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Particulate matter accumulation capacity of plants in Hanoi, Vietnam

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Abstract

Population growth, urbanization, environmental conditions and rapid development have caused particulate matter (PM) levels to rise above all national and international health standards during the last two decades in many South-East Asian countries. These PM levels needs to be reduced urgently as they increase the risk of cardiovascular and respiratory health problems for millions of people. Plants have shown to efficiently reduce PM in the air by accumulation on their leaves. In order to investigate which plant species accumulate most PM, we screened 49 common plant species for their PM accumulation capacity in one of the tropical cities with the highest PM concentrations of the world, Hanoi (Vietnam). Using this subset of plants, we tested if certain leaf characteristics (leaf hydrophilicity, stomatal densities and the specific leaf area) can predict the PM accumulation efficiency of plant species. Our results show that the PM accumulation capacity varies substantially among species and that *Muntingia calabura* accumulated most PM in our subset of plants. We observed that plants with hydrophilic leaves, a low specific leaf area and a high abaxial stomatal density accumulated significantly more PM. Plants with these characteristics should be preferred by urban architects to reduce PM levels in tropical environments.

Capsule:

Muntingia calabura can be used as an efficient bio-remediation strategy to reduce PM. Plants with a lower SLA, a more hydrophilic leaf surface and higher (abaxial) stomatal densities showed higher PM accumulating capacities.

Key words:

Air pollution, Bioremediation, *Muntingia calabura* (strawberry tree), Particulate matter (PM), Saturation isothermal remanant magnetization (SIRM)

1. Introduction

The World Health Organization (WHO) estimated that seven million people die each year from particulate matter (PM) related diseases and other kinds of air pollution (WHO, 2018). Common health effects associated with high PM levels are respiratory and cardiovascular problems, while less common effects include reductions in the cognitive abilities and overall productivity (e.g. increased risk to Alzheimer; Daisey et al., 2003; Fadeyi et al., 2014; Pope, 1996; Pope et al., 2002; Pope et al., 2015; Volk et al., 2013). As a result, the WHO declared that PM concentrations need to be reduced urgently and that well-defined limits should not be surpassed (WHO, 2018).

One cheap and (relatively) easy-to-implement way to reduce PM levels in cities is bioremediation (Beckett et al., 1998; Mitchell et al., 2010). Plants can accumulate and retain PM in their canopy and hence reduce PM up to 25%, which typically occurs by accumulation (short-term removal) on the leaf surface or by encapsulation (long-term removal by sequestration) in the leaf wax (McDonald et al., 2007; Popek et al., 2013; Tallis et al., 2015; Weyens et al., 2015). The amount of accumulated and encapsulated PM on the leaf surface can differ substantially between species and depends mainly on differences in the leaf characteristics (Dzierzanowski et al., 2011; Kardel et al., 2011; Lehndorff et al., 2006; Mitchell et al., 2010). Plants with big, rough, rigid, sticky and hairy leaves, a hydrophilic leaf surface and a complex leaf shape are suggested to accumulate more PM (Balasooriya et al., 2009; Goldsmith et al., 2017; Kardel et al., 2012a; Mitchell et al., 2010; Mo et al., 2015; Muhammad et al., 2019; Szonyi et al., 2008; Weerakkody et al., 2018). The effects of hairiness, size, stomatal density and specific leaf area (SLA) of leaves are still under discussion as different studies have found contrasting results (Freer-Smith et al., 2005; Kardel et al., 2013; Leonard et al., 2016; Perini et al., 2017; Weerakkody et al., 2017, 2018).

Besides biotic effects, the conditions for PM accumulation can also be affected by several abiotic factors including seasonal, meteorological and climate effects (Weyens et al., 2015; Zhang et al., 2017). Furthermore, we highlight that different PM concentrations can reversely affect the plant's leaf characteristics and even it's growt by limiting photosynthesis through shading (Grantz et al., 2003; Prajapati and Tripathi, 2008). For example, it is known that PM concentration affect the stomatal size and density of several plant species (Balasooriya et al., 2009; Kardel et al., 2013). Alternatively, chemical reactions between PM and the leaf cells can alter the leaf area, leaf mass or SLA (Kardel et al., 2013; Poorter et al., 2009; Shafiq et al., 2009; Verma and Singh, 2006).

An inexpensive, non-destructive, reliable and rapid bio-monitoring technique to measure air pollution is the saturation isothermal remanent magnetization (SIRM) or maximal magnetic remanence of an object achieved after short exposure to a strong magnetic field (Beckett et al., 1998; Dzierzanowski et al., 2011; Matzka and Maher, 1999; Mitchell et al., 2010; Richter et al., 2007). Unlike PM, the SIRM is not defined by its size distribution and is not prone to changing chemical and physical properties (Evans and Heller, 2003; Hofman et al., 2014; Muxworthy et al., 2003; Rai, 2016a). Because the SIRM is a measurement for the total concentration of magnetic grains and linearly relates to the presence of Cu, Pb, Zn and Fe concentrations, the parameter can also be used as a proxy for PM pollution plus its associated toxic heavy metals that are typically related to combustion, corrosion and abrasion processes (Castanheiro et al., 2016; Flanders, 1994; Matzka and Maher, 1999; Morris et al., 1995; Tomašević and Aničić, 2010; Vercauteren et al., 2011).

Since bioremediation would be a cost-efficient way to reduce air pollution in tropical urban environments, we investigated the PM accumulation capacity of local plant species in Hanoi, Vietnam. The city was chosen for several reasons. First, little research has been done on the PM accumulation capacity of tropical plants in this part of the world. Second, PM pollution in Hanoi is very high, resulting in a large affected population experiencing air pollution related diseases (e.g. asthma, chronic bronchitis or cancer; MONRE, 2008). Third, the city is estimated to lose around 2-8 percent of its gross domestic product due to air pollution (Huan et al., 2014; Hung, 2010; MONRE, 2008). For all these reasons and because air pollution is already a major concern of both the government and the citizens of Hanoi, we expect that Hanoians will support the implementation of bioremediation as a low-budget tool to reduce PM concentrations in their city (Hanoi People's Council, 2017; MOIT, 2016).

We test two hypotheses: (I) plant species in Hanoi differ significantly in their PM accumulation capacity; (II) plant species with specific characteristics (a hydrophilic leaf surface, a low SLA and a high stomatal density) have a higher PM accumulation capacity. To correct for possible spatial variation in local PM concentrations and to put our data in the right context, it was necessary to analyse and briefly discuss the overall spatio-temporal characteristics of PM in Hanoi.

2. Methods

2.1. Study site

Hanoi has a sub-tropical climate, which has an average annual air temperature and air humidity of 25 °C and 78%, respectively. The annual rainfall is on average1685 mm but 80% falls during July and August when heavy rains, tropical depressions and cyclones pass the city (GSO, 2017; Hien et al., 2002; Luo et al., 2018). The city expierences a high economic and population growth, resulting in a population of around seven and a half million inhabitants (in 2016) and a vehicle fleet of around six million registered vehicles (in 2015; Arouri et al., 2017; GSO, 2017; Leducq and Scarwell, 2018; Sanders et al., 2015). Because PM in Hanoi has a mix of sources (e.g. high PM emitting vehicles and the burning of coal and waste), which is reflected in the city its specific PM2.5 composition of "29 ± 8% ammonium sulfate, 8.9 ± 3.3% soil, 28 ± 11% organic matter, 0.6 ± 1.4% salt, 9.2 ± 2.8% black carbon, nitrates and absorbed water" (Cohen et al., 2010a; p. 320), the annual average PM2.5 concentration (47.7 µg/m³ in 2017) is around five times higher than WHO guidelines (10 µg/m³; CENMA, 2008; Son and Van Sy, 2008; WHO, 2006).

2.2. Collection of leaves

From mid-August to the beginning of September 2017, leaves of 49 plant species (herbs, shrubs and trees) were collected in various streets and squares throughout Hanoi, Vietnam (21° 01' N, 105° 50' E; Fig. 1). Ten leaves were collected from at least three individuals at different locations and as close as possible to the road (Table S1-S4 in Appendix; Beevers et al., 2013). We selected leaves of approximately the same age because temporal effects of leaf growth and leaf senescence (i.e. different accumulation periods) can affect the SIRM values (Hofman et al., 2014; Rai and Chutia, 2016). To prevent PM accumulation pollution on the leaves by dirt splashing during heavy rains, leaves were sampled at heights of two, one and a half, and half a meter for trees, shrubs and herbs, respectively (Dzierzanowski et al., 2011; Kardel et al., 2012b). Leaves were always collected at the street-facing side of the individual plant (Matzka and Maher, 1999). Only full-grown and undamaged leaves were sampled and stored in sealed paper envelopes. Coordinates of each individual plant were determined using a Garmin etrex 30 handheld GPS. Nine leaves of each individual plant were brought to the Institute of Ecology and Biological Resources (IEBR) in Vietnam, where the leaves were pressed between newspapers and put to dry for six days in a dry oven at 50 °C.

2.3. Methods of measuring

2.3.1. General characteristic measurements

The SLA was calculated by dividing the single leaf area by the corresponding oven-dry mass of the leaf. Therefore, the dried leaves were processed at the University of Antwerp (UA) in Belgium where their petioles were removed. The dried leaves were measured with an area meter (LI-3100 Area Meter, LI-COR Biosciences Inc., Lincoln, NE, US) and weighed with an analytical balance (BP1215 Analytical Balance, Sartorius, Göttingen, Germany).

2.3.2. Leaf stomata

To calculate the stomatal densities, we first made an imprint of the leaf stomata by putting nail polish on both sides of one leaf from each individual (Kardel et al., 2013). Transparent adhesive tape was then put on the dried nail polish for the final imprint, which was placed on a labeled microscopic slide. Stomatal counts and stomatal characteristics (i.e. the stomatal length and width) were measured three times with a microscope and appropriate imaging software (CX41RF and CELL-D, Olympus Corp., Tokyo, Japan).

2.3.3. Leaf wettability/hydrophilicity

The hydrophilicity of the leaves was assessed using the droplet contact angle (DCA) method (Aryal and Neuner, 2010; Jagels, 1994). Depending on the species and the presence of wax or trichomes, water droplet contact angles can range between 22° to 180° (Kardel et al., 2012a; Neinhuis and Barthlott, 1997; Rosado and Holder, 2013). Before drying the leaves at IEBR, three leaves of each sampled plant were used for the DCA analysis following the protocol of Kardel et al. (2012a). Three droplets of distilled water (7.5 µL for leaves and 4.5 µL for needles) were put on both sides of the leaves. Then, a macro photographical picture was taken from each droplet with a camera equipped with 18-55 mm standard lens and three extension tubes. The pictures were taken at the same height as the leaves allowing a clear vision on the angles formed by the leaf surface and the distilled water droplets (Fig. S2 in Appendix). After labelling the pictures, the droplet contact angle was measured with ImageJ (Schneider et al., 2012).

2.3.4. Magnetic intensity, magnetic moment & SIRM

To assess the PM accumulation capacity of the leaves, we measured the SIRM (Kardel et al., 2011). Each dried leaf was first folded into a compact package of leaf material and transparent cling film, and pressed into clean jars with a volume of 10 cm^3. The high sensitivity (~ 0.1×10^{-10} Am^2) magnetometer (Minispin Magnetometer, Molspin Ltd., UK) was then calibrated with a stable rock specimen to an orientation between 359.5 to 0.5 degrees and a magnetic intensity between 1323 to 1333 A/m. This process of recalibration was repeated each nine samples (Mitchell et al., 2010). After calibration, the samples were magnetized to full saturation in a magnetizer (Minispin Magnetizer, Molspin Ltd., UK) with a pulsed magnetic field of 0.8 T. Subsequently, the magnetic intensity of each magnetized sample was measured twice with the magnetometer (Matzka and Maher, 1999; Power et al., 2009). To correct for background magnetization values and contamination, the mean value of 18 blank samples (i.e. jars with only cling film) was subtracted from the leaf material samples' magnetization values. To obtain the magnetic moment (Am^2), the corrected magnetic intensity value was then multiplied by the volume of the jars and by a correction value of 2.6137. Finally, the SIRM value was calculated by normalizing the magnetic moment values by the leaf area (SIRMa), which also linearly correlates with the SIRM normalized by leaf mass (SIRMw; Fig. S3 in Appendix; Hofman et al., 2014; Kardel et al., 2011; Mitchell et al., 2010; Szonyi et al., 2008).

2.4. Statistical analyses

2.4.1. Linear mixed models

To investigate if the SIRM differed among the leaves of one plant, we used a linear mixed model with the leaf number as predictor variable, the SIRM as response variable and the sampled plant as random effect. After checking for normality assumptions, we log-transformed the SIRM values following Zuur and Ieno (2016).

Before testing for differences in SIRM among plant species, we explored the scale of the effect of spatial variation in PM on the SIRM. We first assigned a same location number to all plants in a 100 m radius, assuming that plants within this location encounter similar PM conditions (e.g. different exposure to PM due to difference traffic rates; Fig. S4 in Appendix). We considered a radius of 100 m as valid because PM constituents from vehicles are depositing or decaying, exponentially or linear, within 75-150 m of their source depending on the wind direction (perpendicular or parallel to the road) and PM size (Hitchins et al., 2000; Weijers et al., 2004; Zhu et al., 2002). In total, we assigned 32 locations using ArcMap 10.3.1 (ESRI, 2011). Then, we made a linear model with as predictor variable the species and as response variable the log-transformed SIRM. Subsequently, another linear model with as predictor variable location and as response variable the residuals of the previous linear model was made. To correct for multiple comparisons, a Bonferroni correction was applied to each locations' p-value. No general effect of location on

SIRM was found ($p > 0.05$), except for locations 16, 27 and 31 ($p = 0.007$-0.04; only *Bauhinia variegata*, *Celtis sinensis*, *Dalbergia tonkinensis*, *Peltophorum tonkinensis* and *Prunus persica* were sampled in these locations and none of these species accumulated much PM). Finally, to test if the SIRM differed among different plant species, we made a linear mixed model with the species as response variable, the log-transformed SIRM as response variable and date and location as random effects.

To test which leaf characteristics contribute to PM accumulation on leaves, a linear mixed model was made with the predictor variables adaxial DCA, abaxial DCA, abaxial stomatal density and SLA, SIRM as response variable and species as random factor.

All statistical analyses were done using R, version 3.6.0 (R Core Team, 2019). When fitting the models, we started with the fully parameterised models and sequentially dropped variables that had the highest insignificant p-values calculated by Pearson's chi-square test (DROP1). The R package 'lme4' was used for the linear mixed models (LMER; Bates et al., 2015).

2.4.2. PCA analyses

To test for correlations between the leaf-variables (adaxial DCA, abaxial DCA, abaxial stomatal density, leaf area and SLA), a principal component analyses (PCA) was performed. First, a linear mixed model was made with the adaxial DCA as predictor variable, the abaxial DCA as response variable and species as random factor. Second, after checking for normality assumptions, we log-transformed the leaf area values and we made a linear mixed model with the leaf area as predictor variable, the abaxial stomatal density as response variable and species as random factor. Third, after checking for normality assumptions, we log-transformed the SLA values and made a linear mixed model with the log-transformed SLA as predictor variable, the abaxial stomatal density as response variable and species as random factor. The packages 'FactoMineR' and 'factoextra' were used for the PCA (Kassambara and Mundt, 2017; Lê et al., 2008).

2.4.3. Hierarchical cluster analyses

To look for groups of plant species with similar leaf characteristics, the same set of variables as in the PCA was used in a hierarchical cluster analysis. A bootstrap test (PVCLUST) was used to determine the significance of each cluster by providing p-values. Afterwards, the plant species were assigned the same number for the significant ($p < 0.05$) cluster they belonged to. Subsequently, bar plots and linear models were made with SIRM as the response variable and one of the leaf characteristics (adaxial DCA, abaxial DCA, abaxial stomatal density, SLA or leaf area) as predictor variable. These models were used to test if the groups of plant species differed significantly in their SIRM values and their leaf variables. P-values were derived using the multiscale Bootstrapping procedure from the package 'pvclust' (Suzuki and Shimodaira, 2015).

