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Urban domestic gardens (IX): Composition and richness of the vascular plant flora, and implications for native biodiversity

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ABSTRACT

Garden floras interact with native biodiversity by providing resources for wildlife and by acting as a source of non-native species. Understanding the composition and richness of garden floras will help evaluate the relationships between these floras and the wider environment. The composition and richness of vascular plant floras were measured in a stratified sample of 61 urban, domestic gardens in Sheffield, UK, based on complete garden inventories. The entire garden flora contained 1166 species, of which 30% were native and 70% alien. Across gardens, aliens showed lower occupancy than natives, comprising 79% of the species recorded only once. The garden flora contained 146 plant families, which included 72% of the native, naturalised or recurrent casual families recorded in the wild in Britain and Ireland. Gardens contained on average 45% natives, irrespective of garden size. Garden area explained 30% of the variation in species richness within individual gardens. Doubling garden size led to an increase in species richness of 25%. The garden flora comprised 10% annuals, 63% biennial/perennials, 18% shrubs and 8% trees; shrubs were disproportionately composed of alien species. The floras of urban domestic gardens probably form the greatest source of potentially invasive alien plants. However, the plants found in domestic gardens have closer affinities with the uncultivated flora than is often perceived, and their role for wildlife in gardens deserves reassessment. Declines in garden size that result from recommendations on the density of new housing are unlikely to have major consequences for plant richness in gardens.

1. Introduction

The floras of private gardens associated with houses are among the more unusual forms of botanical assemblage. Compared to most naturally developing communities, these domestic garden floras are diverse mixtures of both planted and volunteer species, containing a very high proportion of aliens (Díaz-Betancourt et al., 1987; Thompson et al., 2003). Humans have an apparently overwhelming influence on the assembly of garden floras, one reason, perhaps, that garden plants are rarely viewed from an ecological perspective.

Data on entire garden floras are, nonetheless, needed to inform two principal ecological issues. First, there is increasing recognition of the potential value of gardens to biological diversity (Owen, 1991; Miotk, 1996; Mason, 2000; Gaston et al., in press), and domestic gardens are now included in

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numerous UK conservation initiatives (Local Biodiversity Action Plans, e.g., London Biodiversity Partnership, 2001), but knowledge about them remains poor. Since gardens probably contribute the greatest extent of vegetated land ('green space') in cities (Gaston et al., in press), then the composition and configuration of such landcovers will probably exert a strong influence on the pools of species that temporarily use, colonise, or persist in urban areas.

Vegetation plays a key role in urban environments by providing food, breeding sites and shelter for animals and plants, and also by modifying microclimate. The identity of plants may be less important than growth form or architecture in delivering many of these functions, e.g., cover for small mammals (Dickman, 1987). Here, the determinants of landcover composition in gardens, of which garden size is of overwhelming importance (Smith et al., 2005), will have a substantial effect. However, the taxonomic or native status of plants may be important in determining the strengths of relationships with associated organisms, e.g., herbivores, nectarivores (Kuschel, 1990; Corbet et al., 2001; French et al., 2005). In such cases, quantified descriptions of the occurrence and abundance of individual plant taxa are required for understanding how garden floras may affect wildlife.

The second reason for learning more about the composition of garden floras is the economic and ecological importance of invasive alien plants (Manchester and Bullock, 2000; Defra, 2003). Harmful effects due to non-native species are now regarded as one of the greatest threats to biological diversity worldwide (IUCN, 2000), and ornamental plants comprise more than 40% of widespread invasive plant species, far exceeding the share due to plants introduced for other purposes (Weber, 2003). In the UK only 1% of plant introductions are self-sustaining outside cultivation, and just 0.1% lead to widespread problems (Williamson, 1996). However, ornamental plants have been the source of many notorious invaders (e.g., in the UK *Buddleja davidii*, *Crassula helmsii*, *Fallopia japonica*, *Impatiens glandulifera*, *Rhododendron ponticum*). Given the immense costs of dealing with problem alien plants, acquiring basic knowledge about garden floras would be an important step in assessing risks to habitats outside cultivation.

