Research

Native and exotic woody vegetation communities in domestic gardens in relation to social and environmental factors

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ABSTRACT. Vegetation in private gardens contributes significantly to plant species richness and vegetation volume across urban areas. Drivers of garden diversity and structure are complex, reflecting the diversity of social, cultural, and socioeconomic characteristics of the householders who manage their gardens, as well as their predecessors. Here we investigate the woodiness of gardens, and focus on (1) the prevalence of native versus exotic woody plants and (2) the influence of characteristics of garden owners, the gardens, and their proximity to neighborhood green spaces to identify the degree to which these factors explain patterns in native and exotic woody species communities in entire (back and front) gardens in southern temperate New Zealand. We found few consistent patterns in structure in woody species community composition. Outlying gardens were characterized by low species richness and abundance. Thirty-seven species commonly occurred across most gardens: most of these were exotic. Twelve native species were common throughout most gardens. There was significant but weak matching to social and environmental variables: vegetated area, species knowledge, and education explained pattern in native communities, whereas vegetated area, species knowledge, and householder age explained variation in exotic communities. Native trees > 5 m tall occurred in only 58% of gardens. Tall tree density was 10/ha, and 29% of gardens lacked any trees > 5 m. Tree presence was weakly (positively) associated with extent and proximity of neighborhood green space. We suggest that the legacy of previous owners' gardening practices is important to consider when identifying drivers of garden plant community structure.

Key Words: *assemblages; communities; community composition; diversity; plants*

INTRODUCTION

Vascular plant diversity in urban areas can be high, particularly in private gardens or yards, which cover substantial areas within cities (Thompson et al. 2003, Colding et al. 2006, Godefroid and Koedam 2007, Mathieu et al. 2007, Loram et al. 2008a). A number of factors influence how people manage private and community gardens, with implications for plant diversity and the provision of ecosystem services: these include the level of local ecological knowledge and sense of place (Andersson et al. 2007, Barthel et al. 2010), conformity to social and cultural norms (Nassauer et al. 2009, Marco et al. 2010, Kurz and Baudains 2012), and socioeconomic factors (Hope et al. 2003, Martin et al. 2004, Kinzig et al. 2005, Luck et al. 2009, van Heezik et al. 2013). Garden floras also depend on the characteristics of the garden itself, such as its size, with large gardens supporting a greater diversity of usages than small gardens, configuration, and the age of the house (Hope et al. 2003, Kinzig et al. 2005, Smith et al. 2005, Kirkpatrick et al. 2007, 2011, Troy et al. 2007, Loram et al. 2008b, Loss et al. 2009, van Heezik et al. 2013). Spaciousness allows for the prominence of such features as tall, wide-canopied trees, vegetable patches, compost areas, and lawns as well as unmown areas. The high species richness found in gardens can also be attributed to both the large pool of plants available to gardeners and the intensity of gardening management whereby plant species can persist singly or in very small populations (Thompson et al. 2003).

The structure, composition, and cover types of garden vegetation are likely to play critical roles in determining the quality and abundance of resources for wildlife, with informally managed green spaces such as private gardens and allotment gardens supporting greater abundance and different communities of species delivering ecosystem services such as pollination, seed dispersal, and insectivory (Andersson et al. 2007). The occurrence of native plants is also likely to determine whether gardens are useful as a resource for native animals. For example, native birds and native invertebrates have been shown to be more abundant and/or diverse in neighborhoods with native vegetation (Day 1995, Daniels and Kirkpatrick 2006a, Parsons et al. 2006, Smith et al. 2006a, Burghardt et al. 2009, Lerman and Warren 2011, Ikin et al. 2013). However, urban plant communities typically include large numbers of introduced exotic (non-native) species, which may outnumber those that are native: for example, in UK gardens about 30% of garden plants were native and 70% exotic (Thompson et al. 2003, Loram et al. 2007) while in New Zealand, in the city of Auckland, northern North Island, 29% of front garden trees were recorded as native (Meurk et al. 2009). In gardens in Hong Kong 81.9% of tree species were exotic, and they comprised 91.1% of the total tree count (Zhang and Jim 2014). The general preference for exotic plant species reflects a number of factors including colonization history in some countries, associated inherited values, familiarity, as well as socioeconomic considerations (Zagorski et al. 2004, Smith et al. 2005, Stewart et al. 2009, Rozzi 2013). Exotic species may also be more tolerant of common urban stresses, such as compact and limited soil, are often fast-growing, and have showy flowers (Kareiva et al. 2007).

Tall trees and shrubs can provide habitat for small mammals (Dickman and Doncaster 1987), birds (Jokimäki and Suhonen 1993, Daniels and Kirkpatrick 2006a, van Heezik et al. 2008, Penningon and Blair 2011), and invertebrates (Smith et al. 2006a), and they are an important generator of ecosystem services (Dobbs et al. 2011, Cameron et al. 2012, Zheng et al. 2013). Tall tree occurrence in gardens appears to be related to garden size and socioeconomic status; large gardens tend to have more trees, and trees are far less evident in low-income areas (Smith et al. 2005,

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Kirkpatrick et al. 2007). In Australia, trees greater than eight meters tall were found to be generally absent from front gardens in low-income areas, leading Kirkpatrick et al. (2007) to infer that because many tree species establish readily in gardens following wind or bird-assisted dispersal, this absence reflects deliberate tree removal.

The factors that influence the structure, composition, and cover types associated with plant communities in gardens are poorly known. To date, most of the detailed studies of vegetation have been in the UK and Australia and these have often focused on front gardens only, or on trees, mainly because of ease of visibility from the street (Cannon 1999, Thompson et al. 2003, 2004, Smith et al. 2005, 2006b, Kirkpatrick et al. 2007, 2009, Loram et al. 2008a, Zhang and Jim 2014). In this paper, we focus on entire gardens using a southern New Zealand city as a case study, and focus on woody vegetation because it represents long-term gardening decisions, is structurally complex, and likely to make a greater contribution to ecosystem services and the provision of habitat for wildlife. We set out to quantify the structure of woody vegetation communities and garden land-cover types in relation to the physical attributes of these gardens and the attributes of the householders, to investigate the factors that determine plant communities in these contexts. In particular, we aimed to establish (1) the degree to which woody native species are represented in gardens; (2) the structure (vertical distribution) of woody species and the occurrence of trees; (3) whether it is possible to identify distinct garden types on the basis of woody species community composition, both exotic and native; and (4) whether woody species community composition can be readily associated with variables describing the gardeners themselves.

