Research article

Impact of Street Tree Base Management on the Plants Colonizing Street Tree Bases in Western Japanese City

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Abstract The space at the base of street trees (hereafter referred to as "street tree bases") is invaded and colonized by a diverse plant population, primarily consisting of native species. As such, it is implied that street tree bases contribute to urban biodiversity. Various types of street tree bases exist (hereafter referred to as "street tree base types"). These include trees with garden beds at their bases, and trees with bases covered by artificial structures. However, there is a lack of information regarding the plants that invade and colonize street tree bases and comprehensive research is required in this direction. Therefore, we conducted a study involving street tree bases (n=104) and we examined the effects of street tree base types on the plant species that colonize the bases of street trees, in Fukuoka City, one of Japan's five largest cities. In addition, the street tree base's contribution to urban biodiversity was examined and was based on the presence of buried seed populations. Our results show that many plants that were not found in other types invaded and colonized in each street tree base type, forming a plant community that differed from other types. We believe that street tree bases can further increase urban biodiversity by establishing various street tree base types and management of their street tree bases. In addition, it was found that buried seed communities were present in many street tree bases indicating that they also serve as urban soil seed banks.

Keywords street tree base type, urban biodiversity, nature positive, buried seed

INTRODUCTION

The development of natural spaces (Ishii et al., 2010; Xiu et al., 2020), overfishing (Wolanski et al., 2020; Zhang et al., 2022), alien species (Mohammad et al., 2013; Lucero et al., 2022), climate change (Kapuka et al., 2022; Zhang et al., 2022), and other factors have contributed to the destruction of natural habitats and seriously affected ecosystems. As a result, the concept of 'nature positive', which is an ecological concept based on the prevention and restoration of biodiversity loss, has received increased worldwide attention in recent years (Ermgassen et al., 2022). In order to realize 'nature positive', it is necessary to not only protect spaces with healthy ecosystems, but also to create biodiversity within urban areas (Birkeland, 2022).

Studies on the creation and maintenance of urban biodiversity have been conducted in woodlands (Ishii et al., 2010; Muluneh and Worku, 2022), temples and shrines (Imanishi et al., 2005), rivers (Cheang et al., 2020; Hwang et al., 2021), gardens (Oishi, 2019; Prendergast et al., 2022), green roofs (Furuno et al., 2021a; Durà et al., 2023), road gaps (Uchida et al., 2014), street trees (Hotta et al., 2015; Jian et al., 2021), and other urban environments.

Additionally, several studies have examined the creation of urban biodiversity in the space around the roots of street trees (hereafter referred to as “street tree bases”). The findings of these studies show that herbaceous and woody plants invade and colonize street tree bases from other environments (Furuno et al., 2014a; Furuno et al., 2014b; Furuno et al., 2022; Omar et al., 2018). Since many of these colonizers are native species, street tree bases can play a role in increasing urban biodiversity (Furuno et al., 2014a; Furuno et al., 2014b; Furuno et al., 2022; Omar et al., 2018). Although the spatial scale of each of these spaces is very small and does not contain many plant species, the cumulative impact of these street tree bases on urban biodiversity is considered to be comparable to that of large urban green spaces (Furuno et al., 2022). This is consistent with the findings of the Single Large or Several Small patches controversy in which a single large area of space is considered effective in creating biodiversity, while there are some findings that multiple small areas of space are effective (Bolgovies et al., 2019; Deane et al., 2020; Murakami et al., 2005). However, there is still much that is unknown about the plants that invade and colonize street tree bases and more knowledge is required.

There are various types of street tree base (hereafter, “street tree base types”), some have garden beds at their bases, and some have their bases covered by man-made structures such as iron grating, at the base (Furuno et al., 2021b). However, no studies have explored the relationship between “street tree base types” and “invasive plants.”

OBJECTIVES

The purpose of this study was to gain new insights into how street tree bases affect urban biodiversity. We explored the effects of the aforementioned street tree base types on the plant species that invade and colonize these bases. In addition, we report the results of an investigation into the contribution to urban biodiversity of seeds buried in the soil at the street tree bases.

MATERIALS AND METHODS

Invading and Colonizing Plants

The study was conducted in Fukuoka City, Fukuoka Prefecture in western Japan (Fig. 1). Fukuoka City (33°36’N, 130°25’E), which is one of Japan’s five largest cities, had a population of approximately 1.51 million people as of October 2013 (Fukuoka city, 2025).

We randomly selected 33 intersections in Chuo Ward, which is predominantly urbanized and has the lowest green coverage in Fukuoka City at 22.2% (Fukuoka city, 2009). All intersections were located in similar environments, with no large green spaces and were along arterial, prefectural or city roads. The survey targeted four street tree base types (Types A, B, C, and D) maintained within 50 m of each intersection (n=104) (Fig 1). Type A trees had bases that were not maintained (n=23), Type B trees had garden beds at their bases (n=18), Type C trees had bases that were covered by artificial structures, such as iron grating (n=31), and Type D has a narrower base of the tree due to trees being trimmed low to form hedges (n=32). Tall trees and subcanopy trees such as *Ginkgo biloba* L., *Ilex rotunda* Thunb., *Zelkova serrata* (Thunb.) Makino. were planted in Types A, B, and C, and species resistant to trimming such as *Rhaphiolepis indica* (L.) Lindl., *Abelia x grandiflora* (Rovelli ex André) Rehder, *Camellia japonica* L. were planted in Type D (Table 1). There were 24 unique tree species (including Ericaceae sp. and Rosaceae sp.) which were assigned to one to three street tree base types (Table 1). We placed quadrats over each street tree base and recorded the invading/colonizing plant species in the quadrats. The size of the quadrats was adjusted to the conditions at each street tree base (Type A: 1.4 m^2 on average, Type B: 1.8 m^2 on average, Type C: 2.2 m^2 on average, Type D: 2.2 m^2 on average). The survey was conducted from early September to mid-October 2013.