2.4.4. Analyses of PM data

To assess the spatial variation in PM, hourly PM, humidity, temperature and wind speed data for 2017 was provided by data aggregator AirVisual (https://www.airvisual.com/vietnam/hanoi). The data originates from ten governmental air quality measurement stations and the US embassy in Hanoi. To manage all spatio-temporal data, the functions 'pollutionRose', 'timeVariation' and 'timePlot' of the 'openair' package were used (Carslaw and Ropkins, 2012).

3. Results

3.1. PM accumulation capacity of plants

The PM accumulation capacity did not differ among the leaves of one individual (p = 0.5). However, our second analyses shows that the PM accumulation capacity differed among species ($p = 2*10^{-16}$). To have an idea on the variation in SIRM concentrations and which plant species accumulated most PM, we ordered all plant species according to their SIRM values (Fig. 2). *Muntingia calabura* had the highest PM accumulation followed by *Chukrasia tabularis*, *Nerium oleander*, *Sabina chinensis* and *Acacia auriculiformes*. The bar plot provided a clear gradient in SIRM values of different species.

The hierarchical cluster analysis showed that plant species significantly clustered in two clusters (groups) based on their leaf variables ($p < 0.05$; Fig. 3 and Table S2 in Appendix). Group one had a significantly lower mean SIRM than group two ($p = 1.10^{-10}$), suggesting that plant species in group two have leaf characteristics (i.e. a lower SLA, a more hydrophilic leaf surface and higher (abaxial) stomatal densities) that are favourable for PM accumulation.

3.2. Leaf characteristics leading to efficient PM accumulation

The linear mixed models testing for the effect of the leaf variables on the PM accumulation capacity with random effect species showed that only the abaxial DCA significantly negatively correlated with the SIRM ($p = 5.37*10^{-3}$). This showed that more PM was accumulated on more hydrophilic abaxial leaf surfaces. No significant correlations were found between the adaxial DCA, SLA and abaxial stomatal density ($p > 0.05$).

The PCA showed five potentially correlated leaf-variables (the adaxial and abaxial DCA, the abaxial stomatal density, the SLA and the leaf area; Fig. S5 in Appendix). However, the linear mixed models testing the results of the PCA found only a significant positive correlation between the adaxial and abaxial DCA (p = 2.00*10^{-16}) and a significant negative correlation between the SLA and the abaxial stomatal density (p = 7.12*10^{-3}). No correlation was found by the linear mixed models between the leaf area and the abaxial stomatal density (p = 0.92).

For the groups of plants built with the cluster analysis, group one had a significantly higher adaxial and abaxial mean DCA than group two (p = 2*10^{-8}). Group one also had a significantly lower mean abaxial stomatal density (p = 5*10^{-14}) and a significantly higher mean SLA than group two (p = 1*10^{-7}). Between the two groups, no difference was found in the mean leaf area.

3.3. Spatio-temporal PM dynamics

3.3.1. Temporal PM dynamics

In addition, to the spatial variation in PM, Hanoi also experienced different climatic conditions that contributed to a high temporal variation in PM concentrations (Fig. 4). The average wind speed (1 m/s) was low and high PM concentrations were observed in winds from the North-East and North-West. Large differences in calm (May to December) and turbulent (January to April) wind periods were observed as well. During spring and winter, PM concentrations increased significantly and episodes of extreme PM values occurred frequently (e.g. hourly PM2.5 and PM10 concentrations of over 800 and 1200 µg/m³, respectively). High concentrations of PM occurred simultaneously with low humidity levels, strong winds and low temperatures.

The diurnal PM pollution pattern for 2017 peaked around 4 am, gradually declined until 5 pm and increased again during the night (Fig. S6 in Appendix).

3.3.3. Spatial PM dynamics

PM does not only travel horizontally, dependent on its aerodynamic size, but also vertically in the air (Maher et al., 2008; Zhu et al., 2002). At the same time, decreasing distance to the road increases SIRM values exponentially, causing roads, intersections and other highways of transport to be significant sources of spatial variation in PM. Consequently, local traffic intensities largely determine the spatial variation (Fruin et al., 2014; Kardel et al., 2012b). The few monitoring stations the city of Hanoi currently owns limit the city to a distorted representation of their air pollution by showing only air pollution levels directly close to those stations (Hien et al., 2014). In addition, several construction projects throughout the city can impact the PM distribution and have a large impact on the PM exposure of nearby citizens.

Pollution roses showed that the stations of Thanh Cong (97 µg/m³), Hang Dau (85 µg/m³) and Minh Khai Bac Tu Liem (84 µg/m³) experienced the highest average annual PM10 levels in 2017 (Fig. S7 in Appendix). Only the station of Nguyen Van Cu (31 µg/m³) experienced PM10 levels under the Vietnamese average annual standard (50 µg/m³). For PM2.5, the highest average annual levels were measured in the stations of Thanh Cong (75 µg/m³), Hang Dau (61 µg/m³) and Tan Mai (52 µg/m³; Fig. S8 in Appendix). No stations showed average annual PM2.5 levels under the Vietnamese average annual PM2.5 standard (25 µg/m³). During congestion times, pollutant levels locally increased rapidly throughout important streets (Son and Van Sy, 2008).

4. Discussion

4.1. PM deposition capacity of plants

4.1.1. PM deposition capacity order

This study confirms the hypothesis that plant species have different PM accumulation capacities that depend on their leaf characteristics. When compared with literature, the observed SIRM range was very wide (i.e. the SIRM ranged from 4±1 µA to 337±118 µA) and had particulary high maxima per species (see Table S2 in Appendix; Dzierzanowski et al., 2011; Kardel et al., 2013; Mitchell et al., 2010; Rai and Chutia, 2016). The wide SIRM ranges and high maxima can be explained by the large traffic volumes, the large number of sampled species and corresponding variation in the PM accumulation capacities.

Based on the PM accumulation capacity, our results concurred only partly with results found in literature. For example, our results concurred with those of Rai and Chutia (2016) who also found a high accumulation capacity for the genus *Bougainvillea* and a low accumulation capacity for the genus *Cassia* and the species *B. variegata*. In contrast, the species *Hibiscus rosa-sinensis* had a very high PM acummulation capacity in their research. Our results are also partly in agreement with those of Shrivastava et al. (2007), as *Bambusa sp., B. variegata* and the genus *Cassia* accumulated low amounts of PM, while the species *Thevetia peruviana* and *Alstonia scholaris*, and the genera *Bougainvillea* and *Nerium* accumulated high amounts. In contrast, the genus *Acacia* had a high PM accumulation capacity in our study. It should be noted that for some genera (e.g. *Ficus and Acacia*), the different studies tested different species and these species showed different PM accumulation capacities, which suggest that there is a large variation in the PM accumulation capacity within one genus. Our study showed that the differences in PM accumulation capacity between *Ficus benjamina*, *Ficus pumila* and *Ficus religiosa* genus were small and only *Ficus annulata* seemed to accumulate significantly more PM.

Two reasons might explain the differences in the PM accumulation capacities of genera found between our study and the other two. First, while we used the SIRMa as a proxy for PM accumulation in leaves, Rai and Chutia (2016) used the SIRMw and Shrivastava et al. (2007) used dust capture. Second, plants have species-specific charasteristics that lead to variation within a plant genus (Mitchell et al., 2010; Rai and Chutia, 2016; Shrivastava et al., 2007). For future research, it is important to keep in mind that different measurement techniques might measure different aspects of PM (e.g. PM with different size distributions). Furthermore, factors that determine the LAI of a plant (age, vegetation density, management, canopy size) could strongly influence the total PM accumulation and dispersal capacities of a plant (Janhäll, 2015; Shrivastava et al., 2007).

4.1.2. High PM depositing plant species

The PM accumulation capacity of plants in Hanoi varied significantly among species. Here, we present the top four species from our study that can be used for bioremediation in Hanoi (and other tropical cities with similar climatologic conditions). *Muntingia calabura* was the plant species with the highest PM accumulation capacity. Its leaves are medium sized (14±1 cm^2) and relatively hydrophobic (the adaxial and abaxial DCA were 82±10° and 115±4°, respectively). The high PM accumulation capacity could be explained by its very hairy and sticky leaves (Kardel et al., 2011; Mitchell et al., 2010; Petroff et al., 2008). The tree is ideal to plant in tropical cities for green infrastructure because it grows fast in poor soils and stressful conditions. It is also well-known by local people due to its traditional, practical and medical usage possibilities, while the fruit could be used for biofuel (Ravishankar et al., 2017; Thangadurai et al., 2014). *Muntingia calabura* can spread quickly with the help of birds and bats eating the fruits, thereby enhancing overall biodiversity in the city (Bawa and Webb, 1983; Bayer et al., 1998; Fleming et al., 1985; Kaneda et al., 1991; Laura et al., 1994; Ramirez-Pulido et al., 1993; Ruiz et al., 1997; Webb, 1984). Planted on a city scale, a significant reduction of PM can be expected due to the fact that it does not become too high, which is a requirement to ensure sufficient air dispersal. The tree's white flowers have a certain aesthetic effect and its widespread distribution in tropical regions over the world makes it an excellent candidate species in other cities for bio-remediation of the air.

Chukrasia tabularis, the species with respectively the second highest PM accumulation capacity, is a pioneering tree native to East and South-East Asia, where it is highly valued for its texture. The tree has several practical and medicinal usages, and can grow up to 30 m in stressful conditions (Barstow, 2017; Nagalakshmi et al., 2001). Its big leaves (44±8 cm long) have a low SLA (108±3 cm^2 g^{-1}), a hydrophilic leaf surface (the adaxial and abaxial DCA were 61±4° and 70±6°, respectively), a high abaxial stomatal density (30421±2678 cm^{-2}) and a surprisingly smooth surface for a high PM accumulating species (Beckett et al., 1998).

The species with the third highest PM accumulation capacity is *N. oleander*, a shrub with medium sized (14±1 cm^2), hairy, thick, lanceolate-shaped and waxy leaves with a hydrophilic leaf surface (the adaxial and abaxial DCA were 76±3° and 92±2°, respectively) and a low SLA (79±11 cm^2 g^{-1}). Previously, *N. oleander* has also been shown to be a good candidate for biomonitoring of air pollution (Espinosa and Oliva, 2006; Mingorance and Oliva, 2006; Rai, 2016b).

Another species, *S. chinensis*, is a 20 m tall evergreen tree of the Cupressaceae family that showed to be the fourth highest PM accumulating plant species. The tree has distinctive needle-like leaves and is suggested to reduce PM more than broadleaf species (Zhang et al., 2017). Wu et al. (2018) also recognized *S. chinensis* as an efficient PM reducer, especially for PM2.5.

4.2. Leaf characteristics leading to efficient PM deposition

In general, we found that plants with a lower SLA, a more hydrophilic leaf surface and higher (abaxial) stomatal densities had a higher PM accumulating capacity. We highlight that these are correlations only, making it impossible to determine if these plant accumulate more PM because of an adaptive response to survive high atmospheric PM concentrations or as an evolutionary neutral side effect.

The hierarchical cluster analysis of the plant species suggested that the sampled plant species can be divided in two groups based on their SIRM and leaf characteristics. Leaves from plants in group one had a significantly lower SIRM than those in group two and were significantly more hydrophobic on the adaxial and abaxial side. Such a positive correlation between the hydrophilicity of a leaf and its PM accumulation was also described in other studies (Faini et al., 1999; Kardel et al., 2012a). The hydrophilicity range of the leaves (i.e. DCA's ranging from 40° to 140°) also covered all possible hydrophilicity levels found in literature (Aryal and Neuner, 2010; Kardel et al., 2012a; Rosado and Holder, 2013). Because most sampled species were hydrophilic (i.e. had a contact angle < 110°), we assume that the sampled species have low numbers of microstructures given that it decreases their leaf roughness and water repellence (Aryal and Neuner, 2010; Rosado and Holder, 2013). Previous findings also show that that extreme environmental conditions, such as prolonged and heavy rainfalls or elevated pollution rates, are unfavorable for the hydrophobic wax layers of evergreen plant species. Because of this unfavourable effect, wax layers in evergreen plants are almost absent (Goldsmith et al., 2017; Neinhuis and Barthlott, 1997).

Plants in group two had leaves with a significantly higher mean abaxial stomatal density suggesting that leaves experiencing higher PM pollution respond by having a higher stomatal density and smaller stomata (Balasooriya et al., 2009; Kardel et al., 2013). Probably, this is because PM can block stomata. The specific leaf area of plants in group two was also significantly lower than those in group one suggesting that leaves with a lower SLA accumulate more PM (Kardel et al., 2013; Poorter et al., 2009; Shafiq et al., 2009; Verma and Singh, 2006). A reason could be that leaves which accumulate more PM are affected by the PM levels they experience, as leaves might respond to pollution by having smaller leaf areas or masses leading to lower SLA's. Small leaf areas, in turn, were related to higher PM accumulation (Weerakkody et al., 2018).

Results of the linear mixed models also showed that more hydrophilic leaves with lower SLA values accumulated more PM. In addition, a positive correlation was found between the adaxial and abaxial DCA. Plants invest in the same chemical and structural components of their abaxial and adaxial leaf surface in response to the requirements of their environment or specific species characteristics. Yet, the adaxial and abaxial side of leaves were found to have different structures and compositions (e.g. trichomes and trichome densities) in response to their needs (Fernandez et al., 2014). Because a negative correlation was found between the abaxial stomatal density and the SLA, we conclude that an increased PM accumulation and exposure to high levels of air pollution alter both abaxial stomatal density and SLA.

When designing green infrastructure of cities, it is advisable to select plants based on their PM accumulation capacity, as this reduces air pollution. However, selecting specific plants alone will not be efficient if they are planted at the wrong places. One must take care to the design of green infrastructure plantings in order to allow for sufficient air dispersal depending on the roads requirements (Janhäll, 2015). For example, wide promenades with lower building heights on the side could be highly efficient in reducing PM concentrations when combined with shrubs or relatively small trees that provide shade, while green infrastructure in living areas with narrow streets and high fences around tall buildings might enhance the problem of insufficient PM dispersal by allowing only little air dispersal. Because using plants for the reduction of PM is no stand-alone goal, the selection of plants for urban development and modern city planning should also be based on the aesthetical, practical (e.g. the urban heat island cooling effect, provisioning of shade, attraction of fauna) and economic (e.g. aesthetic aspects attracts tourist) value of these plants.

4.3. Factors controlling PM concentrations

PM concentrations in Hanoi are mostly influenced by large regional air masses that determine the local climate and weather, the North-East and South-East monsoons in particular (Co et al., 2014; Hai and Oanh, 2013). During the dry season, the dry and cold climate brought by the North-East monsoon leads to a stable athmopshere with limited vertical air dispersion and, in the morning and evening, several temperature inversions (Hien et al., 2002). While the temperatures decline, PM increases and becomes trapped by these temperature inversions (Co et al., 2014; Cohen et al., 2010a; Thanh et al., 2015). Meanwhile, the North-East monsoon brings more PM polluted air from industrial regions (i.e. Quang Ninh and Hai Phong) or neighbouring countries (i.e. China) in the North (Cohen et al., 2010b; Lasko et al., 2018). As a result, PM levels are high from winter to spring and decrease in summer. Hanoi's specific topography (i.e. located in the flat parts of the Red River Delta) can partly explain the episodes of high PM during winter because the topography contributes to the right conditions for fog and rainfall, which can lead to increased occult deposition or reduced dry deposition (the most important process of PM deposition), respectively (Grantz et al., 2003; Mitchell et al., 2010). In fact, fog, low wind speeds and high temperatures are suggested to cause photochemical smog in Hanoi (Hung, 2010).

Elevated PM levels in spring are likely caused by desert dust arriving from Chinese deserts (e.g. Gobi, Taklamakan) and this desert PM can account for 76% of all daily windblown PM (Cohen et al., 2010a; Cohen et al., 2010b; Littmann, 2007). In addition, high PM concentration in dry periods can be caused by burnings or PM resuspension (Kim Oanh et al., 2006; Kristofer et al., 2017). In summer, air arrives from the Equatorial Pacific regions and the Indian Ocean bringing monsoon rains and subsequently decreasing PM levels (Hien et al., 2002; Kim Oanh et al., 2006).

5. Conclusion

This study provides the first data to identify differences in PM accumulation capacity among plants species in Hanoi. Given the high air pollution in Hanoi and its adverse effects on human health, we recommend planting more of the high PM accumulating species we identified for bioremediation. The species with the highest PM accumulating capacity was *M. calabura*, which could be planted next to roadsides in combination with trees such as *C. tabularis*, *S. chinensis* or *P. rubra*. In general, we found that plants with a lower SLA, a more hydrophilic leaf surface and higher (abaxial) stomatal densities had a higher PM accumulating capacity. We suggest that urban architects should consider to use these plants in tropical cities.

