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THE INTRODUCTION AND MAINTENANCE TRENDS OF STREET TREES IN JAPAN

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ABSTRACT: Street trees are one of the important components of green infrastructure in urban area. This study surveyed the relationship between introduction trends of street trees in Japan and factors such as latitude and climatic conditions. The results showed that Japanese street trees tended to be mainly broad-leaved rather than coniferous, and many of these were native species. In addition, we found that street trees not only fulfill the roles of disaster prevention and disaster reduction, but also contribute to citizen welfare and recreation because a relatively large number were flowering trees (generally planted to enjoy flowers). Also, it was suggested that *Cerasus* sp. are the street trees that represent Japan, because could be confirmed in all 47 prefectures. Meanwhile, Japan is categorized into four groups with characteristic street trees introduced under the influence of the latitude and temperature in each group. Particularly, while the introduction of street trees is conducted by the individual municipalities (prefectures, cities, towns, villages, and areas), similarities in the response in terms of latitude and temperature regarding the street trees in Japan are being observed beyond the administrative borders. Incidentally, weeds which invade at the base of street trees were managed by periodic weeding, instead of any special treatment, is the most common weed management strategy in Japan. In addition, installation of shrubs, artificial inorganic cover such as concrete, and equipment, etc. has also been observed and may lead to a reduction in the weeding previously mentioned.

Keywords: Street trees, Green infrastructure, Trend in Japan, Weed management

1. INTRODUCTION

Urban areas face serious problems such as urban heat island phenomena, air pollution, and earthquakes (e.g., in Japan, the Nankai trough earthquakes and Tokyo near-field earthquakes), as well as increased risks of weather-related disasters due to global warming [1-21]. Recently, green infrastructure in urban areas has attracted attention as a means of eliminating or mitigating the damage from such risks [22-28]. Green infrastructure is a nature-based solution that incorporates elements of the natural environment with conventional infrastructure and uses functions of the natural environment to eliminate or reduce the aforementioned risks [22-28]. Street trees play a key role in mitigating environmental risks in urban areas and are one example of green infrastructure that is actively introduced [29-33].

In urban areas, green infrastructure is difficult to achieve as development of new large parks or green areas requires vast amounts of land, which is not easily available. Additionally, numerous studies on vegetation colonizing in rooftops and building walls have been conducted, and, in urban areas where securing land is difficult and expensive, efforts have been made to install green infrastructure on rooftops and walls of office buildings and commercial facilities [34-43]. However, the maintenance and management of green infrastructure is expensive; particularly, green roofs and walls require advanced technology. However, compared to these green infrastructures, street trees are far less costly in terms of the construction, maintenance, and management of the land used, and the land required is overwhelmingly smaller. This makes street trees a promising component of future green infrastructure.

The condition of street trees in each municipality in Japan has been investigated by the government (National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure and Transport (NILIM MLIT)) since 1982 at five-year intervals [44]. Due to this, the types and number of street trees in administrative units such as prefectures, cities, towns, and villages have been identified. These data were used to identify the species and number of trees in administrative units such as Kanto and Kinki regions and all over Japan. Furthermore, the “tree type” (e.g., broad-leaved evergreen trees and needle-leaved evergreen trees) introduced in municipalities such as Kanto and Kinki regions, as well as throughout Japan, are mentioned as well.

Photo 1 Weeds at base of street tree

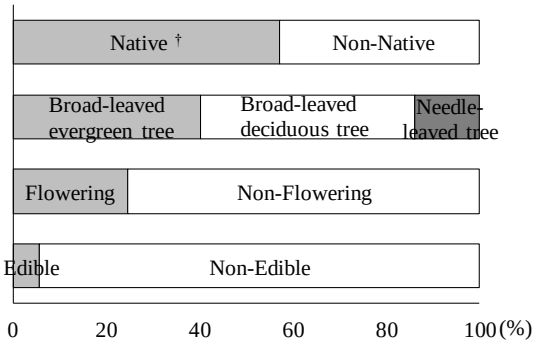

Fig.1 Characteristics of street trees in Japan
252 species were analyzed, excluding duplicates from 2350 species in the research target.
† Varieties were included.

