	(±72)	100.00	.04
Palm species	Dead or Dying	0	(±0)	.00	.00
	Poor	72	(±72)	3.59	.04
	Fair	435	(±277)	21.66	.24
	Good	1,501	(±976)	74.75	.83
	Total	2,008	(±1,165)	100.00	1.11

Functional (Foliage) Condition of All Trees by Species

13/9/2014

Species	Condition	Tree Count	Standard Error	% of Species	% of All Trees
Peltophorum pterocarpum	Dead or Dying	81	(±81)	1.04	.04
	Poor	1,459	(±1,450)	18.77	.81
	Fair	1,378	(±983)	17.73	.76
	Good	4,855	(±3,913)	62.46	2.69
	Total	7,773	(±5,411)	100.00	4.30
Pithecellobium dulce	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	81	(±81)	100.00	.04
	Total	81	(±81)	100.00	.04
Plumeria species	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	76	(±75)	16.67	.04
	Good	378	(±375)	83.33	.21
	Total	453	(±450)	100.00	.25
Polyalthia longifolia	Dead or Dying	145	(±144)	1.40	.08
	Poor	48	(±48)	.47	.03
	Fair	2,024	(±1,829)	19.52	1.12
	Good	8,151	(±7,363)	78.61	4.51
	Total	10,368	(±8,105)	100.00	5.74
Pterocarpus indicus	Dead or Dying	997	(±385)	2.32	.55
	Poor	6,324	(±1,491)	14.71	3.50
	Fair	17,907	(±3,887)	41.64	9.91
	Good	17,704	(±3,979)	41.17	9.80
	Total	42,932	(±8,358)	99.83	23.77
Salix matsudana	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	0	(±0)	.00	.00
	Good	72	(±72)	100.00	.04
	Total	72	(±72)	100.00	.04
Samanea saman	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	72	(±72)	47.11	.04
	Good	81	(±81)	52.89	.04
	Total	153	(±108)	100.00	.08
Swietenia mahagoni	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	954	(±440)	11.79	.53
	Good	7,137	(±4,193)	88.21	3.95
	Total	8,091	(±4,580)	100.00	4.48
Tabebuia aurea	Dead or Dying	151	(±150)	2.17	.08
	Poor	243	(±242)	3.50	.13
	Fair	2,200	(±1,233)	31.62	1.22
	Good	4,364	(±2,587)	62.72	2.42
	Total	6,958	(±3,888)	100.00	3.85
Tabebuia species	Dead or Dying	514	(±257)	5.62	.28
	Poor	3,950	(±1,327)	43.20	2.19
	Fair	3,886	(±1,318)	42.50	2.15
	Good	794	(±569)	8.68	.44
	Total	9,144	(±2,680)	100.00	5.06
Tamarindus indica	Dead or Dying	0	(±0)	.00	.00
	Poor	505	(±502)	14.85	.28
	Fair	1,300	(±1,213)	38.17	.72
	Good	661	(±406)	19.41	.37
	Total	2,466	(±2,060)	72.43	1.37

Thailand

Functional (Foliage) Condition of All Trees by Species

13/9/2014

Species	Condition	Tree Count	Standard Error	% of Species	% of All Trees
Terminalia catappa	Dead or Dying	0	(±0)	.00	.00
	Poor	0	(±0)	.00	.00
	Fair	72	(±72)	15.74	.04
	Good	387	(±258)	84.26	.21
	Total	459	(±284)	100.00	.25

Appendix 1-D

Thailand

Importance Values of Public Trees

13/9/2014

Species	Number of Trees	% of Total Trees	Leaf Area (m²)	% of Total Leaf Area	Canopy Cover (m²)	% of Total Canopy Cover	Importance Value
Pterocarpus indicus	43,004	23.81	2,985,628	22.07	2,224,008	31.53	25.80
Lagerstroemia speciosa	26,246	14.53	1,926,895	14.24	911,627	12.92	13.90
Cassia fistula	20,209	11.19	1,314,971	9.72	465,413	6.60	9.17
Broadleaf Evergreen Mediu	13,556	7.51	1,530,076	11.31	493,273	6.99	8.60
Broadleaf Evergreen Small	10,652	5.90	632,455	4.67	267,752	3.80	4.79
Polyalthia longifolia	10,369	5.74	206,732	1.53	94,114	1.33	2.87
Tabebuia species	9,144	5.06	510,562	3.77	297,161	4.21	4.35
Mimusops caffra	8,297	4.59	597,840	4.42	204,220	2.90	3.97
Swietenia mahagoni	8,091	4.48	231,290	1.71	179,644	2.55	2.91
Peltophorum pterocarpum	7,773	4.30	1,505,821	11.13	810,222	11.49	8.97
Tabebuia aurea	6,958	3.85	203,576	1.50	112,479	1.59	2.32
Calophyllum inophyllum	3,624	2.01	86,123	0.64	19,865	0.28	0.97
Tamarindus indica	3,404	1.88	616,978	4.56	328,183	4.65	3.70
Broadleaf Deciduous Mediu	2,513	1.39	283,021	2.09	113,465	1.61	1.70
Palm species	2,008	1.11	55,590	0.41	40,962	0.58	0.70
Artocarpus heterophyllus	877	0.49	215,953	1.60	111,910	1.59	1.22
Terminalia catappa	459	0.25	85,551	0.63	67,247	0.95	0.61
Mangifera indica	457	0.25	39,392	0.29	23,397	0.33	0.29
Plumeria species	453	0.25	13,944	0.10	6,743	0.10	0.15
Azadirachta indica	453	0.25	45,030	0.33	26,445	0.37	0.32
Delonix regia	449	0.25	36,695	0.27	30,051	0.43	0.32
Casuarina equisetifolia	325	0.18	14,101	0.10	5,684	0.08	0.12
Ficus religiosa	217	0.12	167,342	1.24	92,525	1.31	0.89
Ficus benjamina	169	0.09	79,782	0.59	42,655	0.60	0.43
Acacia koa	166	0.09	25,179	0.19	13,944	0.20	0.16
Samanea saman	153	0.08	48,796	0.36	36,757	0.52	0.32
Averrhoa bilimbi	83	0.05	663	0.00	803	0.01	0.02
Pithecellobium dulce	81	0.04	18,577	0.14	9,883	0.14	0.11
Broadleaf Deciduous Small	81	0.04	1,568	0.01	871	0.01	0.02
Broadleaf Evergreen Large	76	0.04	32,955	0.24	16,526	0.23	0.17
Salix matsudana	72	0.04	7,025	0.05	2,399	0.03	0.04
Moringa oleifera	72	0.04	7,025	0.05	2,399	0.03	0.04
Ficus benghalensis	72	0.04	576	0.00	697	0.01	0.02
Morinda citrifolia	48	0.03	1,278	0.01	639	0.01	0.02
Total	180,613	100.00	13,528,988	100.00	7,053,962	100.00	100.00

Appendix 1-E

Thailand

Sidewalk Heave Conflicts by Species for All Trees

13/9/2014

Species	Conflict	Tree Count	Standard Error	% of Species	% of All Trees
Acacia koa	0 - 3/4 inches	166	(±165)	100.00	.09
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	166	(±165)	100.00	.09
Artocarpus heterophyllus	0 - 3/4 inches	805	(±722)	91.77	.45
	3/4 - 1 1/2 inches	72	(±72)	8.23	.04
	>1 1/2 inches	0	(±0)	.00	.00
	Total	877	(±717)	100.00	.49
Averrhoa bilimbi	0 - 3/4 inches	83	(±83)	100.00	.05
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	83	(±83)	100.00	.05
Azadirachta indica	0 - 3/4 inches	453	(±377)	100.00	.25
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	453	(±377)	100.00	.25
Broadleaf Deciduous Medium Other	0 - 3/4 inches	2,270	(±1,448)	90.32	1.26
	3/4 - 1 1/2 inches	243	(±242)	9.68	.13
	>1 1/2 inches	0	(±0)	.00	.00
	Total	2,513	(±1,670)	100.00	1.39
Broadleaf Deciduous Small Other	0 - 3/4 inches	81	(±81)	100.00	.04
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	81	(±81)	100.00	.04
Broadleaf Evergreen Large Other	0 - 3/4 inches	76	(±75)	100.00	.04
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	76	(±75)	100.00	.04
Broadleaf Evergreen Medium Other	0 - 3/4 inches	11,307	(±3,830)	83.40	6.26
	3/4 - 1 1/2 inches	1,830	(±1,393)	13.50	1.01
	>1 1/2 inches	420	(±345)	3.10	.23
	Total	13,556	(±4,699)	100.00	7.51
Broadleaf Evergreen Small Other	0 - 3/4 inches	9,229	(±3,426)	86.64	5.11
	3/4 - 1 1/2 inches	971	(±628)	9.11	.54
	>1 1/2 inches	453	(±308)	4.25	.25
	Total	10,652	(±3,938)	100.00	5.90
Calophyllum inophyllum	0 - 3/4 inches	3,624	(±3,600)	100.00	2.01
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	3,624	(±3,600)	100.00	2.01
Cassia fistula	0 - 3/4 inches	19,220	(±9,390)	95.11	10.64
	3/4 - 1 1/2 inches	612	(±386)	3.03	.34
	>1 1/2 inches	378	(±304)	1.87	.21
	Total	20,209	(±9,752)	100.00	11.19
Casuarina equisetifolia	0 - 3/4 inches	325	(±259)	100.00	.18
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	325	(±259)	100.00	.18
Delonix regia	0 - 3/4 inches	449	(±272)	100.00	.25
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	449	(±272)	100.00	.25

Sidewalk Heave Conflicts by Species for All Trees

13/9/2014

Species	Conflict	Tree Count	Standard Error	% of Species	% of All Trees
Ficus benghalensis	0 - 3/4 inches	72	(±72)	100.00	.04
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	72	(±72)	100.00	.04
Ficus benjamina	0 - 3/4 inches	121	(±86)	71.35	.07
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	48	(±48)	28.65	.03
	Total	169	(±120)	100.00	.09
Ficus religiosa	0 - 3/4 inches	144	(±96)	66.67	.08
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	72	(±72)	33.33	.04
	Total	217	(±110)	100.00	.12
Lagerstroemia speciosa	0 - 3/4 inches	25,043	(±5,022)	95.42	13.87
	3/4 - 1 1/2 inches	1,037	(±478)	3.95	.57
	>1 1/2 inches	166	(±101)	.63	.09
	Total	26,246	(±5,277)	100.00	14.53
Mangifera indica	0 - 3/4 inches	385	(±311)	84.22	.21
	3/4 - 1 1/2 inches	72	(±72)	15.78	.04
	>1 1/2 inches	0	(±0)	.00	.00
	Total	457	(±319)	100.00	.25
Mimusops caffra	0 - 3/4 inches	8,149	(±4,262)	98.22	4.51
	3/4 - 1 1/2 inches	76	(±75)	.91	.04
	>1 1/2 inches	72	(±72)	.87	.04
	Total	8,297	(±4,315)	100.00	4.59
Morinda citrifolia	0 - 3/4 inches	48	(±48)	100.00	.03
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	48	(±48)	100.00	.03
Moringa oleifera	0 - 3/4 inches	72	(±72)	100.00	.04
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	72	(±72)	100.00	.04
Palm species	0 - 3/4 inches	2,008	(±1,165)	100.00	1.11
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	2,008	(±1,165)	100.00	1.11
Peltophorum pterocarpum	0 - 3/4 inches	4,774	(±3,219)	61.41	2.64
	3/4 - 1 1/2 inches	1,702	(±1,160)	21.90	.94
	>1 1/2 inches	1,297	(±1,289)	16.69	.72
	Total	7,773	(±5,411)	100.00	4.30
Pithecellobium dulce	0 - 3/4 inches	81	(±81)	100.00	.04
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	81	(±81)	100.00	.04
Plumeria species	0 - 3/4 inches	453	(±450)	100.00	.25
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	453	(±450)	100.00	.25
Polyalthia longifolia	0 - 3/4 inches	10,368	(±8,105)	100.00	5.74
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	10,368	(±8,105)	100.00	5.74

Thailand

Sidewalk Heave Conflicts by Species for All Trees

13/9/2014

Species	Conflict	Tree Count	Standard Error	% of Species	% of All Trees
Pterocarpus indicus	0 - 3/4 inches	37,743	(±7,675)	87.77	20.90
	3/4 - 1 1/2 inches	3,400	(±1,089)	7.91	1.88
	>1 1/2 inches	1,861	(±709)	4.33	1.03
	Total	43,004	(±8,347)	100.00	23.81
Salix matsudana	0 - 3/4 inches	72	(±72)	100.00	.04
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	72	(±72)	100.00	.04
Samanea saman	0 - 3/4 inches	153	(±108)	100.00	.08
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	153	(±108)	100.00	.08
Swietenia mahagoni	0 - 3/4 inches	8,091	(±4,580)	100.00	4.48
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	8,091	(±4,580)	100.00	4.48
Tabebuia aurea	0 - 3/4 inches	6,261	(±3,530)	89.99	3.47
	3/4 - 1 1/2 inches	308	(±239)	4.42	.17
	>1 1/2 inches	389	(±277)	5.59	.22
	Total	6,958	(±3,888)	100.00	3.85
Tabebuia species	0 - 3/4 inches	7,509	(±2,220)	82.12	4.16
	3/4 - 1 1/2 inches	907	(±416)	9.91	.50
	>1 1/2 inches	729	(±334)	7.97	.40
	Total	9,144	(±2,680)	100.00	5.06
Tamarindus indica	0 - 3/4 inches	3,116	(±2,079)	91.52	1.73
	3/4 - 1 1/2 inches	217	(±215)	6.36	.12
	>1 1/2 inches	72	(±72)	2.12	.04
	Total	3,404	(±2,150)	100.00	1.88
Terminalia catappa	0 - 3/4 inches	459	(±284)	100.00	.25
	3/4 - 1 1/2 inches	0	(±0)	.00	.00
	>1 1/2 inches	0	(±0)	.00	.00
	Total	459	(±284)	100.00	.25