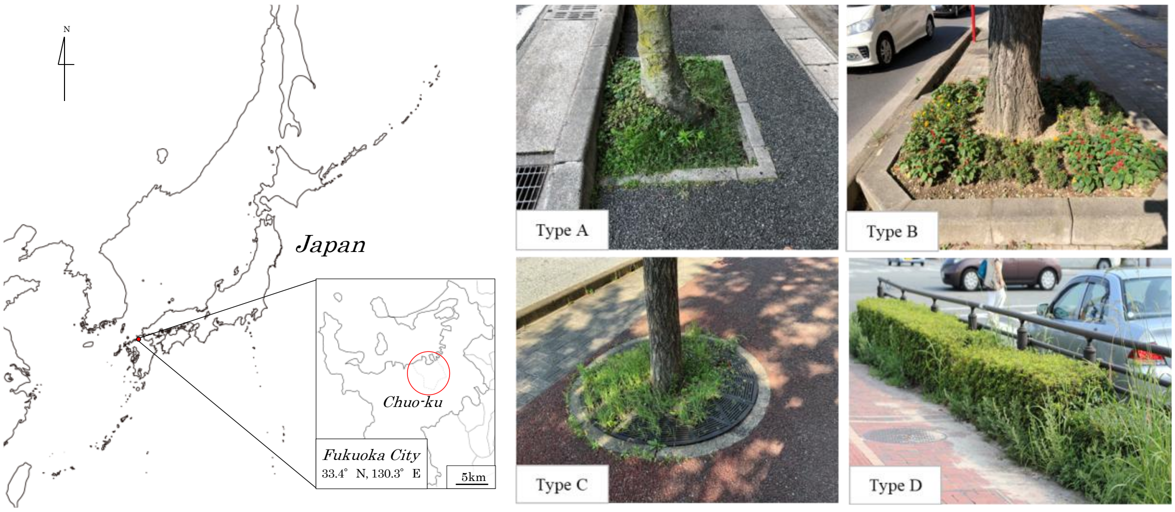

Fig. 1 Location of the study site in Fukuoka city, Fukuoka prefecture, Japan and targeted street tree base types

Table 1 Street tree species in each street tree base types

Species	Family	Street tree base types †			
		A (n=23)	B (n=18)	C (n=31)	D (n=32)
Abelia x *grandiflora* (Rovelli ex André) Rehder *	Caprifoliaceae				11
Acer buergerianum Miq.	Sapindaceae	5	2		
Aesculus hippocastanum L.	Sapindaceae			1	
Aesculus turbinata Blume	Sapindaceae			1	
Aesculus x *carnea* J.Zeyh.	Sapindaceae			2	
Camellia japonica L. *	Theaceae				3
Diospyros kaki Thunb.	Ebenaceae		1		
Elaeocarpus zollingeri K.Koch	Elaeocarpaceae	1	2	2	
Eurya emarginata (Thunb.) Makino *	Theaceae				1
Fraxinus griffithii C.B.Clarke	Oleaceae		2	3	
Ginkgo biloba L.	Ginkgoaceae	6	3	8	
Ilex rotunda Thunb.	Aquifoliaceae	5	4	7	
Liquidambar styraciflua L.	Altinglaceae			2	
Lithocarpus edulis (Makino) Nakai	Fagaceae	1	1		
Magnolia kobus DC.	Magnoliaceae			1	
Machilus thunbergii Siebold	Lauraceae	1			
Pieris japonica (Thunb.) D.Don *	Ericaceae				1
Pinus thunbergii Parl.	Pinaceae		1		
Pittosporum tobira (Thunb.) W.T.Aiton *	Pittosporaceae				3
Rhaphiolepis indica (L.) Lindl. *	Rosaceae				11
Toona sinensis (A.Juss.) M.Roem.	Meliaceae	1			
Zelkova serrata (Thunb.) Makino	Ulmaceae	1	1	3	
Ericaceae sp. *	Ericaceae				2
Rosaceae sp.	Rosaceae	2	1	1	
Total number of species		9	10	11	7

Notes: † Values are planting locations by street tree base type

Buried Seed

To assess buried seed, topsoil samples were collected from any of the selected street tree bases (n=86).

Furthermore, the pH and Electrical conductivity (EC) of the topsoil were 7.7±0.5 and 0.05±0.04 mS/cm, respectively, the values were approximately similar. A seeding-out test was conducted to identify seeds buried within the collected topsoil. In the seeding-out test, 500 ml of vermiculite was placed in a vinyl pot (top diameter: 105 mm, bottom diameter: 75 mm, height: 90 mm) and covered with 200 ml of the collected topsoil. The pots were maintained under a photoperiod of 12h dark:12h light at a room temperature of 25 degrees Celsius. For lighting, 9 fluorescent lamps with a color temperature of 4,000 K and a total luminous flux of 2,850 lm were used. The soil was sprinkled with water.