METHODS

Selection of gardens
We recruited 55 householders in Dunedin (population 120,000) in southeastern South Island, New Zealand. Householders responded to advertisements placed in local newspapers, which emphasized that "Gardens of all types, sizes and condition are required." From 110 responses, we selected 55 gardens across 30 suburbs to represent different garden types and sizes. All the householders were the owners of properties that mostly included a fully detached house, usually surrounded on all sides by garden. The detached house is the most common type of urban property in New Zealand. "Property area" refers to the entire property and "vegetated area" was the total property area minus the area of the house and garage or other structures, and any paved or surfaced areas such as patios, decks, paths, and driveways, but including lawns, beds, hedges, and areas of trees and shrubs.

Measurement of plants and garden land covers
We recorded all woody plants taller than 0.5 m, identified them to species level where possible and labelled them as native or exotic. For the purposes of this study we also included tree ferns in our woody species classification because of their tree-like form. We recorded vegetation structure in height tiers: shrub (0.5 - < 2 m); single or multistemmed tree (2 - < 5 m; diameter at breast height < 10 cm); and tree (≥ 5 m). We measured the areas of all garden beds (defined by discrete plantings of shrubs, herbaceous flowers, vegetables, etc.), lawns, and hedges and

summed them to give a total for the vegetated area in each garden. We noted the occurrence of native and exotic plant species within garden beds, and ranked them relatively as follows: 0 = no native plants; 1 = very few native plants; 2 = some native plants, and 3 = many native plants.

Variables describing properties, householders, and neighborhoods
We obtained socioeconomic information by interview as follows: (1) householder age (1 = 15-24 yr; 2 = 25-34; 3 = 35-44; 4 = 45-54; 5 = 55-64; 6 = > 64yr); (2) level of education (ranked from 1 = no high school certificate; 2 = minimum high school certificate; 3 = high school entrance to university; 4 = trade certificate; 5 = tertiary graduate degree; 6 = tertiary postgraduate degree; 7 = other); (3) length of residence (years); and (4) capital value of the property, used to indicate socioeconomic status. We obtained the latter data along with the total area of each property, the distance to the nearest green space > 4 ha, and the distance to the coast from the Dunedin City Council Rating Information database (http://www.dunedin.govt.nz/services/rates-information/rates). We gave each garden a "green space rating" on a 1 to 3 scale as follows: 1 = only one or zero natural green spaces of small size (< 3 ha) within 1 km of home; 2 = two natural green spaces of small size (< 3 ha) within 1 km of home; 3 = three or more natural green spaces > 3 ha, or one very large green space.

To establish the environmental attitude and knowledge of garden owners, we also gathered data on the following variables: (1) knowledge of names of common garden plants and animals presented as images (combined score from 15 birds, 15 plants, and 15 nonavian fauna, including invertebrates, reptiles, and mammals = "CorrectID"); (2) knowledge of whether these species were native or exotic ("Correct native/exotic"); and (3) New Ecological Paradigm (NEP) scores. The latter relates to Dunlap's revised NEP scale, which is a Likert scale designed to reflect proenvironmental orientation, or "ecological worldview" (Dunlap et al. 2000) and is a widely used quantitative measure of environmental concern.

Data
We examined gardens with regard to woody plant species richness and diversity (the reciprocal of Simpson's index), and woody plant community composition, using Primer Version 6 (Clarke and Gorley 2006). Species richness is the most conceptually simple representation of biodiversity and species diversity integrates information on species richness and the relative abundance of different species. Analyses of community composition examine similarities or dissimilarities between entire assemblages, which can be missed when just focusing on richness or diversity. They can identify differences in community structure in relation to a suite of variables describing householders, their properties and their neighborhoods. SIMPROF analyses, i.e., "similarity profiles", can be used to look for clusters of gardens based on similarities in community composition, and nonmetric multidimensional scaling (MDS) clusters gardens into groups on the basis of their similarity and creates an ordination plot in which gardens are mapped such that distances between pairs of gardens reflect the relative dissimilarity of species composition. Nonmetric MDS is the most robust ordination technique available (Quinn and Keogh 2002): It is designed to graphically represent relationships between objects in multidimensional space, and can be applied in a wide variety of situations with fewer

assumptions made about the data than when using other ordination techniques (Clarke and Warwick 2001). However, examination of stress values, which provide an indication of how well the ordination represents the assemblage structure, is important when interpreting MDS configurations. Further exploration of the data (BVSTEP analysis) can reveal the key species that structure the full assemblage (Clarke and Gorley 2006). In addition, the community composition in the gardens can be matched against a number of potential explanatory variables in a BIO-ENV (Best Biota Environmental) analysis to address the question: Are the gardens that are very different from each other in their species composition, also very different in terms of a number of environmental/social variables? We carried out BIO-ENV analysis (excluding the variable "property size" as it was highly correlated with "vegetated area") to identify the combination of variables that best explained the patterns within the species assemblage and the environmental/social variables (Clarke and Gorley 2006).

These procedures require the calculation in Primer 6 of a Bray-Curtis similarity/resemblance matrix for the woody species found in all gardens, representing the calculated similarities between every pair of gardens, such that species that have significant representation in the same set of gardens are treated as "similar" (Clarke and Warwick 2001). Plant species that occurred less than five times across all gardens were removed from the data set. The matrix of species abundances across the 55 gardens was standardized against the total number of plants per garden to account for larger gardens having more plants. The matrix data were then square root transformed. Draftsman plots of the matrix of environmental variables then were used to indicate which variables required log transformation to satisfy requirements for normality.

When running the BIO-ENV analyses a total of 99 permutations were run to derive rho and p values. These analyses were executed on the full data set, and also on the native and exotic plant species separately. The tall tree, i.e., woody plants > 5 m in height, species data were also examined independently. However, as initial MDS ordinations for both native and exotic species revealed a very tight cluster of gardens, surrounded by outlying gardens in which tall trees were absent, gardens with no tall trees were excluded from these latter analyses.