Quantitative descriptions of plant assemblages in gardens, and knowledge of the factors that determine their size and membership, would contribute to a better understanding of how gardens interact with the wider environment. The need for this research is all the more urgent because the potential benefits and problems associated with domestic gardens are likely to increase in the near future. First, urbanisation is accelerating worldwide (UNDP et al., 2000). In the UK, urbanisation occurred at a rate of about 5% in the period 1998–2003 (Defra, 2004), and currently 155,000 new homes are built each year in England alone (ODPM, 2003). Although the UK government aims to reduce the percentage of house building on previously undeveloped ('greenfield') land to 40% by 2008 (DETR, 2000), an increasing area of the countryside will be influenced by the presence of gardens and their plants (the main source of alien plant introductions; Hodkinson and Thompson, 1997; Welch et al., 2001). Second, since 1997 the number of new cultivars or species available from nurseries has ranged from 5% to 10% of the total in any one year (J. Cubey, pers. comm.). Consequently, habitats outside gardens are likely to remain exposed to a reservoir of novel, potentially invasive, plants for the foreseeable future.

1.1. *Aims of the study*

There are very few sources of systematically collected data on domestic garden floras. We therefore aimed to understand better the overall composition of such floras, and how they were affected via relationships with the age, type and size of the gardens in which they occurred. This knowledge would help to assess the role of gardens in urban systems as habitats for biodiversity and as sources of plants to other areas.

The work reported here is part of the wider 'Biodiversity in Urban Gardens in Sheffield' (BUGS) project. This project surveyed habitats and biodiversity in 61 gardens across Sheffield, and aimed to evaluate the potential resources of urban gardens for biological diversity (Gaston et al., in press; Smith et al., 2005); the means of enhancing biodiversity through 'wildlife gardening' (Gaston et al., 2005); and the determinants of species richness (Smith et al., in press b) and abundance (Smith et al., in press a) of the invertebrate fauna.

Three articles have already focused on particular aspects of the Sheffield garden flora. First, using quadrat samples, small-scale plant diversity (in flowerbeds/cultivated borders) was compared with semi-natural habitats and urban derelict land (Thompson et al., 2003); second, a detailed inventory of lawn floras showed that lawns share many attributes with semi-natural habitats (Thompson et al., 2004); and third, a study of garden soil seed banks (Thompson et al., 2005). The present paper complements the above studies by taking an overview of the Sheffield garden flora, based on complete garden inventories (incorporating data for lawns). These inventories were able to include all rare species and those growth forms less likely to be sampled within quadrats (e.g., shrubs and trees). To our knowledge this is the first attempt to obtain a quantified description of the flora from a range of domestic gardens. The specific aims were:

1. Measure the size of a garden species pool and the frequency of occurrence of its members across gardens. The pool of plants available to gardeners is certainly very large, estimated at 14,000 species (Macaulay et al., 2002). However, it is unknown what proportion is actually planted in domestic gardens, and how widespread individual species may be.
2. Examine how plant families are represented across gardens, and how native and alien species contribute to composition within families. Alien plant species may still provide useful resources if they are related to native plants at a higher taxonomic level: a large proportion of herbivores select hosts within a genus or family (Hodkinson and Hughes, 1982), and 76% of British herbivores are specific to a single plant family (Ward and Spalding, 1993).
3. Understand the determinants of taxonomic richness in individual gardens, at the species and family levels. As plant species richness is a significant factor for the richness of some guilds in the garden insect fauna (Smith et al., in press b), we wished to identify the drivers of plant richness.

4. Discover whether alien species make uneven contributions to different growth forms in gardens. Woody plants are over-represented in the naturalised, alien British flora (Crawley et al., 1996), a large proportion of which is derived from garden plants. We wished to test whether this is because woody plants comprise a disproportionate number of potentially naturalising species, or because woody plants are more likely to naturalise.

2. Methods

2.1. Study site

The city of Sheffield, South Yorkshire, UK (53°23′N, 1°28′W; Ordnance Survey (O.S.) grid reference SK 38) lies in the centre of England. Residential areas in Sheffield, as in most urban areas of the UK, comprise four principal types of dwelling: blocks of apartments, or terraced (two or more adjoining dwellings), semi-detached (one adjoining dwelling), and detached (no adjoining dwellings) housing, usually built in rows. Housing nearly always incorporates a private garden, whereas apartments are much less likely to possess either a communal or a private garden. According to a random telephone sample of homes ($n = 250$), 87% of dwellings in the urban area of Sheffield possess a garden, with a mean area of 173 m^2 (Gaston et al., in press). These values are similar to national estimates, respectively, of 80% and 186 m^2 (Hessayon and Hessayon, 1973).