Analysis

To evaluate the impact of street tree base types on the species diversity of the plant community of street tree bases, the Shannon-Wiener diversity index, H', was calculated. The Bray-Curtis index was calculated to evaluate the similarity among the plant communities at each street tree base. In addition, to further clarify the similarity between plant communities at the base of each street tree, the non-metric multidimensional scaling (nMDS) was performed using the Bray-Curtis index. This index was calculated based on the cover scores of plant species at the base of each street tree, determined using the Braun–Blanquet total estimation method. In addition, percentage differences, such as the percentage of native species, were calculated using the $\chi 2$ test. The R software package (Ver. 4.2.1) was used to calculate Shannon-Wiener's diversity index, Bray-Curtis index, and nMDS, and SPSS Statistics Ver. 27 (IBM) was used to calculate for the $\chi 2$ test.

RESULTS

Plants that Invade and Colonize Different Types of Street Tree Bases

Invasion and Colonization Status of Plants

A total of 123 plant species (excluding Rosaceae sp.) in 46 families were observed at the bases of street trees (n=104) (Table 2). Of these species, 81 (65.8%) were native species. Also, ephemeral species (annuals, biennials and winter annuals) accounted for 50 species (40.7%), perennials for 49 species (39.8%), and woody plants for 24 species (19.5%).

By street tree base types, in Type A (n=23), 56 species in 26 families (excluding cherry species) were found, of which 16 species such as *Eragrostis minor* Host, *Eragrostis multicaulis* Steud., *Ginkgo biloba* L., *Hydrocotyle ramiflora* Maxim., *Ipomoea nil* (L.) Roth. were found only in this type and not in other types (Table 2). In Type B (n=18), 40 species (excluding cherries) in 21 families were found, 38 species in 14 families were found in Type C (n=31), and 76 species in 35 families were found in Type D (n=32), respectively (Table 2). Some of these plants, as in Type A, were not found in the other types: 12 species such as *Acer palmatum* Thunb., *Acer buergerianum* Miq., *Ambrosia artemisiifolia* L., *Calystegia japonica* Choisy in Type B, 10 species such as *Aster microcephalus* (Miq.) Franch., *Centipeda minima* (L.) A.Braun, *Cerastium glomeratum* Thuill., *Dactyloctenium aegyptium* (L.) P.Beauv. in Type C, and 39 species such as *Achyranthes bidentata* Blume, *Agrostis gigantea* Roth, *Aphananthe aspera* (Thunb.) Planch., *Boehmeria nivea* (L.) Gaudich. in Type D (Table 2). The percentage of plants not found in other types ranged from 26.3% to 51.3%.

Bray-Curtis index values ranged from 0.59 to 0.75 among the types, and the species composition of each type differed greatly, with diversity indices (H') of 3.81 obtained for Type A, 3.57 for Type B, 3.22 for Type C, and 4.5 for Type D (Tables 2 and 3, Fig. 2). Furthermore, A total of 17 species, including *Acalypha australis* L., *Artemisia indica* Willd., *Cyperus amuricus* Maxim., *Digitaria ciliaris* (Retz.) Koeler. were common to all types (Table 2).