In this study, we report the results of investigating the relationship between introduction trends of street trees in Japan and factors such as latitude and climatic conditions (e.g., temperature and precipitation). On the other hand, a field survey was conducted to observe weed management because weeds often invade the area at the base of the tree (Photo 1).

2. MATERIALS AND METHODS

In this study, we extracted the 50 most-planted tall tree species in each prefecture in Japan (47 prefectures × 50 species = 2,350 species) from "The Roadside Trees of Japan VIII" by the NILIM MLIT [44]. From the tall tree species extracted, we calculated the proportion of native trees, broad-leaved evergreen trees, broad-leaved deciduous trees, needle-leaved trees, flowering (generally planted to enjoy flowers), and edible (generally edible fruit-bearing trees). To investigate introduction trends of street trees in Japan based on latitude and climate conditions, we classified the prefectures using PC-ORD Ver. 4.25 (MjM Software Design) for two-way indicator species analysis (TWINSPAN) and detrended correspondence analysis (DCA) and Pearson's product-moment correlation to identify the relationships between the stand score and the latitude and climate conditions (Kira's warmth index, annual precipitation, daylight hours, and snowfall [45]).

On the other hand, weed management around the base of the street trees was evaluated by observations of maintenance conditions at the base of street trees during a field survey conducted in Fukuoka City in Fukuoka Prefecture in western Japan—one of the five major cities in Japan—during which 1,632 samples were collected.

3. RESULTS

3.1 Introduction Trends of Street Trees in Japan

3.1.1 Tree types

The types of street trees analyzed in this study consisted of broad-leaved deciduous trees (46.0%) (the most common type in this study), followed by broad-leaved evergreen trees (40.1%) and needle-leaved trees (13.9%). Additionally, more than half (57.1%) of the trees were native, while 24.6% were flowering and 5.2% were edible (Fig. 1). For reference, broad-leaved deciduous trees included *Aphananthe aspera*, *Deutzia crenata*, *Toxicodendron succedaneum*, broad-leaved evergreen trees included *Dendropanax trifidus*, *Planchonella obovata*, *Quercus acuta*, needle-leaved trees included *Abies homolepis*, *Juniperus chinensis*, *Picea glehnii*, flowering included *Cerasus* sp, *Lagerstroemia* sp, *Camellia* sp, and edible included *Armeniaca mume*, *Malus prunifolia*, *Olea europaea* for prunes and crabapples, respectively (Appendix 1).

3.1.2 Classification

Using TWINSPAN, the prefectures in Japan were classified into four major groups (A, B, C, and D) based on the street trees planted therein (Fig. 2). Group A consisted of 4 prefectures and 96 species; Group B, 20 prefectures and 141 species; Group C, 22 prefectures and 155 species; and Group D, 1 prefecture and 50 species. Group A had 27 species not present in the other groups, including *Abies homolepis*, *Abies sachalinensis*, *Aria alnifolia*, *Malus prunifolia* (Appendix 1). Similarly, Group B had 21 unique species including *Aesculus* x *carne*, *Carpinus tschonoskii*, *Cercis chinensis*, *Chamaecyparis obtusa*. Groups C had 44 unique species including *Aphananthe aspera*, *Cinnamomum daphnoides*, *Erythrina crista-galli*, *Podocarpus macrophyllus*, and Group

D had 29 unique species including *Araucaria heterophylla*, *Bombax ceiba*, *Calophyllum inophyllum*, *Casuarina stricta* (Appendix 1).

There were no significant differences in the ratios of native trees, flowering trees, and trees for food among the groups; however, there were significant differences in the ratios of broad-leaved evergreen trees, broad-leaved deciduous trees, and needle-leaved trees. The ratio of broad-leaved deciduous trees was highest in Group A, followed by Groups B, C, and D in decreasing order. The same order was observed for needle-leaved trees, while the reverse order was observed for broad-leaved evergreen trees (Table 1). Incidentally, five species (*Cerasus* sp, *Lagerstroemia* sp, *Camellia* sp, *Juniperus chinensis*, *Acacia* sp) could be confirmed in all groups, further, *Cerasus* sp. (such as *Cerasus* x *yedoensis*) could be confirmed in all 47 prefectures (Appendix 1).