2.2. Sample gardens

The study was carried out in the rear gardens (hereafter called 'gardens') of private, owner-occupied houses, located throughout the predominantly urbanised region of the city (about 143 km^2, defined as those 1 km × 1 km cells having more than 25% coverage by residential or industrial zones, as judged from O.S. 1:25000 scale maps). The study focussed on rear gardens because they form the major garden component of most properties. Sixty-one gardens were selected as a stratified sample from a sample of 161 householders, derived from contacts among cleaning, clerical, technical and academic staff at the University of Sheffield, and from members of the public at lectures or displays about the project. The sample size was the maximum permitted by the constraints of other aspects of the project (e.g., faunal sampling). By stratifying the sample along key axes of interest – house age and plot size, and selecting values along the length of each axis – our method enabled us to explore the influence on plant richness of such axes, over their full ranges of variation. By this means the results from the study could be generalised to other urban areas even if the distribution of plot sizes differed. House age and plot size were the sole information used in generating the garden sample. Blocks of apartments, which generally lack private gardens, were excluded from the study. The areas of rear gardens ranged from 32 to 940 m^2 and the ages of their associated properties ranged from 5 to 165 years. Altitude was recorded to the nearest 10 m, from O.S. 1:50000 scale maps, and gardens ranged between 40 and 250 m above sea level. An *index of management intensity* in each garden was calculated by summing questionnaire responses: garden owners stated how intensely they carried out various activities (either, weak 1–5 strong, or no = 0 and yes = 1) for: weeding, pruning, watering, removing dead flower heads, collecting fallen leaves, and using fertilisers, herbicides and pesticides.

2.3. Recording the garden flora and vegetation

Gardens were surveyed in a core period between July and September 2000, and lawns in June 2001 (a single lawn was surveyed in June 2002). Lawns were defined as an area of grass mown more than once per month during the growing season, and 52 gardens possessed a lawn. Data for plants only detectable in the spring were gathered during visits for other sampling procedures, and during an interview held with each household. Principal garden dimensions were measured to the nearest 0.5 m, and a scale plan of each garden was drawn; this included the side portion on properties occupying corner plots. A complete list was made of all vascular plant taxa during the garden survey, including those in pots and ponds.

Each species was also assigned to one of the following growth forms: annual, biennial/perennial, shrub, or tree; and allocated to alien or native categories (nomenclature, form and status followed Stace (1997) where possible, otherwise Wright (1984)). Some plants were allocated to the native taxon (e.g., *Primula vulgaris*, *Aquilegia vulgaris*), even though numerous garden plants are of hybrid origin. While garden plants are often subspecies or cultivars, we did not attempt to classify plants below the species level. For example, we did not distinguish *Festuca rubra* ssp. *rubra* from the commonly sown *F. rubra* ssp. *commutata*.

The genus was recorded for each plant that could not be identified to species; if other plants occurred in the same genus, within the same garden, and could be distinguished repeatedly (e.g., within *Hebe*), they were treated as a separate species. As the plant identifiers were experienced with the British native flora, all plants that remained unidentified were assigned as aliens, which formed the majority of the positively identified, rare garden plants. Unidentified plants coming from different gardens were distinguished using reference specimens.

2.4. Garden measurements using a geographic information system (GIS)

For analysing relationships between plant species/family richness and environmental variables, a series of variables for landcover surrounding each garden was measured; this used Ordnance Survey digital 'Land-line Plus' (1:1250) maps, imported to an ArcView GIS (Environmental Systems Research Institute, Inc.). Measured for a circular area of 10,000 m^2 (1 ha) centred on each garden, the variables were: *area of roads*, *area of buildings*, and *area of domestic gardens*. The area of land not in the former categories was also measured, and termed *unclassified*, because we could not reliably interpret more detailed landcover types (including, e.g., farmland, recreational space, and semi-natural vegetation). Using 1:1250 scale aerial photographs ('Cities Revealed', The GeoInformation Group, Cambridge, UK), the *total ground area of green* *space* (non-built up, unmetalled ground, including gardens, parks, waste ground, woodland and landscaping) was measured within a 10,000 m^2 (1 ha) plot centred on each garden.

2.5. *Analyses*

Species accumulation curves were plotted for native and alien species, and for different growth forms, to identify groups showing relatively low or high levels of turnover between gardens. An average species accumulation curve was calculated for 100 randomly shuffled runs (Software used: Species conservation and richness, PISCES Conservation Ltd.), to remove the effect of sample order and to produce a smoothed curve.

Correlates of taxonomic richness in individual gardens were explored using separate, stepwise multiple regressions for the numbers of species and families. The independent variables included in the regressions were *garden area*, *garden age*, *altitude*, *index of management intensity* and the series of variables measured from the GIS: *area of roads*, *area of buildings*, *area of domestic gardens*, *area of unclassified land*, and *area of total green space*. The areas of gardens and of the GIS-derived variables were logarithmically transformed to linearise the relationship with the dependent variable.