Table 2 Plants found by street tree base type

Species	Family	Native	Herbaceous: Ephemeral [†]	Herbaceous: Perennials	Woody	Plant life types [‡]: Dormant	Plant life types: Underground organ	Plant life types: Seed dispersal	Plant life types: Growth	Street tree base types [*]: A (n=23)	B (n=18)	C (n=31)	D (n=32)
Acalypha australis L.	Euphorbiaceae	●	●			Th	R5	D3	e	0.991	0.005	0.006	0.166
Artemisia indica Willd.	Asteraceae	●		●		Ch	R2	D4	e	0.026	1.984	0.181	0.881
Cyperus amuricus Maxim.	Cyperaceae	●	●			Th	R5	D4	t	5.870	2.895	1.210	2.344
Digitaria ciliaris (Retz.) Koeler	Poaceae	●	●			Th	R4	D4	t	1.957	0.274	3.145	1.875
Digitaria radicosa (J.Presl) Miq.	Poaceae	●	●			Th	R4	D4	t	2.948	1.979	0.171	0.794
Eleusine indica (L.) Gaertn.	Poaceae	●	●			Th	R5	D4	t	2.391	0.005	0.329	0.003
Erigeron annuus (L.) Pers.	Asteraceae		●			Th(w)	R5	D1	pr	0.004	0.005	0.006	0.009
Euphorbia maculata L.	Euphorbiaceae		●			Th	R5	D3	b	2.835	1.189	2.023	0.184
Oxalis corniculata L.	Oxalidaceae	●		●		Ch	R4	D3	p	0.817	0.553	0.355	0.656
Oxalis dillenii Jacq.	Oxalidaceae			●		Ch	R4	D3	p	0.009	0.268	0.003	0.025
Paederia foetida L.	Rubiaceae	●		●		Ch	R3	D4	l	0.004	0.005	0.003	1.416
Plantago asiatica L.	Plantaginaceae	●		●		H	R3	D2	r	0.009	0.005	0.019	0.009
Setaria viridis (L.) P.Beauv.	Poaceae	●	●			Th	R5	D4	t	7.304	1.716	2.994	0.806
Solanum nigrum L.	Solanaceae	●	●			Th	R5	D2	b	0.009	0.016	0.010	0.159
Taraxacum officinale Weber	Asteraceae			●		H	R3	D1	r	2.426	0.295	0.510	0.044
Youngia japonica (L.) DC.	Asteraceae	●	●			Th(w)	R5	D1	ps	0.004	0.005	0.010	0.003
Zoysia japonica Steud.	Poaceae			●		H	R1	D4	t	0.009	0.789	6.619	1.347
Eragrostis minor Host	Poaceae		●			Th	R5	D4	t	0.004			
Eragrostis multicaulis Steud.	Poaceae	●	●			Th	R5	D4	t	0.761			
Ginkgo biloba L.	Ginkgoaceae	●			●	MM	R5	D4	e	0.217			
Hydrocotyle ramiflora Maxim.	Araliaceae	●		●		Ch	R4	D4	p	1.848			
Ipomoea nil (L.) Roth	Convolvulaceae		●			Th	R5	D4	l	0.009			
Lepidium virginicum L.	Brassicaceae		●			Th(w)	R5	D4	pr	0.004			
Lolium multiflorum Lam.	Poaceae		●			Th(w)	R5	D4	t	0.004			
Mirabilis jalapa L.	Nyctaginaceae		●			Th	R5	D4	e	0.217			
Persicaria capitata (Buch.-Ham. ex D.Don) H.Gross	Polygonaceae			●		H	R5	D4	b	0.004			
Rumex crispus L.	Polygonaceae		●			H	R5	D4	ps	0.004			
Sedum mexicanum Britton	Crassulaceae			●		Ch	R4	D4	p	0.217			
Setaria pumila (Poir.) Roem.	Poaceae	●	●			Th	R5	D4	t	0.004			
Talinum paniculatum (Jacq.) Gaertn.	Talinaceae		●			Th	R5	D4	b	0.987			
Toona sinensis (A.Juss.) M.Roem.	Meliaceae				●	MM	R5	D4	e	0.217			
Vicia hirsuta (L.) Gray	Fabaceae	●	●			Th(w)	R5	D3	l	0.004			
Wahlenbergia marginata (Thunb.) A.DC.	Campanulaceae	●		●		H	R2	D4	ps	0.004			
Acer palmatum Thunb.	Sapindaceae	●			●	MM	R5	D1	e		0.005		
Acer buergerianum Miq.	Sapindaceae				●	MM	R5	D1	e		0.005		
Ambrosia artemisiifolia L.	Asteraceae		●			Th	R5	D4	e		0.005		
Calystegia japonica Choisy	Convolvulaceae	●		●		G	R2	D5	l		0.263		

Table 2 Continued

Species	Family	Native	Herbaceous		Woody	Plant life types ‡				Street tree base types *			
			Ephemeral †	Perennials		Dormant	Underground organ	Seed dispersal	Growth	A (n=23)	B (n=18)	C (n=31)	D (n=32)
Cyperus iria L.	Cyperaceae	●	●			Th	R5	D4	t		0.005		
Diospyros kaki Thunb.	Ebenaceae	●			●	MM	R5	D2	e		0.005		
Lygodium japonicum (Thunb.) Sw.	Lygodiaceae			●		H	R2	D1	l		0.005		
Oenothera speciosa Nutt.	Onagraceae			●		Th(w)	R5	D1	ps		0.005		
Persicaria lapathifolia (L.) Delarbre	Polygonaceae	●	●			Th	R5	D4	e		0.005		
Plantago virginica L.	Plantaginaceae			●		H	R3	D2	r		0.005		
Trigastrotheca stricta (L.) Thulin	Molluginaceae	●	●			Th	R5	D4	b		0.005		
Viola mandshurica W.Becker	Violaceae	●		●		H	R3	D3	r		0.005		
Aster microcephalus (Miq.) Franch.	Asteraceae	●		●		Ch	R3	D1	pr			0.003	
Centipeda minima (L.) A.Braun	Asteraceae	●	●			Th	R3	D4	p			0.003	
Cerastium glomeratum Thuill.	Caryophyllaceae		●			Th(w)	R5	D4	b			0.003	
Dactyloctenium aegyptium (L.) P.Beauv.	Poaceae		●			Th	R4	D4	p			0.003	
Draba nemorosa L.	Brassicaceae	●	●			Th(w)	R5	D4	ps			0.003	
Elymus tsukushiensis Honda	Poaceae	●		●		H	R5	D4	t			0.161	
Geranium carolinianum L.	Geraniaceae		●			M	R5	D4	e			0.161	
Kummerowia striata (Thunb.) Schindl.	Fabaceae	●	●			Th	R5	D4	e			0.003	
Rumex japonicus Houtt.	Polygonaceae	●		●		H	R5	D4	ps			0.003	
Spergula arvensis L.	Caryophyllaceae		●			Th(w)	R5	D4	b			0.006	
Achyranthes bidentata Blume	Amaranthaceae	●		●		H	R3	D2	e				0.003
Agrostis gigantea Roth	Poaceae	●		●		H	R3	D4	t				0.003
Aphananthe aspera (Thunb.) Planch.	Cannabaceae	●			●	MM	R5	D2	e				0.156
Boehmeria nivea (L.) Gaudich.	Urticaceae	●		●		Ch	R3	D4	e				1.175
Briza minor L.	Poaceae		●			Th	R5	D4	t				0.003
Celtis sinensis Pers.	Cannabaceae	●			●	MM	R5	D2	e				0.706
Chenopodium album L.	Amaranthaceae	●	●			Th	R5	D4	e				0.003
Cinnamomum camphora (L.) J.Presl	Lauraceae	●			●	MM	R5	D4	e				1.097
Commelina communis L.	Commelinaceae	●	●			Th	R5	D4	b				0.013
Cyperus pygmaeus Rottb.	Cyperaceae	●	●			Th	R5	D4	e				0.003
Dioscorea japonica Thunb.	Dioscoreaceae	●		●		G	R5	D1	l				0.156
Dioscorea tenuipes Franch.	Dioscoreaceae	●		●		G	R5	D1	e				0.003
Elymus racemifer (Steud.) Tzvelev	Poaceae	●		●		H	R5	D4	t				0.003
Equisetum arvense L.	Equisetaceae	●		●		G	R1	D1	e				0.003
Erigeron bonariensis L.	Asteraceae		●			Th(w)	R5	D1	pr				0.003
Farfugium japonicum (L.) Kitam.	Asteraceae	●		●		H	R2	D1	ps				0.003
Ficus erecta Thunb.	Moraceae	●			●	M	R5	D2	e				0.006
Gnaphalium japonicum Thunb.	Asteraceae	●		●		H	R5	D1	b				0.003
Ipomoea triloba L.	Convolvulaceae		●			Th	R5	D4	l				0.547