RESULTS

Woody species richness, diversity, density, and vertical structure in gardens

Total woody species richness across all 55 gardens was 553 taxa, of which 272 were identified to species level, the remainder were mainly exotic horticultural specimens. Of the identified species, 93 were native (34.4%) and 179 (66.3%) were exotic. However, if all taxa are taken into account, the proportion of native species and exotic taxa approximates to 17% and 83%, respectively. The most popular woody taxa overall were roses (*Rosa* spp.) and rhododendrons (*Rhododendron* spp.). Of the top 30 most common species across all gardens, 12 (40%) were native (Fig. 1). On average, each garden contained about twice as many exotic woody species and individuals as there were native (Table 1). Simpson's diversity values were also higher for exotic than native woody species (Table 1). Species accumulation curves indicated that the total species richness across the suburban landscape was mostly

Fig. 1. The 15 most abundant woody genera/species recorded across 55 gardens; N indicates native.
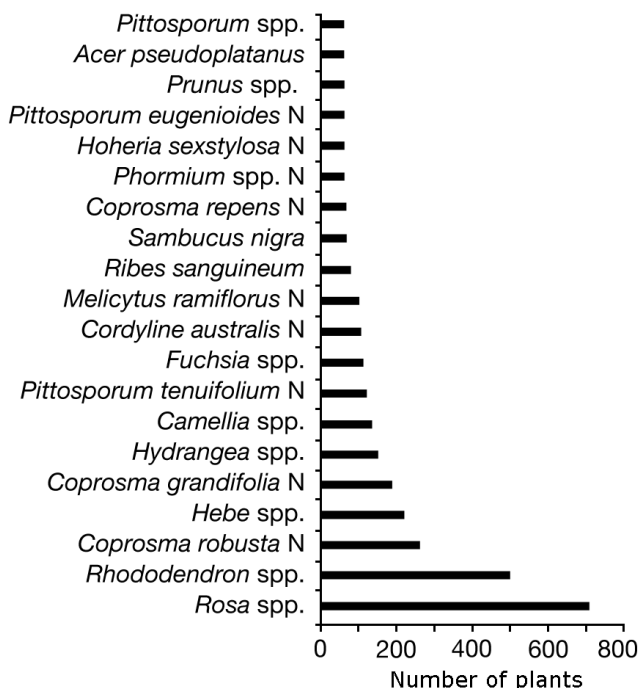
captured within the 55 gardens we sampled, for both native and exotic species (Fig. 2).

The number of woody plants in each garden ranged from 8 to 534 with the majority being less than 2 m tall (Table 1). Only 7.2% of all woody plants were ≥ 5 m tall and 30.6% were small trees (2 - < 5 m). Nearly half of the gardens (n = 23; 42%) lacked any tall native trees (≥ 5 m), and about one third (n = 16; 29%) lacked tall exotic trees (≥ 5 m; Fig. 3) with 16 gardens (29%) lacking trees ≥ 5 m in height altogether. All gardens had small trees (2 - < 5 m) although there were seven gardens (13%) that lacked native species in this height class. All gardens contained exotic shrubs and most (n = 52: 95%) native shrubs (0.5 < 2 m). The mean density of tall trees (≥ 5 m) across properties was 10.0/ha (Table 1), and the mean number of tall trees ≥ 5 m /garden was 7.8 (SD = 15.7, median = 3; range 0 - 105). Densities of native and exotic species in each height tier were similar except in the lowest (0.5 - < 2 m), where exotic shrubs were nearly twice as dense as native (Table 1). The frequency of occurrence across gardens of the 20 most abundant woody species overall, and the native species that occurred at least 20 times, is shown in Table 2 with numbers of individual plants in each height category.

Garden beds, hedges, and lawns

Gardens typically contained a number of beds (100% of gardens), patches of lawn (96%) and hedges (67%). Mean bed area was greatest, followed by lawn (Table 1). The mean rank representing native species presence in garden beds was 1.4 (SD = 0.83, median = 1), where a value of 1 indicates very few native plants and 2

Table 1. Mean and median number of species and individual woody plants in each garden, diversity (the reciprocal of the Simpson's index), the total area/garden covered by beds, hedges and lawns, and the density of woody plants/ha.

Variable	Mean	Median	SD	Range
S overall	37.8	36	22.8	5-122
S Native	12.8	12	9.6	1-50
S Exotic	25.1	22	14.9	4-72
N overall	112.5	87	94.5	11-540
N Native	42.9	25	62.7	1-434
N Exotic	69.6	56	51.2	9-262
1/Simpsons	18.2	15.2	12.4	1.6-51.6
1/Simpsons Native	8.5	7.5	5.2	0.69-22.79
1/Simpsons Exotic	13.7	10.8	9.4	1.18-49.03
No. beds	9.3	8	5.0	1-24
Bed area (m²)	273	210	208	104-1337
Hedge area (m²)	26	14	33	0-139
Lawn area (m²)	180	111	173	0-760
Density/ha				
All > 5m	10.0	32.6	2.0	
All 2-5m	35.4	76.4	17.3	
All 0.5-2m	65.7	104.9	36.4	
Native > 5m	5.5	24.0	0.55	
Native 2-5m	18.8	59.7	6.2	
Native 0.5-2m	24.9	53.1	11.1	
Exotic > 5m	4.5	10.0	1.1	
Exotic 2-5m	16.6	3.6	9.4	
Exotic 0.5-2m	40.8	70.0	22.7	