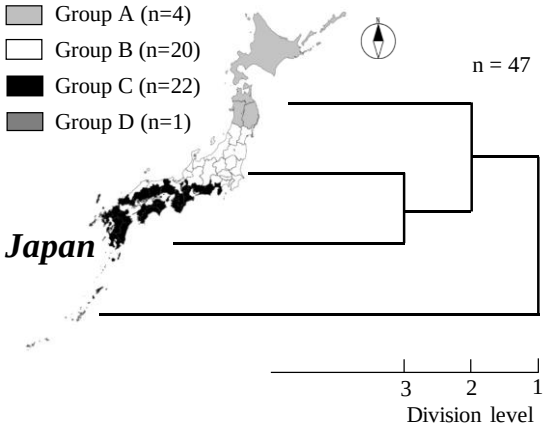

Fig.2 Classification of Japan by TWINSPAN
The 50 most-planted tall tree species in number used in each Japanese prefectures and the number of each planted was set as a variable.

3.1.3 Relationship between latitude and climate conditions

Using DCA, we seriated each group on two axes (contribution rate of Axis 1 to 2 = 0.536, Fig. 3). Along Axis 1, the groups were roughly ordered (from left): Group A, Group B, Group C, and Group D; we observed positive correlations with Kira's warmth index and annual precipitation ($p < 0.01$) and a negative correlation with latitude ($p < 0.01$, Fig. 3 and Table 2). Particularly, along Axis 1, the coordinates on the left side correspond to higher latitude, lower temperature, and lower precipitation. Along Axis 2, the groups were roughly ordered (from bottom): Group A, Group B, Group C, and Group D; they showed positive correlations with Kira's warmth index and daylight hours ($p < 0.01$ and $p < 0.05$, respectively) and negative correlations with latitude and snowfall (each at $p < 0.01$, Fig. 3 and Table 2). Particularly, along Axis 2, low coordinates correspond to high latitude, low temperature, and low precipitation in a manner similar to Axis 1. Furthermore, lower coordinates along Axis 2 correspond to higher snowfall and shorter daylight hours.

The above results lead us to conclude that latitude increased in the ascending order: A, B, C, and D. Furthermore, temperatures decreased, snowfall increased, precipitation decreased, and daylight hours decreased in the order of Groups A, B, C, and D (Fig. 3 and Table 2).

3.2 Maintenance Trends at Base of Street Trees

We investigated weed management based on the maintenance conditions at the base of street trees and confirmed the following six categories: "No installation" (n = 614) was observed most often, "Installation of artificial inorganic cover" (e.g., concrete and steel covers, n = 333), "Gardening" (n = 168), "Installation of shrubs" (n = 343), "Installation of equipment" (e.g., traffic lights, road signs, and streetlights, n = 126), and

Table 1 Characteristics of street trees in each group

	Group				*P-value* ‡
	A (n = 4)	B (n = 20)	C (n = 22)	D (n = 1)	
Total number of species	96	141	155	50	-
Native (%) †	56.3	64.5	61.3	52.0	.360
Broad-leaved evergreen tree (%)	7.3	30.4	49.0	68.0	.000
Broad-leaved deciduous tree (%)	71.9	54.6	42.6	24.0	.000
Needle-leaved tree (%)	20.8	14.8	8.4	8.0	.022
Flowering (%)	25.0	24.1	23.2	34.0	.481
Edible (%)	5.2	5.0	5.8	6.0	.986

† Varieties were included.

‡ Pearson's χ^2

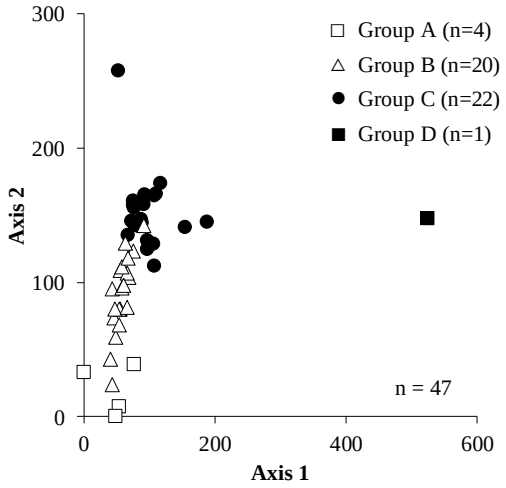

Fig.3 Seriation of each group by DCA

"Others" (n = 48, Fig. 4 and Photo 2).