Table 2 Continued

Species	Family	Native	Herbaceous		Woody	Plant life types ‡				Street tree base types *			
			Ephemeral †	Perennials		Dormant	Underground organ	Seed dispersal	Growth	A (n=23)	B (n=18)	C (n=31)	D (n=32)
Ixeris japonica (Burm.f.) Nakai	Asteraceae	●		●		H	R3	D1	ps				0.003
Ixeris stolonifera A.Gray	Asteraceae	●		●		H	R4	D1	p				0.003
Ligustrum japonicum Thunb.	Oleaceae	●			●	M	R5	D2	e				0.003
Lolium arundinaceum (Schreb.) Darbysh.	Poaceae			●		H	R3	D4	t				0.547
Machilus thunbergii Siebold	Lauraceae	●			●	MM	R5	D4	e				0.156
Magnolia kobus DC.	Magnoliaceae	●			●	MM	R5	D4	e				0.006
Paspalum dilatatum Poir.	Poaceae			●		H	R3	D4	t				0.003
Paspalum urvillei Steud.	Poaceae			●		H	R3	D4	t				0.003
Pleioblastus argenteostriatus (Regel) Nakai	Poaceae	●			●	M	R1	D4	e				0.156
Pterostyrax hispida Siebold	Styracaceae	●			●	MM	R5	D4	e				0.003
Quercus glauca Thunb.	Fagaceae	●			●	MM	R5	D4	e				0.156
Rhaphiolepis indica (L.) Lindl.	Rosaceae	●			●	N	R5	D4	b				0.003
Rorippa indica (L.) Hiern	Brassicaceae	●	●			Th(w)	R5	D4	pr				0.003
Rumex conglomeratus Murray	Polygonaceae			●		H	R5	D4	ps				0.003
Solidago altissima L.	Asteraceae			●		Ch	R2	D1	pr				0.006
Sorghum halepense (L.) Pers.	Poaceae			●		G	R1	D1	e				0.003
Toxicodendron succedaneum (L.) Kuntze	Anacardiaceae	●			●	MM	R5	D2	e				0.003
Trichosanthes cucumeroides (Ser.) Maxim.	Cucurbitaceae	●		●		G	R5	D4	l				0.547
Ulmus parvifolia Jacq.	Ulmaceae	●			●	MM	R5	D1	e				0.859
Zelkova serrata (Thunb.) Makino	Ulmaceae	●			●	MM	R5	D4	e				0.156
Bromus catharticus Vahl	Poaceae			●		H	R3	D4	t		0.005		0.003
Calystegia hederacea Wall.	Convolvulaceae	●		●		G	R2	D5	l				0.156
Capsella bursa-pastoris (L.) Medik.	Brassicaceae	●	●			Th(w)	R5	D4	ps			0.003	0.003
Carex leucochlora Bunge	Cyperaceae	●		●		M	R3	D4	t	0.761		0.568	
Causonis japonica (Thunb.) Raf.	Vitaceae	●		●		G	R2	D5	l		0.268	0.003	0.547
Cynodon dactylon (L.) Pers.	Poaceae	●		●		H	R4	D4	t	0.004			
Cyperus compressus L.	Cyperaceae	●	●			Th	R5	D4	t	0.222			0.156
Echinochloa crus-galli (L.) P.Beauv.	Poaceae	●	●			Th	R5	D4	t	1.635	0.005		
Eragrostis ferruginea (Thunb.) P.Beauv.	Poaceae	●		●		H	R3	D4	t	0.004	0.005	0.003	
Erigeron canadensis L.	Asteraceae		●			Th(w)	R5	D1	pr	0.013		0.168	0.006
Erigeron sumatrensis Retz.	Asteraceae		●			Th(w)	R5	D1	pr	0.013			0.003
Fraxinus griffithii C.B.Clarke	Oleaceae	●			●	N	R5	D2	e	0.004	0.005		0.009
Gamochaeta coarctata (Willd.) Kerguélen	Asteraceae			●		H	R5	D1	b	0.217		0.810	0.166
Gamochaeta pensylvanica (Willd.) Cabrera	Asteraceae		●			Th	R5	D1	b	0.004			
Ilex rotunda Thunb.	Aquifoliaceae	●			●	MM	R5	D2	e				0.003
Imperata cylindrica (L.) Raeusch.	Poaceae	●		●		G	R1	D1	e	0.004		1.210	0.159
Lactuca indica L.	Asteraceae	●	●			Th	R5	D1	pr	0.765		0.161	0.013