Fig. 2. Species accumulation plots of all, native, and exotic woody species (solid dot = observed S, solid triangle = Jackknifed, and open square = bootstrapped values) across the 55 gardens.
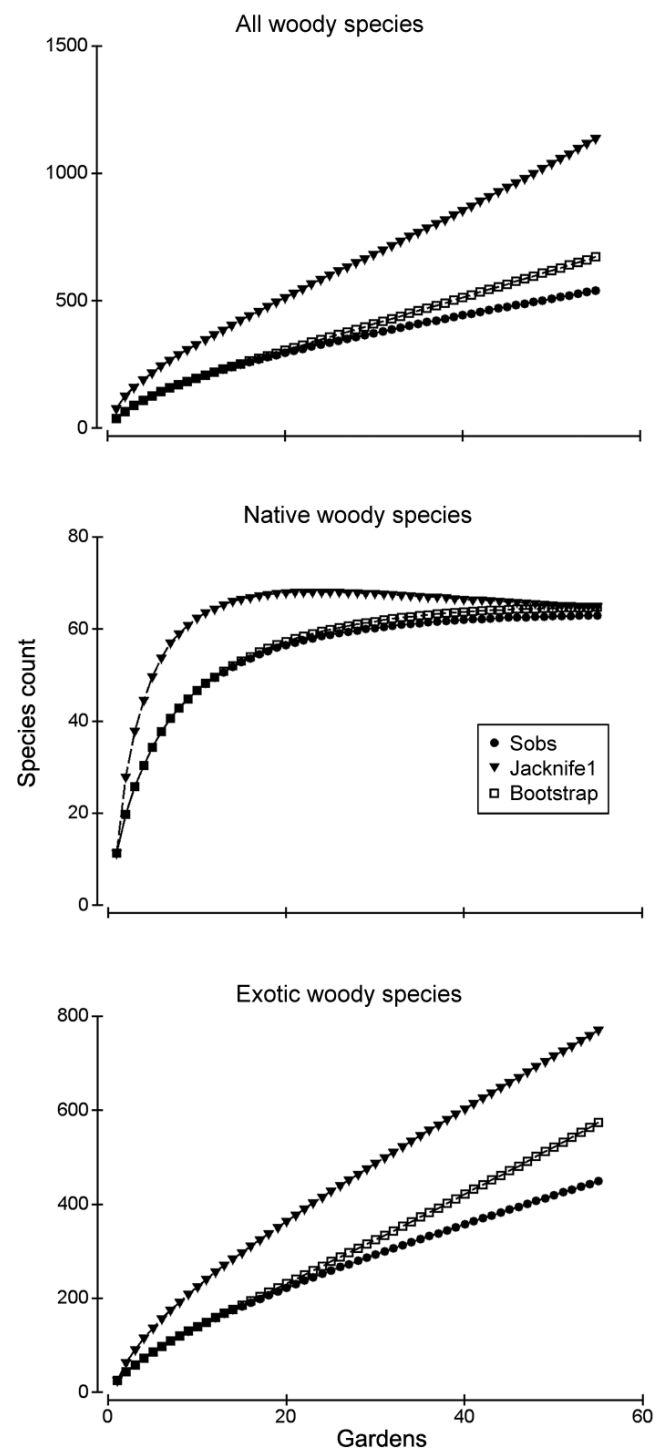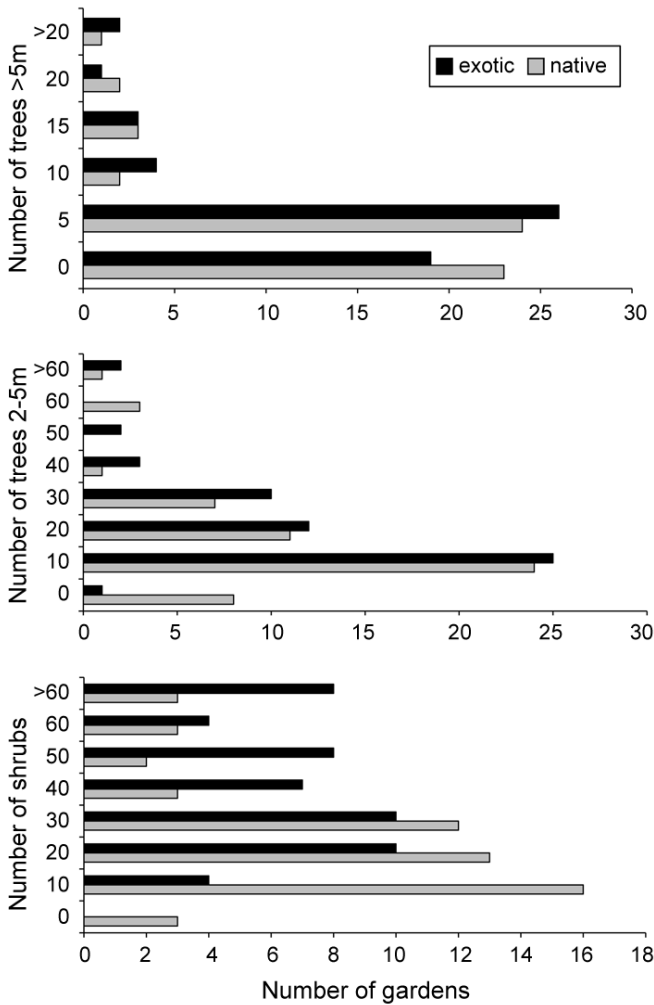

some native plants present. In all, 31 native taxa were recorded in garden beds: of these 42% of native species occurrences were ferns and 22% native grasses. Vegetables were grown in 67% and fruit in 85% of gardens with apple, pear, and plum trees in 47%, 22%, and 42% of gardens, respectively. In the study a diverse range of householders strongly emphasized the importance of vegetable growing for environmental, social, and financial reasons (Freeman et al. 2012).

Factors driving community structure across gardens

All woody species
Although a SIMPROF analysis indicated significant structure in plant community composition across the 55 gardens ($Pi = 3.339$; $P = 0.001$), the MDS ordination for all woody species (n = 160, excluding species occurring < 5 times across all gardens) did not identify distinct clusters of gardens: instead there were few differences between most (43) gardens with respect to community composition. Stress was high (0.22), reflecting the large scatter of gardens, which caused difficulty in compressing the relationships between the gardens into a small number of dimensions (Clarke and Warwick 2001). The main cluster was surrounded by 12 outliers (Fig. 4). BVSTEP identified six optimal selections of between 36 and 37 species that varied very little from each other, and which occurred in the gardens in the central cluster. The

Fig. 3. Distribution of different height classes of woody vegetation across 55 gardens.

Table 2. Total number (N), number within each height tier, and frequency of occurrence across gardens (%FO) of (A) the 20 most abundant species overall (N = native), and (B) native woody species occurring at least 20 times. S = shrub 0.5 - 2 m; M/ST = multi/single stemmed tree 2 - 5 m; T = Tree > 5 m. [†] > three-quarters occur in one or two gardens.

A. Species	%FO	N	Shrub	M/ST	Tree
Rosa spp.	87	709	615	74	0
Rhododendron spp.	84	500	358	115	27[†]
Coprosma robusta (N)	56	262	146	108	8
Hebe spp. (N)	78	221	190	31	0
Coprosma grandifolia (N)	5	189	78	98	13[†]
Hydrangea spp.	60	152	144	8	0
Camellia spp.	69	136	85	51	0
Pittosporum tenuifolium (N)	64	122	70	45	7
Fuchsia spp.	58	113	92	21	0
Cordyline australis (N)	62	107	53	37	17
Melicytus ramiflorus (N)	33	102	48	42	12
Ribes sanguineum	33	80	56	24	0
Sambucus nigra	42	69	26	39	4
Coprosma repens (N)	33	68	43	22	3
Phormium spp. (N)	31	63	61	2	0
Hoheria sexstylosa (N)	5	63	17	23	23[†]
Pittosporum eugenioides (N)	44	63	29	21	3
Prunus spp. (flowering cherry)	55	63	14	36	13
Acer pseudoplatanus	25	62	36	19	7
Pittosporum spp. (N)	31	62	37	24	1
B. Native					
Sophora spp.	31	54	34	20	0
Cyathea spp.	25	52	18	33	1
Dodonea viscosa	33	50	22	25	3
Dicksonia fribrosa	18	43	30	13	0
Solanum laciniatum	24	43	32	11	0
Myrsine australis	15	37	16	14	7
Brachyglottis repanda	9	36	21	13	2
Pseudopanax crassifolium	36	36	11	16	9
Fuchsia excorticata	25	35	7	14	14[†]
Pseudopanax colensoi	29	34	25	5	4
Sophora microphylla	47	34	10	15	9
Griselinia littoralis	18	29	16	9	4
Carpodetus serratus	20	26	8	7	11
Schefflera digitata	7	25	16	8	1
Aristotelia serrata	15	22	8	11	3
Cordyline indivisa	11	22	12	5	5
Myoporum laetum	13	21	10	11	0
Cyathea smithii	4	20	6	14	0

BIOENV analysis on the Bray Curtis resemblance matrix and the matrix of transformed environmental/social data identified four variables consistently: "Vegetated area," "CorrectID," "Correct native/exotic," and "Age" ($\rho = 0.416$, $P = 0.01$; Table 3).