4. DISCUSSION

4.1 Introduction Trends of Street Trees in Japan

We investigated the introduction trends of street trees in Japan and found that there were more broad-leaved trees introduced than needle-leaved trees (Fig. 1) and some street trees were commonly introduced across Japan; particularly, *Cerasus* sp. (such as *Cerasus* x *yedoensis*), which are representative of Japan, as evident form the results presented in this paper (Appendix 1). Only the results indicating that there are more broad-leaved trees than conifers agree with existing knowledge by NILIM MLIT [44]. Furthermore, as the majority of street trees in Japan (57.1%) are native (144 species), they might play a role in biodiversity in urban areas. Additionally, 24.6% of the street trees were flowering trees and 5.2% were trees that produce food (Fig. 1); these street tree species are highly expected to serve as recreational objects to enhance public health and welfare rather than a food source.

Meanwhile, Japan is categorized into four groups with characteristic street trees introduced under the influence of the latitude and temperature in each group. Particularly, while the introduction of street trees is conducted by the individual municipalities (prefectures, cities, towns, villages, and areas), similarities in the response in terms of latitude and temperature regarding the street trees in Japan are being observed beyond the administrative borders.

4.2 Weed Management at Base of Street Trees

The bases of street trees are often invaded by many weeds (Photo 1). Therefore, we investigated maintenance conditions at the base of street trees in consideration of weed management. The results show that the "No installation" category was very common (n = 614) at the base of street trees (Fig. 4 and Photo 2). Particularly, periodic weeding, instead of any special treatment, is the most common weed management strategy in Japan (in Fukuoka, there are periodic (once or twice a year) weeding efforts [46]). Recently, conditions such as "Installation of artificial inorganic cover" (n = 333) and "Installation of shrubs" (n = 343) have also been observed (Fig. 4 and Photo 2) and may lead to a reduction in the weeding previously mentioned.

The maintenance conditions observed at the base of the street trees also included "Gardening" (n = 168) and "Installation of equipment" (n = 126). Fig. 4 and Photo 2 show that the street trees have been used to improve the city landscape, recreational activity, installation of traffic light and road signs. Particularly, weeds may have being removal along with these maintenance and management.

Table 2 Correlations between stand scores, latitude, and climate conditions using DCA

	Axis 1 ‡	Axis 2 ‡
Latitude	−0.760**	−0.697**
Kira's Warmth Index†	0.793**	0.668**
Annual precipitation †	0.379**	0.278
Daylight hours †	−0.090	0.344*
Snowfall†	−0.282	−0.685

† Data were obtained from the Automated Meteorological Data Acquisition System (2009–2018).

‡ Pearson's correlation coefficient.

* $p < 0.05$, ** $p < 0.01$.