Table 2 Continued

Species	Family	Native	Herbaceous		Woody	Plant life types ‡				Street tree base types *			
			Ephemeral †	Perennials		Dormant	Underground organ	Seed dispersal	Growth	A (n=23)	B (n=18)	C (n=31)	D (n=32)
Lithocarpus edulis (Makino) Nakai	Fagaceae	●			●	MM	R5	D4	e	0.761	0.263		
Mallotus japonicus (L.f.) Müll.Arg.	Euphorbiaceae	●			●	MM	R5	D4	e	0.004	0.263		0.003
Melia azedarach L.	Meliaceae	●			●	MM	R5	D2	e				0.003
Miscanthus sinensis Andersson	Poaceae	●		●		H	R3	D1	t	0.004		0.003	2.188
Oenothera laciniata Hill	Onagraceae		●			Th(w)	R5	D4	ps	0.004			0.003
Phyllanthus lepidocarpus Siebold	Phyllanthaceae	●	●			Th	R5	D3	e	0.217	0.005		0.009
Plantago lanceolata L.	Plantaginaceae			●		H	R3	D2	r	0.004	0.006		
Portulaca oleracea L.	Portulacaceae	●	●			Th	R5	D4	b	0.009	0.921		0.163
Sagina japonica (Sw.) Ohwi	Caryophyllaceae	●	●			Th	R5	D4	b	0.004		0.010	
Setaria faberi R.A.W.Herrm.	Poaceae	●	●			Th	R5	D4	t	0.004	0.005		
Trifolium repens L.	Fabaceae			●		Ch	R4	D4	p	0.217		0.161	0.003
Zephyranthes candida (Lindl.) Herb.	Amaryllidaceae			●		G	R5	D5	r	0.004			0.003
Rosaceae sp.	Rosaceae	–	–	–	–	–	–	–	–	0.004	0.263		
Diversity indices（H'）										3.81	3.57	3.22	4.50

† Annuals, biennials and winter annuals, ‡ Plant life types were confirmed using the illustrated books by Numata, (1990) and Numata and Yoshizawa, (2002)

** Values are average cover by street tree type*

Table 3 Relationships estimated by the Bray-Curtis index for different street tree base types

	Type A	Type B	Type C
Type B	0.64	–	–
Type C	0.63	0.65	–
Type D	0.75	0.59	0.69

Notes: Calculated by average coverage of each species

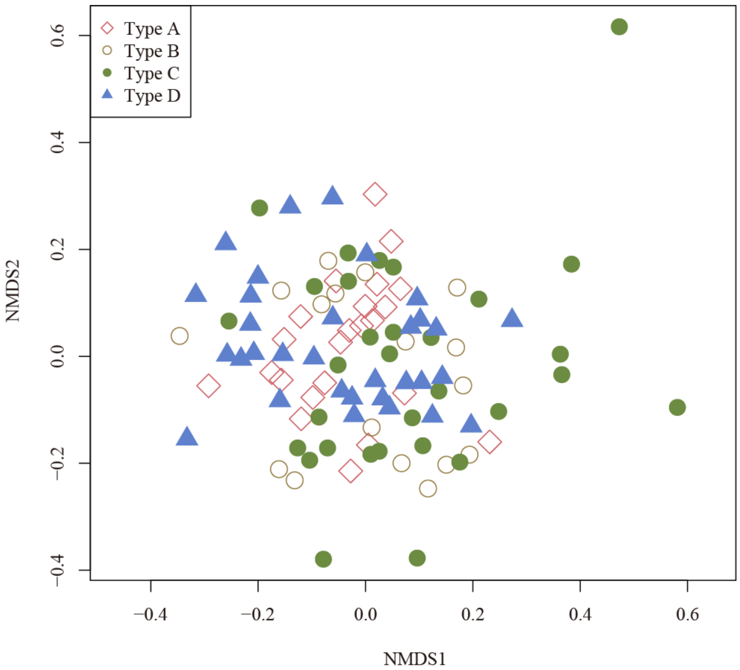

Fig. 2 Survey plot shown on the non-metric multidimensional scaling (nMDS)

Plant Characteristics

No woody species were identified exclusively in Type C, indicating a significant difference in the proportion of woody species among the street tree base types ($P < 0.01$) (Table 2 and Fig. 3). In contrast, the percentage of native species exceeded 50% for all street tree base types, and the proportion of native species did not vary between types ($P > 0.05$) (Table 2 and Fig 4). The percentage of dormant types was generally highest for Th (not overwinter), followed by H (dormant buds located just above the ground), a trend consistent across all types (Fig. 5). Similarly, R3 (rhizomes short and branched, forming the narrowest contacts) and R5 (those standing alone without underground or above-ground contacts) were prominent for the underground organ type, D1 (wind or water) and D4 (gravity) for the seed dispersal type, and e (erect with a distinct above-ground main axis), b (the lower part of the stem with many branches and an unclear main axis), and t (stems growing in clusters from a plant) for the growth type (Figs. 6, 7, and 8). There were no significant differences ($P > 0.05$) among the different modes of plant life types (dormant type, underground organ type, seed dispersal type, and growth type).