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Author Contributions

B.M. and R.S. designed the experiment. B.M. and N.X.H. collected data. N.T.C. determined difficult plant species. B.M. performed all analyses but N.X.H prepared most stomatal samples. B.M. and J.M. wrote the text. All authors contributed to discussions and revisions.

References

Arizona State University, 1987. public.asu.edu, Arizona, America.
Arouri, M., Ben Youssef, A., Nguyen, C., 2017. Does urbanization reduce rural poverty? Evidence from Vietnam. Econ. Model. 60, 253-270.
Aryal, B., Neuner, G., 2010. Leaf wettability decreases along an extreme altitudinal gradient. Oecologia 162, 1-9.
Balasooriya, B.L.W.K., Samson, R., Mbikwa, F., Vitharana, U.W.A., Boeckx, P., Van Meirvenne, M., 2009. Biomonitoring of urban habitat quality by anatomical and chemical leaf characteristics. Environ. Exp. Bot. 65, 386-394.
Barstow, M., 2017. Chukrasia tabularis. The IUCN Red List of Threatened Species 2018: e.T32651A68080787.
Bates, D., Machler, M., Bolker, B.M., Walker, S.C., 2015. Fitting Linear Mixed-Effects Models Using lme4. J. Stat. Softw. 67, 1-48.
Bawa, K.S., Webb, C.J., 1983. Floral Variation and Sexual Differentiation in Muntingia Calabura (Elaeocarpaceae), a Species with Hermaphrodite Flowers. Evolution 37, 1271-1282.
Bayer, C., Chase, M.W., Fay, M.F., 1998. Muntingiaceae, a new family of dicotyledons with malvalean affinities. Taxon 47, 37-42.
Beckett, K.P., Freer-Smith, P.H., Taylor, G., 1998. Urban woodlands: their role in reducing the effects of particulate pollution. Environ. Pollut. 99, 347-360.
Beevers, S.D., Kitwiroon, N., Williams, M.L., Kelly, F.J., Ross Anderson, H., Carslaw, D.C., 2013. Air pollution dispersion models for human exposure predictions in London. J Expo Sci Environ Epidemiol 23, 647-653.
Carslaw, D.C., Ropkins, K., 2012. openair — An R package for air quality data analysis. Environ. Model. Software 27-28, 52-61.
Castanheiro, A., Samson, R., De Wael, K., 2016. Magnetic- and particle-based techniques to investigate metal deposition on urban green. Sci. Total Environ. 571, 594-602.
CENMA, 2008. Pilot Emission Inventory in Hanoi, in: Centre for Environmental and Natural Resources Monitoring and Analysis (Ed.), Hanoi, Vietnam.
Co, H.X., Dung, N.T., Oanh, N.T.K., Hang, N.T., Phuc, N.H., Le, H.A., 2014. Levels and Composition of Ambient Particulate Matter at a Mountainous Rural Site in Northern Vietnam. Aerosol and Air Quality Research 14, 1917-U1178.
Cohen, D.D., Crawford, J., Stelcer, E., Bac, V.T., 2010a. Characterisation and source apportionment of fine particulate sources at Hanoi from 2001 to 2008. Atmos. Environ. 44, 320-328.
Cohen, D.D., Crawford, J., Stelcer, E., Vuong, T.B., 2010b. Long range transport of fine particle windblown soils and coal fired power station emissions into Hanoi between 2001 to 2008. Atmos. Environ. 44, 3761-3769.
Daisey, J.M., Angell, W.J., Apte, M.G., 2003. Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. Indoor Air 13, 53-64.
Dzierzanowski, K., Popek, R., Gawronska, H., Saebo, A., Gawronski, S.W., 2011. Deposition of particulate matter of different size fractions on leaf surfaces and in waxes of urban forest species. Int. J. Phytoremediation 13, 1037-1046.
Espinosa, A.J.F., Oliva, S.R., 2006. The composition and relationships between trace element levels in inhalable atmospheric particles (PM10) and in leaves of Nerium oleander L. and Lantana camara L. Chemosphere 62, 1665-1672.
ESRI, 2011. ArcGIS Desktop, 10 ed. Redlands, CA: Environmental Systems Research Institute.
Evans, M.E., Heller, F., 2003. Environmental Magnetism: Principles and Applications of Enviromagnetics, Int. Geophys. Ser 86, 299.

Fadeyi, M.O., Alkhaja, K., Sulayem, M.B., Abu-Hijleh, B., 2014. Evaluation of indoor environmental quality conditions in elementary schools' classrooms in the United Arab Emirates. Front. Archit. Res. 3, 166-177.
Faini, F., Labbe, C., Coll, J., 1999. Seasonal changes in chemical composition of epicuticular waxes from the leaves of Baccharis linearis. Biochem. Syst. Ecol. 27, 673-679.
Fern, K., Fern, A., Morris, R., 2014. Useful Tropical Plants, Lostwithiel.
Fernandez, V., Sancho-Knapik, D., Guzman, P., Peguero-Pina, J.J., Gil, L., Karabourniotis, G., Khayet, M., Fasseas, C., Heredia-Guerrero, J.A., Heredia, A., Gil-Pelegrin, E., 2014. Wettability, polarity, and water absorption of holm oak leaves: effect of leaf side and age. Plant Physiol. 166, 168-180.
Flanders, P.J., 1994. Collection, measurement, and analysis of airborne magnetic particulates from pollution in the environment (invited). J. Appl. Phys. 75, 5931-5936.
Fleming, T.H., Williams, C.F., Bonaccorso, F.J., Herbst, L.H., 1985. Phenology, Seed Dispersal, and Colonization in Muntingia-Calabura, a Neotropical Pioneer Tree. Am. J. Bot. 72, 383-391.
Forest Inventory And Planning Institute, 2009. Vietnam Forest Trees Second edition ed, Hanoi.
Freer-Smith, P.H., Beckett, K.P., Taylor, G., 2005. Deposition velocities to Sorbus aria, Acer campestre, Populus deltoides X trichocarpa 'Beaupre', Pinus nigra and X Cupressocyparis leylandii for coarse, fine and ultra-fine particles in the urban environment. Environ. Pollut. 133, 157-167.
Fruin, S., Urman, R., Lurmann, F., McConnell, R., Gauderman, J., Rappaport, E., Franklin, M., Gilliland, F.D., Shafer, M., Gorski, P., Avol, E., 2014. Spatial Variation in Particulate Matter Components over a Large Urban Area. Atmos Environ (1994) 83, 211-219.
Goldsmith, G.R., Bentley, L.P., Shenkin, A., Salinas, N., Blonder, B., Martin, R.E., Castro-Ccossco, R., Chambi-Porroa, P., Diaz, S., Enquist, B.J., Asner, G.P., Malhi, Y., 2017. Variation in leaf wettability traits along a tropical montane elevation gradient. New Phytol. 214, 989-1001.
Grantz, D.A., Garner, J.H., Johnson, D.W., 2003. Ecological effects of particulate matter. Environ. Int. 29, 213-239.
GSO, 2017. Statistical Yearbook of Vietnam 2016. Statistical Publishing House, Hanoi.
Hai, C.D., Oanh, N.T.K., 2013. Effects of local, regional meteorology and emission sources on mass and compositions of particulate matter in Hanoi. Atmos. Environ. 78, 105-112.
Hanoi People's Council, 2017. Resolution on a project of strengthening management of vehicles to reduce traffic congestion and environmental pollution in Ha Noi in 2017-2020 period with a vision to 2030 ath the fourth meeting of the 15th municipal People's Council, in: Department of Transport (Ed.), Hanoi, Vietnam.
Hien, P.D., Bac, V.T., Tham, H.C., Nhan, D.D., Vinh, L.D., 2002. Influence of meteorological conditions on PM2.5 and PM2.5−10 concentrations during the monsoon season in Hanoi, Vietnam. Atmos. Environ. 36, 3473-3484.
Hien, P.D., Hangartner, M., Fabian, S., Tan, P.M., 2014. Concentrations of NO2, SO2, and benzene across Hanoi measured by passive diffusion samplers.
Hitchins, J., Morawska, L., Wolff, R., Gilbert, D., 2000. Concentrations of submicrometre particles from vehicle emissions near a major road. Atmos. Environ. 34, 51-59.
Hofman, J., Wuyts, K., Van Wittenberghe, S., Samson, R., 2014. On the temporal variation of leaf magnetic parameters: seasonal accumulation of leaf-deposited and leaf-encapsulated particles of a roadside tree crown. Sci. Total Environ. 493, 766-772.
Huan, H.N., Hai, X.N., Yem, T., 2014. Economic valuation of health impacts of air pollution due to H2S emission from To Lich river, Vietnam. ARPN J. Agric. Biol. Sci. 9, 1-13.
Hung, N.T., 2010. Urban air quality modelling and management in Hanoi, Vietnam, National Environmental Research Institute, Department of Atmospheric Environment. Aarhus University, Denmark, p. 211.

Jagels, R., 1994. Leaf Wettability as a Measure of Air Pollution Effects. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 97-105.
Janhäll, S., 2015. Review on urban vegetation and particle air pollution – Deposition and dispersion. Atmos. Environ. 105, 130-137.
Kaneda, N., Pezzuto, J.M., Soejarto, D.D., Kinghorn, A.D., Farnsworth, N.R., Santisuk, T., Tuchinda, P., Udchachon, J., Reutrakul, V., 1991. Plant anticancer agents, XLVIII. New cytotoxic flavonoids from Muntingia calabura roots. J. Nat. Prod. 54, 196-206.
Kardel, F., Wuyts, K., Babanezhad, M., Wuytack, T., Adriaenssens, S., Samson, R., 2012a. Tree leaf wettability as passive bio-indicator of urban habitat quality. Environ. Exp. Bot. 75, 277-285.
Kardel, F., Wuyts, K., Khavaninzhadeh, A.R., Wuytack, T., Babanezhad, M., Samson, R., 2013. Comparison of leaf saturation isothermal remanent magnetisation (SIRM) with anatomical, morphological and physiological tree leaf characteristics for assessing urban habitat quality. Environ. Pollut. 183, 96-103.
Kardel, F., Wuyts, K., Maher, B.A., Hansard, R., Samson, R., 2011. Leaf saturation isothermal remanent magnetization (SIRM) as a proxy for particulate matter monitoring: Inter-species differences and in-season variation. Atmos. Environ. 45, 5164-5171.
Kardel, F., Wuyts, K., Maher, B.A., Samson, R., 2012b. Intra-urban spatial variation of magnetic particles: Monitoring via leaf saturation isothermal remanent magnetisation (SIRM). Atmos. Environ. 55, 111-120.
Kassambara, A., Mundt, F., 2017. factoextra: Extract and Visualize the Results of Multivariate Data Analyses.
Kim Oanh, N.T., Upadhyay, N., Zhuang, Y.H., Hao, Z.P., Murthy, D.V.S., Lestari, P., Villarin, J.T., Chengchua, K., Co, H.X., Dung, N.T., 2006. Particulate air pollution in six Asian cities: Spatial and temporal distributions, and associated sources. Atmos. Environ. 40, 3367-3380.
Kristofer, L., Krishna, P.V., Vinh, T.T., Evan, E., Thanh, T.N.N., Hung, Q.B., Christopher, J., 2017. Satellites may underestimate rice residue and associated burning emissions in Vietnam. Environmental Research Letters 12, 085006.
Lasko, K., Vadrevu, K.P., Nguyen, T.T.N., 2018. Analysis of air pollution over Hanoi, Vietnam using multi-satellite and MERRA reanalysis datasets. PLOS ONE 13, e0196629.
Laura, V.A., Dealvarenga, A.A., Arrigoni, M.D., 1994. Effects of Growth-Regulators, Temperature, Light, Storage and Other Factors on the Muntingia-Calabura L Seed-Germination. Seed Sci. Technol. 22, 573-579.
Lê, S., Josse, J., Husson, F., 2008. FactoMineR: AnRPackage for Multivariate Analysis. J. Stat. Softw. 25, 1-18.
Leducq, D., Scarwell, H.J., 2018. The new Hanoi: Opportunities and challenges for future urban development. Cities 72, 70-81.
Lehndorff, E., Urbat, M., Schwark, L., 2006. Accumulation histories of magnetic particles on pine needles as function of air quality. Atmos. Environ. 40, 7082-7096.
Leonard, R.J., McArthur, C., Hochuli, D.F., 2016. Particulate matter deposition on roadside plants and the importance of leaf trait combinations. Urban For. Urban Green. 20, 249-253.
Littmann, T., 2007. Dust storm frequency in Asia: Climatic control and variability. International Journal of Climatology 11, 393-412.
Luo, P., Mu, D., Xue, H., Ngo-Duc, T., Dang-Dinh, K., Takara, K., Nover, D., Schladow, G., 2018. Flood inundation assessment for the Hanoi Central Area, Vietnam under historical and extreme rainfall conditions. Scientific Reports 8, 12623.
Maher, B.A., Moore, C., Matzka, J., 2008. Spatial variation in vehicle-derived metal pollution identified by magnetic and elemental analysis of roadside tree leaves. Atmos. Environ. 42, 364-373.
Matzka, J., Maher, B.A., 1999. Magnetic biomonitoring of roadside tree leaves: identification of spatial and temporal variations in vehicle-derived particulates. Atmos. Environ. 33, 4565-4569.

McDonald, A.G., Bealey, W.J., Fowler, D., Dragosits, U., Skiba, U., Smith, R.I., Donovan, R.G., Brett, H.E., Hewitt, C.N., Nemitz, E., 2007. Quantifying the effect of urban tree planting on concentrations and depositions of PM10 in two UK conurbations. Atmos. Environ. 41, 8455-8467.
Mingorance, M.D., Oliva, S.R., 2006. Heavy metals content in N. oleander leaves as urban pollution assessment. Environ. Monit. Assess. 119, 57-68.
Missouri Botanical Garden, 2002. Missouri Botanical Garden Plant Finder.
Missouri Botanical Garden, St. Louis, M., Harvard University Herbaria, Cambridge, M., 2015. Flora of China.
Mitchell, R., Maher, B.A., Kinnersley, R., 2010. Rates of particulate pollution deposition onto leaf surfaces: temporal and inter-species magnetic analyses. Environ. Pollut. 158, 1472-1478.
Mo, L., Ma, Z., Xu, Y., Sun, F., Lun, X., Liu, X., Chen, J., Yu, X., 2015. Assessing the Capacity of Plant Species to Accumulate Particulate Matter in Beijing, China. PLoS One 10, e0140664.
MOIT, 2016. Decision 428-QD-TTg of the Prime Minsiter of 18 March 2016 National Master Power Development Plan for period of 2011-2020 with outlook to 2030 revised (2016), in: Ministry of Industry and Trade (Ed.), Hanoi, Vietnam.
MONRE, 2008. Annual report on National Air Environmental state of 2007, in: Ministry of Natural Resource and Environment (Ed.), Hanoi, Vietnam.
Morris, W.A., Versteeg, J.K., Bryant, D.W., Legzdins, A.E., Mccarry, B.E., Marvin, C.H., 1995. Preliminary Comparisons between Mutagenicity and Magnetic-Susceptibility of Respirable Airborne Particulate. Atmos. Environ. 29, 3441-3450.
Muhammad, S., Wuyts, K., Samson, R., 2019. Atmospheric net particle accumulation on 96 plant species with contrasting morphological and anatomical leaf characteristics in a common garden experiment. Atmos. Environ. 202, 328-344.
Muxworthy, A.R., Matzka, M., Davila, A.F., Petersen, N., 2003. Magnetic signature of daily sampled urban atmospheric particles. Atmos. Environ. 37, 4163-4169.
Nagalakshmi, M.A., Thangadurai, D., Rao, D.M., Pullaiah, T., 2001. Phytochemical and antimicrobial study of Chukrasia tabularis leaves. Fitoterapia 72, 62-64.
National Parks Board Singapore, 2013. NParks: Flora & Fauna Web, Singapore.
Neinhuis, C., Barthlott, W., 1997. Characterization and distribution of water-repellent, self-cleaning plant surfaces. Ann. Bot. 79, 667-677.
Perini, K., Ottele, M., Giulini, S., Magliocco, A., Roccotiello, E., 2017. Quantification of fine dust deposition on different plant species in a vertical greening system. Ecol. Eng. 100, 268-276.
Petroff, A., Mailliat, A., Amielh, M., Anselmet, F., 2008. Aerosol dry deposition on vegetative canopies. Part I: Review of present knowledge. Atmos. Environ. 42, 3625-3653.
Poorter, H., Niinemets, U., Poorter, L., Wright, I.J., Villar, R., 2009. Causes and consequences of variation in leaf mass per area (LMA): a meta-analysis. New Phytol. 182, 565-588.
Pope, C.A., 3rd, 1996. Adverse health effects of air pollutants in a nonsmoking population. Toxicology 111, 149-155.
Pope, C.A., 3rd, Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., Thurston, G.D., 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 287, 1132-1141.
Pope, C.A., 3rd, Ezzati, M., Dockery, D.W., 2015. Tradeoffs between income, air pollution and life expectancy: Brief report on the US experience, 1980-2000. Environ. Res. 142, 591-593.
Popek, R., Gawronska, H., Wrochna, M., Gawronski, S.W., Saebo, A., 2013. Particulate matter on foliage of 13 woody species: deposition on surfaces and phytostabilisation in waxes--a 3-year study. Int. J. Phytoremediation 15, 245-256.
Power, A.L., Worsley, A.T., Booth, C., 2009. Magneto-biomonitoring of intra-urban spatial variations of particulate matter using tree leaves. Environ. Geochem. Health 31, 315-325.