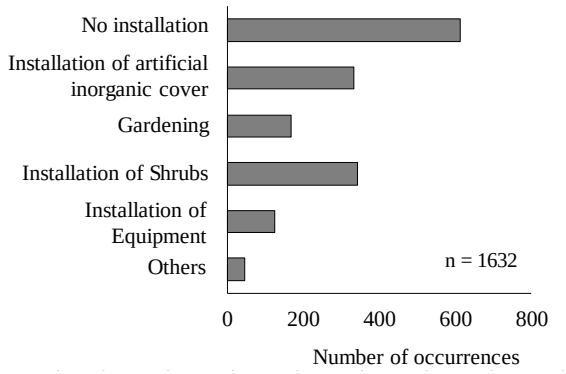

Fig.4 Maintenance conditions at base of street trees

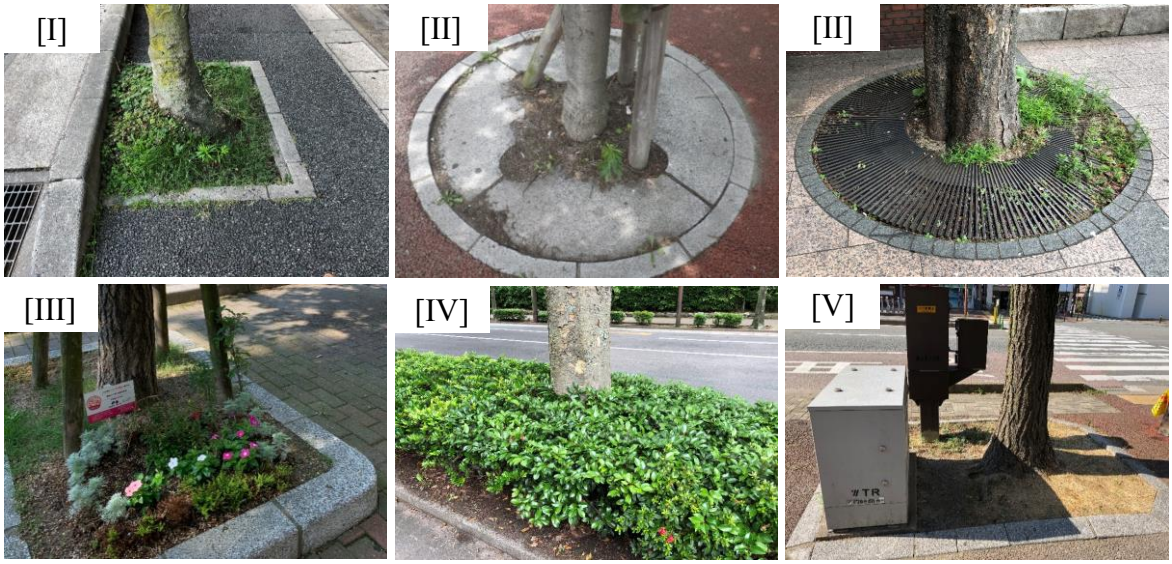

Photo 2 Different maintenance conditions at the base of street trees
[I] No installation, [II] Installation of artificial inorganic cover, [III] Gardening, [IV] Installation of shrubs, [V] Installation of equipment

Appendix 1 Street trees present in each group

Species	Family	Group				Native	Flowering	Edible
		A (n = 4)	B (n = 20)	C (n = 22)	D (n = 1)			
Cerasus sp. *1,‡	Rosaceae	V	V	V	V	●	●	
Lagerstroemia sp. *2,‡	Lythraceae	IV	V	V	V		●	
Camellia sp. *3,†	Theaceae	III	V	V	V	●	●	
Juniperus chinensis ♮	Cupressaceae	IV	IV	V	V	●		
Acacia sp. *4,†	Fabaceae	III	II	II	V		●	
Abies homolepis ♮	Pinaceae	III				●		
Abies sachalinensis ♮	Pinaceae	III				●		
Aria alnifolia ‡	Rosaceae	III				●	●	
Catalpa sp. *5,‡	Bignoniaceae	III						
Malus prunifolia ‡	Rosaceae	III					●	●
Picea glehnii ♮	Pinaceae	III				●		
Picea pungens ♮	Pinaceae	III						
Populus alba ‡	Salicaceae	III						
Quercus dentata ‡	Fagaceae	III				●		
Acer negundo ‡	Aceraceae	II						
Acer platanoides ‡	Aceraceae	II						
Acer saccharum ‡	Aceraceae	II						
Euonymus oxyphyllus ‡	Celastraceae	II				●		
Fraxinus mandshurica †	Oleaceae	II				●		
Hamamelis japonica ‡	Hamamelidaceae	II				●		
Osmanthus sp. *6,†	Oleaceae	II				●		
Oxydendrum arboreum ‡	Ericaceae	II					●	
Phellodendron amurense ‡	Rutaceae	II				●		
Pinus banksiana ♮	Pinaceae	II						
Pinus mugo ♮	Pinaceae	II						
Pinus sylvestris ♮	Pinaceae	II						
Populus suaveolens ‡	Salicaceae	II				●		
Prunus sp. *7,‡	Rosaceae	II					●	●
Quercus rubra ‡	Fagaceae	II						
Syringa reticulata ‡	Oleaceae	II				●		
Thuja orientalis ♮	Cupressaceae	II						
Weigela coraeensis ‡	Caprifoliaceae	II				●	●	
Abelia sp. *8,†	Linnaeaceae		I				●	
Aesculus x *carnea* ‡	Sapindaceae		I					