Native woody species
Although the SIMPROF analysis of the 63 native woody species identified significant structure across gardens in native woody species composition ($Pi = 5.237$; $P = 0.01$), the MDS ordination revealed no distinct groupings. The stress value (0.16) indicated a potentially useful ordination. There was a central cluster of about 46 gardens, with about 9 outliers: Garden 41, which had only one specimen of one of the less common native species was positioned far from the main group (Fig. 4). BVSTEP identified 8 optimal selections of between 12 and 14 species (the 12 common to all sets are shown in Appendix 1), which were common within the central cluster of gardens but largely absent from the outlying gardens. Outlying gardens typically had very low species richness (1-3 species) and abundance (1-7 plants) of native woody plants.

The BIO-ENV analysis identified four variables consistently: "Vegetated Area," "CorrectID," "Correct native/exotic," and "Education" (Table 3) but although overall ρ was significant (0.382; $P = 0.01$) correlations were weak (0.378 - 0.382). Outlying gardens tended to have small vegetated areas and their associated householders had poor ID knowledge. Less extreme outliers also had low species richness and low abundances but they included one or two species from the group of 12 common species.

Exotic woody species
SIMPROF analysis indicated the presence of structure in the data ($Pi = 3.145$; $P = 0.01$), and the MDS ordination for all exotic

Table 3. Top four best-matching patterns within the species assemblage identified by Best Biota Environmental (BIO-ENV) of woody plants in 55 gardens. Vegarea = vegetated area; Distcoast = distance to the coast; Distgrnspce = distance to nears green space (> 4ha); Grnspcrate = green space rating within neighbourhood; NEP = New Ecological Paradigm score; CorrID = score for correctly identifying common species; Nat/exID = score for correctly discriminating between common native and exotic species; Age = age of householder; LengthRes = length of residence (yrs).

No. Variables	Correlation	Variables
All woody plants		
4	0.416	Vegarea, CorrID, Nat/ex,ID Age
5	0.416	Vegarea, NEP, CorrID, Nat/exID, Age
5	0.411	Vegarea, Distgrnspce, CorrID, Nat/exID, Age
3	0.404	Vegarea, CorrID, Age
Native woody plants		
3	0.382	Vegarea, CorrID; Nat/exID; Educ
3	0.382	Vegarea, CorrID; Nat/exID; Educ, LengthRes
5	0.379	Veg area, NEP, CorrID; Nat/exID; Educ
4	0.378	Vegarea, Grnspcerat; CorrID; Nat/exID; Educ
Exotic woody plants		
5	0.314	Vegarea, Distgrnspce; CorrID; Nat/exID, Age
3	0.306	Vegarea, CorrID, Age
5	0.304	Vegarea; NEP, CorrID, NatexID, Age
4	0.304	Vegarea, CorrID, Nat/exID, Age
Native trees > 5m		
3	0.295	Distcoast, Grnspcrat, LengthRes
4	0.294	Distscoast, Distgrnspce, Grnspcerat, LengthRes
5	0.289	Distcoast, Distgrnspce, Grnspcerat, LengthRes, Age
5	0.288	Distcoast, Distgrnpce, Grnspcerat, Nat/exID, LengthRes
Exotic trees > 5m		
1	0.207	Distgrnspce
2	0.164	Distgrnspce, Nat/exID
2	0.151	Distgrnspce, Age
3	0.142	Dstgrnspce, CorrID, Age

Fig. 4. Multidimensional scaling (MDS) ordination on woody plant community structure: all woody plants (stress = 0.22), exotic woody plants (stress = 24), and native woody plants (stress = 0.16) in 55 gardens in Dunedin. Garden numbers are indicated on the plot. Species occurring < 5 times across all gardens are excluded.
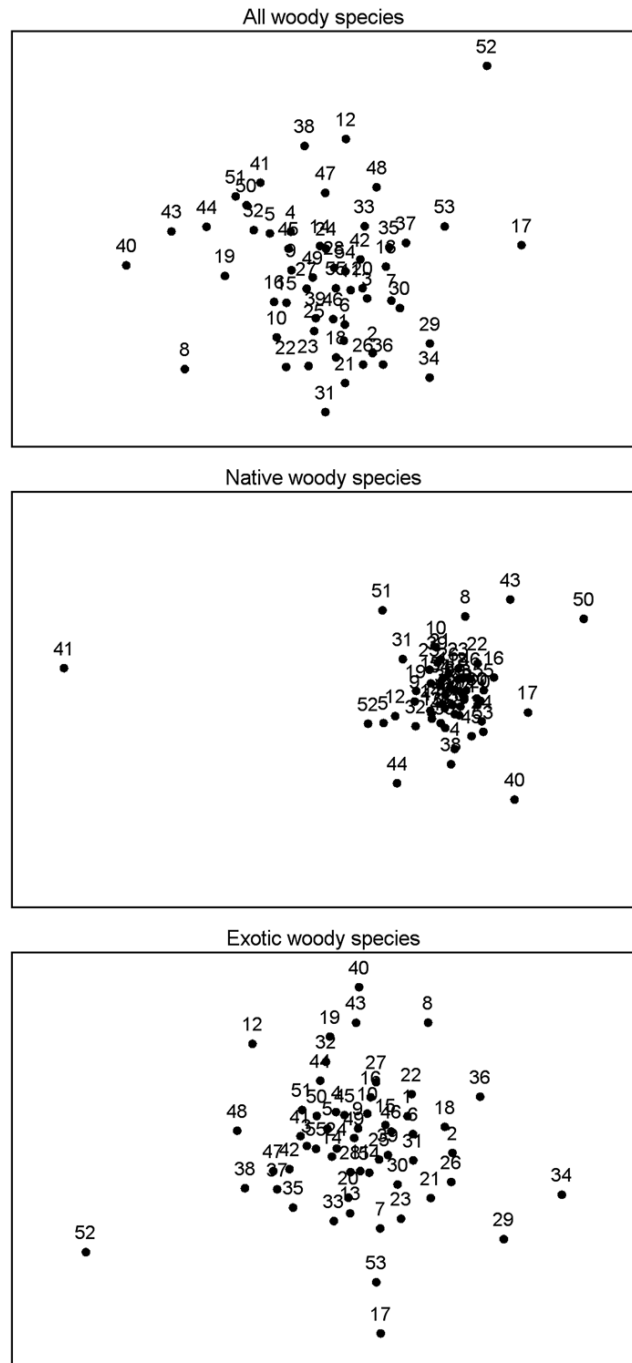

woody species (n = 97) also identified a single cluster of gardens surrounded by about 10 outliers, one of which (G52) was outstanding because it contained the lowest number of species (4) and individual exotic woody plants (12; Fig. 4). However, stress was high (0.24), again reflecting the large scatter of gardens and lack of any groupings or consistent gradient. BVSTEP identified 8 optimal selections of the same 27 species with these being largely absent from the outlying gardens. The furthest outliers tended to have the lowest species richness (1-11 species) and abundance (2-28 individual woody plants). Otherwise there were few unifying features with respect to species composition across these outliers. The BIO-ENV analysis identified four variables consistently: "Vegetated area," "Age," "Correct ID," and "Correct native/ exotic," however although the overall ρ was significant (*P* < 0.04), the highest value of ρ was still low (0.314).