Prajapati, S.K., Tripathi, B.D., 2008. Seasonal variation of leaf dust accumulation and pigment content in plant species exposed to urban particulates pollution. J Environ Qual 37, 865-870.
R Core Team, 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
Rai, P.K., 2016a. Biomonitoring of Particulate Pollution Using Magnetic Properties of Ficus bengalensis, Biomagnetic Monitoring of Particulate Matter. Elsevier, pp. 137-153.
Rai, P.K., 2016b. Impacts of particulate matter pollution on plants: Implications for environmental biomonitoring. Ecotoxicol. Environ. Saf. 129, 120-136.
Rai, P.K., Chutia, B.M., 2016. Particulate matter bio-monitoring through magnetic properties of an Indo-Burma hotspot region. Chem. Ecol. 32, 550-574.
Ramirez-Pulido, J., Armella, M.A., Castro-Campillo, A., 1993. Reproductive Patterns of Three Neotropical Bats (Chiroptera: Phyllostomidae) in Guerrero, Mexico. Soutwest. Nat. 38, 24-29.
Ravishankar, B.V., Vikas, S.B., Akarshi, M.R., Rangaswamy, B.E., Sreenivas, R.B., 2017. Production of Bio-ethanol from an Underexploited Fruit of Muntingia calabura and Studying Performance and Emission Characteristics of Single Cylinder CI Engine. Bioprocess Eng. 1, 1-6.
Richter, C., Acton, G., Endris, C., Radsted, M., 2007. Handbook For Shipboard Paleomagnetists.
Rosado, B.H.P., Holder, C.D., 2013. The significance of leaf water repellency in ecohydrological research: a review. Ecohydrology 6, 150-161.
Ruiz, A., Santos, M., Soriano, P.J., Cavelier, J., Cadena, A., 1997. Relaciones Mutualisticas entre el Murcielago Glossophaga longirostris y las Cactaceas Columnares en la Zona Arida de La Tatacoa, Colombia1. Biotropica 29, 469-479.
Sanders, P., Zuidgeest, M., Geurs, K., 2015. Liveable streets in Hanoi: A principal component analysis. Habitat Int. 49, 547-558.
Schneider, C.A., Rasband, W.S., Eliceiri, K.W., 2012. NIH Image to ImageJ: 25 years of image analysis. Nat. Methods 9, 671-675.
Shafiq, M., Iqbal, M.Z., Athar, M., Qayyum, M., 2009. Effect of auto exhaust emission on the phenology of Cassia siamea and Peltophorum pterocarpum growing in different areas of Karachi. Afr. J. Biotechnol. 8, 2469-2475.
Shrivastava, N., Sharma, C., Bhatnagar, S., 2007. Phytoremediation of particulate matter from ambient environment trough dust capturing plant species. Ministry of Environment & Forests, Delhi, p. 123.
Son, D., Van Sy, L., 2008. Air Quality Report, in: Ministry of Natural Resources and Environment (Ed.), Hanoi, Vietnam.
Suzuki, R., Shimodaira, H., 2015. pvclust: Hierarchical Clustering with P-Values via Multiscale Bootstrap Resampling, R package version 2.0-0 ed.
Szonyi, M., Sagnotti, L., Hirt, A.M., 2008. A refined biomonitoring study of airborne particulate matter pollution in Rome, with magnetic measurements on *Quercus Ilex* tree leaves. Geophys. J. Int. 173, 127-141.
Tallis, M., Amorim, J., Calfapietra, C., Freer-Smith, P., Grimmond, S., Kotthaus, S., Lemes de Oliveira, A., Toscano, P., 2015. The impacts of green infrastructure on air quality and temperature, Handbook on Green Infrastructure: Planning, design and implementation, pp. 30-49.
Thangadurai, D., Bhat, S.V., Sangeetha, J., Mundaragi, A.C., 2014. Production of bioethanol from Muntingia calabura fruits using Saccharomyces cervisiae and Schizosaccharomyces pombe. Faculty of Agriculture, University of Ruhuna, Kamburupitiya, pp. 343-345.
Thanh, T.N.N., Hung, Q.B., Ha, V.P., Hung, V.L., Chuc, D.M., Hai, N.P., Ha, T.L., Thuy, T.N., 2015. Particulate matter concentration mapping from MODIS satellite data: a Vietnamese case study. Environmental Research Letters 10, 095016.
Tomašević, M., Institute of Physics, Belgrade (Serbia), Aničić, M., Institute of Physics, Belgrade (Serbia), 2010. Urban tree leaves: trace element content and deposited particles. v. 8.

Vercauteren, J., Matheeussen, C., Wauters, E., Roekens, E., van Grieken, R., Krata, A., Makarovska, Y., Maenhaut, W., Chi, X.G., Geypens, B., 2011. Chemkar PM10: An extensive look at the local differences in chemical composition of PM10 in Flanders, Belgium. Atmos. Environ. 45, 108-116.
Verma, A., Singh, S.N., 2006. Biochemical and ultrastructural changes in plant foliage exposed to auto-pollution. Environ. Monit. Assess. 120, 585-602.
Volk, H.E., Lurmann, F., Penfold, B., Hertz-Picciotto, I., McConnell, R., 2013. Traffic-related air pollution, particulate matter, and autism. JAMA Psychiatry 70, 71-77.
Webb, C.J., 1984. Flower and Fruit Movements in Muntingia-Calabura - a Possible Mechanism for Avoidance of Pollinator-Disperser Interference. Biotropica 16, 37-42.
Weerakkody, U., Dover, J.W., Mitchell, P., Reiling, K., 2017. Particulate matter pollution capture by leaves of seventeen living wall species with special reference to rail-traffic at a metropolitan station. Urban For. Urban Green. 27, 173-186.
Weerakkody, U., Dover, J.W., Mitchell, P., Reiling, K., 2018. Evaluating the impact of individual leaf traits on atmospheric particulate matter accumulation using natural and synthetic leaves. Urban For. Urban Green. 30, 98-107.
Weijers, E.P., Khlystov, A.Y., Kos, G.P.A., Erisman, J.W., 2004. Variability of particulate matter concentrations along roads and motorways determined by a moving measurement unit. Atmos. Environ. 38, 2993-3002.
Weyens, N., Thijs, S., Popek, R., Witters, N., Przybysz, A., Espenshade, J., Gawronska, H., Vangronsveld, J., Gawronski, S.W., 2015. The Role of Plant-Microbe Interactions and Their Exploitation for Phytoremediation of Air Pollutants. Int J Mol Sci 16, 25576-25604.
WHO, 2006. Air Quality Guidelines, Global Update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide, p. 484.
WHO, 2018. WHO Global Urban Ambient Air Pollution Database (update 2016).
Wu, Y., Ma, W., Liu, J., Zhu, L., Cong, L., Zhai, J., Wang, Y., Zhang, Z., 2018. Sabina chinensis and Liriodendron chinense improve air quality in Beijing, China. PLoS One 13, e0189640.
Zhang, Z., Liu, J., Wu, Y., Yan, G., Zhu, L., Yu, X., 2017. Multi-scale comparison of the fine particle removal capacity of urban forests and wetlands. Sci Rep 7, 46214.
Zhu, Y.F., Hinds, W.C., Kim, S., Shen, S., Sioutas, C., 2002. Study of ultrafine particles near a major highway with heavy-duty diesel traffic. Atmos. Environ. 36, 4323-4335.
Zuur, A.F., Ieno, E.N., 2016. A protocol for conducting and presenting results of regression-type analyses. Methods Ecol. Evol. 7, 636-645.

FIGURES

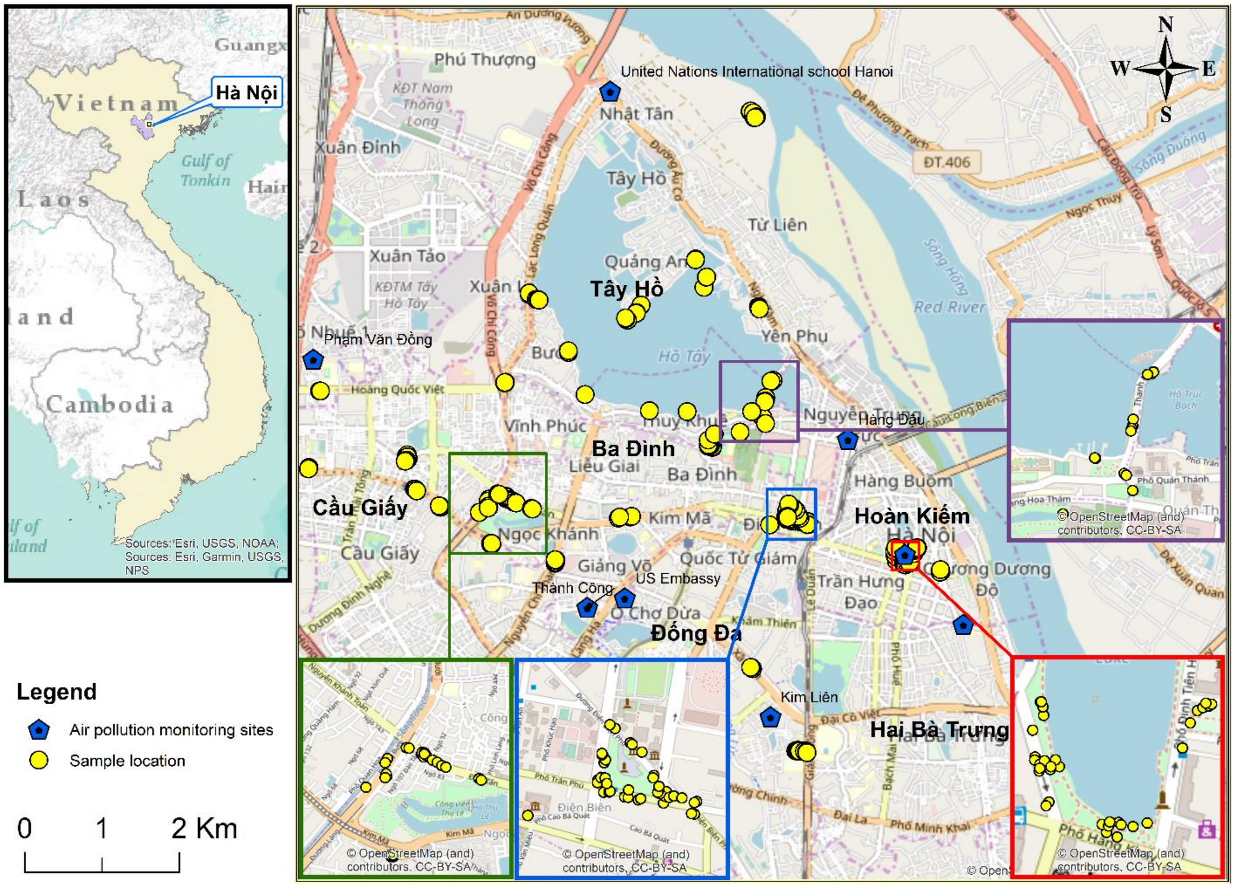
Figure 1: Vietnam with indication of Hanoi (left) and the sampled plant individuals (right). Yellow circles indicate sample locations. Blue hexagons indicate permanent air pollution measurement stations. District names are printed in bold.

Figure 2: The PM accumulation capacity of plant species in Hanoi according to SIRM values normalized by leaf area. Error bars indicate standard errors. Red dots indicate mean values.

Figure 3: Hierarchical cluster analysis of the sampled plant species. Blue rectangles indicate a difference in leaf characteristics with a p-value < 0.05. Group one are the species in the rectangle on the left, group two are the species in the rectangle on the right. Green numbers indicate the bootstrap probability (BP) multiplied by 100. Red numbers indicate the approximately unbiased p-value (AU) multiplied by 100 and is a number that limits the bias of the BP value.

Figure 4: Time series of PM2.5 (µg/m^3; red), PM10 (µg/m^3; blue), humidity (%; green), temperature (°C; purple) and wind speed (m/s; orange) data of 2017 averaged over days. The data is provided by data aggregator AirVisual (https://www.airvisual.com/vietnam/hanoi) and originates from ten governmental air quality measurement stations and the US embassy in Hanoi. Smooth lines are indicated for each variable in their respective colour. Shaded areas around the smooth lines indicate 95% confidence intervals. The dashed blue lines indicate our sampling period from mid-August to the beginning of September.