Appendix 1 Continued

Species	Family	Group				Native	Flowering	Edible
		A (n = 4)	B (n = 20)	C (n = 22)	D (n = 1)			
Carpinus tschonoskii ‡	Betulaceae		I			●		
Cercis chinensis ‡	Fabaceae		I				●	
Chamaecyparis obtusa ♮	Cupressaceae		I			●		
Chamaecyparis obtusa ♮	Cupressaceae		I			●		
Chamaecyparis pisifera ♮	Cupressaceae		I					
Chamaecyparis pisifera ♮	Cupressaceae		I			●		
Deutzia crenata ‡	Hydrangeaceae		I			●		
Dracaena sp. *9, †	Asparagaceae		I					
Euonymus sp. *10, †	Celastraceae		I			●		
Hypericum sp. *11, †	Guttiferae		I				●	
Ilex serrata ‡	Aquifoliaceae		I			●	●	
Kerria japonica ‡	Rosaceae		I			●	●	
Koelreuteria paniculata ‡	Sapindaceae		I			●		
Larix kaempferi ♮	Pinaceae		I			●		
Picea jezoensis ♮	Pinaceae		I			●		
Quercus acuta †	Fagaceae		I			●		
Tilia cordata ‡	Malvaceae		I					
Tilia platyphyllos ‡	Lecythidaceae		I					
Tilia x *vulgaris* ‡	Malvaceae		I					
Erythrina crista-galli ‡	Fabaceae			II			●	
Phoenix sp. *12, †	Arecaceae			II				●
Podocarpus macrophyllus ♮	Podocarpaceae			II				
Pterocarya sp. *13, ‡	Juglandaceae			II		●		
Aphananthe aspera ‡	Cannabaceae			I		●		
Arecaceae sp. *14, †	Arecaceae			I				
Aucuba sp. *15, †	Aucubaceae			I		●		
Butia sp. *16, †	Arecaceae			I				
Buxus sempervirens †	Buxaceae			I				
Cinnamomum daphnoides †	Lauraceae			I		●		
Citrus sp. *17, †	Rutaceae			I		●	●	●
Daphniphyllum teijsmannii †	Daphniphyllaceae			I		●		
Dendropanax trifidus †	Fabaceae			I		●		
Erythrina x *bidwillii* ‡	Fabaceae			I			●	
Euonymus sieboldianus ‡	Celastraceae			I		●		
Eurya emarginata †	Theaceae			I		●		
Ficus superba †	Moraceae			I		●		
Gardenia jasminoides †	Rubiaceae			I		●	●	
Hibiscus rosa-sinensis ‡	Malvaceae			I			●	
Ilex latifolia †	Aquifoliaceae			I		●		
Juniperus scopulorum ♮	Cupressaceae			I				
Laurus nobilis †	Lauraceae			I				
Litsea japonica †	Lauraceae			I		●		
Loropetalum chinense †	Hamamelidaceae			I		●	●	
Magnolia figo †	Magnoliaceae			I			●	
Malvaviscus penduliflorus †	Malvaceae			I			●	
Nageia nagi †	Podocarpaceae			I		●		
Nandina sp. *18, †	Berberidaceae			I		●		
Olea europaea †	Oleaceae			I				●
Osmanthus fragrans †	Oleaceae			I				
Paulownia kawakamii ‡	Paulowniaceae			I				
Phoenix canariensis †	Arecaceae			I				
Phoenix roebelenii †	Arecaceae			I				
Phoenix sp. *19, †	Arecaceae			I				
Phyllostachys sp. *20, †	Poaceae			I		●		
Pinus parviflora ♮	Pinaceae			I		●		
Pistacia chinensis ‡	Anacardiaceae			I				
Populus tremula ‡	Salicaceae			I		●		
Pyracantha sp. *21, †	Rosaceae			I				
Rhaphiolepis sp. *22, †	Rosaceae			I		●		
Spiraea cantoniensis ‡	Rosaceae			I			●	
Syagrus romanzoffiana †	Arecaceae			I				