Tree (≥ 5 m) presence in gardens
The ordination of native trees ≥ 5 m tall revealed one dispersed cluster of gardens (Fig. 5). Stress was low (0.09), indicating that

Fig. 5. Multidimensional scaling (MDS) ordination on trees taller than 5 m: all (stress = 0.17), native (stress = 0.16), and exotic (stress = 0.24) in 55 gardens in Dunedin. Garden numbers are indicated on the plot. Gardens lacking trees of this height were excluded.
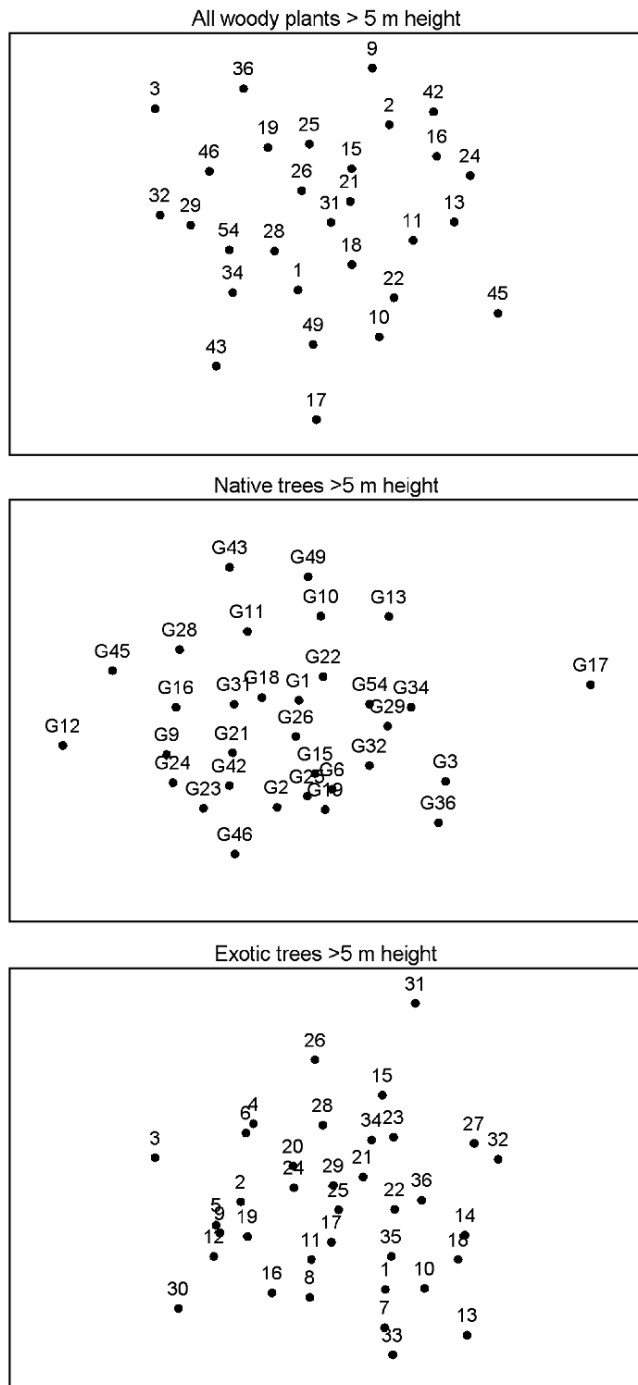
the ordination represented the assemblage structure well. From a total of 41 species, BVSTEP identified one selection of 10 species: *Carpodetus serratus, Cordyline australis, Fuchsia excorticata, Muehlenbeckia, Nothofagus fusca, Pittosporum eugenioides, Pittosporum tenuifolium, Pseudopanax colensoi, Pseudopanax crassifolium,* and *Sophora microphylla*. Outlying gardens had only one or two native trees ≥ 5 m, species that were not typical of the central cluster, e.g., tree ferns. When matched against environmental and social data, important variables were "Distance to the coast," "Green space rating," "Distance to green space," and "Length of residence": "Correct Native/exotic ID" and "Age" were less important (Table 3). Correlation values were low (0.228-0.295) but ρ (0.295) was significant (*P* = 0.02). A similar pattern emerged for exotic trees (Fig. 5), and the stress value (0.12) indicated a potentially useful ordination. BVSTEP identified 8 optimal sets of 11 species that were largely the same from a total of 42 species. Variables selected by the BIO-ENV procedure are shown in Table 3, however correlations were low (0.207 - 0.142) and ρ was 0.207 (*P* = 0.08).

DISCUSSION

Gardens are typically species-rich, but many species occur rarely: in this study 331 species occurred < 5 times across all gardens. They are also diverse in their community structure relative to more natural habitats. These features have been attributed to the large pool of species available to gardeners, the active management of gardens that allows plants to exist at very low population densities, the value placed on individualism in Western societies (Thompson et al. 2003, Daniels and Kirkpatrick 2006b), and gardeners' penchant for diverse habitats and functional spaces in gardens, e. g., ponds, sitting spaces, pot gardens, shrubberies. Despite diverse preferences, aesthetic traits related to flower size, leaf width, and foliage color are consistently favored (Kendal et al. 2012). The most common woody species in this study were roses and rhododendrons, both colorful and showy species. Nonvisual traits such as nativeness may also influence planting decisions. Although this heterogeneity of preferences has been attributed to diversity in the social environment (Kirkpatrick et al. 2007, Kendal et al. 2012), we did not identify any strong matching between the characteristics of residents that we recorded, and the community structure of the woody vegetation in their gardens. Even though we standardized the numbers of plants to account for different garden sizes, the vegetated area of the garden was present in all best matches in our analyses, indicating that larger gardens not only support higher woody species richness (van Heezik et al. 2013) but also characteristic communities of both exotic and native woody plants when compared to smaller gardens.