Figure 1



Hà Nội
Vietnam
Laos
Cambodia
Gulf of Tonkin
Sources: Esri, USGS, NOAA; Sources: Esri, Garmin, USGS, NPS
Legend
Air pollution monitoring sites
Sample location
0 1 2 Km
United Nations International school Hanoi
Tây Hồ
Ba Đình
Cầu Giấy
Hoàn Kiếm
Đống Đa
Hai Bà Trưng
Phạm Văn Đồng
Hàng Đậu
US Embassy
Thành Công
Kim Liên
Red River
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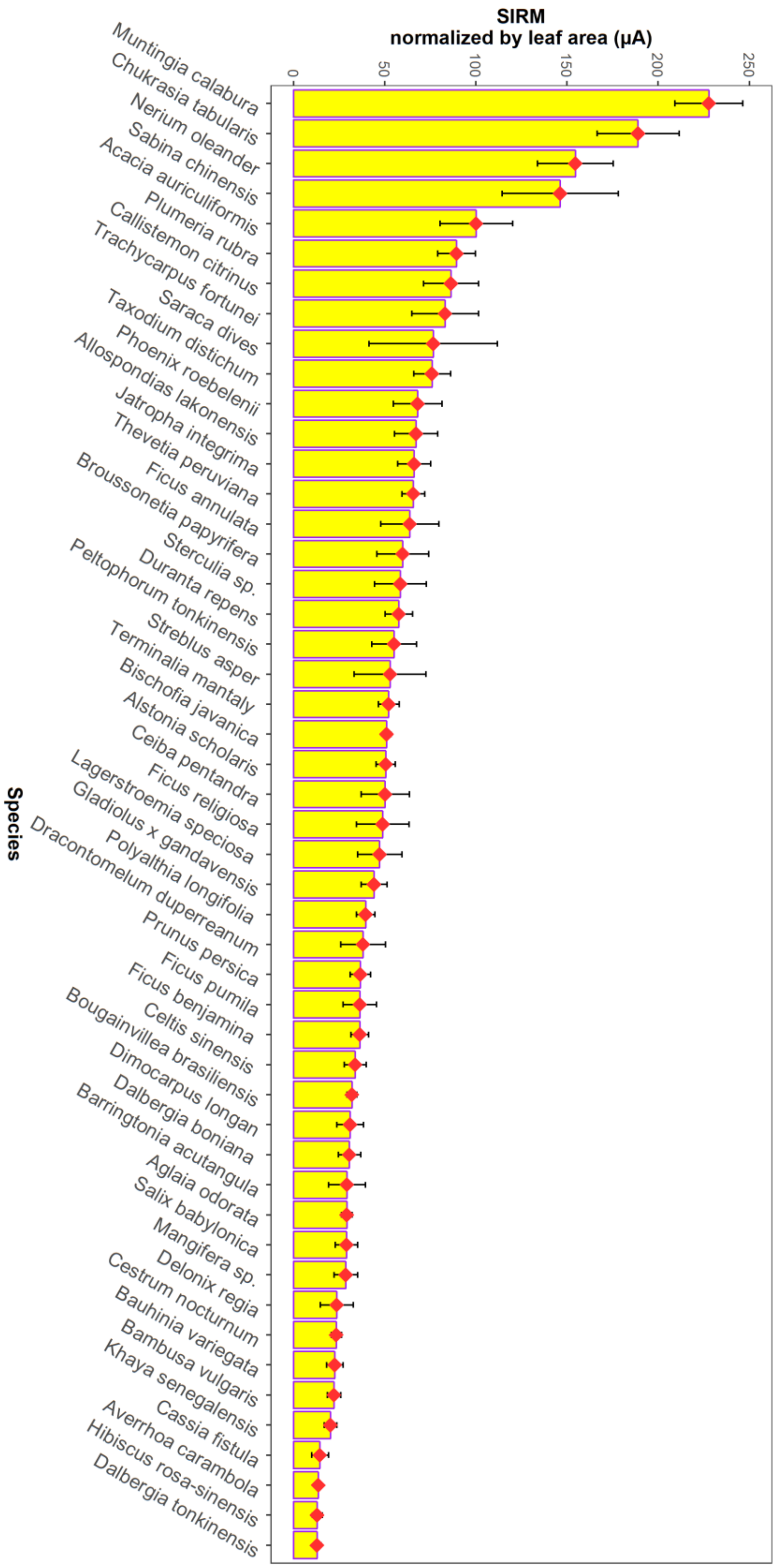
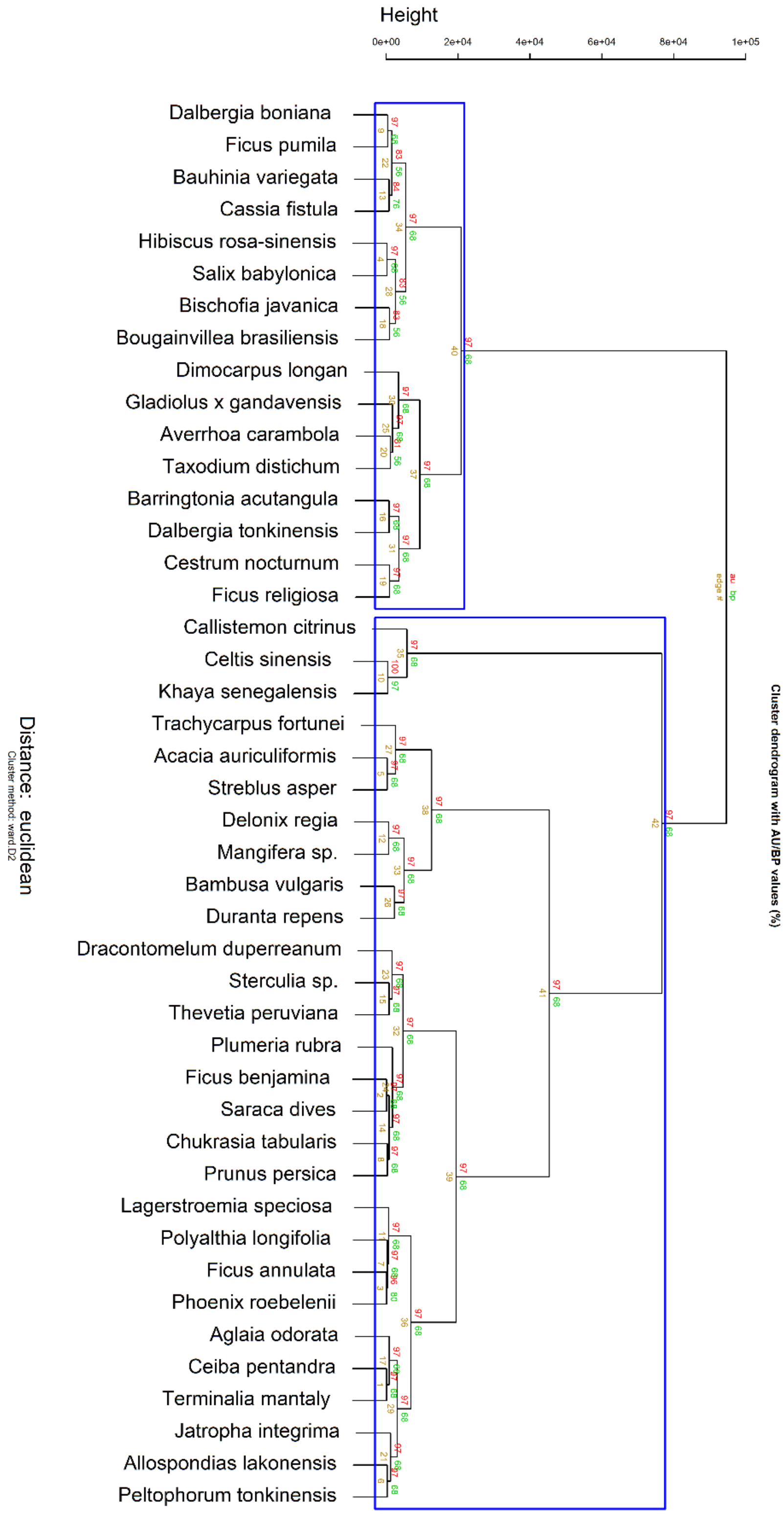
Figure 2



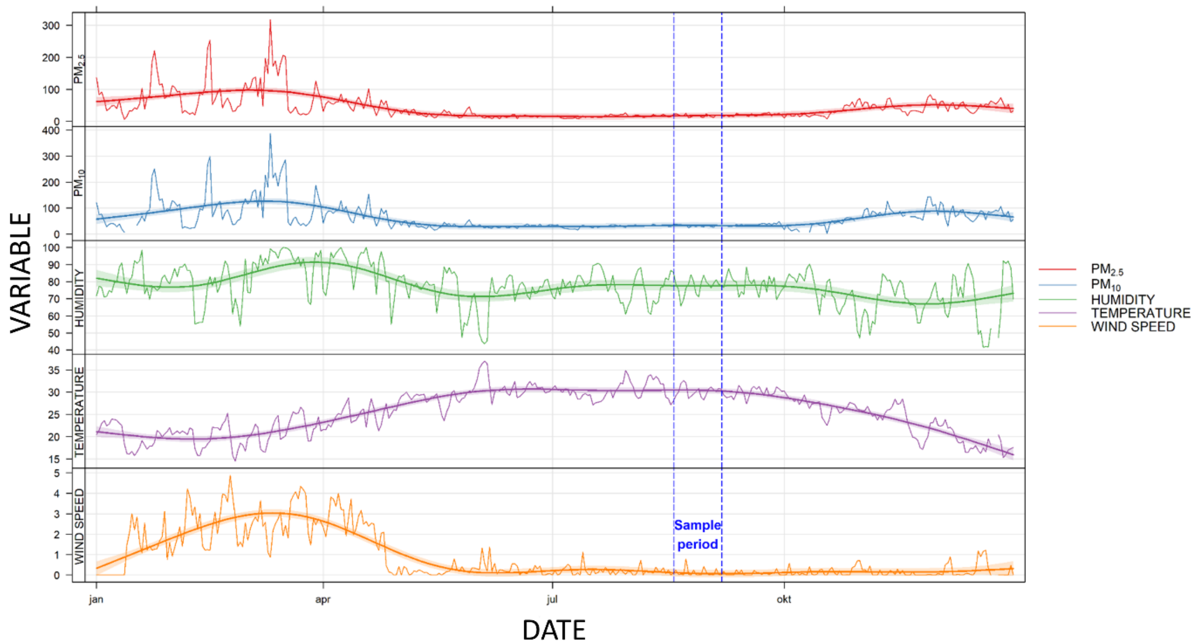
SIRM
normalized by leaf area (μA)
0
50
100
150
200
250
Species
Muntingia calabura
Chukrasia tabularis
Nerium oleander
Sabina chinensis
Acacia auriculiformis
Plumeria rubra
Callistemon citrinus
Trachycarpus fortunei
Saraca dives
Taxodium distichum
Phoenix roebelenii
Allospondias lakonensis
Jatropha integrima
Thevetia peruviana
Ficus annulata
Broussonetia papyrifera
Sterculia sp.
Duranta repens
Peltophorum tonkinensis
Streblus asper
Terminalia mantaly
Bischofia javanica
Alstonia scholaris
Ceiba pentandra
Ficus religiosa
Lagerstroemia speciosa
Gladiolus x gandavensis
Polyalthia longifolia
Dracontomelum duperreanum
Prunus persica
Ficus pumila
Ficus benjamina
Celtis sinensis
Bougainvillea brasiliensis
Dimocarpus longan
Dalbergia boniana
Barringtonia acutangula
Aglaia odorata
Salix babylonica
Mangifera sp.
Delonix regia
Cestrum nocturnum
Bauhinia variegata
Bambusa vulgaris
Khaya senegalensis
Cassia fistula
Averrhoa carambola
Hibiscus rosa-sinensis
Dalbergia tonkinensis

Figure 3



Height
0e+00
2e+04
4e+04
6e+04
8e+04
1e+05
Dalbergia boniana
Ficus pumila
Bauhinia variegata
Cassia fistula
Hibiscus rosa-sinensis
Salix babylonica
Bischofia javanica
Bougainvillea brasiliensis
Dimocarpus longan
Gladiolus x gandavensis
Averrhoa carambola
Taxodium distichum
Barringtonia acutangula
Dalbergia tonkinensis
Cestrum nocturnum
Ficus religiosa
Callistemon citrinus
Celtis sinensis
Khaya senegalensis
Trachycarpus fortunei
Acacia auriculiformis
Streblus asper
Delonix regia
Mangifera sp.
Bambusa vulgaris
Duranta repens
Dracontomelum duperreanum
Sterculia sp.
Thevetia peruviana
Plumeria rubra
Ficus benjamina
Saraca dives
Chukrasia tabularis
Prunus persica
Lagerstroemia speciosa
Polyalthia longifolia
Ficus annulata
Phoenix roebelenii
Aglaia odorata
Ceiba pentandra
Terminalia mantaly
Jatropha integrima
Allospondias lakonensis
Peltophorum tonkinensis
Distance: euclidean
Cluster method: ward.D2
Cluster dendrogram with AU/BP values (%)
au bp
edge #

Figure 4



VARIABLE
$PM_{2.5}$
PM_{10}
HUMIDITY
TEMPERATURE
WIND SPEED
Sample period
jan
apr
jul
okt
DATE

Appendix

FIGURES

Figure S1: Photographs of 20x magnified stomatal imprints on the abaxial leaf sides of *Khaya senegalensis* (A) and *Hibiscus rosa-sinensis* (B)

Figure S2: Photograph of a distilled water droplet, expressing the possibility to measure the droplet contact angle (DCA) to determine the leaf surface wettability for a non-wettable abaxial leaf surface (A) and a highly wettable adaxial leaf surface (B).

Figure S3: Linear relationship between the SIRM normalized by leaf area and SIRM normalized by leaf mass. The grey band around the trend line indicates the 95% confidence interval.

Figure S4: Vietnam with indication of Hanoi (left) and the plant groups (right). Green circles indicate plant group locations. The same group number was assigned to all individuals from which the radius of 100 meters from each individual crossed each other's radius. District names are printed in bold.

Figure S5: Principal component analyses showing the contributions of the leaf characteristics; leaf area (LA), abaxial stomatal density (SDB), adaxial DCA (DCAD), abaxial DCA (DCAB) and the specific leaf area (SLA) to the PCA. These are the leaf characteristics potentially influencing PM deposition.

Figure S6: Time variation plot of the diurnal pollution pattern for 2017. Trend lines in green, red, cyan and purple show mean hourly PM10 (μg/m³), PM2.5 (μg/m³), humidity (%) and temperature (°C) values, respectively. The shaded areas around the trend lines indicate 95% confidence intervals.

Figure S7: Pollution rose per governmental station and the US embassy in Hanoi showing data of PM10 (μg/m³) in relation to the wind speed (m/s) and wind direction for 2017. Classification is based on the classification of PM concentrations in the Air Quality Index (AQI).

Figure S8: Pollution rose per governmental station and the US embassy in Hanoi showing data of PM2.5 (μg/m³) in relation to the wind speed (m/s) and wind direction for 2017. Classification is based on the classification of PM concentrations in the Air Quality Index (AQI).