Appendix 1-F

Thailand

Overhead Utility Lines Conflicts by Species for All Trees

13/9/2014

Species	Conflict	Tree Count	Standard Error	% of Species	% of All Trees
Acacia koa	No lines	0	(±0)	.00	.00
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	166	(±165)	100.00	.09
	Total	166	(±165)	100.00	.09
Artocarpus heterophyllus	No lines	0	(±0)	.00	.00
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	877	(±717)	100.00	.49
	Total	877	(±717)	100.00	.49
Averrhoa bilimbi	No lines	83	(±83)	100.00	.05
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	0	(±0)	.00	.00
	Total	83	(±83)	100.00	.05
Azadirachta indica	No lines	0	(±0)	.00	.00
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	453	(±377)	100.00	.25
	Total	453	(±377)	100.00	.25
Broadleaf Deciduous Medium Other	No lines	0	(±0)	.00	.00
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	2,513	(±1,670)	100.00	1.39
	Total	2,513	(±1,670)	100.00	1.39
Broadleaf Deciduous Small Other	No lines	81	(±81)	100.00	.04
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	0	(±0)	.00	.00
	Total	81	(±81)	100.00	.04
Broadleaf Evergreen Large Other	No lines	0	(±0)	.00	.00
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	76	(±75)	100.00	.04
	Total	76	(±75)	100.00	.04
Broadleaf Evergreen Medium Other	No lines	9,053	(±3,601)	66.78	5.01
	Present and no potential conflict	178	(±125)	1.31	.10
	Present and conflicting	4,326	(±3,052)	31.91	2.40
	Total	13,556	(±4,699)	100.00	7.51
Broadleaf Evergreen Small Other	No lines	4,197	(±2,025)	39.40	2.32
	Present and no potential conflict	48	(±48)	.45	.03
	Present and conflicting	6,406	(±3,365)	60.14	3.55
	Total	10,652	(±3,938)	100.00	5.90
Calophyllum inophyllum	No lines	0	(±0)	.00	.00
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	3,624	(±3,600)	100.00	2.01
	Total	3,624	(±3,600)	100.00	2.01
Cassia fistula	No lines	83	(±83)	.41	.05
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	20,126	(±9,748)	99.59	11.14
	Total	20,209	(±9,752)	100.00	11.19
Casuarina equisetifolia	No lines	250	(±248)	76.78	.14
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	76	(±75)	23.22	.04
	Total	325	(±259)	100.00	.18
Delonix regia	No lines	0	(±0)	.00	.00
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	449	(±272)	100.00	.25
	Total	449	(±272)	100.00	.25

Thailand

Overhead Utility Lines Conflicts by Species for All Trees

13/9/2014

Species	Conflict	Tree Count	Standard Error	% of Species	% of All Trees
Ficus benghalensis	No lines	0	(±0)	.00	.00
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	72	(±72)	100.00	.04
	Total	72	(±72)	100.00	.04
Ficus benjamina	No lines	0	(±0)	.00	.00
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	169	(±120)	100.00	.09
	Total	169	(±120)	100.00	.09
Ficus religiosa	No lines	0	(±0)	.00	.00
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	217	(±110)	100.00	.12
	Total	217	(±110)	100.00	.12
Lagerstroemia speciosa	No lines	3,075	(±1,678)	11.71	1.70
	Present and no potential conflict	228	(±166)	.87	.13
	Present and conflicting	22,943	(±5,441)	87.42	12.70
	Total	26,246	(±5,277)	100.00	14.53
Mangifera indica	No lines	0	(±0)	.00	.00
	Present and no potential conflict	83	(±83)	18.19	.05
	Present and conflicting	374	(±308)	81.81	.21
	Total	457	(±319)	100.00	.25
Mimusops caffra	No lines	6,131	(±4,047)	73.89	3.39
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	2,166	(±1,496)	26.11	1.20
	Total	8,297	(±4,315)	100.00	4.59
Morinda citrifolia	No lines	48	(±48)	100.00	.03
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	0	(±0)	.00	.00
	Total	48	(±48)	100.00	.03
Moringa oleifera	No lines	0	(±0)	.00	.00
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	72	(±72)	100.00	.04
	Total	72	(±72)	100.00	.04
Palm species	No lines	1,792	(±1,145)	89.22	.99
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	217	(±215)	10.78	.12
	Total	2,008	(±1,165)	100.00	1.11
Peltophorum pterocarpum	No lines	0	(±0)	.00	.00
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	7,773	(±5,411)	100.00	4.30
	Total	7,773	(±5,411)	100.00	4.30
Pithecellobium dulce	No lines	81	(±81)	100.00	.04
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	0	(±0)	.00	.00
	Total	81	(±81)	100.00	.04
Plumeria species	No lines	453	(±450)	100.00	.25
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	0	(±0)	.00	.00
	Total	453	(±450)	100.00	.25
Polyalthia longifolia	No lines	10,293	(±8,105)	99.27	5.70
	Present and no potential conflict	76	(±75)	.73	.04
	Present and conflicting	0	(±0)	.00	.00
	Total	10,368	(±8,105)	100.00	5.74

Thailand

Overhead Utility Lines Conflicts by Species for All Trees

13/9/2014

Species	Conflict	Tree Count	Standard Error	% of Species	% of All Trees
Pterocarpus indicus	No lines	6,816	(±2,632)	15.85	3.77
	Present and no potential conflict	580	(±405)	1.35	.32
	Present and conflicting	35,608	(±6,887)	82.80	19.71
	Total	43,004	(±8,347)	100.00	23.81
Salix matsudana	No lines	0	(±0)	.00	.00
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	72	(±72)	100.00	.04
	Total	72	(±72)	100.00	.04
Samanea saman	No lines	81	(±81)	52.89	.04
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	72	(±72)	47.11	.04
	Total	153	(±108)	100.00	.08
Swietenia mahagoni	No lines	5,966	(±4,325)	73.74	3.30
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	2,125	(±1,521)	26.26	1.18
	Total	8,091	(±4,580)	100.00	4.48
Tabebuia aurea	No lines	2,594	(±2,578)	37.28	1.44
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	4,364	(±3,020)	62.72	2.42
	Total	6,958	(±3,888)	100.00	3.85
Tabebuia species	No lines	178	(±125)	1.95	.10
	Present and no potential conflict	217	(±153)	2.37	.12
	Present and conflicting	8,750	(±2,688)	95.69	4.84
	Total	9,144	(±2,680)	100.00	5.06
Tamarindus indica	No lines	2,249	(±2,074)	66.07	1.25
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	1,155	(±856)	33.93	.64
	Total	3,404	(±2,150)	100.00	1.88
Terminalia catappa	No lines	242	(±240)	52.78	.13
	Present and no potential conflict	0	(±0)	.00	.00
	Present and conflicting	217	(±153)	47.22	.12
	Total	459	(±284)	100.00	.25

Appendix 1-G

Thailand

Annual Energy Benefits of All Trees

13/9/2014

Species	Total Electricity (MWh)	Electricity ($)	Total Natural Gas (Therms)	Natural Gas ($)	Total ($)	Standard Error	% of Total Trees	% of Total $	Avg. $/tree
Pterocarpus indicus	1,955.4	211,178	0.0	0	211,178	(±43,773)	23.8	23.6	4.91
Lagerstroemia speciosa	1,194.9	129,052	0.0	0	129,052	(±25,631)	14.5	14.4	4.92
Cassia fistula	599.6	64,753	0.0	0	64,753	(±27,988)	11.2	7.2	3.20
Broadleaf Evergreen Mediur	724.5	78,243	0.0	0	78,243	(±28,309)	7.5	8.7	5.77
Broadleaf Evergreen Small (	346.1	37,380	0.0	0	37,380	(±14,782)	5.9	4.2	3.51
Polyalthia longifolia	85.0	9,177	0.0	0	9,177	(±7,132)	5.7	1.0	.89
Tabebuia species	412.3	44,530	0.0	0	44,530	(±13,166)	5.1	5.0	4.87
Mimusops caffra	300.4	32,444	0.0	0	32,444	(±16,196)	4.6	3.6	3.91
Swietenia mahagoni	238.2	25,722	0.0	0	25,722	(±14,921)	4.5	2.9	3.18
Peltophorum pterocarpum	1,070.4	115,607	0.0	0	115,607	(±77,519)	4.3	12.9	14.87
Tabebuia aurea	159.3	17,208	0.0	0	17,208	(±9,711)	3.9	1.9	2.47
Calophyllum inophyllum	27.8	3,003	0.0	0	3,003	(±2,984)	2.0	0.3	.83
Tamarindus indica	409.8	44,255	0.0	0	44,255	(±27,844)	1.9	4.9	13.00
Broadleaf Deciduous Mediu	151.7	16,385	0.0	0	16,385	(±10,587)	1.4	1.8	6.52
Palm species	54.1	5,846	0.0	0	5,846	(±3,428)	1.1	0.7	2.91
Artocarpus heterophyllus	140.0	15,118	0.0	0	15,118	(±13,582)	0.5	1.7	17.23
Terminalia catappa	59.0	6,368	0.0	0	6,368	(±4,402)	0.3	0.7	13.88
Mangifera indica	31.4	3,389	0.0	0	3,389	(±2,379)	0.3	0.4	7.41
Plumeria species	8.1	876	0.0	0	876	(±870)	0.3	0.1	1.93
Azadirachta indica	35.8	3,862	0.0	0	3,862	(±2,753)	0.3	0.4	8.53
Delonix regia	36.6	3,949	0.0	0	3,949	(±2,659)	0.2	0.4	8.79
Casuarina equisetifolia	11.4	1,231	0.0	0	1,231	(±865)	0.2	0.1	3.79
Ficus religiosa	102.6	11,080	0.0	0	11,080	(±6,569)	0.1	1.2	51.16
Ficus benjamina	50.0	5,395	0.0	0	5,395	(±4,275)	0.1	0.6	31.91
Acacia koa	18.7	2,018	0.0	0	2,018	(±2,006)	0.1	0.2	12.13
Samanea saman	32.2	3,475	0.0	0	3,475	(±2,529)	0.1	0.4	22.67
Averrhoa bilimbi	0.9	93	0.0	0	93	(±92)	0.0	0.0	1.11
Pithecellobium dulce	13.2	1,421	0.0	0	1,421	(±1,413)	0.0	0.2	17.53
Broadleaf Deciduous Small (	0.9	96	0.0	0	96	(±95)	0.0	0.0	1.18
Broadleaf Evergreen Large (	20.4	2,200	0.0	0	2,200	(±2,185)	0.0	0.2	29.13
Salix matsudana	3.6	385	0.0	0	385	(±383)	0.0	0.0	5.34
Moringa oleifera	3.6	385	0.0	0	385	(±383)	0.0	0.0	5.34
Ficus benghalensis	0.7	80	0.0	0	80	(±80)	0.0	0.0	1.11
Morinda citrifolia	0.7	81	0.0	0	81	(±80)	0.0	0.0	1.67
Total	8,298.9	896,286	0.0	0	896,286	(±80,494)	100.0	100.0	4.96