Buried Seeds

Plant germination was confirmed at 84 of the 86 (97.7%) sites where topsoil was collected. Of the seeds sampled, a total of 31 plant species in 14 families were identified (Table 4). Twelve of these species, including *Cardamine occulta* Hornem., *Cotula australis* (Sieber ex Spreng.) Hook.f., *Galium gracilens* (A.Gray) Makino., *Galium spurium* L. were not observed during the field survey.

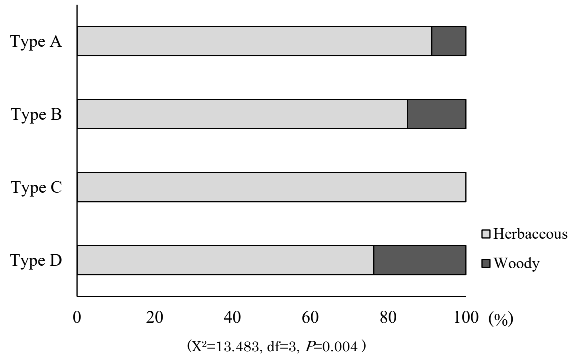

Fig. 3 Percentage of herbaceous and woody species by each street tree base type

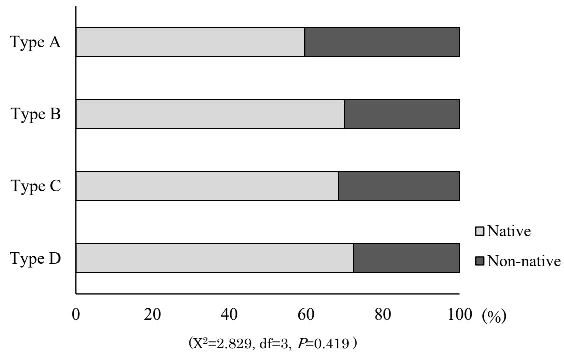

Fig. 4 Percentage of native species by each street tree base type

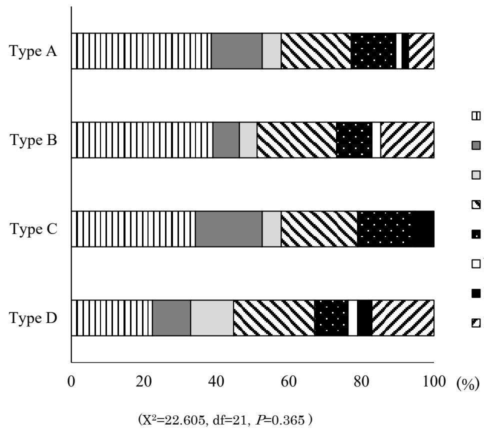

Fig. 5 Percentage of dormant type by each street tree base types

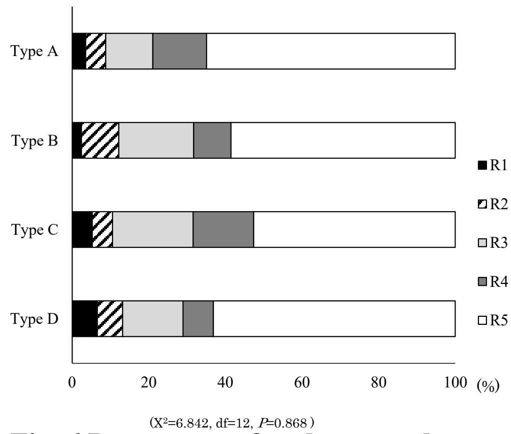

Fig. 6 Percentage of underground organ type by each street tree base type

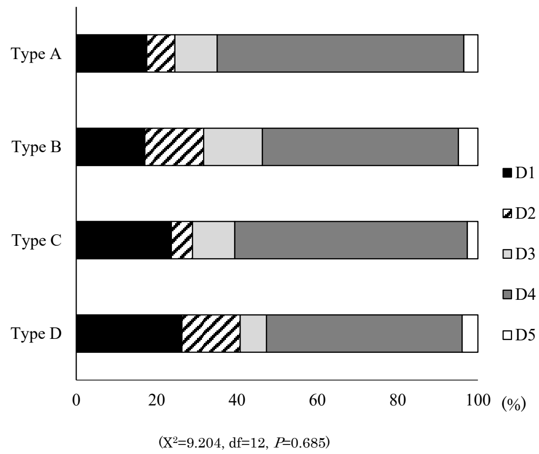

Fig. 7 Percentage of seed dispersal type by each street tree base type

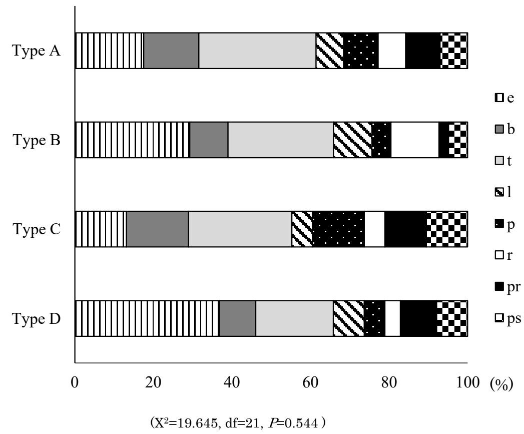

Fig. 8 Percentage of growth type by each street tree base type

DISCUSSION

A variety of street tree species planting were identified in this study (Table 1). In addition, plant communities consisting of herbaceous as well as woody species, most of which were native species, were observed at the street tree bases (Table 2). We consider that, in addition to the trees planted at the planting sites examined in this study, the street tree bases also contribute significantly to urban biodiversity. This is consistent with the findings of Hotta et al. (2015), Jian et al. (2021), Uchida et al. (2014), Furuno et al. (2014), Furuno et al. (2022), and Omar et al. (2018). On the other hand, like woodlands (Brown and Oosterhuist, 1981; Godefroid et al., 2006), grasslands (Kinugasa and Oda, 2014; Ghasempour et al., 2022), waterside (Alderton et al., 2017; Keddy and Reznicek, 1986), sand dunes (Fujiki et al., 2000), and road gaps (Sudo et al., 2009), this study also found well-developed seed banks in the soil at the street tree bases (Table 4). We believe that these street tree bases also function as seed banks in urban areas. Furthermore, since these seed banks contained the seeds of many species that were not identified in the field survey, we consider that street tree bases have the potential to further increase urban biodiversity.

Table 4 Plants confirmed to seeding-out test

Species †	Family	Species †	Family
Sagina japonica (Sw.) Ohwi	Caryophyllaceae	*Briza minor* L.	Poaceae
Acalypha australis L.	Euphorbiaceae	*Youngia japonica* (L.) DC.	Asteraceae
Stellaria neglecta Weihe *	Caryophyllaceae	*Cynodon dactylon* (L.) Pers.	Poaceae
Cardamine occulta Hornem. *	Brassicaceae	*Atocion armeria* (L.) Raf. *	Caryophyllaceae
Gamochaeta pensylvanica (Willd.) Cabrera	Asteraceae	*Trifolium repens* L.	Fabaceae
Eragrostis minor Host	Poaceae	*Veronica arvensis* L. *	Plantaginaceae
Cerastium glomeratum Thuill.	Caryophyllaceae	*Galium gracilens* (A.Gray) Makino *	Rubiaceae
Oxalis corniculata L.	Oxalidaceae	*Galium spurium* L. *	Rubiaceae
Lamium amplexicaule L. *	Labiatae	*Lygodium japonicum* (Thunb.) Sw.	Lygodiaceae
Cotula australis (Sieber ex Spreng.) Hook.f. *	Asteraceae	*Miscanthus sinensis* Anderss.	Poaceae
Oxalis dillenii Jacq.	Oxalidaceae	*Nephrolepis cordifolia* (L.) C.Presl *	Davalliaceae
Gamochaeta coarctata (Willd.) Kerguélen	Asteraceae	*Solanum nigrum* L.	Solanaceae
Erigeron sumatrensis Retz.	Asteraceae	*Thelypteris acuminata* (Houtt.) C.V.Morton *	Asplaniaceae