Figure S1

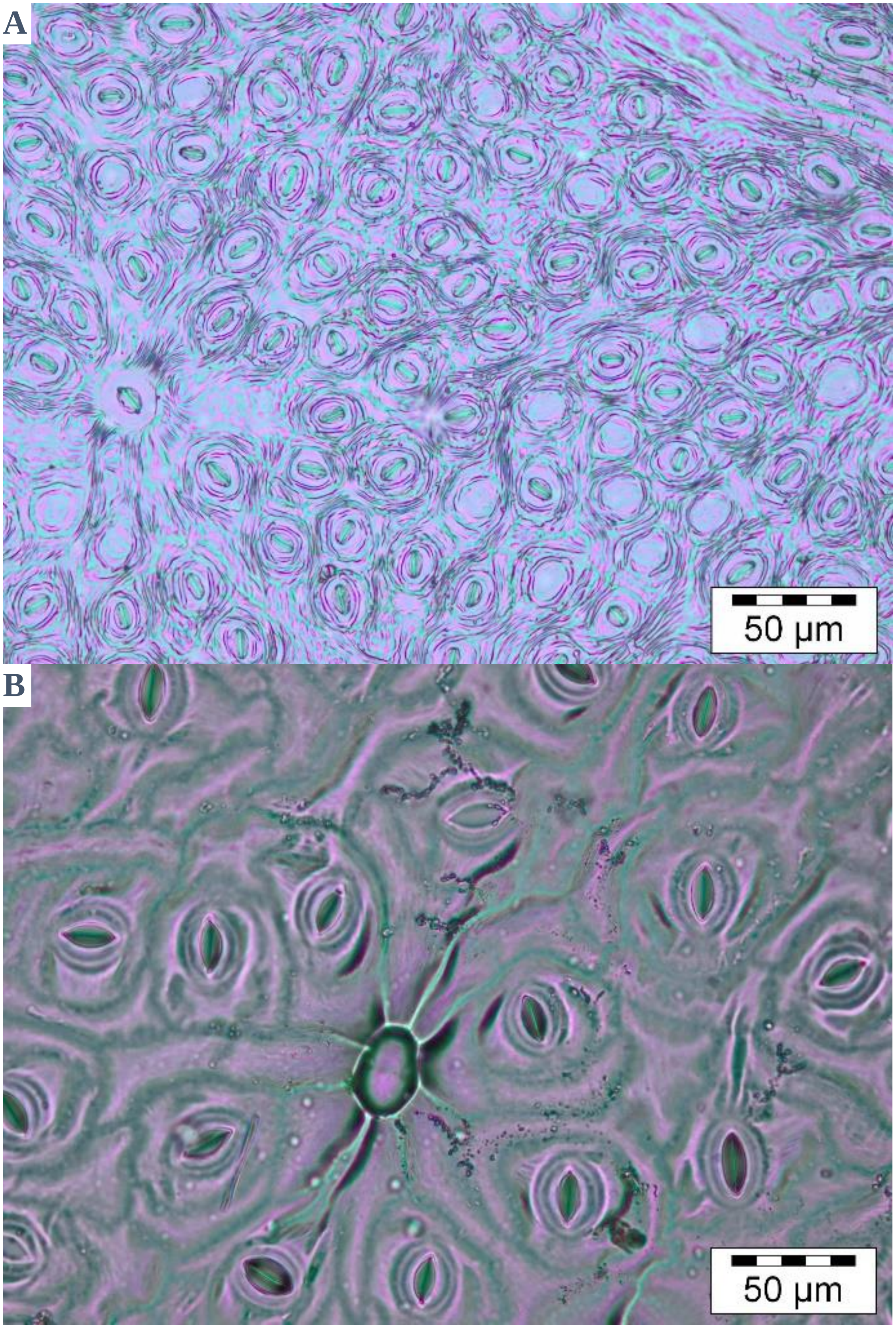


Figure S2

Figure S3

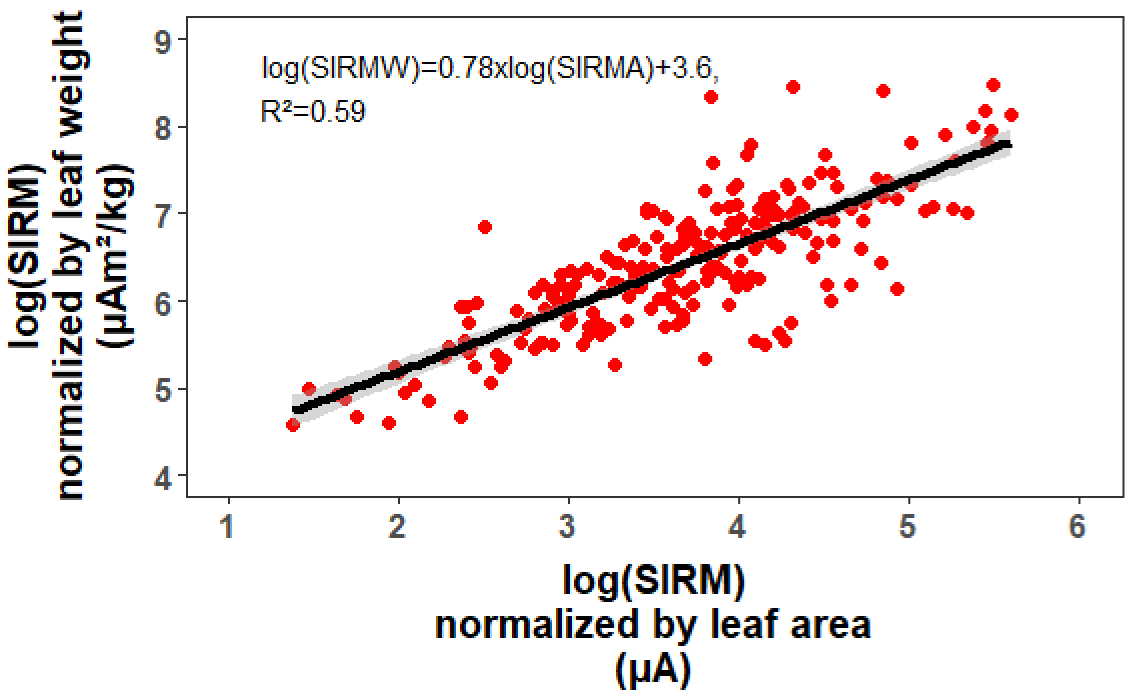
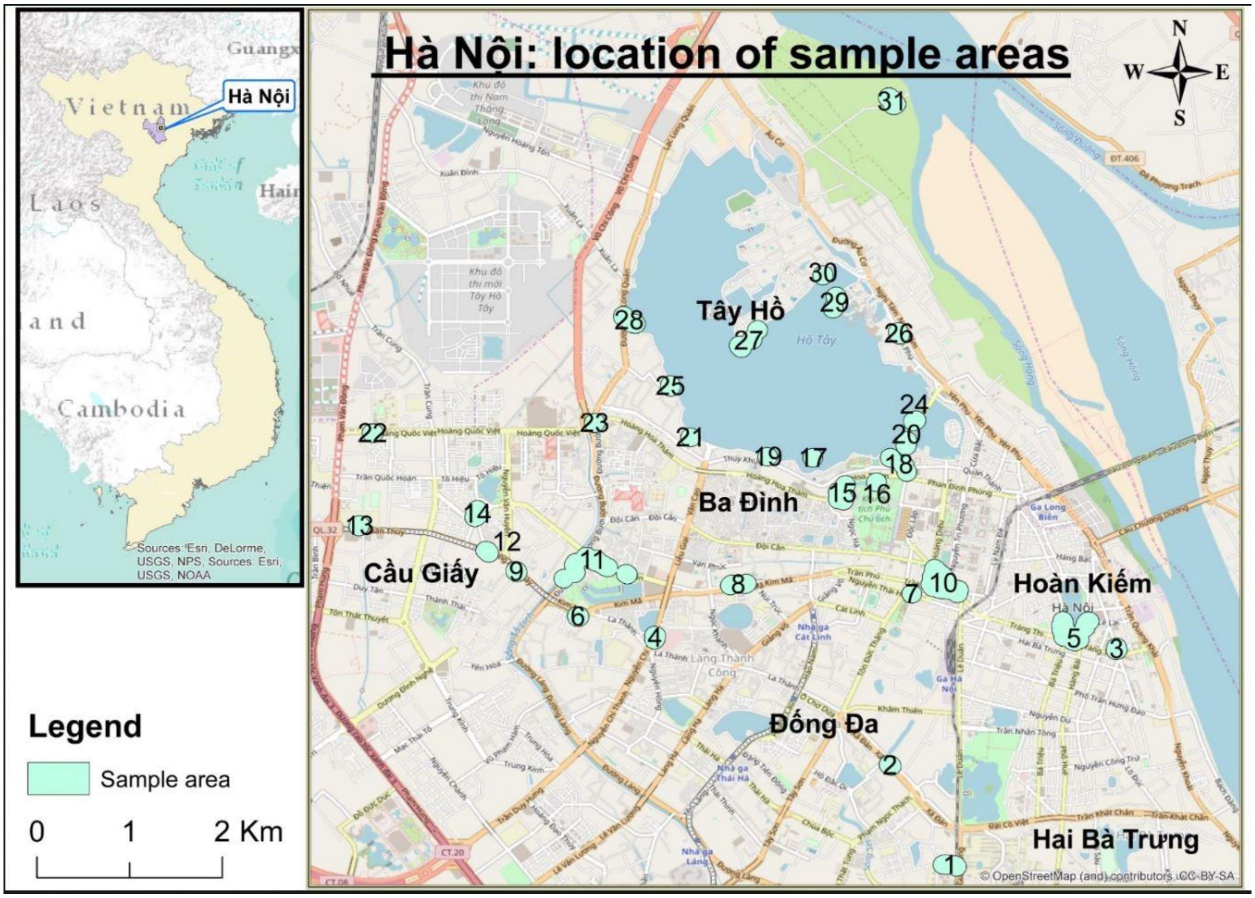

log(SIRMW)=0.78xlog(SIRMA)+3.6,
R²=0.59
log(SIRM)
normalized by leaf weight
(μAm²/kg)
log(SIRM)
normalized by leaf area
(μA)
1
2
3
4
5
6
4
5
6
7
8
9

Figure S4


Hà Nội: location of sample areas
N
S
W
E
Vietnam
Hà Nội
Laos
Cambodia
Sources: Esri, DeLorme, USGS, NPS, Sources: Esri, USGS, NOAA
Legend
Sample area
0 1 2 Km
Tây Hồ
Ba Đình
Cầu Giấy
Hoàn Kiếm
Đống Đa
Hai Bà Trưng
1
2
3
4
5
6
7
8
9
10
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31
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Figure S5

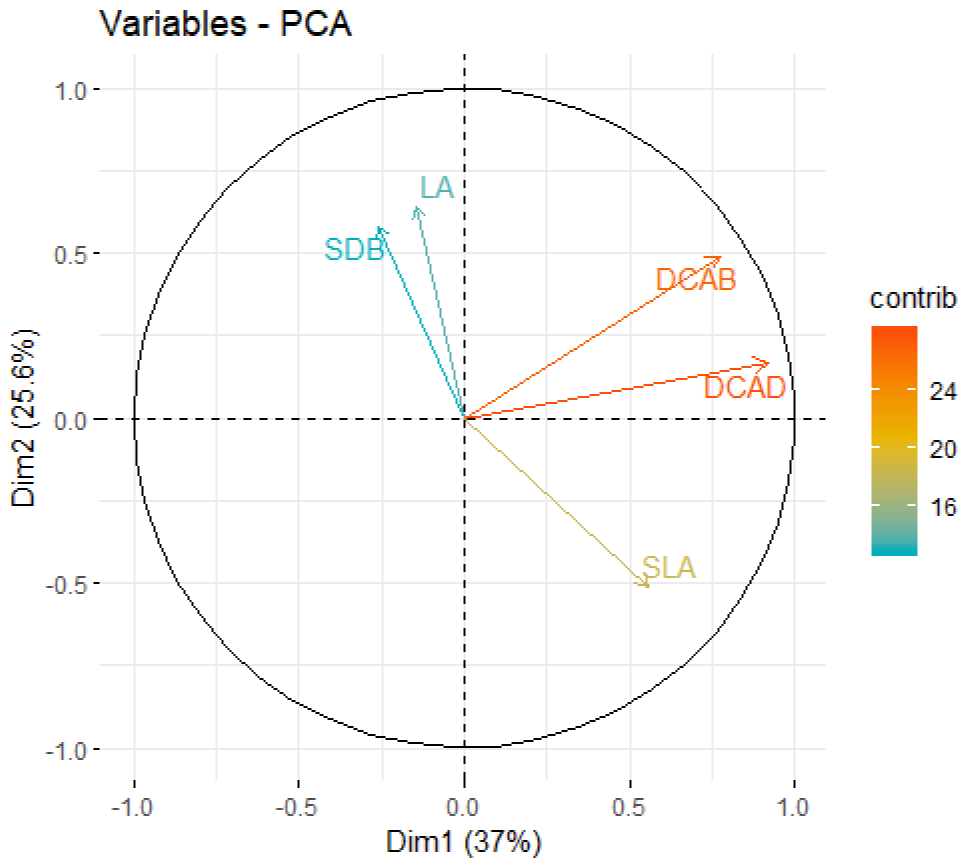

Variables - PCA
contrib
24
20
16
LA
SDB
DCAB
DCAD
SLA
Dim2 (25.6%)
Dim1 (37%)
1.0
0.5
0.0
-0.5
-1.0
-1.0
-0.5
0.0
0.5
1.0

Figure S6

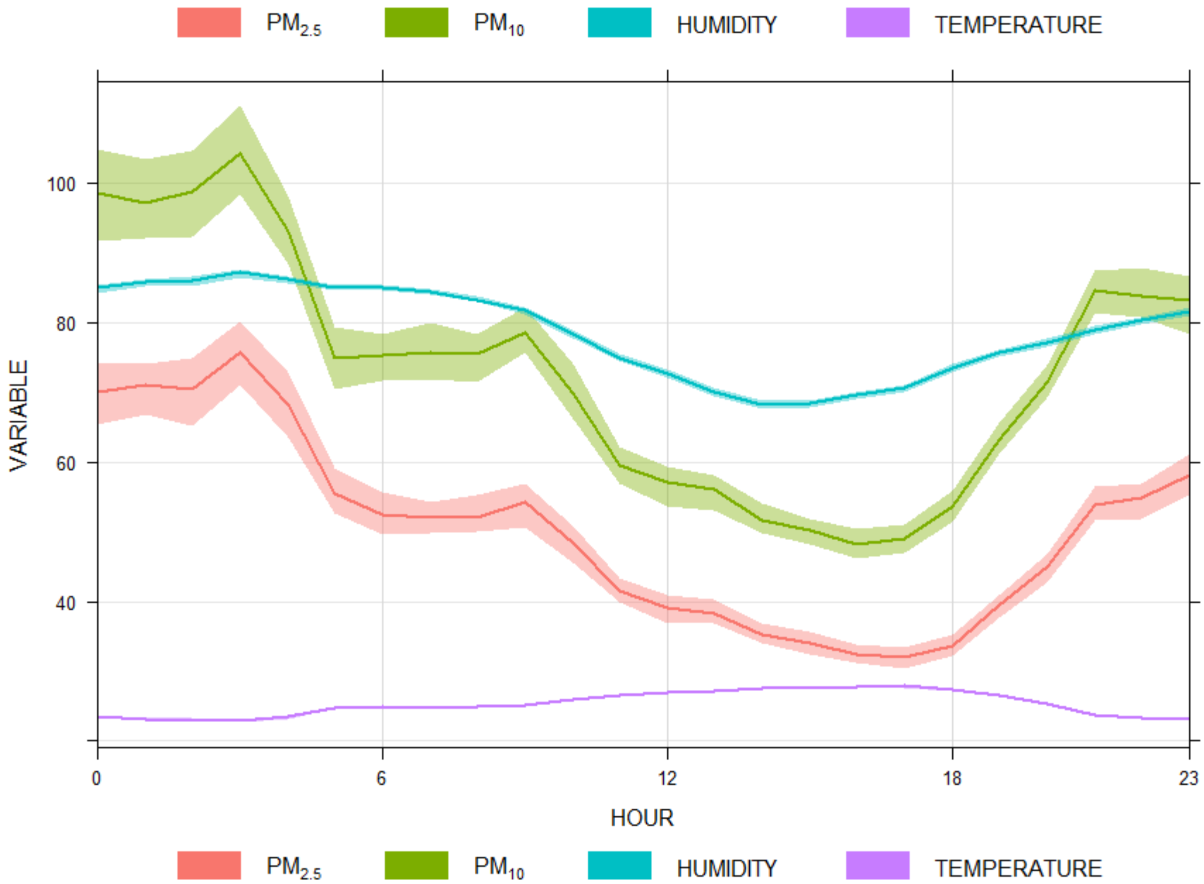

PM2.5
PM10
HUMIDITY
TEMPERATURE
VARIABLE
100
80
60
40
0
6
12
18
23
HOUR
PM2.5
PM10
HUMIDITY
TEMPERATURE

Figure S7

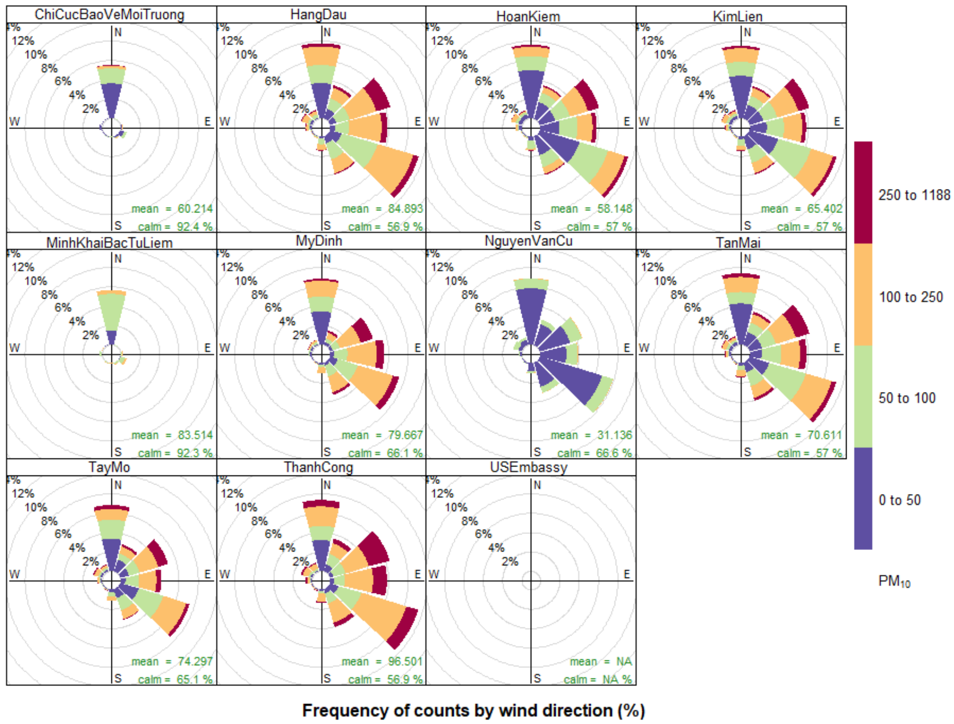
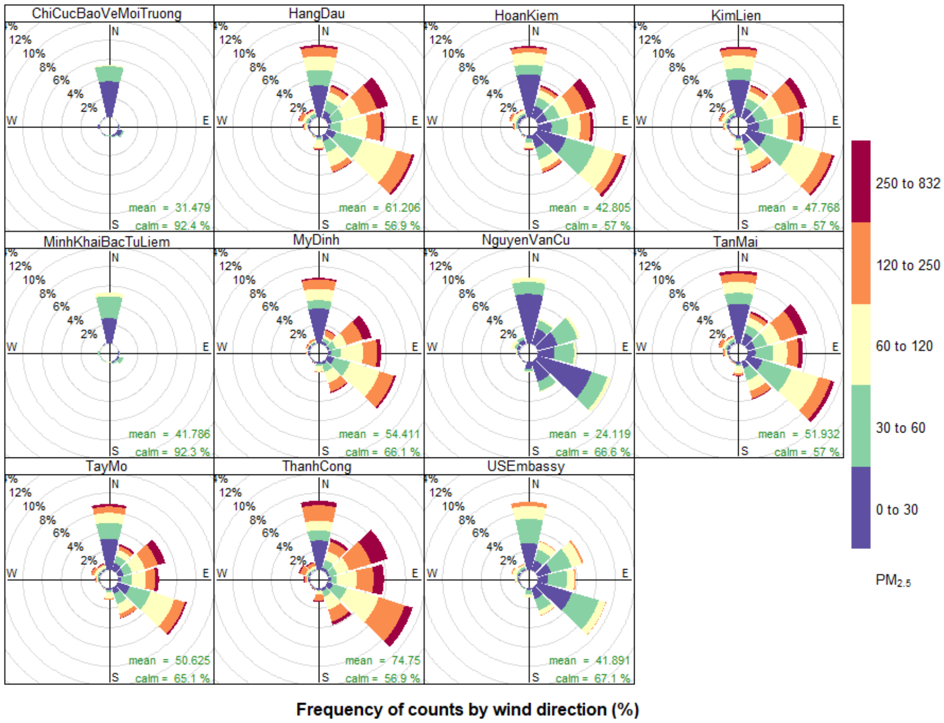