Appendix 1-H

Thailand

Annual CO_2 Benefits of All Trees

13/9/2014

Species	Sequestered (kg)	Sequestered ($)	Decomposition Release(kg)	Maintenance Release(kg)	Total Released ($)	Avoided (kg)	Avoided ($)	Net Total (kg)	Total Standard ($) Error	% of Total Trees	% of Total $	Avg. $/tree
Pterocarpus indicus	2,037,192	14,821	-50,557	-59,445	-800	1,639,686	11,929	3,566,876	25,950 (±5,313)	23.8	27.7	.60
Lagerstroemia speciosa	1,057,635	7,695	-27,173	-28,576	-406	1,002,019	7,290	2,003,904	14,579 (±2,896)	14.5	15.6	.56
Cassia fistula	553,997	4,030	-10,562	-14,822	-185	502,776	3,658	1,031,390	7,504 (±3,294)	11.2	8.0	.37
Broadleaf Evergreen Medi	438,573	3,191	-24,347	-17,999	-308	607,520	4,420	1,003,747	7,303 (±2,562)	7.5	7.8	.54
Broadleaf Evergreen Small	284,226	2,068	-8,682	-10,829	-142	290,238	2,112	554,954	4,037 (±1,570)	5.9	4.3	.38
Polyalthia longifolia	149,822	1,090	-3,490	-6,053	-69	71,252	518	211,532	1,539 (±1,199)	5.7	1.6	.15
Tabebuia species	224,466	1,633	-16,237	-16,181	-236	345,751	2,515	537,799	3,913 (±1,124)	5.1	4.2	.43
Mimusops caffra	191,302	1,392	-9,415	-8,017	-127	251,913	1,833	425,783	3,098 (±1,549)	4.6	3.3	.37
Swietenia mahagoni	179,827	1,308	-4,926	-8,825	-100	199,718	1,453	365,793	2,661 (±1,548)	4.5	2.8	.33
Peltophorum pterocarpum	432,470	3,146	-25,776	-14,126	-290	897,627	6,530	1,290,195	9,386 (±6,303)	4.3	10.0	1.21
Tabebuia aurea	171,967	1,251	-5,393	-8,057	-98	133,609	972	292,126	2,125 (±1,193)	3.9	2.3	.31
Calophyllum inophyllum	33,847	246	-436	-1,674	-15	23,320	170	55,057	401 (±398)	2.0	0.4	.11
Tamarindus indica	167,747	1,220	-12,874	-5,389	-133	343,613	2,500	493,098	3,587 (±2,252)	1.9	3.8	1.05
Broadleaf Deciduous Medi	123,704	900	-3,259	-3,062	-46	127,224	926	244,608	1,780 (±1,154)	1.4	1.9	.71
Palm species	14,905	108	-1,490	-2,435	-29	45,392	330	56,371	410 (±240)	1.1	0.4	.20
Artocarpus heterophyllus	55,175	401	-4,324	-1,684	-44	117,380	854	166,547	1,212 (±1,085)	0.5	1.3	1.38
Terminalia catappa	52,131	379	-2,206	-1,181	-25	49,446	360	98,190	714 (±491)	0.3	0.8	1.56
Mangifera indica	14,560	106	-613	-562	-9	26,315	191	39,700	289 (±203)	0.3	0.3	.63
Plumeria species	8,346	61	-154	-289	-3	6,802	49	14,705	107 (±106)	0.3	0.1	.24
Azadirachta indica	16,266	118	-692	-610	-9	29,987	218	44,951	327 (±236)	0.3	0.3	.72
Delonix regia	17,214	125	-1,121	-1,020	-16	30,662	223	45,735	333 (±221)	0.2	0.4	.74
Casuarina equisetifolia	14,943	109	-651	-320	-7	9,557	70	23,529	171 (±121)	0.2	0.2	.53
Ficus religiosa	38,530	280	-6,133	-904	-51	86,033	626	117,525	855 (±503)	0.1	0.9	3.95
Ficus benjamina	19,016	138	-2,360	-498	-21	41,889	305	58,047	422 (±333)	0.1	0.5	2.50
Acacia koa	7,822	57	-410	-269	-5	15,671	114	22,815	166 (±165)	0.1	0.2	1.00
Samanea saman	26,930	196	-1,518	-550	-15	26,978	196	51,839	377 (±273)	0.1	0.4	2.46
Averrhoa bilimbi	796	6	-14	-50	0	719	5	1,451	11 (±10)	0.0	0.0	.13
Pithecellobium dulce	5,160	38	-313	-164	-3	11,036	80	15,719	114 (±114)	0.0	0.1	1.41
Broadleaf Deciduous Smal	934	7	-10	-49	0	744	5	1,618	12 (±12)	0.0	0.0	.15
Broadleaf Evergreen Large	7,690	56	-669	-214	-6	17,079	124	23,886	174 (±173)	0.0	0.2	2.30
Salix matsudana	2,658	19	-99	-88	-1	2,992	22	5,464	40 (±39)	0.0	0.0	.55
Moringa oleifera	2,658	19	-99	-88	-1	2,992	22	5,464	40 (±39)	0.0	0.0	.55

Annual CO_2 Benefits of All Trees

13/9/2014

Species	Sequestered (kg)	Sequestered ($)	Decomposition Release(kg)	Maintenance Release(kg)	Total Released ($)	Avoided (kg)	Avoided ($)	Net Total (kg)	Total ($) Standard Error	% of Total Trees	% of Total $	Avg. $/tree
Ficus benghalensis	691	5	-12	-44	0	624	5	1,259	9 (±9)	0.0	0.0	.13
Morinda citrifolia	897	7	-11	-29	0	628	5	1,486	11 (±11)	0.0	0.0	.22
Citywide total	6,354,097	46,228	-226,029	-214,103	-3,202	6,959,194	50,630	12,873,160	93,655 (±6,969)	100.0	100.0	.52

Appendix 1-I

Thailand

Annual Air Quality Benefits of All Trees

13/9/2014

Species	Deposition (kg) O_3	Deposition (kg) NO_2	Deposition (kg) PM_{10}	Deposition (kg) SO_2	Total Depos. ($)	Avoided (kg) NO_2	Avoided (kg) PM_{10}	Avoided (kg) VOC	Avoided (kg) SO_2	Total Avoided ($)	BVOC Emissions (kg)	BVOC Emissions ($)	Total Emissions	Total ($)	Standard Error	% of Total Trees	Avg. $/tree
Pterocarpus indicus	4,961.8	660.5	3,378.3	556.0	30,064	5,243.8	884.3	884.3	5,977.7	40,808	-117.2	-155	22,429.4	70,716	(±14,657)	23.8	1.64
Lagerstroemia speciosa	1,889.8	237.0	1,228.9	217.9	11,253	3,204.5	540.4	540.4	3,653.0	24,938	0.0	0	11,511.9	36,191	(±7,188)	14.5	1.38
Cassia fistula	1,080.7	136.8	698.6	125.2	6,429	1,607.9	271.1	271.1	1,833.0	12,513	-43.8	-58	5,980.6	18,884	(±8,179)	11.2	0.93
Broadleaf Evergreen Medium	1,257.8	162.8	821.3	144.0	7,513	1,942.9	327.6	327.6	2,214.8	15,120	-119.2	-158	7,079.7	22,475	(±8,143)	7.5	1.66
Broadleaf Evergreen Small Ot	682.8	88.4	445.8	78.2	4,078	928.2	156.5	156.5	1,058.1	7,223	-692.7	-916	2,901.8	10,385	(±4,091)	5.9	0.97
Polyalthia longifolia	210.0	28.0	143.0	23.5	1,272	227.9	38.4	38.4	259.8	1,773	-8.1	-11	960.8	3,035	(±2,358)	5.7	0.29
Tabebuia species	757.8	98.1	494.8	86.8	4,526	1,105.7	186.5	186.5	1,260.5	8,605	-1,114.3	-1,474	3,062.2	11,657	(±3,447)	5.1	1.27
Mimusops caffra	520.8	67.4	340.0	59.6	3,110	805.6	135.9	135.9	918.4	6,269	-46.6	-62	2,937.0	9,318	(±4,654)	4.6	1.12
Swietenia mahagoni	458.1	59.3	299.1	52.5	2,736	638.7	107.7	107.7	728.1	4,970	-9.5	-13	2,441.7	7,694	(±4,450)	4.5	0.95
Peltophorum pterocarpum	2,066.1	267.4	1,349.0	236.6	12,340	2,870.6	484.1	484.1	3,272.4	22,340	-7,132.8	-9,435	3,897.5	25,245	(±16,944)	4.3	3.25
Tabebuia aurea	286.8	37.1	187.3	32.8	1,713	427.3	72.1	72.1	487.1	3,325	-444.3	-588	1,158.3	4,451	(±2,512)	3.9	0.64
Calophyllum inophyllum	50.7	6.6	33.1	5.8	303	74.6	12.6	12.6	85.0	580	-384.1	-508	-103.3	375	(±372)	2.0	0.10
Tamarindus indica	836.9	108.3	546.4	95.8	4,998	1,098.9	185.3	185.3	1,252.7	8,552	-2,922.5	-3,866	1,387.1	9,684	(±6,094)	1.9	2.84
Broadleaf Deciduous Medium	263.5	33.4	170.3	30.5	1,567	406.9	68.6	68.6	463.8	3,166	-9.4	-12	1,496.1	4,721	(±3,051)	1.4	1.88
Palm species	104.5	13.5	68.2	12.0	624	145.2	24.5	24.5	165.5	1,130	-361.2	-478	196.5	1,276	(±747)	1.1	0.64
Artocarpus heterophyllus	285.4	36.9	186.3	32.7	1,704	375.4	63.3	63.3	427.9	2,921	-1,022.9	-1,353	448.3	3,273	(±2,933)	0.5	3.73
Terminalia catappa	150.0	20.0	102.1	16.8	909	158.1	26.7	26.7	180.3	1,231	-3.4	-4	677.3	2,135	(±1,476)	0.3	4.65
Mangifera indica	59.7	7.7	39.0	6.8	356	84.2	14.2	14.2	95.9	655	-186.6	-247	135.1	764	(±536)	0.3	1.67
Plumeria species	17.2	2.2	11.2	2.0	103	21.8	3.7	3.7	24.8	169	-15.3	-20	71.2	252	(±250)	0.3	0.56
Azadirachta indica	67.4	8.7	44.0	7.7	403	95.9	16.2	16.2	109.3	746	-213.3	-282	152.2	867	(±622)	0.3	1.91
Delonix regia	69.1	8.7	44.8	7.8	411	98.1	16.5	16.5	111.8	763	-1.5	-2	371.7	1,172	(±787)	0.2	2.61
Casuarina equisetifolia	14.5	1.9	9.5	1.7	87	30.6	5.2	5.2	34.8	238	-1,018.2	-1,347	-915.0	-1,022	(±745)	0.2	-3.14
Ficus religiosa	235.9	30.5	154.1	27.0	1,409	275.1	46.4	46.4	313.6	2,141	-792.7	-1,049	336.5	2,502	(±1,504)	0.1	11.55
Ficus benjamina	108.8	14.1	71.0	12.5	650	134.0	22.6	22.6	152.7	1,043	-377.9	-500	160.3	1,192	(±948)	0.1	7.05
Acacia koa	35.6	4.6	23.2	4.1	212	50.1	8.5	8.5	57.1	390	-119.3	-158	72.3	445	(±442)	0.1	2.67
Samanea saman	82.0	10.9	55.8	9.2	497	86.3	14.5	14.5	98.4	671	-1.9	-3	369.8	1,166	(±849)	0.1	7.61
Averrhoa bilimbi	2.0	0.3	1.3	0.2	12	2.3	0.4	0.4	2.6	18	-3.1	-4	6.4	26	(±26)	0.0	0.31
Pithecellobium dulce	25.2	3.3	16.5	2.9	151	35.3	6.0	6.0	40.2	275	-88.0	-116	47.2	309	(±307)	0.0	3.81
Broadleaf Deciduous Small O	2.0	0.3	1.3	0.2	12	2.4	0.4	0.4	2.7	19	-0.1	0	9.6	30	(±30)	0.0	0.37
Broadleaf Evergreen Large Ot	42.1	5.5	27.5	4.8	252	54.6	9.2	9.2	62.3	425	-156.1	-206	59.1	470	(±467)	0.0	6.23
Salix matsudana	6.1	0.8	4.0	0.7	37	9.6	1.6	1.6	10.9	74	-0.5	-1	34.8	110	(±110)	0.0	1.53
Moringa oleifera	6.1	0.8	4.0	0.7	37	9.6	1.6	1.6	10.9	74	-0.5	-1	34.8	110	(±110)	0.0	1.53
Ficus benghalensis	1.8	0.2	1.2	0.2	11	2.0	0.3	0.3	2.3	16	-2.7	-4	5.6	23	(±22)	0.0	0.31
Morinda citrifolia	1.6	0.2	1.1	0.2	10	2.0	0.3	0.3	2.3	16	-1.4	-2	6.7	24	(±23)	0.0	0.49

Thailand

Annual Air Quality Benefits of All Trees

13/9/2014

Species	Deposition (kg)				Total Depos. ($)	Avoided (kg)				Total Avoided ($)	BVOC Emissions (kg)	BVOC Emissions ($)	Total Emissions	Total ($)	Standard Error	% of Total Trees	Avg. $/tree
	O_3	NO_2	PM_{10}	SO_2		NO_2	PM_{10}	VOC	SO_2								
Citywide total	16,640.4	2,161.9	11,001.9	1,895.4	99,788	22,255.8	3,753.1	3,753.1	25,370.8	173,196	-17,411.4	-23,031	69,421.0	249,953	(±19,524)	100.0	1.38

Appendix 1-J

Thailand

Annual Stormwater Benefits of All Trees

13/9/2014

Species	Total rainfall interception (m³)	Total ($)	Standard Error	% of Total Trees	% of Total $	Avg. $/tree
Pterocarpus indicus	147,173	388,790	(±80,144)	23.8	26.6	9.04
Lagerstroemia speciosa	67,459	178,208	(±35,432)	14.5	12.2	6.79
Cassia fistula	38,076	100,585	(±44,125)	11.2	6.9	4.98
Broadleaf Evergreen Medium	52,263	138,065	(±50,761)	7.5	9.4	10.18
Broadleaf Evergreen Small Ot	23,702	62,615	(±24,728)	5.9	4.3	5.88
Polyalthia longifolia	7,609	20,102	(±15,650)	5.7	1.4	1.94
Tabebuia species	23,934	63,226	(±18,692)	5.1	4.3	6.91
Mimusops caffra	20,936	55,306	(±28,079)	4.6	3.8	6.67
Swietenia mahagoni	12,934	34,168	(±19,816)	4.5	2.3	4.22
Peltophorum pterocarpum	68,778	181,693	(±121,412)	4.3	12.4	23.38
Tabebuia aurea	9,269	24,486	(±13,817)	3.9	1.7	3.52
Calophyllum inophyllum	2,031	5,366	(±5,330)	2.0	0.4	1.48
Tamarindus indica	28,021	74,024	(±47,296)	1.9	5.1	21.74
Broadleaf Deciduous Medium	8,886	23,475	(±15,181)	1.4	1.6	9.34
Palm species	3,066	8,099	(±4,799)	1.1	0.6	4.03
Artocarpus heterophyllus	9,678	25,565	(±23,152)	0.5	1.7	29.14
Terminalia catappa	4,372	11,548	(±7,963)	0.3	0.8	25.17
Mangifera indica	1,894	5,002	(±3,483)	0.3	0.3	10.94
Plumeria species	560	1,480	(±1,470)	0.3	0.1	3.27
Azadirachta indica	2,152	5,685	(±3,996)	0.3	0.4	12.55
Delonix regia	1,965	5,190	(±3,461)	0.2	0.4	11.56
Casuarina equisetifolia	460	1,214	(±857)	0.2	0.1	3.73
Ficus religiosa	7,789	20,575	(±12,415)	0.1	1.4	94.99
Ficus benjamina	3,645	9,629	(±7,817)	0.1	0.7	56.96
Acacia koa	1,167	3,083	(±3,065)	0.1	0.2	18.53
Samanea saman	2,430	6,420	(±4,698)	0.1	0.4	41.89
Averrhoa bilimbi	49	130	(±129)	0.0	0.0	1.56
Pithecellobium dulce	844	2,229	(±2,215)	0.0	0.2	27.50
Broadleaf Deciduous Small O	66	175	(±173)	0.0	0.0	2.15
Broadleaf Evergreen Large Ot	1,453	3,838	(±3,813)	0.0	0.3	50.84
Salix matsudana	248	656	(±651)	0.0	0.0	9.09
Moringa oleifera	248	656	(±651)	0.0	0.0	9.09
Ficus benghalensis	43	112	(±112)	0.0	0.0	1.56
Morinda citrifolia	52	139	(±137)	0.0	0.0	2.86
Citywide total	553,252	1,461,537	(±130,775)	100.0	100.0	8.09