Capsella bursa-pastoris (L.) Medik.	Brassicaceae	*Trifolium dubium* Sibth. *	Fabaceae
Digitaria radicosa (J.Presl) Miq.	Poaceae	*Veronica peregrina* L. *	Plantaginaceae
Eragrostis ferruginea (Thunb.) P.Beauv.	Poaceae		

*Notes: n=86 (Confirmation of plant germination: n=84), † Ferns were included, * Unconfirmed in the field survey*

On the other hand, there are various street tree base types: some have garden beds at their bases, and some have their bases covered by man-made structures such as iron grating, at the base (Fig. 1). In this study, we surveyed street tree bases in similar environments and found no differences in the proportions of native species and life types in the plant communities identified in the street tree bases of each type (Table 2 and Figs. 4, 5, 6, 7 and 8). However, each type of plant community consisted of species, many of which were not found in the other types, and thus formed a plant community that differed from the others (Tables 2 and 3, Figs. 2 and 3). In other words, we consider that the maintenance of various street tree base types can further enhance urban biodiversity.

In Type D, the trees are trimmed to form a hedge, which means that plants that invade and colonize this type are less likely to be weeded out. Further, compared to Type A, the beds of Type B are maintained, which implies that there is more soil disturbance due to weeding and digging of the soil to plant flowers. In Type A, nothing is maintained at the street tree bases, but in Type C, the street tree bases are covered with artificial structures such as iron grating, which is thought to suppress the growth of invading and colonizing plants. In other words, the environment of the street tree bases differs greatly depending on the street tree base types, and this is considered to be a factor in the establishment of diverse plant communities.

On the other hand, 17 species, such as *Acalypha australis* L., *Artemisia indica* Willd., *Cyperus amuricus* Maxim., *Digitaria ciliaris* (Retz.) Koeler. are found in all street tree base types, (Table 2), and thus are representative of the street tree bases in Fukuoka city.

CONCLUSION

This study highlights three key findings. First, both planted street trees and their bases play a significant role in enhancing urban biodiversity. Second, street tree bases function as seed banks within urban areas and have the potential to further boost urban biodiversity. Third, the management of street tree bases differs significantly among various base types, and these differences can lead to environmental changes that may influence the establishment of diverse plant communities.

In rapidly urbanizing areas where space for new habitats or green spaces is limited, street trees which require far less land than traditional green spaces may emerge as a promising solution for enhancing urban biodiversity. This study underscores the importance of incorporating a variety of street tree base types in urban planning to maximize their potential benefits on biodiversity. Finally, while this survey did not pinpoint the definitive characteristics of plant species that invade and colonize different street tree base types, future research will focus on characterizing these plant communities. This will help in designing street tree planting strategies that further support urban biodiversity.

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