ChiCucBaoVeMoiTruong
mean = 60.214
calm = 92.4 %
HangDau
mean = 84.893
calm = 56.9 %
HoanKiem
mean = 58.148
calm = 57 %
KimLien
mean = 65.402
calm = 57 %
MinhKhaiBacTuLiem
mean = 83.514
calm = 92.3 %
MyDinh
mean = 79.667
calm = 66.1 %
NguyenVanCu
mean = 31.136
calm = 66.6 %
TanMai
mean = 70.611
calm = 57 %
TayMo
mean = 74.297
calm = 65.1 %
ThanhCong
mean = 96.501
calm = 56.9 %
USEmbassy
mean = NA
calm = NA %
250 to 1188
100 to 250
50 to 100
0 to 50
PM_{10}
Frequency of counts by wind direction (%)

Figure S8



ChiCucBaoVeMoiTruong
HangDau
HoanKiem
KimLien
MinhKhaiBacTuLiem
MyDinh
NguyenVanCu
TanMai
TayMo
ThanhCong
USEmbassy
mean = 31.479
calm = 92.4 %
mean = 61.206
calm = 56.9 %
mean = 42.805
calm = 57 %
mean = 47.768
calm = 57 %
mean = 41.786
calm = 92.3 %
mean = 54.411
calm = 66.1 %
mean = 24.119
calm = 66.6 %
mean = 51.932
calm = 57 %
mean = 50.625
calm = 65.1 %
mean = 74.75
calm = 56.9 %
mean = 41.891
calm = 67.1 %
250 to 832
120 to 250
60 to 120
30 to 60
0 to 30
PM2.5
Frequency of counts by wind direction (%)

TABLES

Table S1: Overview with common names, sample location, mean diameter, mean height and mean distance to the road for each plant species.

Table S2: Overview of the mean and standard error (SDE) of the SIRMA, SIRMW, adaxial DCA (DCAD), abaxial DCA (DCAB), SLA, abaxial SDB and leaf area (LA) for each plant species.

Table S3: Overview of the foliage, LAI, max. height (m) and biogeography for each plant species. Species with underlined biogeographies are species also present in natural Vietnamese forests (Arizona State University, 1987; Fern et al., 2014; Forest Inventory And Planning Institute, 2009; Missouri Botanical Garden, 2002; Missouri Botanical Garden et al., 2015; National Parks Board Singapore, 2013).

Table S4: Overview of the ecology, potential beneftis and remarks for each plant species (Arizona State University, 1987; Fern et al., 2014; Forest Inventory And Planning Institute, 2009; Missouri Botanical Garden, 2002; Missouri Botanical Garden et al., 2015; National Parks Board Singapore, 2013).

Table S1

Species	Author	(Sub)-family	Vernacular name: English	Vernacular name: Vietnamese	Location	Mean Value: Diameter (m)	Mean Value: Height (m)	Mean Value: Distance to the road (m)
Acacia auriculiformis	A. Cunn. Ex Benth.	Mimosaceae	Earleaf Acacia	Keo lá tràm, tràm bông vàng	12	1,23	22,67	0,00
Aglaia odorata	Lour.	Meliaceae	Chinese Perfume Plant	Ngâu thơm	14	0,05	NA	3,00
Allospondias lakonensis	(Pierre) Stapf.	Anacardiaceae	NA	Dâu da xoan	*1, 11*	0,58	4,63	0,00
Alstonia scholaris	(L.) R. Br.	Apocynaceae	Devil Tree	Sữa, Mò cua	*1, 2, 11*	0,95	10,00	0,00
Averrhoa carambola	L.	Oxalidaceae	Starfruit	Khế chua	*10, 17, 19*	0,27	6,33	2,67
Bambusa vulgaris	Schrad.	Poaceae	Common Bamboo	Tre vàng sọc	*10*	NA	9,00	5,00
Barringtonia acutangula	(L.) Gaertn.	Lecythidaceae	Freshwater Mangrove	Lộc vừng	*5, 6, 29*	1,01	9,50	3,67
Bauhinia variegata	L.	Caesalpiniaceae	Variegeted Orchid-tree	Hoa Ban, Ban tráng, Móng bò soc	*1, 4, 5, 10, 11, 14, 24, 31*	0,38	6,07	4,82
Bischofia javanica	Blume	Euphorbiaceae	Bishop Wood	Nhội tía	*3*	1,99	19,67	0,00
Bougainvillea brasiliensis	Rauesch.	Nyctaginaceae	NA	Hoa giấy	*10, 22*	0,74	8,50	4,50
Broussonetia papyrifera	(L.) Vent.	Moraceae	Paper Mulberry	Dướng	*1, 10*	0,24	6,17	4,67
Callistemon citrinus	Sweet	Myrtaceae	Lemon Bottlebrush	Tràm bông đỏ	*1, 11*	26,70	7,17	0,00
Cassia fistula	L.	Caesalpiniaceae	Golden RainTree	Bò cạp nước, Muồng hoàng yến	*5, 10, 13, 14, 18, 28*	1,02	15,13	4,63
Ceiba pentandra	(L.) Gaertn.	Bombacaceae (now: Malvaceae)	Kapok	Bông gòn	*26*	2,03	32,00	0,00
Celtis sinensis	Pers.	Ulmaceae	Chinese Hackberry	Sếu, Cơm nguội	*10, 16*	0,75	8,00	11,33
Cestrum nocturnum	L.	Solanaceae	Night-blooming Jasmine	Dạ hương	*5*	0,12	1,60	8,00
Chukrasia tabularis	A. Juss.	Meliaceae	Chickrassy	Lát hoa	*4*	0,64	17,00	0,00
Dalbergia boniana	Gagnep.	Fabaceae	NA	Sưa trắng	*5, 14, 15*	1,01	15,43	2,86
Dalbergia tonkinensis	Prain	Fabaceae	NA	Sưa bắc bộ, Trắc thối	*15, 27*	0,91	21,13	0,00

Delonix regia	(Bojer ex Hook.) Raf.	Caesalpiniaceae	Royal Poinciana	Phượng đỏ, phượng vĩ	*11, 20, 21, 28*	1,13	16,63	0,00
Dimocarpus longan	Lour.	Sapindaceae	Longan	Nhãn	*10, 20*	0,81	12,25	0,00
Dracontomelum duperreanum	Pierre	Anacardiaceae	Dracontomelum	Sấu	*10*	1,11	10,50	0,00
Duranta repens	L.	Verbenaceae	Golden Dewdrop	Dâm xanh	*6, 9, 10*	0,13	2,72	3,13
Ficus annulata	Blume	Moraceae	NA	Đa tía	*5, 15*	5,03	25,67	8,67
Ficus benjamina	L.	Moraceae	Weeping Fig	Si	*5, 10, 24*	2,50	17,93	11,14
Ficus pumila	L.	Moraceae	Creeping Fig	Trâu cổ	*10, 15*	NA	16,00	3,67
Ficus religiosa	L.	Moraceae	Sacred Fig	Đề	*1, 5, 25*	2,30	14,50	0,00
Gladiolus x gandavensis	Van Houtte	Iridaceae	Gladioli	Lay ơn	*5*	NA	0,91	0,00
Hibiscus rosa-sinensis	L.	Malvaceae	Chinese Hibiscus	Giâm bụt	*23, 24*	0,05	0,50	0,00
Jatropha integerrima	Jacq.	Euphorbiaceae	Spicy Jatropha	NA	*23*	0,09	0,80	0,00
Khaya senegalensis	(Desr.) A. Juss.	Meliaceae	African Mahogany	Xà cừ	*10*	2,06	15,13	0,00
Lagerstroemia speciosa	(L.) Pers.	Lythraceae	Queen's Crape-myrtle	Bằng lăng nước	*1, 5, 10, 13*	0,87	16,83	1,67
Mangifera sp.	NA	Anacardiaceae	Mango	Xoài	*14*	0,98	11,20	3,00
Muntingia calabura	L.	Muntingiaceae	Strawberry Tree	Trứng cá	*1, 11*	0,53	6,38	0,00
Nerium oleander	L.	Apocynaceae	Oleander	Trúc đào	*11*	0,02	2,38	0,00
Peltophorum tonkinensis	A. Chev.	Caesalpiniaceae	Copperpod	Lim sẹt cánh	*5, 10, 22, 27, 28*	1,00	13,00	5,00
Phoenix roebelenii	O' Brien	Arecaceae	Miniature Date Palm	Chà là cảnh	*6*	0,26	2,17	12,00
Plumeria rubra	L.	Apocynaceae	Franjipani	Đại hoa đỏ	*23*	0,27	2,50	0,00
Polyalthia longifolia	Sonn.	Annonaceae	Indian mast tree	Liễu ấn độ	*6, 8*	0,36	6,13	16,88
Prunus persica	(L.) Batsch	Rosaceae	Peach	Đào	*28, 31*	0,45	4,00	0,00
Sabina chinensis	(L.) Antoine	Cuppressaceae	Red cedar	Tùng xà	*1*	0,20	10,00	20,00
Salix babylonica	L.	Salicaceae	Weeping Willow	Liễu rủ	*1, 5, 30*	0,73	7,00	9,50
Saraca dives	Pierre	Caesalpiniaceae	NA	Vàng anh, Cọ ma	*5*	1,51	16,33	12,33
Sterculia sp.	NA	Sterculiaceae	NA	Trôm	*10*	0,69	7,00	0,00
Streblus asper	Lour.	Moraceae	Toothbrush Tree	Duối, Ruối	*15, 18*	0,73	7,50	0,00

Taxodium distichum	Rich.	Cupressaceae	Bald Cypress	Bụt mọc	*6, 12, 14, 26*	0,88	11,50	16,80
Terminalia mantaly	H. Perrier	Combretaceae	NA	Bàng đài loan	*2, 8*	0,40	8,75	0,00
Thevetia peruviana	(Pers.) K. Schum.	Apocynaceae	Yellow Oleander	Thông thiên	*9, 10*	0,45	7,50	6,00
Trachycarpus fortunei	(Hook.) H. Wendl.	Arecaceae	Windmill Palm	Cọ cảnh	*11*	NA	2,50	0,00

Table S2

Species	Mean													
	Value							SE						
	SIRMa (μA)	SIRMw (μAm² kg^{-1})	DCAD (°)	DCAB (°)	SLA (cm² g^{-1})	SDB (cm^{-2})	LA (cm²)	SIRMa (μA)	SIRMw (μAm² kg^{-1})	DCAD (°)	DCAB (°)	SLA (cm² g^{-1})	SDB (cm^{-2})	LA (cm²)
Acacia auriculiformis	100,2	953,3	58	57	97,56	45120	20,05	19,9	177,9	8	6	6,37	5758	3,94
Aglaia odorata	29,3	654,3	79	65	222,48	25816	1,80	2,9	150,0	5	5	41,34	1202	0,16
Allospondias lakonensis	67,2	1661,0	74	75	247,45	23025	20,02	11,8	333,2	7	7	41,70	14227	3,71
Alstonia scholaris	50,6	561,1	80	121	115,05	NA	34,45	5,3	85,0	8	4	7,18	NA	5,35
Averrhoa carambola	13,7	288,1	95	99	200,19	7675	9,43	1,9	101,7	13	18	40,82	5483	1,45
Bambusa vulgaris	22,2	598,2	73	126	248,24	34538	19,53	3,7	110,6	14	3	12,70	4272	2,78
Barringtonia acutangula	29,3	402,6	58	60	134,68	9652	47,82	10,1	151,0	6	12	8,39	4656	11,16
Bauhinia variegata	22,6	396,3	114	114	212,76	14013	101,68	4,6	52,2	5	7	14,36	3762	11,72
Bischofia javanica	51,1	1009,3	50	41	188,95	17211	22,17	2,40	271,8	7	9	42,89	8863	7,61
Bougainvillea brasiliensis	32,0	871,5	81	73	267,42	16310	9,13	2,7	120,4	5	12	18,30	3299	0,69
Broussonetia papyrifera	60	1130,7	71	129	189,24	NA	68,33	14,2	320,8	11	10	12,54	NA	10,21
Callistemon citrinus	86,3	735,4	85	85	88,21	66517	2,73	15,1	145,4	13	22	4,64	23182	0,68
Cassia fistula	14,5	286,1	104	115	224,67	16397	32,09	4,6	71,8	6	4	25,41	4410	7,25
Ceiba pentandra	50,3	607,2	72	101	120,45	25002	18,10	13,3	151,6	8	8	3,19	707	6,96
Celtis sinensis	33,9	1729,3	85	76	218,85	50411	25,93	4,9	933,6	5	5	38,92	9257	14,57
Cestrum nocturnum	23,5	561,6	68	78	233,16	12071	18,29	2,8	74,2	7	5	10,57	2124	1,18
Chukrasia tabularis	189,0	2037,0	61	70	108,46	30421	44,03	22,5	278,6	4	6	2,73	2678	8,41
Dalbergia boniana	30,7	638,0	65	74	208,01	13307	19,55	6,2	137,0	3	8	16,22	2942	3,61
Dalbergia tonkinensis	12,9	349,9	72	84	267,52	19275	11,08	2,1	71,6	NA	NA	29,50	4569	1,74
Delonix regia	23,7	950,7	75	93	183,36	39538	5,92	7,8	530	14	26	13,61	20580	2,37
Dimocarpus longan	31,1	364,8	77	125	119,95	4535	25,23	7,4	75,3	8	11	7,83	3173	2,17