Appendix 1-K

Thailand

Stored CO2 Benefits of All Trees

13/9/2014

Species	Total Stored CO2 (kg)	Total ($)	Standard Error	% of Total Trees	% of Total $	Avg. $/tree
Pterocarpus indicus	15,542,862	113,078	(±24,274)	23.8	22.3	2.63
Lagerstroemia specios	8,487,207	61,747	(±12,569)	14.5	12.2	2.35
Cassia fistula	3,285,215	23,901	(±9,633)	11.2	4.7	1.18
Broadleaf Evergreen M	7,607,639	55,347	(±21,815)	7.5	10.9	4.08
Broadleaf Evergreen S	2,710,707	19,721	(±8,041)	5.9	3.9	1.85
Polyalthia longifolia	512,933	3,732	(±2,896)	5.7	0.7	.36
Tabebuia species	5,074,187	36,916	(±10,955)	5.1	7.3	4.04
Mimusops caffra	2,935,043	21,353	(±11,981)	4.6	4.2	2.57
Swietenia mahagoni	1,538,970	11,196	(±6,566)	4.5	2.2	1.38
Peltophorum pterocar	8,055,052	58,602	(±38,916)	4.3	11.5	7.54
Tabebuia aurea	1,685,333	12,261	(±6,949)	3.9	2.4	1.76
Calophyllum inophyll	129,618	943	(±937)	2.0	0.2	.26
Tamarindus indica	4,022,345	29,264	(±19,683)	1.9	5.8	8.60
Broadleaf Deciduous	1,018,500	7,410	(±4,657)	1.4	1.5	2.95
Palm species	465,739	3,388	(±2,014)	1.1	0.7	1.69
Artocarpus heterophyl	1,351,370	9,832	(±9,053)	0.5	1.9	11.21
Terminalia catappa	689,287	5,015	(±3,508)	0.3	1.0	10.93
Mangifera indica	191,638	1,394	(±960)	0.3	0.3	3.05
Plumeria species	47,507	346	(±343)	0.3	0.1	.76
Azadirachta indica	216,250	1,573	(±1,077)	0.3	0.3	3.47
Delonix regia	350,404	2,549	(±1,808)	0.2	0.5	5.68
Casuarina equisetifoli	202,640	1,474	(±1,125)	0.2	0.3	4.53
Ficus religiosa	1,916,702	13,944	(±9,391)	0.1	2.7	64.38
Ficus benjamina	737,378	5,365	(±4,723)	0.1	1.1	31.73
Acacia koa	128,031	931	(±926)	0.1	0.2	5.60
Samanea saman	474,501	3,452	(±2,661)	0.1	0.7	22.52
Averrhoa bilimbi	4,389	32	(±32)	0.0	0.0	.38
Pithecellobium dulce	97,877	712	(±708)	0.0	0.1	8.78
Broadleaf Deciduous	3,255	24	(±24)	0.0	0.0	.29
Broadleaf Evergreen I	208,916	1,520	(±1,510)	0.0	0.3	20.13
Salix matsudana	30,893	225	(±223)	0.0	0.0	3.11
Moringa oleifera	30,893	225	(±223)	0.0	0.0	3.11
Ficus benghalensis	3,809	28	(±28)	0.0	0.0	.38
Morinda citrifolia	3,400	25	(±24)	0.0	0.0	.51
Citywide total	69,760,489	507,525	(±46,323)	100.0	100.0	2.81

The value of stored carbon dioxide is calculated as the total amount of carbon dioxide sequestered annually over the life of each tree, summed for the population. This value should not be added to the Replacement Value or double-counting of the carbon dioxide storage benefit will occur.

Appendix 2

Questionnaire for public officials in districts of Bangkok

The information you will provide from your knowledge and expertise will be valuable for my research and it will be cited in my dissertation. The purpose of my research is to assess the ecosystem services of green spaces of Bangkok in term of mitigating environmental degradation and regulating local climate. Please answer the following questions:

1. Please provide your name and the name of your office
2. Please provide your title
3. Please briefly describe your responsibilities
4. Please define how long have you been in that position
5. Maintaining a diverse and healthy population of trees can the city expand their ecosystem services. Can you please explain how your district defines its policy for planting trees? It will be helpful if you could explain what are factors that influence the following decisions?
    a. What factors are considered when selecting what species of tree should be planted (e.g. native vs. introduced; esthetic vs. space availability)?
    b. How is determined the number of trees to plant?
    c. How is the location of planting sites defined
    d. Who makes all these decision (agency, public official?
    e. Are these decisions part of a local plan (if yes, please specify the name)?

6. Has there been any opposition to tree planting or any other conflict related to trees among the constituency in your district? If yes, please specify what are they and in what area (if possible define specific locations or address)?
7. Can you please identify what are the main problems associated with the maintenance of trees in your district?
8. How would you consider the health of trees in your district?
9. Based on your experience and knowledge, has the number of trees in your district increased or decreased for the last ten years?
10. Are there plans to:
    a) Maintain the current number of trees in your district?
    b) Increase the number of tress (please specify where)?
    c) Reduce the number of tress (please specify where)?
    d) In case the response is b or c please ask how that decision is been made.
11. Can you please let me know the total budget used for green areas and trees on the streets in your district?
12. Can you please specify what percentage of that budget is used for trees?
    a. For planting
    b. For maintenance (pruning, pest/disease control, irrigation)
    c. For stump removal and disposal
13. Are there any costs from infrastructure damage or litigation due to tree-related claims?
14. Does the district have initiatives for green areas and vegetation? What is the expected outcome from them?
15. Do you consider the presence of trees in your district have:
    a. Economic benefits (please explain)?
    b. Environmental benefits (please explain)?
    c. Social benefits (please explain)?

16. Is there a public campaign in your district to help the people know about benefits and services trees provide to the city and its inhabitants?
17. Do you believe this type of campaign is important?
18. If yes, would your district be interested in creating more campaigns in the future?

Thank you very much for your time and cooperation.

Appendix 3

Questionnaire-Street vendors

The objective of the interview is to take into account the street vendors' opinions about the existence of vegetation in Bangkok.

1. How long has your business been in this location?
2. The number of trees in this street has increased or decreased since you have been in this location?
    - 2.a It has increased (please explain when and an estimation how much)
    - 2.b It has decreased (please explain when and an estimation how much)

3. Do you consider having trees near you shop negatively affects your business?
    - 3.a If yes, please answer these sub-questions
        - i. Explain how trees have negative impacted your business
        - ii. Would you consider accepting trees that do not block the view of your shop from potential customers?
        - iii. Please take a look at the following pictures of several types of trees and let me know which ones you consider acceptable to be planted nearby your shop. (show pictures of different species of trees and let them choose).
        - iv. If you consider trees should not be near your business, which type of vegetation do you consider can be planted nearby your shop ?

          (1.Shrub 2. Vine 3. Herbs- horticultural plants 4. Ground cover)

    - 3.b If no, please answer the following sub-questions
        - i. Explain why you like to have trees nearby your shop

ii. Please take a look at the following pictures of several types of trees and let me know which ones you consider acceptable to be planted nearby your shop. (show pictures of different species of threes and let them choose).

4. Are you aware of the benefits that trees can provide for our city and its inhabitants?

4.a) do you know trees can help regulate the negative impact of extreme weather?

4.a.1) yes (please provide examples)   4.a.2) No

4.b) Do you know trees con help reduce air pollution?

4.b.1) yes (please explain)   4.b.2) No

4.c) Do you know trees can improve the aesthetic of the city and attracts people to the streets?

4.c.1) yes   4.c.2) no

5) The Bangkok Metropolitan Administration is planning to expand the number of trees in the city. Considering the benefits of trees mentioned before, do you agree increasing the number of trees in the city?

5. a) in this neighborhood	5.b) in other parts of the city
1) Yes, I support the tree planting policy policy	1) Yes, I support the tree planting (please explain where)
2) No, I oppose this policy (please elaborate the reasons)	2) No, I oppose this policy (please elaborate the reasons)

4) From your perspective, what is/are your recommendation(s) to Bangkok Metropolitan Administration's officials on how they can improve on tree planting/maintenance?

Please provide the following information:

Age_______

Female ___   or Male_____

Size of business (number of people working in this business)?

Type of business?

Chapter 4

Examining the relationship of $\delta^{15}N$ and $\delta^{13}C$ of urban street tree leaves and environmental quality variables by principal component analysis

Abstract

Trees can function as a sink for air pollutants, and some of their physiological responses can be used as biological indicators of air quality. In this chapter, I investigate nitrogen and carbon isotopic compositions ($\delta^{15}N$ and $\delta^{13}C$) identified in street tree leaves in Bangkok being used as early indicators of air pollution and to detect tree species that absorb high concentrations of air pollutants. Principal component analysis is used to investigate how the environmental benefits of street trees in Bangkok correlate with environmental and social parameters. Additionally, the variation in $\delta^{15}N$ of tree leaves is compared with the finding from the i-Tree Streets model, in term of ranking of tree species with respect to their ability to reduce nitrogen dioxide pollution.

The results indicate that $\delta^{15}N$ values of tree leaves vary by land use zonings. The $\delta^{15}N$ from trees in the outer Bangkok area (agricultural and low-density residential zones) are higher than $\delta^{15}N$ of trees that are in or near the center of Bangkok (commercial and Thai identity and cultural conservation zones). While $\delta^{15}N$ has moderately positive correlation with traffic-related pollutants, including NO_2, PM 10, and CO level (high level of air pollutants are found in inner Bangkok), $\delta^{13}C$ values have weakly negative correlations with these pollutants. The evidence suggests that $\delta^{15}N$ of street tree leaves

could be a potential early indicator of NO_2 pollution (under the assumption that trees have similar inputs of other nitrogen sources), while $\delta^{13}C$ does not seem to have that ability. *Lagerstroemia* spp. is a good example of a deciduous tree species that could be planted in the streets of Bangkok with high NO_2 pollution. The species has a relatively high average $\delta^{15}N$, which is positively correlated with the NO_2 level found in Bangkok streets. On the other hand, the analysis indicates no correlation between $\delta^{15}N$ of tree leaves and the estimated NO_2 deposition benefit from the i-Tree Street model. More research should be conducted to make the study more informative and precise, such as examining $\delta^{15}N$ of soil and in more tree species within the same land use zone.

4.1 Introduction

In Bangkok, the increased numbers of high emission motor vehicles, long travel distances, and extreme traffic congestion cause street-level air pollution along the city's major roads to reach hazardous levels. . The major source of air pollution in the city is the transportation sector. According to the Thailand Ministry of Transport (2013), around 80% of NO_x emissions, 75% of CO emission, and 54% of PM emission are generated by the transportation sector.

Indicators of vegetation responses to pollution, such as stable isotopic ratios or morphological responses, can be used to assess the stress from pollution experienced by urban flora (Akkuzu and Ayberk 2001). Knowledge of stable isotopic compositions of some elements can help in tracing the sources of environmental pollution, as well as reflecting the physical and chemical reactions that cause changes in the stable isotope composition (Peterson and Fry 1987; Muccio and Jackson 2009).

In this context, the study of the relationship between the stable isotopic compositions of nitrogen and carbon in tree leaves, and factors such as air quality, traffic volume, and socioeconomic parameters could be useful in tracing air pollution levels, as well investigating which tree species can absorb high amounts of air pollutants.

4.1.1 Nitrogen stable isotopes

There are a number of studies on the uses of nitrogen isotope abundance ($\delta^{15}N$) in ecosystem and organismal research. $\delta^{15}N$ can be used as a natural tracer of sources of pollutants (Xiao et al. 2011) to determine the impacts from pollution by acting as an environmental indicator (Hofmann et al. 1997; Stewart et al. 2002; Vallano and Sparks 2007), to trace pollutant transfers across food webs and also as an integrator of nitrogen cycle processes (Robinson 2001; Lepoint, Dauby, and Gobert 2004), or to investigate interactions among plants, fungi, and soil processes (Hobbie, Macko, and Williams 2000). Additionally, $\delta^{15}N$ can be used to estimate a plant's ability in fixing atmospheric N_2 (Peterson and Fry 1987).

Regarding $\delta^{15}N$ as an environmental indicator, given that plants uptake nitrogen both from natural and anthropogenic sources through different pathways, including foliar and root uptake, some parts of the plants such as the leaves and tree rings can be analyzed to detect pollutants and their sources (Ammann et al. 1999; Akkuzu and Ayberk 2001; Vallano and Sparks 2007; Hietz et al. 2011; Xiao et al. 2011) For example, Xiao et al.

(2011) identified positive values of $\delta^{15}N$ in camphor leaves located in areas near roads, and negative values in industrial areas in China (Xiao et al. 2011). In the Swiss Middle Land, $\delta^{15}N$ of spruce needle leaves was 2% higher than that of the control after four months of exposure to high concentrations of NO_x, representative of highway conditions (Ammann et al. 1999). In this study, I focus on identifying the relationship of $\delta^{15}N$ of tree leaves and NO_2 concentration, as well as variations of $\delta^{15}N$ in different tree species.