Appendix 1 Continued

Species	Family	Group				Native	Flowering	Edible
		A (n = 4)	B (n = 20)	C (n = 22)	D (n = 1)			
Toona sinensis ‡	Meliaceae			I				
Toxicodendron succedaneum ‡	Anacardiaceae			I		●		
Araucaria heterophylla ♮	Araucariaceae				V			
Bauhinia sp. *23, †	Leguminosae				V	●		
Bombax ceiba ‡	Malvaceae				V		●	
Callistemon sp. *24, †	Myrtaceae				V		●	
Calophyllum inophyllum †	Clusiaceae				V		●	
Casuarina stricta †	Casuarinaceae				V			
Ceiba pentandra ‡	Bombacaceae				V			
Ceiba speciosa ‡	Bombacaceae				V		●	
Cerbera manghas †	Apocynaceae				V	●		
Cocos nucifera †	Arecaceae				V			●
Delonix regia ‡	Fabaceae				V		●	
Erythrina variegata ‡	Fabaceae				V	●	●	
Ficus bengalensis †	Moraceae				V			
Ficus benjamina †	Moraceae				V			
Ficus microcarpa †	Moraceae				V			
Heliotropium foertherianum †	Boraginaceae				V	●		
Hibiscus tiliaceus †	Malvaceae				V	●	●	
Koelreuteria henryi ‡	Sapindaceae				V		●	
Millettia pinnata †	Fabaceae				V	●		
Neodypsis decaryi †	Arecaceae				V			
Palaquium formosanum †	Sapotaceae				V			
Pandanus boninensis †	Pandanaceae				V	●		●
Pinus luchuensis ♮	Pinaceae				V	●		
Planchonella obovata †	Sapotaceae				V	●		
Satakentia liukiuensis †	Arecaceae				V	●		
Senna surattensis †	Fabaceae				V		●	
Tabebuia rosea ‡	Bignoniaceae				V		●	
Terminalia catappa ‡	Combretaceae				V	●		
Thespesia populnea †	Malvaceae				V	●	●	
Abies firma ♮	Pinaceae	II	I			●		
Acer buergerianum ‡	Aceraceae	IV	V	V				
Acer rubrum ‡	Aceraceae	II	I					
Adonidia merrillii †	Arecaceae			I	V			
Aesculus x *carnea* ‡	Hippocastanaceae		I	I			●	
Aesculus hippocastanum ‡	Hippocastanaceae	III	II	I				
Aesculus turbinata ‡	Hippocastanaceae	V	V	III				
Ailanthus altissima ‡	Simaroubaceae	II	I	II				
Albizia julibrissin ‡	Leguminosae	III	II	I				
Alnus hirsuta ‡	Betulaceae	II	I					
Alnus japonica ‡	Betulaceae	II	I					
Amelanchier asiatica ‡	Rosaceae		I	I			●	
Others (114 species)	-	(55 species)	(104 species)	(98 species)	(15 species)	(82 species)	(25 species)	(6 species)

Frequency: I, <20; II, <40; III, <60; IV, <80; V, ≦100

*1~24 The following species were used in the analysis: *1 *Cerasus* x *yedoensis*, *2 *Lagerstroemia indica*, *3 *Camellia japonica*, *4 *Acacia dealbata*, *5 *Catalpa ovata*, *6 *Osmanthus heterophyllus*, *7 *Prunus salicina*, *8 *Abelia* x *grandiflora*, *9 *Dracaena fragrans*, *10 *Euonymus japonicus*, *11 *Hypericum patulum*, *12 *Phoenix dactylifera*, *13 *Pterocarya rhoifolia*, *14 *Washingtonia robusta*, *15 *Aucuba japonica*, *16 *Butia yatay*, *17 *Citrus unshiu*, *18 *Nandina domestica*, *19 *Chrysalidocarpus lutescens*, *20 *Phyllostachys reticulata*, *21 *Pyracantha coccinea* *22 *Rhaphiolepis indica*, *23 *Bauhinia japonica*, *24 *Callistemon rigidus.*

† Broad-leaved evergreen tree

‡ Broad-leaved deciduous tree

♮ Needle-leaved tree

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