The variables that best matched exotic plant community composition were similar to those that matched native plant community composition, in that knowledge about species and vegetated area were important. Gardens represented in the MDS plot as positioned furthest away from the group were all small, had low species richness and plant numbers, and the majority of these householders had poor species knowledge, although a minority scored high in this respect. Education was a consistent variable in the sets matched to native plant communities, in that householders of outlying gardens with low species richness had lower levels of education. Householder age was consistently

matched to exotic woody communities: the main group of gardens were characterized by owners who tended to be older and/or more knowledgeable at identifying species. The importance of knowledge and householder age in influencing exotic woody garden community structure was also identified in a study of Swedish allotment gardens where new types of information are interwoven with social-ecological memory, enhancing gardeners' overall ecological knowledge (Barthel et al. 2010). Several householders in this study communicated their reluctance to move house and leave gardens in which they had invested efforts nurturing and planting over years, thus providing a more stable environment for woody species growth.

Variables that did not feature in the optimal sets in our analyses included the capital value of the property. Socioeconomic status is known to influence species richness and diversity (Hope et al. 2003, Kinzig et al. 2005, van Heezik et al. 2013); that it did not influence community structure indicates that preferred species do not vary significantly in relation to affluence. Other unimportant variables were NEP score (proenvironmental orientation), the amount of neighborhood green space and its proximity, the gender of the householder, and the length of residence. These variables (except gender) were included in analyses because they had been shown to influence the structural complexity of woody vegetation and exotic woody plant diversity in these gardens (van Heezik et al. 2013). However, they had no effect on the composition of the woody plant community. Gender was included because we noted that different genders were often responsible for maintaining different parts of the garden (*unpublished data*), however these preferences for different kinds of gardening did not translate into differences in woody plant community composition.

Native representation in woody plant communities

The relative values of native and exotic species are debated. Smith et al. (2006b) state that gardens probably comprise the greatest source of potentially invasive exotic species. The spread of alien species is a major cause of biotic homogenization, i.e., the increasing similarity of species across the globe as a result of concurrent increases in common widespread alien species and extirpations of endemic native species (McKinney and Lockwood 1999, Davis 2003), which is particularly evident in urban areas. In Dunedin, New Zealand 44% of the urban bird species are exotic, and they comprise just over half the total count (van Heezik et al. 2008). Biodiversity tends to increase with the use of native plants (Burghardt et al. 2009, Hostetler and Main 2010), because the diversity of native animals, e.g., birds, butterfly larvae, bees, increases with the occurrence of native plants (Mills et al. 1989, McIntyre and Hostetler 2001, Collinge et al. 2003, MacGregor-Fors 2008). Mutualistic relationships between native plants and native birds mean many woody plants are reliant on birds for dispersal and pollination, and the local maintenance of native bird numbers is important for this to continue (Kelly et al. 2010). However, some exotic plants can be important resources for native wildlife (Shapiro 2002, French et al. 2005, Daniels and Kirkpatrick 2006a, Smith et al. 2006b) and exotic birds can contribute to dispersal and pollination (Kelly et al. 2010).

Some argue that a "pronative tyranny" has developed out of a proposed link between native plant advocacy and anti-immigrant "nativism," and that landscape professionals should not feel constrained to use native species over more attractive exotic species (Hitchmough 2011, Mastnak et al. 2014). Others argue that the value that people place in native plants may be seen in the context of a contemporary response to a history of "botanical colonization," whereby the natural landscape was replaced with an English landscape (Mastnak et al. 2014). New Zealand's indigenous vegetation, especially in lowland areas where urban areas are mostly located, has experienced significant removal of native forests (Meurk and Swaffield 2000). Native plant advocacy in California has developed out of a wider concern about species decline and wildlife conservation (Mastnak et al. 2014); a similar process has taken place in New Zealand, where a greater sense of national identity is achieved by planting species "of this place."

Exotic plant species of all types are very common in urban landscapes: 40% of plant species richness in Europe, 43% in Burundi, 45% of species in home gardens in Brazil, and between 18% and 34% in U.S. cities (Pyšek 1998, Wania et al. 2006, Akinnifesi et al. 2010, Bigirimana et al. 2011, Knapp et al. 2012). Native species are also usually outnumbered in private gardens: across five UK cities 30% of the garden flora and about a third of the 50 most frequently occurring species were native (Thompson et al. 2003, Smith et al. 2006b, Loram et al. 2008a, Knapp et al. 2012). Native representation in gardens in this study was even lower than in the UK. Gardens typically contained twice as many exotic as native species, and a number of gardens had no native woody plants at all. Moreover, in our analyses we only quantified woody species: native presence of herbaceous species in garden beds was poor, and in New Zealand lawns only 13% of the total species richness has been found to be native (Stewart et al. 2009). This suggests that in New Zealand the valuing of natives as a process is much more delayed than that in Europe, where urban ecology is more developed as a discipline and is part of the national consciousness, with strong urban wildlife movements (Breuste et al. 1998).

The optimal subset of native woody species that characterized most of the pattern across the 55 gardens included only 12 - 14 species, also about half the number identified as the optimum set for exotic species (27). These numbers are low in relation to the potential pool of native woody species that could be planted in gardens, although the national native vascular flora (approx. 2500 species) is vastly outnumbered by exotics (30,000; Meurk et al. 2009). Over half of the top 20 most abundant woody plants across all gardens were native, but frequency of occurrence of two of these species was very low (5%), as virtually all individuals were found in one garden. The average frequency of occurrence of native woody species across all gardens was 28%.

When garden owners were surveyed as to their predilection for native and exotic vegetation, most expressed a preference for native plant species or a mix, but this is not necessarily reflected in the composition of their gardens (van Heezik et al. 2012). In Australia, preference for native plants varied considerably with some householders strongly disliking native plants (Kendal et al. 2012). Conservation attitudes tend to be associated with a preference for native plants in gardens (Head and Muir 2006, Zagorski et al. 2004), however the householders in our study showed only a weak positive association between proenvironmental orientation and native species richness (van Heezik et al. 2013).

In another southern temperate city in New Zealand, Stewart et al. (2009) found native trees and shrubs were common in private woodland gardens, particularly in the lower height categories, and suggested sites such as these were "hotspots" of native woody diversity. They attributed the abundance of native woody species in residential gardens to a number of factors, including education programs and the rise of dedicated native plant nurseries, as well as natural regeneration, involving dispersal from nearby reserves by exotic and native birds. Our results, which represent the entire spectrum of garden types, suggest that although these highly diverse "hotspot" gardens exist (2/55 gardens in this study) they are relatively infrequent, and there is certainly scope for greater diversity of urban-tolerant native plants in gardens. We found no relationship between proximity to diverse green spaces and native communities, indicating that either dispersal is not occurring or that naturally dispersed native seedlings are weeded out, a practice reported by Doody et al. (2010).