4.1.2 Carbon stable isotopes

With regard to the study of carbon stable isotopes, the variation in leaf carbon isotope ($\delta^{13}C$) can reflect changes in plant physiology and biogeochemistry, including stomatal conductance driven by climate, which may reflect water use efficiency (Diefendorf et al. 2010; Werner et al. 2012; Marshall, Brooks, and Lajtha 2007). For example, $\delta^{13}C$ decreases when there are more pollutants from carbon fossil fuel sources (Marshall, Brooks, and Lajtha 2007), SO_2 (Thomas et al. 2013) or NO_2 (Wuytack et al. 2013) in the atmosphere. As a result, the stomatal conductance decrease as there is a reduction in the stomata apertures. In those conditions, there is a decline in transpiration, thereby increasing water use efficiency (Marshall, Brooks, and Lajtha 2007).

In the atmosphere, stable carbon isotopes are present as CO_2. It is estimated that around 99% of the carbon atoms are ^{12}C, while 1% are ^{13}C. In plants, during the photosynthesis, fractionation takes place changing the ratio of ^{13}C to ^{12}C, making it different from the atmospheric levels. Through the food chain, the ratio of carbon stable isotopes change from one trophic level to another so it can be used to determine the trophic level, as well as to identify sources of organic residues (Malainey 2011).

Marshall et al. (2007) found that $\delta^{13}C$ in most plants varies between 37‰ and -13.4‰ with a median of -27‰, while the values in seagrass are between -23‰ and -3‰ with the most frequent value being -10‰ (Lepoint, Dauby, and Gobert 2004). On the other hand, the variations in carbon isotopic signatures are not only based on different photosynthetic water use efficiency (i.e., differences in photosynthetic pathways), but they are also based on differences from water sources and nitrogen (ecophysiological differences) (Marshall, Brooks, and Lajtha 2007).

This study investigates variations in nitrogen and carbon isotope abundances ($\delta^{15}N$ and $\delta^{13}C$) in different species of Bangkok's street trees in six land-use zones. The relationships between nitrogen and carbon isotopic composition detected in tree leaves, air quality parameters (NO_2, PM 10, ground-level ozone, SO_2, and volatile organic compound, or VOC), and socioeconomic factors such as population density, housing density, and traffic volume are analyzed using principal component analysis (PCA). PCA is suitable for studying relationships of several variables, as it reduces the dimensions of datasets. Identifying how different tree species absorb air pollutants in Bangkok could be useful in promoting the planting of suitable species on streets with poor air quality as an alternative way to reduce air pollution in the city. In addition, the study will investigate the isotopic compositions from some tree species to determine if they can be used as early indicators of environmental pollution.

4.2 Data and method

4.2.1 Sampling locations of trees

Between three and five leaves per tree, per species were randomly collected from forty-four street segments of Bangkok, Thailand, in the six major land-use zones: agricultural zone (AZ), low-density residential zone (LDRZ), high-density residential zone (HDRZ), commercial zone (CZ), Thai identity and cultural conservation zone (ICZ); and industrial zone (IZ). Some segments have more than one tree species. There are total of 185 samples or observations. The numbers of sampled street segments per land use, and tree species are presented in Table 1. The locations of street trees from which leaves were collected are shown in Figure 1.

Table 1 Tree species and number of street segments in six land-use zones

	Species	Spp. code	No. of sampled street segments					
			Agricultural Zones (AZ)	Low Density Residential Zone (LDRZ)	High Density Resident ial Zone (HDRZ)	Thai Identity & Cultural Conservation zone (ICZ)	Industrial zone (IZ)	Commercial Zone(CZ)
1	*Ptherocarpus indicus*	*P.i.*	3	5	1	1	1	4
2	*Tabebuia rosea*	*T.r.*	1	1		1		3
3	*Cassia fistula*	*C.f.*	4		1			1
4	*Sweitenia macrophylla*	*S.m.*	1	2				1
5	*Lagerstroemia speciosa*	*L.s.*	1	1	1			1
6	*Mimusops elengi*	*M.e.*			1	1		1
7	*Calophyllum inophyllum*	*C.i.*					1	
8	*Lagerstroemia loudonii*	*L.l.*			1	1		1
9	*Lagerstroemia floribunda*	*L.f.*			1	1		3
10	*Peltophorum pterocarpum*	*P.p.*		2				
11	*Lagerstroemia macrocarpa*	*L.m.*	1	2				
12	*Tamarindus indica*	*T.i.*				2		
13	*Millingtonia hortensis*	*M.h.*		2		1		
14	*Ficus benkamina*	*F.b.*						1
15	*Alstonia scholaris*	*A.s.*		3	1			
16	*Tabebuia arentea*	*T.a.*	1	1				
	Total		12	19	6	8	2	16

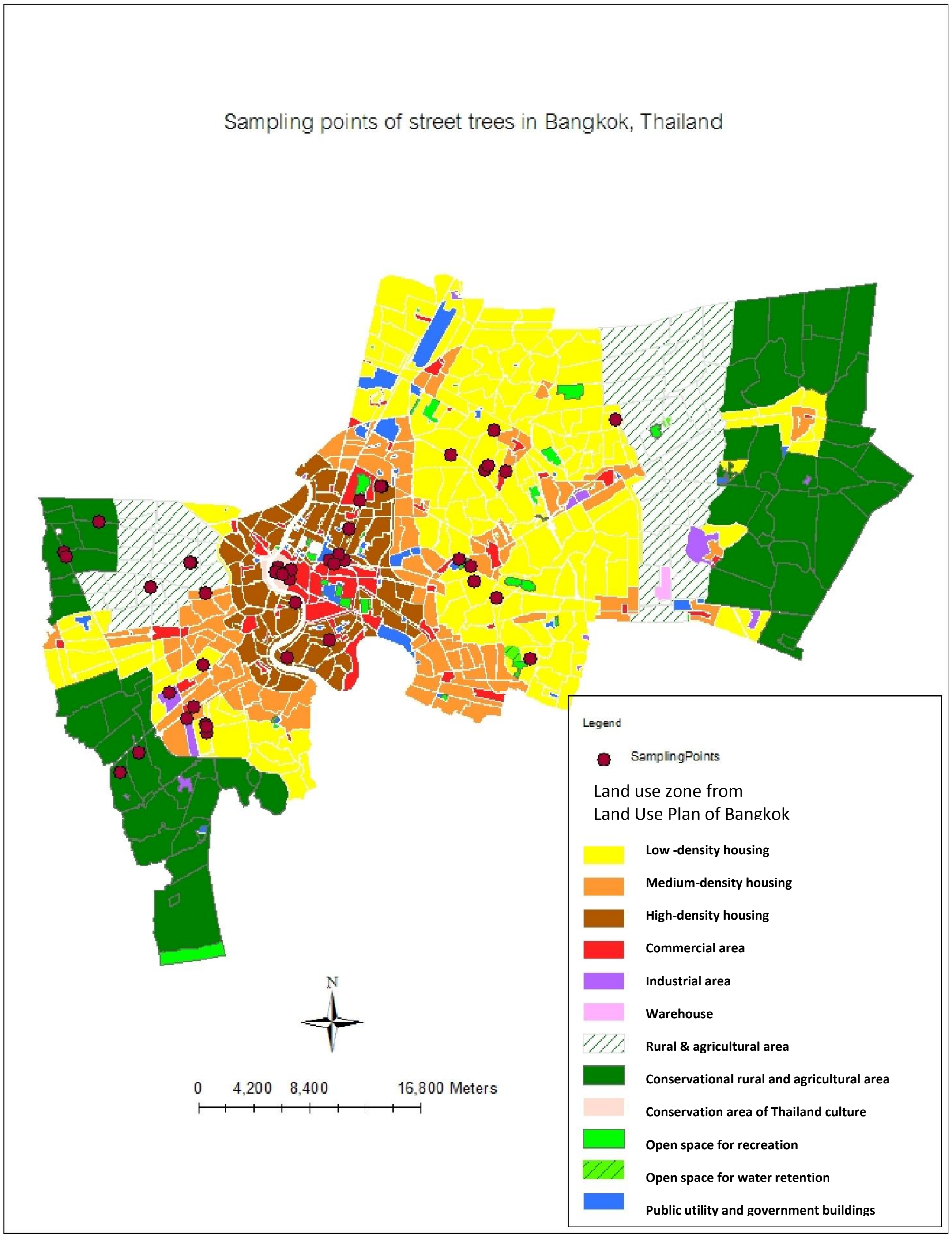

Figure 1 Locations of trees in Bangkok streets of which leaves were collected for isotopic analysis

4.2.2 Air quality data

The air quality data used in the analysis is from the summer of 2012 average values of ground level ozone (O_3), PM10, NO_2, and CO concentrations. The data obtained from the Pollution Control Department was collected from twenty air quality monitoring stations located on the streets of Bangkok and metropolitan areas (Pollution Control Department 2012). The air quality values recorded on the sampled locations were estimated using the using the Inverse Distance Weighted (IDW) interpolation method in ArcGIS 10.

4.2.3 Demographic variable

To account for the effects of differences in population density across the city on pollution levels, data corresponding to the 2012 year for fifty districts of Bangkok were obtained from the Bangkok Metropolitan Administration (Strategy and Evaluation Department of Bangkok Metropolitan Administration). The population density data of the sampled locations were interpolated using the natural neighbor method in ArcGIS 10.

4.2.4 Traffic volume data

Bangkok traffic volume data in the major streets and intersections of Bangkok were derived from the Traffic Statistics Report of 2012 (Traffic and Transportation Department 2013). The traffic volume data were recorded from counting the number of vehicles passing through the streets in one day (7 am – 7 pm). The average daily traffic volume during six months between January and June 2012 of the sampled streets or the streets that are closest to the sampled street segments were used. The unit of the traffic volume is number of vehicles per 12 hours.

4.2.5 Stable isotope analysis (carbon and nitrogen)

Collected street tree leaves were used in this study to measure isotopic signatures. The collected leaves were air-dried and oven-dried at 60^{o}C for twenty-four hours to reduce humidity. The dried leaves were ground and weighed to generate samples with unitary weight of 2mg. Each sample was then placed in a tin capsule before being analyzed for $\delta^{15}N$ and $\delta^{13}C$, using an isotope ratio mass spectrometer (IRMS). The isotopic composition is expressed in terms of δ values in parts per thousand (‰) differences from an international standard (Peterson and Fry 1987). $\delta^{15}N$ and $\delta^{13}C$ were calculated according to the equations:

$$\delta^{15}N\ (‰) = \{(R_{sample}/R_{standard}) - 1\} * 1000 \qquad (1)$$
$$\delta^{13}C\ (‰) = \{(R_{sample}/R_{standard}) - 1\} * 1000 \qquad (2)$$

where R is the ratio of $^{15}N/^{14}N$ and $^{13}C/^{12}C$, respectively. The ratio of heavy to light isotopes in each sample was measured relative to the isotopic standard. Higher δ values indicate higher heavy isotope content and a reciprocal decrease in the light isotope contents (Peterson and Fry 1987; Heaton 1986). The standards in these equations are nitrogen gas and Vienna Pee Dee Belemnite (VPDB) for nitrogen and carbon respectively. The δ values of each of the standards have been defined as 0‰ (Kendall and Caldwell 1998). The standards are selected to eliminate bias in the measurements because they are stable materials that contain a high amount of heavy isotopes (Muccio and Jackson 2009).

4.2.6 Principal component analysis (PCA)

PCA is a statistical technique used for identifying patterns in high dimensional data and to study similarities and differences between variables. One of the major advantages of PCA is that it allows users to reduce the dimensionality of datasets without losing significant information. The PCA algorithm reduces multiple dimensions of data to a new set of variables called principle components that can be represented as a linear combination of the original set of data as:

$$PC_i = l_{1i}X_1 + l_{2i}X_2 + \ldots + l_{ni}X_n \qquad i = 1, 2, \ldots, n \qquad (3)$$

where PC_i is the order of the principal component, and l_{ni} is the loading (correlation) of the observed variable X_n with respect to the principal component i (Ul-Saufie et al. 2013).

PCA has been used in different fields, for instance in image compression and face recognition algorithms (Smith 2002). Dominick et al. (2012) uses PCA to identify motor vehicles, aircrafts, industries, and highly populated areas as major sources of air pollution in Malaysia. PCA also has been used to improve the predictive accuracy of PM10 concentrations in Negeri Sembilan, Malaysia, in combination with multiple linear regression (MLR) and feed-forward back propagation (FFBP) analysis. In that analysis, the authors identified three principal components, from a dataset of seven variables related to PM10, explained a significant proportion of the variability contained (72.2%) in the whole dataset (Ul-Saufie et al. 2013).

PCA is carried out using XLSTAT version 2014.2.03, and data from twenty-five variables of 185 samples that consisted of isotopic composition of tree leaves, tree environmental benefits, environmental, and social characteristics of the sampled street segments. Table 2 presents a summary of the minimum and maximum, mean, and standard deviation values of the twenty-five variables, which are socioeconomic and environmental characteristics in the sample data used in the analysis.

Correlations between variables, eigenvalues, percent variability of each factor, as well as correlations between factors and factor score for all samples or observations were obtained from the analysis. Additionally, varimax rotation was conducted to adjust the factor loadings[2] to make each variable correlate with one (or a few components), at the highest possible level while keeping its correlation with the other components at low levels. By implementing such rotation, we can observe how much each variable has contributed to a particular principal component and how much similarity and dissimilarity exists between the analyzed variables (Dominick et al. 2012). Recall that the loadings indicate the strength and direction of the linear relationship between a component and a variable (i.e., it can be used to estimate the degree of shared information between such component and the variable).

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[2] Variamax rotation is an orthogonal rotation corresponding to the cosine of the angle between the original axis and the new one (Abdi and Williams 2010).