Dracontomelum duperreanum	38,2	644,1	72	71	141,42	27211	20,09	12,3	153,4	6	6	24,82	9271	2,98
Duranta repens	57,7	1288,5	57	65	235,51	36805	5,24	7,5	136,3	5	6	16,29	4449	0,76
Ficus annulata	63,7	420,5	46	56	73,67	31165	103,35	15,9	60,2	3	9	15,51	9958	28,28
Ficus benjamina	36,3	566,6	52	54	166,11	30060	9,69	4,9	109,4	7	5	11,06	2263	0,42
Ficus pumila	36,4	1318,5	59	37	439,92	15466	3,34	9,2	227,1	5	6	119,95	726	0,68
Ficus religiosa	49.0	730,7	74	98	158,38	23112	78,35	14,4	177,6	9	20	18,61	10484	8,29
Gladiolus x gandavensis	44,1	565,1	86	90	134,72	6396	79,71	7,1	41,9	19	25	18,77	3256	17,32
Hibiscus rosa-sinensis	13.0	197,1	68	46	151,18	18752	30,66	2,7	42,9	11	16	4,44	1815	3,82
Jatropha integrima	66,2	983,2	55	66	145,27	24246	41,90	9,1	140,2	13	15	6,49	4283	7,11
Khaya senegalensis	20,2	350,7	73	75	212,34	61313	41,45	3,4	86,2	7	5	69,26	13444	20,09
Lagerstroemia speciosa	47,3	691,6	68	69	144,90	21717	73,43	12,3	165,6	5	4	10,77	3540	7,86
Mangifera sp.	28,7	293,7	66	71	105,89	38811	63,73	6,5	56,3	2	4	16,82	9861	4,19
Muntingia calabura	227,8	3493,2	82	115	156,18	NA	14,36	18,6	470,01	10	4	16,22	NA	1,40
Nerium oleander	154,6	1123,6	76	92	78,75	NA	14,33	20,7	37,8	3	2	10,83	NA	1,45
Peltophorum tonkinensis	55,1	2747,9	86	71	344,92	23330	2,26	11,5	938,61	12	11	86,70	6967	0,84
Phoenix roebelenii	68,2	323,7	40	38	50,45	21164	15,85	13,4	81,9	3	7	4,42	4377	0,86
Plumeria rubra	89,5	937,5	63	76	103,29	31677	66,44	10,3	138,7	10	8	6,41	510	14,67
Polyalthia longifolia	39,6	559,0	57	70	144,84	20932	45,28	5,1	102,6	6	6	10,82	2865	2,65
Prunus persica	36,7	564,1	81	82	153,28	30770	17,40	5,6	94,3	13	8	6,95	13533	1,44
Sabina chinensis	146,3	737,0	76	73	47,68	NA	1,79	31,8	186,7	18	11	1,30	NA	0,34
Salix babylonica	29,0	306,7	66	85	131,07	18490	4,49	6,2	24.0	9	18	41,33	3792	2,10
Saraca dives	76,6	417,9	68	89	120,26	30002	89,14	28,8	174,2	19	1	39,04	2564	45,35
Sterculia sp.	58,6	1102,3	38	40	191,25	28258	41,52	14,2	349,6	1	15	9,29	NA	26,91
Streblus asper	53.0	741,1	62	70	152,19	34537	15,21	19,7	228,0	8	6	8,49	6112	2,99
Taxodium distichum	76,0	NA	125	90	1375,61	7117	0,79	10,2	NA	5	16	162,27	2418	0,08
Terminalia mantaly	52,2	667,9	63	44	133,12	25118	30,18	5,7	133,9	9	8	17,80	3367	16,19
Thevetia peruviana	65,7	1052,1	60	62	132,16	29072	5,80	6,3	100,6	4	3	22,15	5004	0,75
Trachycarpus fortunei	83,1	304,5	49	71	37,55	42823	617,88	18,4	53,8	11	14	1,78	10025	109,99

Table S3

Species	Foliage	Maximum Value LAI (m)	Maximum Value Height (m)	Geography
Acacia auriculiformis	Evergreen, elliptical shaped leaves with acute apex	3	30	Introduced to S.E.A
Aglaia odorata	Evergreen, Obovate (egg-shaped) shaped smooth leaves	4,5	30	Native to S.E.A.
Allospondias lakonensis	Deciduous	NA	15	Native to S.E.A.
Alstonia scholaris	Evergreen, elliptic, obovate shaped leaves with obtuse/concave apex	3	40	Native to S.A., S.E.A. and P.N.G
Averrhoa carambola	Evergreen, obovate shaped, smooth leaves that close when shaken	NA	15	Native to S.E.A.
Bambusa vulgaris	Evergeen, lance-shaped, rough leaves with acuminate apex	NA	20	Native to S.E.A.
Barringtonia acutangula	Semi-deciduous, thick, obovate shaped leaves with acute apex	3	15	Native to Asia (except N.A.) and Australia
Bauhinia variegata	Deciduous,hoof shaped obcordate shaped leaves	NA	12	Native to S.E.A. and E.A.
Bischofia javanica	Evergreen, compound leaves with leaflets with dentate margins	NA	50	Native to S.A., S.E.A., E.A. and Australia
Bougainvillea brasiliensis	Evergeen, ovate shaped leaves	NA	12	Tropics
Broussonetia papyrifera	Deciduous, rough, hairy, variable shaped leaves	NA	20	Native to E.A., Indochina and India
Callistemon citrinus	Evergreen, smooth and elliptical shaped leaves with silky texture	2,5	15	Native to S.E. Australia
Cassia fistula	Evergreen/deciduous, pinnate leaves with acute apex	2,5	18	Native to India and Sri Lanka
Ceiba pentandra	Deciduous,compound, lanceolate leaves with 5-7 lanceolate leaflets	3	40	Introduced to S.E.A, Native to America
Celtis sinensis	Deciduous, ovate shaped, smooth leaves with toothed margins and acute apex	NA	30	Native to E.A.
Cestrum nocturnum	Evergeen, smooth leaves with acute apex	4,5	4	Tropical America
Chukrasia tabularis	Deciduous, smooth leaves with dentate margins	3	40	Native to India
Dalbergia boniana	Evergreen	NA	NA	Endemic to Vietnam
Dalbergia tonkinensis	Evergreen, ovate shaped leaves with subacute apex and 7-17 leaflets	NA	13	Endemic to Vietnam
Delonix regia	(Semi)-deciduous, non-palm foliage shaped leave	2,5	20	Introduced to Vietnam, endemic to Madagascar
Dimocarpus longan	Evergreen, hairy, elliptical shaped leaves with 6-8 leaflets	3	40	Native to S.E.A.

Dracontomelum duperreanum	Deciduous, oblong, hairy leaves split in 6-9 pairs of leaflets with acuminate apex	NA	35	Native to E.A. and Vietnam
Duranta repens	Evergreen, ovate shaped leaves	4,5	6	Introduced to Vietnam, native to America
Ficus annulata	Evergreen, elliptic-lanceolate shaped leaves with acuminate apex	NA	32	Native to S.E.A. and Oceania (Except N.Z.)
Ficus benjamina	drought/Semi-deciduous, smooth, ovate shaped leaves with aristate apex	3	20	Native to S.E.A.
Ficus pumila	Evergreen, rough, ovate shaped leaves with acute apex	NA	4	Native to E.A. and Vietnam
Ficus religiosa	drought/Semi-deciduous, smooth, ovate leaves with tail-like tip	3	30	Native to central Asia
Gladiolus x gandavensis	Deciduous, lanceolate shaped leaves	NA	1	Cultivar
Hibiscus rosa-sinensis	Evergreen, hairy, ovate shaped leaves with acuminate apex	4,5	3	Cultivar
Jatropha integerrima	Evergreen, smooth, oblong/obovate shaped leaves with acute to acuminate apex	4,5	4,5	Native to the West Indies and Cuba
Khaya senegalensis	Evergreen, oblong/elliptical shaped leaves	NA	30	Introduced to Vietnam, native to West Africa
Lagerstroemia speciosa	Drough/semi-deciduous, smooth elliptical shaped leave with obtuse apex	3	15	Native to S.E.A.
Mangifera sp.	NA	NA	NA	NA
Muntingia calabura	Evergreen, very hairy, ovate/lanceolate shaped leaves with assymetrical base	3	12	Introduced to Vietnam, native to America
Nerium oleander	Evergreen, lanceolate shaped, thick leaves	NA	6	Native to S.W.A.
Peltophorum tonkinensis	Deciduous, bipinnately compound leaves with oval shaped leaflets	3	25	Native to S.E.A. and N. Australia
Phoenix roebelenii	Evergreen, pinnate (feather-like) fronds with many glaucous leaflets	2,5	3	Native to Vietnam, Laos and S. China
Plumeria rubra	Deciduous, Smooth, thick, elliptical shaped leaves	2,5	8	Introduced to S.E.A., native to America
Polyalthia longifolia	Evergreen, smooth, lanceolate shaped leaves with long and thin leaf tip	3	30	Nativ eto India and Sri lanka
Prunus persica	Deciduous, lanceolate shaped leaves	NA	8	Native to N.W. China
Sabina chinensis	Evergreen, needle-like foliage	4	20	Native to China and Japan
Salix babylonica	Deciduous, smooth, laceolate shaped leaves with acuminate apex and toothed margins	2,5	25	Native to N. China
Saraca dives	Evergreen, smooth, lanceolate shaped leaves with acuminate tup, 5 pairs of leaflets	4	10	Native to S.E.A.
Sterculia sp.	NA	NA	NA	NA
Streblus asper	Evergreen, distichous oval shaped leaves with obtuse apex	NA	15	Native to S.E.A.
Taxodium distichum	Deciduous, conifer with needles	2,5	40	Introduced to Vietnam, native to America
Terminalia mantaly	Evergreen, smooth,spathulate shaped leaves with undulate margins and obtuse apex	3	20	Introduced to Vietnam, native to Madagascar
Thevetia peruviana	Evergreen, smooth linear leaves with acute apex	4,5	3,5	Introduced to Vietnam, native to America
Trachycarpus fortunei	Evergreen, big leaves with many rough leaflets	NA	20	Native to China

Table S4

Ecology	Ecology	Benefits	Remarks	Source
Acacia auriculiformis	Fast growing and drought resistant	For shade, decoration, soil improvement and covering of the ground	NA	https://florafaunaweb.nparks.gov.sg/special-pages/plant-detail.aspx?id=2693
Aglaia odorata	Grows in well-drained soils, especially in secondary rainforest	Grown as hedge and attracts butterflies	Dried flowers can be added to tea	https://florafaunaweb.nparks.gov.sg/special-pages/plant-detail.aspx?id=1609
Allospondias lakonensis	Grows in well-drained basalt or alluvial soils	For Shade	Edible fruit	http://tropical.theferns.info/viewtropical.php?id=Spondias+lakonensis
Alstonia scholaris	Grows in well-drained soils	For Shade and attracts butterflies	Tree of the devil, leaves used as aphrodisiacum in India	https://florafaunaweb.nparks.gov.sg/special-pages/plant-detail.aspx?id=2705
Averrhoa carambola	Slow growing in well-drained soilsr	For decoration, fruit	Edible fruit, named after Averrhoes	https://florafaunaweb.nparks.gov.sg/special-pages/plant-detail.aspx?id=2736
Bambusa vulgaris	Grows in well-drained soils	For decoration, soil stabilisation and grown as hedge	Edible shoot tips	https://florafaunaweb.nparks.gov.sg/special-pages/plant-detail.aspx?id=3600
Barringtonia acutangula	Grows in dry and loamy soils	NA	Used when blooming by aboriginals as signal for the freshwater mussel hunting	https://www.google.co.uk/search?hl=en&q=Barringtonia+acutangula&meta=
Bauhinia variegata	Fast growing tree, usally grows in open areas	For decoration	Doesn't fix nitrogen	http://tropical.theferns.info/viewtropical.php?id=Bauhinia+variegata
Bischofia javanica	Fast growing tree	For timber	Often used for reforestation	http://tropical.theferns.info/viewtropical.php?id=Bischofia+javanica
Bougainvillea brasiliensis	Grows in well-drained, dry soils	For decoration	Thorny shrub named after french explorer Antoine de Bougainville	http://www.public.asu.edu/~camartin/plants/Plant%20html%20files/bougainvillea.html
Broussonetia papyrifera	Fast growing in well-drained soils in full sun	For paper and roadsides	Tolerated air pollution, used for historical paper	http://tropical.theferns.info/viewtropical.php?id=Broussonetia+papyrifera
Callistemon citrinus	Fast growing tree, likes full sun	For decoration and roadsides	Leaves express oft citrus fragrance when crushed	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=2772
Cassia fistula	Grows in well-drained soils in full sun	For decoration, roadsides and attracts butterflies	Clusters of yellow flowers	https://florafaunaweb.nparks.gov.sg/special-pages/plant-detail.aspx?id=2787
Ceiba pentandra	Grows on slopes	For Shade and roadside	NA	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=2797

Celtis sinensis	Grows in well-frained soils in full sun	For decoration in classical E.A. garden	NA	https://keyserver.lucidcentral.org/weeds/data/media/Html/celtis_sinensis.htm
Cestrum nocturnum	Grows in well-drained soils in full sun	For decoration and attracts butterflies	Flowers at night	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=1802
Chukrasia tabularis	Grows in well-drained soils in full sun	For good wood and roadsides	VU on Vietnam red list (2017)	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=2804
Dalbergia boniana	Grows in full sun	For good wood	NA	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=7328
Dalbergia tonkinensis	NA	For shade	Individual trees sold for more than million $	http://www.efloras.org/florataxon.aspx?flora_id=2&taxon_id=242316810
Delonix regia	Tolerant to poor conditions	For shade	Branches break easily by wind	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=2838
Dimocarpus longan	Grow on rich and sandy soils	For shade, fruit	Edible fruit, needs seasonal differences for blooming	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=2848
Dracontomelum duperreanum	Grows in lowland forests	For shade, fruit	Edible fruit, needs a short dry season	http://tropical.theferns.info/viewtropical.php?id=Dracontomelon+duperreanum
Duranta repens	Grows fast in full sun	Grown as hedge	Thorns	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=1976
Ficus annulata	Grows in montane forests under 1300m	For rubber, leaves edible	Usually starts as an epiphyte with aerial roots, reproduction dependent on fig wasp	http://tropical.theferns.info/viewtropical.php?id=Ficus+annulata
Ficus benjamina	Grow in full sun	For decoratiom	Reproduction dependent on fig wasp, 'weeping' branches	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=2902
Ficus pumila	Grows in well-drained, fertile soils	NA	Reproduction dependant on fig wasp, can 'climb'	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=1403
Ficus religiosa	Reproduction dependant on fig wasp, grows in well-frained soils	NA	Holy tree because Buddha sat under the tree when receiving enlightment	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=2915
Gladiolus x gandavensis	Grows in well-drained and fertile soils	For decoration	sword lilies' because of the shape of the leave	http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?taxonid=254915&isprofile=0&
Hibiscus rosa-sinensis	Grows in full sun	For decoration	China rose'	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=2095
Jatropha integerrima	Grows in well-drained and dry soils	Attracts butterflies	NA	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=2152
Khaya senegalensis	Grows in savannah woodlands	For decoration	Oil can be used for cooking, twigs as toothbrush	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=2979
Lagerstroemia speciosa	Grows in open areas, especially along rivers	For shade and decoration	NA	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=2991

Mangifera sp.	NA	For shade, Fruit	Edible fruit, fruits can create mess	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=3012
Muntingia calabura	Drought resistant, grows in full sun	For fruit, medicine, wood or biofuel	Attracts bats, fruits cause dirty ground	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=3036
Nerium oleander	Grows in moist soils	NA	Very toxic	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=4486
Peltophorum tonkinensis	Grows in moist, well-drained soils	For shade, decoration and roadsides	Shade provisioner	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=3056
Phoenix roebelenii	Grows slow in well-drained and moist soils	For decoration	Palm tree	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=2665
Plumeria rubra	Grows in full sun	NA	Poisonous milk, historically used for perfume	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=3074
Polyalthia longifolia	Grow in full sun	For wood	NA	https://florafahttps://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=3079unaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=3056
Prunus persica	Grows in full sun	For decoration, fruit	Edible fruit, blossoming is signal of spring in Vietnam	https://gobotany.newenglandwild.org/species/prunus/persica/
Sabina chinensis	Grows in well-drained soils in full sun	For decoration	NA	https://florafaunaweb.nparks.gov.sg/special-pages/plant-detail.aspx?id=2976
Salix babylonica	Grows fast in full sun	NA	Can be used for phytoremediation, 'weeping' tree	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=3105
Saraca dives	Grows in well-drained and fertile soils	For shade	Holy tree because Buddha is born under this tree	https://florafaunaweb.nparks.gov.sg/special-pages/plant-detail.aspx?id=3113
Sterculia sp.	NA	NA	Edible star-shaped fruit	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=3140
Streblus aspera	Grows in open areas	Grown as hedge	Can be used to make paper	http://tropical.theferns.info/viewtropical.php?id=Streblus+asper
Taxodium distichum	Grows in full sun	Grown in Uncle Ho's house	NA	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=3176
Terminalia mantaly	Grows quickly in dry soil		Used for reforestation	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=2762
Thevetia peruviana	Grows in full sun	For decoration	Spiral flowers	https://florafaunaweb.nparks.gov.sg/Special-Pages/plant-detail.aspx?id=2505
Trachycarpus fortunei	Grows in well-drained, moist and fertile soil	For decoration	Grows in the mountain forest of China, 'windmill' palm	http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?taxonid=276718&isprofile=0&