Tree community composition
Private trees make up a large proportion of the urban forest in Australia, the U.S., and Canada (Kirkpatrick et al. 2013, Pearce et al. 2013). They provide many benefits such as contributing to ecosystem services and human well-being, and providing important habitats for wildlife (Bolund and Hunhammar 1999, as cited in Davies et al. 2009, Fernández-Juricic and Jokimäki 2001, Stagoll et al. 2010, Dobbs et al. 2011, Millward and Sabir 2011, Nordh et al. 2011, Zheng et al. 2013), however they are frequently removed by residents for a variety of reasons, with the result that the urban forest is highly dynamic (Kirkpatrick et al. 2013). This dynamic turnover may be the reason behind the higher proportions of potentially tall trees we found in the 2 - 5 m height category, if trees are more likely to be removed when they become tall. The influence of neighbors may be a deciding factor also with boundary concerns regarding potential damage from fallen trees and branches as well as unwelcome shading effects.

Large, old trees make a disproportionate positive contribution to above-ground biomass, carbon storage, the removal of particles from the air, and the reduction of storm water runoff (Schmitt-Harsh et al. 2013); however, in this study only a small proportion of woody plants were > 5 m in height (7%), and more than a quarter of gardens (29%) lacked any trees of this size. Taller trees were more likely to be exotic than native, with nearly half of all gardens (42%) lacking native trees of this size. The mean density of trees (> 5 m high) across properties was 10.0/ha: this is low relative to Australian gardens, where the density of trees (> 4-5 m) in six cities ranged from a low of 56/ha in Hobart to 109/ha in Melbourne (Kirkpatrick et al. 2011). Trees may be used to provide shade in Australia, which has a hotter climate than Dunedin, where householders' preference for sun can mitigate against the presence of large trees in close proximity to homes. However, frequency of occurrence was similar: about three-quarters (75% in Australia and 71% this study) of gardens contained one or more trees, considerably more than in the UK where an average of 54% gardens across a number of cities had trees taller than 3 m (Davies et al. 2009). The average number of trees within a garden was higher in our study (8, median = 3) than across the UK (2.4) probably reflecting greater garden sizes: 190 m² in the UK cf. 486 m² in our study (Smith et al. 2005, Davies et al. 2009, van Heezik et al. 2013).

Income and education level of residents are positively associated with greater tree abundance in Australian gardens (Kirkpatrick et al. 2007, 2011 Luck et al. 2009, Kendal et al. 2012), and explain a proportion of the variation in woody species diversity and structural complexity in the gardens in Dunedin (van Heezik et al. 2013). We found no similar association with tree community composition, despite the fact that many garden owners (n = 18) reported removing and planting trees for a variety of reasons. Instead we found weak but significant positive associations with extent and proximity of neighborhood green space for both native and exotic tall trees, and distance to the coast and length of residence in relation to the number of native tall trees. Stewart et al. (2009) found greater regeneration of woody species in gardens close to reserves, and this may to some extent explain the positive associations between woody plant communities and both green space and distance from the coast, because there were no reserves close to the coast. However, the direction of causality is often difficult to determine because it is likely that people who appreciate plants are more likely to choose to live in vegetationally diverse parts of the city. Householders that have been in their residence for long periods of time can demonstrate stronger relationships between preferences for traits and the species in their gardens because they have had sufficient time to create a garden in line with their aesthetic vision (Kendal et al. 2012). The association between length of residence and numbers of tall native trees in our study was complex: the two most outlying gardens in the ordination for native tall trees were associated with particularly long residence (G12, 63 years), whereas a third outlier was associated with very short residence (G17, 4 years). All householders who had lived less than 7 years in their properties had gardens with fewer than five tall native trees, however only a proportion of residents who had resided at their address for more than 20 years (2/13, 15%) had more than three native tall trees on their property.

CONCLUSION
Most gardens in our study had similar woody plant communities comprised of a group of mainly exotic species, and few tall trees. The popular suite of species largely reflects aesthetic preferences for colorful flowers and large glossy leaves, and explains the absence of many native species, which are less "showy." The most commonly occurring native species (*Sophora* spp.) is one of the most colorful and is an "attractant" for one of New Zealand's favorite bird species, the tui (*Prosthemadera novaezelandiae*; http://www.newstalkzb.co.nz/auckland/news/nbnat/117240029-tui-new-zealand-s-favourite-bird). Socioeconomic status, which has been shown in a number of studies to influence species diversity, was not important in driving community composition. Wealth may be associated with greater use of professional landscapers, who may plant a suite of exotic species in keeping with a "theme," however none of the householders in this study had used a professional landscaper. There is scope for greater native representation in gardens but this requires a change in values. During the course of this study and through a process of interactive dialogue and feed-back we noted an increase in knowledge and shift in gardening practices in 64% of householders, with 40% reporting a greater understanding of wildlife, and 26% actually making changes, 13% to support native biodiversity (van Heezik et al. 2012). Householders within any urban area are a diverse group, and the choices they make reflect

a diversity of values, personal histories, socioeconomic status, social-ecological knowledge, and social and cultural traditions. Moreover, householders value their gardens for different reasons (Larson et al. 2009, Freeman et al. 2012). An important consideration is that most gardens are not created from a blank canvas when people acquire a new residence; instead there is typically an ongoing process of small changes, resulting in an assemblage that is the product of a series of compromises and decisions in response to needs, fashions, and values that may change over time. This legacy of previous management most likely strongly influences current vegetation cover and structure (Luck et al. 2009) and tree presence in neighborhoods (Troy et al. 2007) and probably explains much of the lack of pattern in woody species community structure across gardens.

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Appendix 1. Species identified by BVSTEP as explaining most of the pattern in the full data set (in alphabetical order).

Exotic species

Acer palmatum
Acer pseudoplanatus
Amelancha canadensis
Camellia
Clematis spp.
Cotoneaster
Feijoa
Fuschia spp.
Geranium spp.
Hibiscus spp.
Hydrangea spp.
Jasmine pp.
Laurus spp.
Lavandula spp.
Magnolia spp.
Malus domesticus
Prunus sp. (flowering cherry)
Prunus sp. (plum)
Quercus sp.
Rhododendron spp.
Ribes grossularia
Ribes sanguineum
Rosa spp.
Sambucus nigra
Sorbaria sp.
Taxus baccata
Yucca sp.

Native species

Coprosma repens
Coprosma robusta
Cordyline australis
Cyathea spp.
Dodonea spp.
Phormium spp.
Hebe spp.
Melicytus ramiflorus
Pittosporum spp.
Pittosporum eugenioides
Pittosporum tenuifolium
Sophora microphylla