Table 2 Summary statistics for social and environmental variables of sampled data

	Variable	Minimum	Maximum	Mean	Standard deviation
1	%N	0.98	5.83	2.73	0.99
2	$\delta^{15}N$ (‰)	0.21	15.37	5.21	2.61
3	%C	36.90	55.86	46.09	3.64
4	$\delta^{13}C$ (‰)	-35.98	-20.07	-29.88	2.67
5	Land use	1.00	6.00	2.91	1.46
6	NO_2 (ppb)	7.32	30.65	18.10	3.50
7	CO 1 hr. (ppm)	0.53	1.01	0.77	0.10
8	O_3 (ppb)	7.93	11.90	9.06	0.72
9	PM10 (ug/m)	22.65	61.20	38.48	8.25
10	SO_2 (ppb)	1.75	5.88	2.56	0.78
11	Population density (no./ km^2)	1,291	29,730	6,337	4,337
12	O_3 Benefit (kg/tree/year)	0.01	0.85	0.11	0.11
13	NO_2 Benefit (kg/tree/year)	0.02	0.49	0.14	0.09
14	PM10 Benefit (kg/tree/year)	0.01	0.29	0.08	0.05
15	SO_2 Benefit (kg/tree/year)	0.02	0.55	0.16	0.10
16	VOC Benefit (kg/tree/year)	0.00	0.08	0.02	0.01
17	Subtotal reduction (kg/tree/year)	0.08	1.72	0.51	0.33
18	BVOC (kg/tree/year)	-1.14	0.00	-0.09	0.24
19	Total Reduction (kg/tree/year)	-0.03	1.25	0.42	0.20
20	CO2 Sequestration (kg/tree/year)	15.05	198.31	71.59	32.59
21	Electricity Saving (kWh/tree/year)	0.03	1.56	0.20	0.19
22	Stormwater runoff reduction (m^3/tree/year)	0.56	65.29	3.87	6.77
23	Total monetary benefit of environmental services ($/tree/year)	2.50	54.35	16.08	9.83
24	Diameter at Breast Height or DBH (cm)	7.99	41.65	22.50	7.66
25	Traffic volume (no. of vehicles per 12 hr.)	1,766	97,498	32,831	22,274

4.3 Results

4.3.1 Nitrogen and carbon isotopic data of street trees

Variation in $\delta^{15}N$

Pterocarpus indicus, the most dominant tree species in Bangkok, has the widest range of $\delta^{15}N$ values range from 0.21‰ to 15.37‰, with the most frequent $\delta^{15}N$ value being 6‰. Trees in the genus *Lagerstroemia* have the highest average $\delta^{15}N$, with values in the interval 7.08 ±2.76‰; whereas, *Alstonia scholaris* has the lowest mean level at 4.28 ± 1.25‰. The values of $\delta^{15}N$ by sampled species are shown in Table 2.1.

As it is the most dominant species, *Pterocarpus indicus* is the only species that is found and sampled in all the studied land use zones. Therefore, the corresponding results for this species can be used to compare $\delta^{15}N$ values through the city. Table 3.1 shows that *P. indicus* located in the commercial zone (CZ), the industrial zone (IZ), and the Thai identity & cultural conservation zone (ICZ) have relatively high average $\delta^{15}N$ values (6.35 ‰, 6.06‰ and 5.82‰, respectively); whereas the other three land use zones (low-density residential zone (LDRZ), agricultural Zone (AZ), and high-density residential zone (HDRZ)) have lower average $\delta^{15}N$ values (3.10‰, 3.43‰, and 3.77‰, respectively). The lowest most frequent $\delta^{15}N$ value of the tree species *P. indicus* is found in LDRZ (1‰), whereas CZ and ICZ have the highest most frequent $\delta^{15}N$ of 6‰ for the same species. Commercial zone has the largest range of $\delta^{15}N$: between 2.91‰ and 15.37‰.

In all land use zones, $\delta^{15}N$ values of tree leaves range from 0.21‰ to 15.37‰ This is similar to the study of Perterson and Fry (1987) that shows plants that can fix N_2 have $\delta^{15}N$ close to 0‰, while plants that cannot fix N_2 have $\delta^{15}N$ values range from -8 to +10 ‰. $\delta^{15}N$ of atmospheric NO_x pollution ranged in mostly positive values of between -1 and +5‰ (Vallano and Sparks 2007), while the negative $\delta^{15}N$ are found in atmospheric NH_3 ranging about -8 to -4‰ (Peterson and Fry 1987). Therefore, the $\delta^{15}N$ in street tree leaves could probably reflect the sources of nitrogen, which, in this study, can be NO_x from traffic pollution or from soil.

Variation in $\delta^{13}C$

$\delta^{13}C$ values in Bangkok trees range from -35.48‰ in *Cassia fistula* to -20.07‰ in *Lagerstroemia* spp. On the other hand, the most frequent $\delta^{13}C$ value across the different species is -30‰. *Alstonia scholaris* has the highest average $\delta^{13}C$ of -26.84 ± 1.28‰; whereas, *Tabebuia rosea* has the lowest average value (-30.78 ± 1.15‰). The species with the largest range of $\delta^{13}C$ is *Lagerstroemia* spp. (15.41‰), while the species with the smallest range is *Alstonia scholaris* (3.71‰). The values of $\delta^{13}C$ by species are shown in Table 2.1.

By land use, the statistical findings in Table 3.2 show that average of $\delta^{13}C$ values of *P. indicus* in all zones do not vary much (-30.32‰ to -28.92‰). LDRZ has the largest range of $\delta^{13}C$ between -32.32‰ and -25.79‰. The lowest average $\delta^{13}C$ of *P. indicus* is found in CZ (-32‰); whereas, AZ has the highest average $\delta^{13}C$ of -27‰. These findings show a similar trend to the studies of Peterson and Fry (1987) and Marshall et al. (2007), which mentioned that fossil fuel CO_2 has depleted ^{13}C or about -27‰, while the ambient CO_2 is enriched in ^{13}C about -8‰. In this case, the agricultural areas with less fossil fuel combustion from transportation, $\delta^{13}C$ values of tree leaves are higher than those in the commercial areas that have more concentration of traffic.

Table 2.1: Minimum, maximum, mode, mean, and standard deviation of $\delta^{15}N$ and $\delta^{13}C$ (‰) of street trees

Species	Min		Max		MODE		MEAN		SD	
	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$
Alstonia scholaris	2.81	-29.31	6.63	-25.60	4	-26	4.28	-26.84	1.25	1.28
Cassia fistula	1.93	-35.98	9.52	-27.05	5	-28	4.78	-29.53	2.05	2.35
Lagerstroemia spp.	2.79	-35.48	12.72	-20.07	6	-31	7.08	-30.19	2.76	3.69
Pterocarpus indicus	0.21	-32.32	15.37	-25.79	6	-30	4.30	-29.56	2.79	1.61
Sweitenia macrophylla	2.95	-32.85	7.03	-27.59	4	-30	4.55	-29.91	1.22	1.64
Tabebuia rosea	1.77	-33.08	12.50	-28.73	6	-30	5.68	-30.78	2.64	1.15

Table 3.1: Statistics of $\delta^{15}N$ of *Pterocarpus indicus* by land use zone (‰)

	AZ	LDRZ	HDRZ	CZ	ICZ	IZ
MIN	0.56	0.21	2.54	2.91	5.58	2.36
MAX	5.69	7.95	5.72	15.37	6.25	8.34
MODE	2 and 5	1	4	6	6	N/A
MEAN	3.43	3.10	3.77	6.35	5.82	6.06
SD	1.93	2.29	1.71	3.4	0.37	3.23
No. of samples	8	20	3	11	3	3

Table 3.2 Statistics of $\delta^{13}C$ of *Pterocarpus indicus* by land use zone (‰)

	AZ	LDRZ	HDRZ	CZ	ICZ	IZ
MIN	-30.89	-32.32	-30.79	-32.05	-30.65	-31.34
MAX	-26.64	-25.79	-27.79	-26.51	-27.31	-28.89
MODE	-29 and -27	-30	N/A	-32	N/A	N/A
MEAN	-28.92	-29.42	-29.51	-30.32	-29.12	-30
SD	1.61	1.62	1.55	1.7	1.69	1.24
No. of samples	8	20	3	11	3	3

4.3.2 Principal component analysis

Given that the dataset is integrated by 25 variables, a total of 25 factors can be estimated to account for the full variability in the dataset. From the scree plot in Figure 2, it shows the eigenvalues and proportion of variability fit by all 25 components (F1 to F25). From this plot, factors F1 to F7 are considered important, since the corresponding eigenvalues are greater than or very close to 1 (average of eigenvalue). This selection criteria was implemented because the higher the eigenvalue the more significant the component is (Smith 2002), and because one way to consider the number of components to keep is to determine which eigenvalue is larger than the average or larger than one (Abdi and Williams 2010; Ul-Saufie et al. 2013). In this study, the first seven factors can explain about 80% of the variation in the dataset. The first two factors, F1 and F2, can explain 54.1% of the variability in the dataset, while adding a third component, F3, increases the percentage of explained variability in the dataset to 61.4%. Table 4 shows the results used to determine how many components should be considered as relevant to the analysis. It shows the corresponding factors eigenvalues, the percentage of the variability in the dataset explained by each component (% variability), as well as the cumulative explained variance (% cumulative).

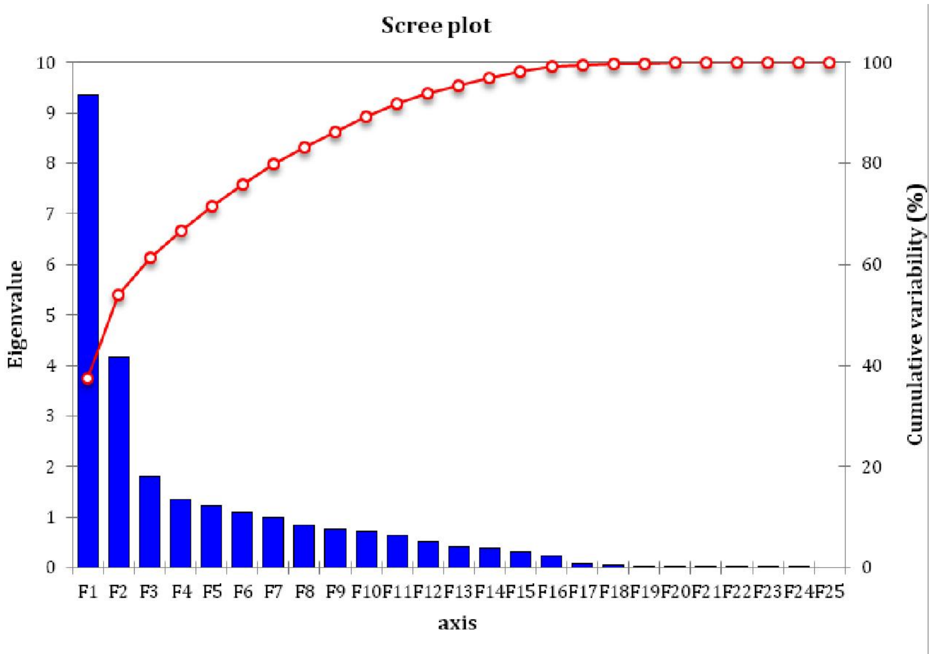

Figure 2 Scree plot of 25 components

Table 4 Eigenvalues and % variability of each factor

	F1	F2	F3	F4	F5	F6	F7
Eigenvalue	9.349	4.177	1.814	1.341	1.228	1.081	0.987
Variability (%)	37.395	16.709	7.257	5.365	4.912	4.326	3.947
Cumulative %	37.395	54.104	61.361	66.726	71.638	75.964	79.911

The correlation between the first two components and the variables in the dataset can be observed in the factor loading plot or correlation circle after Varimax rotation, Figure 3. We can observe that the D1 axis contributes 36.21% of variability in the data set, and the D2 axis contributes 17.91% of the variability of the dataset. These variability percentages are slightly different than those before the rotation, because the rotation adjusts the factor loadings to make each variable correlate with one component at the highest possible level while keeping its correlation with the other component at low levels (Dominick et al. 2012). If the variables are far from the center, and close to one another (same direction), the variables are strongly positively correlated; whereas, if they are on the opposite side, they are negatively correlated. If the variables are orthogonal to each other, they are uncorrelated.

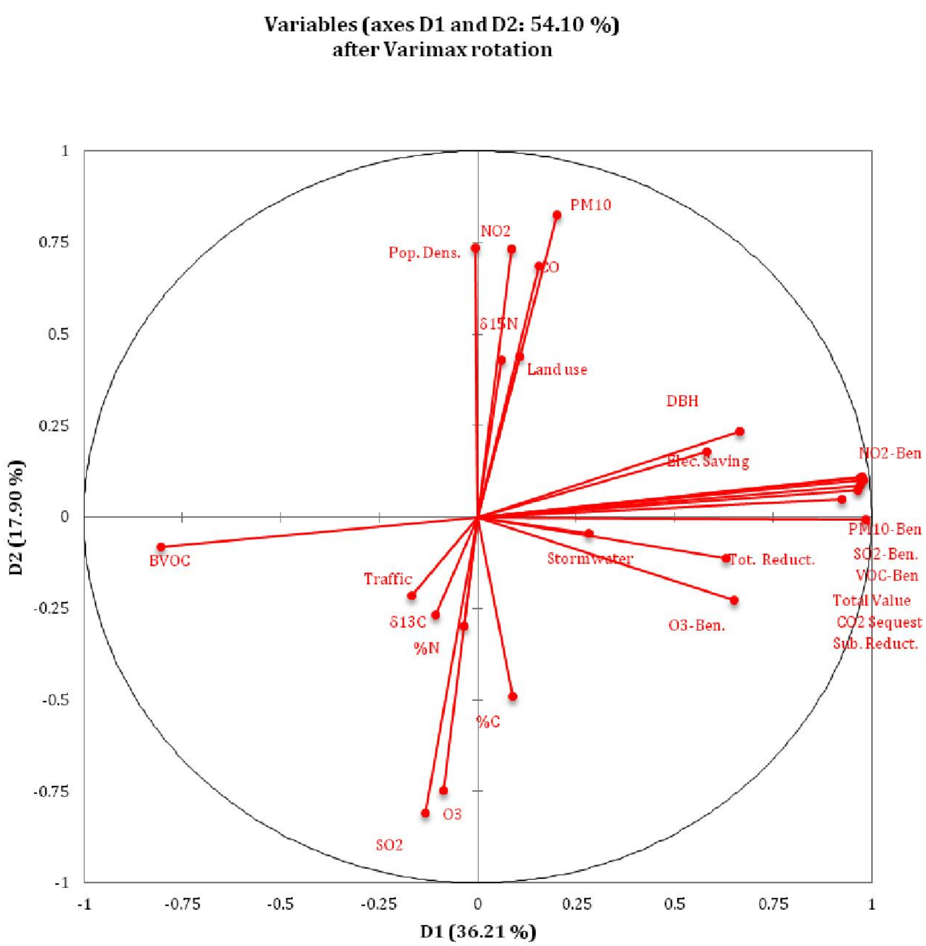

Figure 3 Correlation circle after Varimax rotation

(Pop dens = Population Density; Ben. = Reduction of air pollutants (NO_2, SO_2, PM10, VOC, O_3); CO_2 Sequest.= CO_2 Sequestration; Stormwater = Stormwater runoff reduction; Traffic = Traffic Volume; Total Value = Total monetary benefit of environmental services; DBH = Diameter at Breast Height

Table 5 shows the loading values or correlation coefficient between the variables and the axes (factors). Taylor (1990) suggested that if the absolute correlation coefficient is less than 0.35, the variable has low/weak correlation; at values between 0.36-0.67 the correlation is moderate; values in the range 0.68-0.89 indicate strong correlation; and values greater than 0.90 can be used as indicators of very strong correlation.

The tree environmental service parameters, such as the abilities to reduce PM10, SO_2, O_3, and NO_2, and the monetary benefit of these environmental services, street trees are very strongly positively correlated with each other and well linked with the D1 axis (the principal component 1). These variables have factor loadings greater than 0.90. This indicates that a significant proportion of the variance in the first principal component is explained by variations in those environmental services obtained through the reductions of air pollutants. On the other hand, biological VOC (-0.803) is strongly negatively correlated with those environmental benefit parameters and well linked with this D1 axis. For D2 (the principal component 2), SO_2 and O_3 have factor loadings greater than 0.80, which indicates strong positive correlation with each other and well linked with the axis D2; however, they are strongly negatively correlated with levels of PM10, NO_2, and CO. This may indicate that there is no major source of SO_2 near the city center. Also, during the daytime, O_3 is consumed by NO_2, making the level negatively correlated with NO_2 (Song et al. 2011). The variables that are close to the center in Figure 2 (e.g., electricity saving) are not highly loaded to the first two components. In other words, the information generated by those variables that is captured by other factors.

For the isotope composition values, $\delta^{15}N$ is moderately positively correlated with the axis D2 (r = 0.428) and traffic-related pollutants, including PM10, NO_2, and CO; whereas, $\delta^{13}C$ is weakly negatively correlated with the D2 (r = -0.266) and those pollutants. Thus, there may be some other factors that cause the variations in tree leaf isotopic compositions.

Table 5 Factor loadings after Varimax rotation

	D1	**D2**		**D1**	**D2**
%N	-0.036	-0.297	PM10-Ben.	**0.971**	0.086
$\delta^{15}N$	0.061	0.428	SO_2-Ben.	**0.966**	0.074
%C	0.09	-0.491	VOC-Ben	**0.97**	0.106
$\delta^{13}C$	-0.107	-0.266	Sub. Reduct.	**0.985**	-0.008
Land use	0.106	0.437	BVOC	**-0.803**	-0.08
NO_2	0.087	**0.733**	Tot. Reduct.	0.632	-0.112
CO	0.156	0.687	CO_2 Sequest	**0.926**	0.047
O_3	-0.086	**-0.746**	Elec. Saving	0.582	0.178
PM10	0.201	**0.827**	Stormwater	0.281	-0.044
SO_2	-0.134	**-0.809**	Total Value	**0.98**	0.101
Pop. Dens.	-0.007	**0.736**	DBH	0.665	0.235
O_3-Ben.	0.652	-0.227	Traffic	-0.168	-0.213
NO_2-Ben.	**0.978**	0.111			

Using tree species as observation labels, the Biplot in Figure 4 represents each observation (total of 185 observations) on the plane in the two-dimensional space (two principal components), with the loading plot that shows vectors of each variable. It shows that the majority of observations are concentrated in the center of the plots. The plot indicates that the species on the right (on the D1 axis) are species with the relatively high environmental benefits, while species that are in the opposite side provided relatively low environmental benefits. Also, the species in the top of the plot are in the areas of relatively high NO_2, PM10, and CO pollution; whereas, those on the bottom are located in areas with a relatively low level of those pollutants. Some observations are apparently far from the centers on the right, especially in *Peltophorum pterocarpum* (P.p.) and *Tamarindus indica* (T.i.). Those species share common characteristics, which are provisions of relatively high environmental services (values derived from calculation from i-Tree Streets model). However, they are not correlated with $\delta^{15}N$, meaning the two species do not have relatively high $\delta^{15}N$. Instead, *Lagerstroemia* spp. (*L. floribunda, L. macrophylla, L. loudonii, L. speciosa)* have high $\delta^{15}N$ values. This is not consistent with the trend from the calculation from i-Tree Streets model, in term of NO_2 deposition. Because trees in different species were planted regardless of air quality, the D2 axis has no strong correlation between species and air quality variables.

As for the Biplot of observation scores by land-use zones (observations are categorized by land use) and vectors corresponding to each variable (Figure 5), the findings show differences and similarities between observations, and relationships between observations and variables. The plots show that observations (score points) do not correlate strongly with the environmental benefits variables (vectors on D1 axis) as there are scattered points of observations on this axis. Instead, they correlate with the traffic-related pollutants, PM10, CO, NO_2 as well as with the $\delta^{15}N$ on the D2 axis.

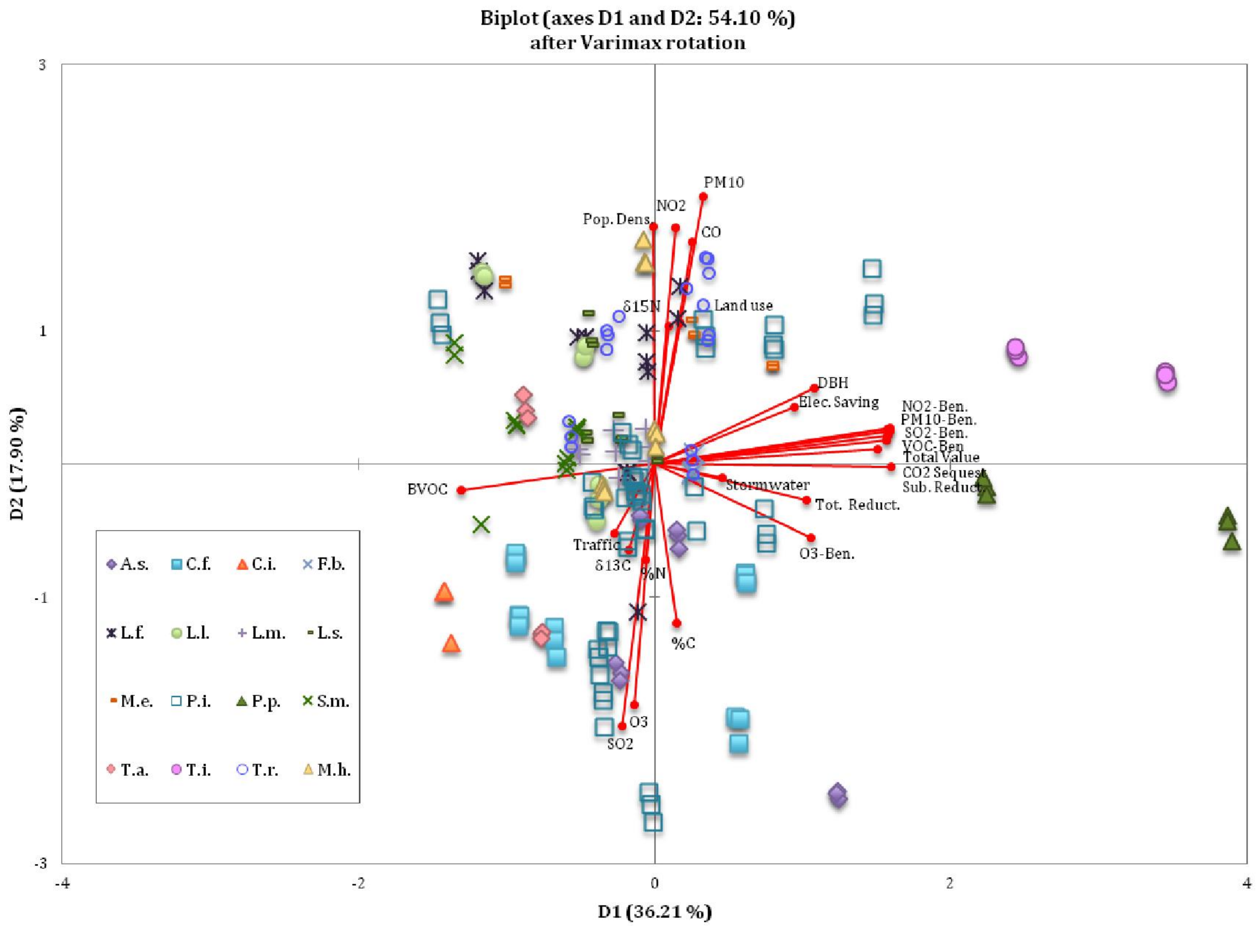

Figure 4 Biplot showing factor scores of each observation by species in D1 and D2 axes after Varimax rotation and vectors of variables. The full names of species and land use zones are in Table 1.

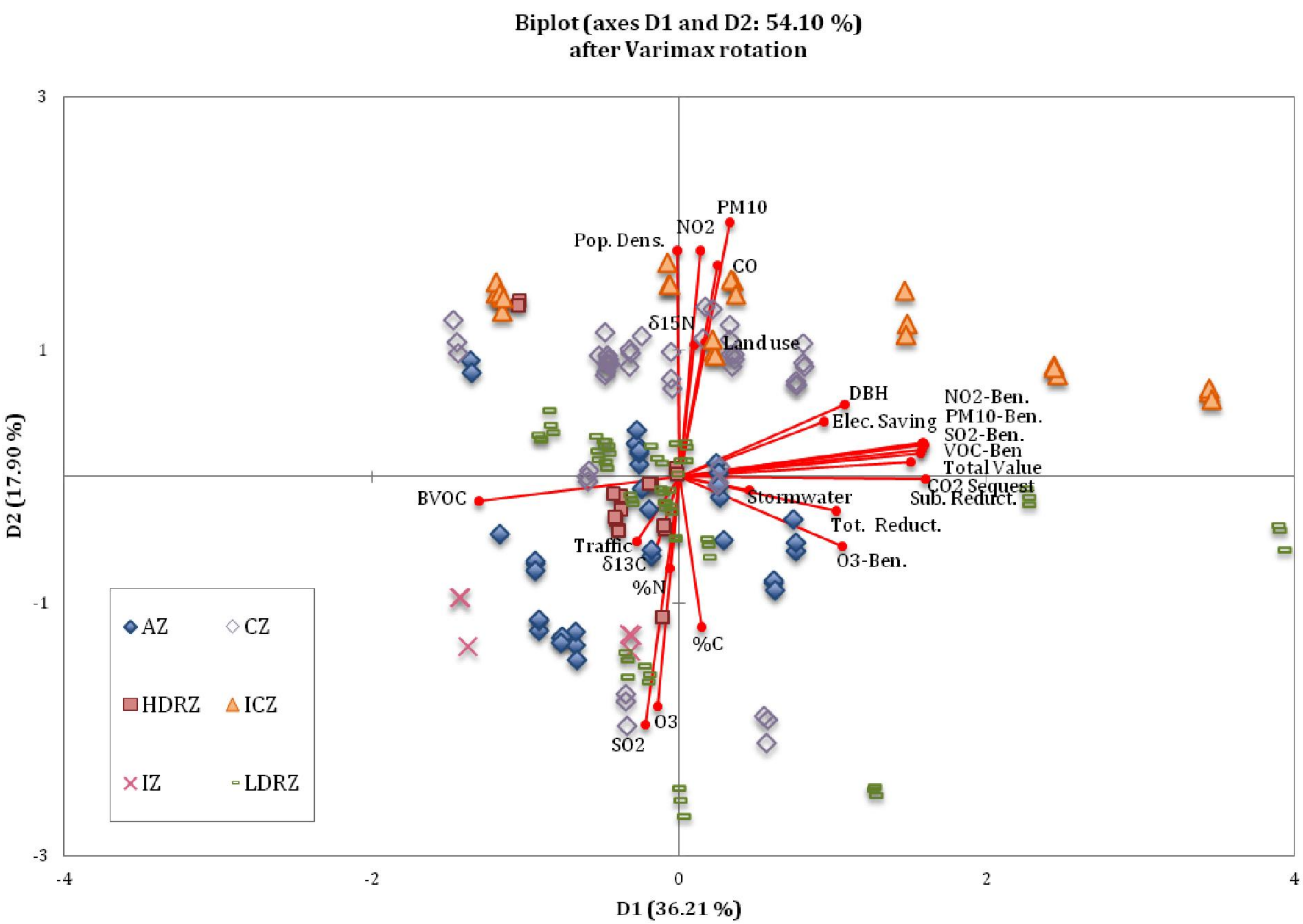

Figure 5 Biplot showing factor scores of each observation by land-use zones in D1 and D2 axes after Varimax rotation and vector of variables. The full names of species and land use zones are in Table 1.

The observations that are on the top of the D2 axis are mostly in the commercial zone (CZ), and some are in the Thai identity and cultural conservation zone (ICZ), which are close to the center of Bangkok. Conversely, the observations that are in the opposite side of the axis are mostly in low-density residential zones and agricultural zones (LDRZ and AZ), which are away from the Bangkok center. Most observations are similar to those mentioned above, however, some observations do not follow this trend (the points that apparently are positioned outside the ranges of most observations). These observations may have extreme values on some characteristics that are uncorrelated with the variables on D2, such as *Peltophorum pterocarpum* (P.p.) and *Tamarindus indica* (T.i.), which provide high environmental benefits. Full names of species and land use zones are in Table 1.

4.4 Discussion

4.4.1 The relationships of $\delta^{15}N$ and $\delta^{13}C$ and air pollution

Trees can remove air pollutants, including NO_x, through stomata and the leaf surface (Stulen et al. 1998; Nowak et al. 1998; Chaparro-Suarez, Meixner, and Kesselmeier 2011). $\delta^{15}N$ values of NO_x broadly vary according to their sources. In Panama and Thailand, respectively, it has been identified that an increase in nitrogen deposition from human activities over time leads to an increase of $\delta^{15}N$ (positive value) in tree leaves and tree rings (Hietz et al. 2011). On the other hand, naturally-derived NO_x has negative $\delta^{15}N$ as is produced through nitrification and denitrification processes that favor lighter isotopes (Peterson and Fry 1987).

$\delta^{15}N$ of street tree leaves in this study vary between +0.21 to +15.37‰ with an average of 5.21 ± 2.61‰. $\delta^{15}N$ values of tree leaves collected in highly NO_2 polluted areas are higher than those from tree leaves sampled in areas with low NO_2. This finding is consistent with many studies that have identified that $\delta^{15}N$ values of NO_x emission from transportation-related sources that range in positive values, or are higher than those measured in less polluted areas (Heaton 1986; Ammann et al. 1999; Vallano and Sparks 2007; Elliott et al. 2007; Redling et al. 2013). For example, according to Redling et al., (2013), NO_x from vehicles in motion have $\delta^{15}N$ levels between +3.7 and +9‰. Also, Elliott et al. (2007) indicate that $\delta^{15}N$ values of NO_x emissions from tailpipe sources and roadside denuders are +3.8‰ and + 5.7‰, respectively, which is consistent with the $\delta^{15}N$ values found on roadside vegetation (+3.7‰). The $\delta^{15}N$ values detected in this study are moderately positively correlated with NO_2 levels and other traffic-related pollutants, including CO, PM10, which is consistent with the findings of Han and Naeher (2006). Given the similarities in the inputs of other nitrogen sources (soil, fertilizers), $\delta^{15}N$ of street tree leaves can be used as an environmental tracer of air pollutants.

Although the nitrogen in plants could be from both soil (primarily NO_3^-, NH_4^+) and atmospheric sources (NO_x, NH_3) (Vallano and Sparks 2007), a trend of higher $\delta^{15}N$ values can be seen along the higher NO_x pollution gradient, which indicates that $\delta^{15}N$ could be the preliminary indicator for atmospheric NO_2 pollution. In Bangkok, there is no major source of NH_3, which is mostly derived from volatilization of agricultural and animal waste (FAO 2001; Vallano and Sparks 2007). However, future studies in this city should consider investigating soil $\delta^{15}N$ in order to assess the differences in the plant $\delta^{15}N$ values, as it can indicate the proportion of nitrogen that is obtained from foliar uptake.

Regarding carbon, the $\delta^{13}C$ values in the sampled street tree leaves range between -35.95 and -20.07‰, with an average of -29.88 ± 2.67‰. $\delta^{13}C$ average values in the commercial areas, which contain more polluted street segments than other zones, is relatively low. It is consistent with the previous findings that identify that $\delta^{13}C$ of natural materials decrease to be more negative than $\delta^{13}C$ of CO_2 in the atmosphere (about -7 to -8‰) if there are more pollutants from fossil fuel carbon sources. However, $\delta^{13}C$ in the sampled tree leaves have a weakly negative correlation with traffic-related pollutant levels. This means that air pollutants only partially influenced the ratio ^{13}C and ^{12}C, and that other factors also impacted $\delta^{13}C$ values in street tree leaves, such as genetics, or fractionation due to diffusion or photorespiration (Marshall, Brooks, and Lajtha 2007). Thus, the results from this study suggest that $\delta^{13}C$ may not be a good indicator of air pollution.

4.4.2 Recommendation for species selection and comparison of the trends in NO_2 absorption with respect to the results from the i-Tree Street model

Lagerstroemia spp. (*L. floribunda, L. macrophylla, L. loudonii, L. speciosa)* are species that have the highest average value of $\delta^{15}N$ (7.26‰), which is correlated with the NO_2 level found on Bangkok streets. This suggests that they can be good candidates for mitigating NO_2 pollution in Bangkok's metropolitan area. As *Lagerstroemia* spp. has a rough and hairy foliar surface, the trees can intercept air pollutants in a more effective way (Vargas et al. 2008), through absorption on leaf surfaces (Vallano and Sparks 2007).

The findings from this study are contrasted with the results from the i-Tree Streets model in term of the ranking of tree species with respect to their ability to reduce nitrogen dioxide. Although the ranking from the i-Tree Streets model is not consistent with the ranking generated from this study (*Lagerstroemia* spp. has low rank in nitrogen deposition in the i-Tree findings), there are some limitations associated with the estimation implemented in the i-Tree software that constrain a direct comparison of the results. Apparently, the unit of $\delta^{15}N$, which is a ratio (‰), cannot directly be compared with the nitrogen deposition estimates computed with the i-Tree software, which is kilograms per year. Also, it is complicated to directly link $\delta^{15}N$ of trees with their levels of NO_2 uptake, as there are other factors influencing $\delta^{15}N$.

According to the i-Tree modeling assumptions, annual tree benefits of nitrogen dioxide flux ($g/m^2/s$) on tree leaves, which are calculated as a function of deposition velocity (m/s) multiplied by pollutant concentration (g/m^3) (Nowak et al. 2008), must take into account the days in which the trees have leaves (leaf-on days) in the estimation. Given that deciduous trees such as *Lagerstroemia* spp. have less leaf-on days than evergreen species, the NO_2 deposition per year of *Lagerstroemia* spp. is lower than that of evergreen trees. In addition, there are other soil-related sources of nitrogen that affect the $\delta^{15}N$. For example, nitrogen-fixing bacteria in the roots of some legume trees can fix nitrogen gas from the atmosphere (Vallano and Sparks 2007). This makes the $\delta^{15}N$ of legumes close to 0‰ (Hietz et al. 2011), which is similar to the atmospheric N_2. So some legume species, even if they are deciduous, may have low to nearly zero $\delta^{15}N$, meaning that those types of trees have low nitrogen dioxide uptake.

In this context, a policy recommendation for the city would be to plant deciduous trees for esthetic purposes (e.g., flowering during some seasons), and *Lagerstroemia* spp. would be a good selection. With regard to evergreen species, there is not clear evidence in this study about which species have the highest uptake of nitrogen from air pollution.

4.5 Conclusion

Finding similarities and differences between tree species in terms of their capability to remove air pollutants is relevant for tree management, since such information can be used to improve the provision of tree-related environmental benefits. In this study of tree species found in Bangkok's metropolitan area, *Lagerstroemia spp*. trees are found to present the highest average value of $\delta^{15}N$ (7.26‰) and a $\delta^{15}N$ that is correlated with NO_2. Those results suggest that these types of trees can be good candidates among the deciduous tree category to help in mitigating NO_2 pollution in the city. Also, as $\delta^{15}N$ values of tree leaves vary by land-use zonings (which reflects a gradient of pollution level), foliar $\delta^{15}N$ of street trees can be used as an early indicator of NO_2 pollution (under the assumption that trees have similar inputs of other nitrogen sources). Additional research is needed to explore the magnitude of foliar nitrogen uptake by incorporating analysis of $\delta^{15}N$ in the soil of the sampled trees. Further identification of native tree species with a high ability to uptake and assimilate atmospheric nitrogen can be helpful for decision makers focused on reducing nitrogen air pollution in the city.

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Chapter 5

Conclusions

As humans and nature are interconnected, studying urban ecosystems, including ecosystem functions or services, can lead to a better understanding of the linkages and dynamics of socio-economic and ecological processes that impact ecosystem health, and human well-being. Considering that urban areas present problems and solutions to sustainability challenges (Grimm et al. 2008; Seto, Sánchez-Rodríguez, and Fragkias 2010), the study of urban ecosystems in an integrative way is important for city planning to mitigate environmental and socioeconomic impacts of urbanization, including changes in supply of ecosystem goods and services (Pickett et al. 2001).

Urban forests can play a significant role in enhancing the environment, increasing community attractiveness and livability, as well as helping to balance economic growth with environmental quality and social well-being (Vargas et al. 2008; UK National Ecosystem Assessment 2011). This study focuses on ecosystem services provided by street trees in Bangkok as a useful tool to address prominent urban and environmental problems, particularly through management policies. I assess the ecosystem services provided by publicly maintained street trees in three aspects: environmental, economic, and social (objective 1). The relationship between stable isotopic data of tree leaves and the environmental quality of Bangkok's streets can be used to determine the best tree species for mitigating air pollution (objective 2). The findings from the two objectives can enhance Bangkok's ecosystem service provision, and can be used as a model for other cities. The highlighted findings and proposed policy implementations derived from the studies described in the previous chapters are summarized in Table 1.

Recommendations derived from this dissertation to the Bangkok Metropolitan Administration (BMA) and to the general public are:

1. Proper species selection is highly relevant in street tree plantings to increase environmental service provisions and to reduce maintenance-related activities or conflicts generated from tree growth.

2. Educational efforts are needed to help policymakers, public officials, and citizens to properly value ecosystem services provided by street trees. This is not only to avoid the loss of some services, but also to aid in their maintenance and conservation (Costanza et al. 2006; Daily 1997). Building a better understanding of the relevance of ecosystem services among the general public can help to raise awareness and create meaningful public participation in tree planting and maintenance activities, as well as to promote tree conservation.

3. The BMA should take into consideration opinions from all related urban actors with respect to tree management suggestions, including those provided by experts, government officials, related stakeholders, and the general public.

Table 1 Summary of findings and proposed policy implementation

Study topics		Findings	Implementation
1. Assessing the ecosystem services provided by public street trees	Environmental benefits	Citywide public street trees can provide benefits: 1. 65,316 kg per year of air pollution reduction 2. 2,112,814 m^3 per year of total rainfall interception. 3. 12,947,824 kg per year of net CO_2 reduction 4. 69,760,489 kg stored carbon over 40 years 5. 8,298,278 kWh annual electricity savings	The findings of how much environmental services street trees can provide can be used to promote awareness to the public on environmental and health benefit, as well as to promote investment in green space enhancement activities.
	Economic benefits	Citywide public street trees can save the city: 1. \$136,127 from air pollution reduction per year 2. \$3,244,430 from total rainfall interception per year 3. \$55,676 from net CO_2 reduction per year 4. \$904,512 from annual electricity saving 5. \$295,017 from stored carbon over 40 years. Total monetary benefit is \$4.34 million per year	The monetary savings that the city can obtain from planting street trees can be used to promote higher investment in green space enhancement activities.
	Social benefits	1. Public official perception of economic benefits from public street trees is relatively low (it achieved a score of 3 on a scale 1-7) compared with the perception of social and environmental benefits (which obtained scores of 5.46 and 5.04, respectively). *2.* Major challenges in tree management are: lack of personnel, conflicts with street vendors, damaged sidewalks, and overhead wire problems. *3.* Bangkok's metropolitan area should increase tree maintenance to reduce damage risks and promote tree health conditions.	Promote education among agricultural officers and the general public through activities such as workshops, and tree planting activities.

Table 1 Summary of findings and proposed policy implementation (continued)

Study topics		Findings	Implementation
2. Selecting tree species to plant (according to the results of Objective 1, and stable isotope analysis)	Small space (minimum width 0.90-1.20 m)	*Lagerstroemia* spp. is greatly recommended	Promote the planting of tree species that provide higher environmental benefits, lower maintenance costs, and fewer conflicts.
	Medium and large space (minimum width greater than 1.80 m)	Benjamin fig (*Ficus benjamina*) is recommended for the median strip plantings. Yellow poinciana (*Peltophorum pterocarpum*), and tamarind (*Tamarindus indica*) are highly recommended for both sidewalk and median strip plantings.	

4. Policymakers, urban foresters, and citizens should help preserve the existing green spaces to at least maintain the provision of ecosystem services at the currently observed levels.

In future research, estimates of the environmental benefits provided by urban trees can be improved through a complete inventory of those resources. In this regard, while doing regular maintenance activities, all districts should collect information on the status of the planted trees (e.g., species, size, and numbers in each jurisdiction). In addition, to calculate the net benefits of urban forests, planting and maintenance costs should be taken into account. To identify species that have higher capacity to reduce NO_x pollution using stable isotope analysis of tree leaves, data on tree health conditions, biomass size, and soil samples should be collected. Also, improving the classification method to identify areas covered only by trees should be pursued in order to improve a future study to investigate areas of high priority in tree planting.

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