The numbers of native and alien families occupying different proportions of the sample gardens were tested for departures from random, according to the rates of occupancy across all families in the dataset, using a *G*-test of independence (tested against χ^2 with 1 degree of freedom). The proportions of native and alien species occurring as different growth forms were similarly tested against the ratio of species for the entire dataset.

3. Results

3.1. *Size and membership of the garden flora: species*

A total of 1166 species were recorded from the 61 sample gardens, of which 344 (30.1%) were native and 798 (69.9%) were alien; the status of 24 species was uncertain in the literature (Stace, 1997; Preston et al., 2002). The accumulation curve for garden species had not reached an asymptote after 61 gardens, with more new species being added by biennials/perennials compared to other growth forms (Fig. 1). Turnover was

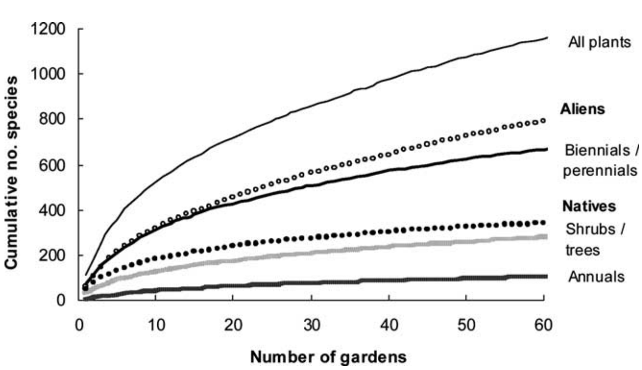

Fig. 1 – Species accumulation curves for inventories of vascular plants in 61 urban gardens, Sheffield, UK. Curves are based on 100 randomly shuffled runs.

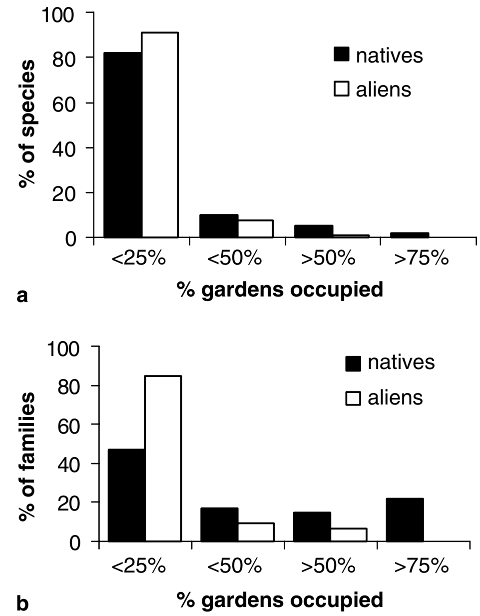

Fig. 2 – Occupancy by vascular plants in 61 urban gardens, Sheffield, UK for (a) species and (b) families.

also greater in aliens compared to natives (Fig. 1), a pattern reflected in the degree of garden occupancy: aliens comprised 387 (79.0%) of the 490 species that were only recorded once. Occupancy by aliens was generally lower than by natives (*G*-test of independence, $G = 20.16$, $p < 0.001$, Fig. 2(a)), and a surprisingly small proportion of species overall – just 2.7% of the total (31) – were found in more than half of the gardens (Table 1). Twenty-five of these widespread species were natives, nearly half of which occurred in lawns. Ninety-eight species (8.4%) were not positively identified, although they could still be distinguished from other plants. On average, 3.5 plants remained unidentified to species in each garden, ranging from 0.4% to 8.3% of each garden inventory.

3.2. *Size and membership of the garden flora: families*

One hundred and forty-six plant families were recorded in the 61 gardens. These families included 120 (72.3%) of the 166 native, naturalised or recurrent casual families recorded in the wild in Britain and Ireland (Stace, 1997). Thus a further 26 alien families recorded in gardens were absent from Stace (1997), while 46 families reported by Stace (19 alien and 27 native) did not feature in Sheffield gardens. More than half of the missing native families were aquatic/marine (10) or had a specialised life history (5, e.g., Cuscutaceae, parasitic; Monotropaceae, saprophytic; Droseraceae, insectivorous). In contrast to the data for species, the composition of garden families by status was reversed, so that the majority of families (94, 64.4%) were native and only 52 (35.6%) were alien.

While most alien and native plant species occurred in less than one quarter of the gardens, the pattern was very different for families. More than 80% of alien families, yet less than 50% of natives, occurred in less than a quarter of the gardens; and 21% of the native families were found in more than three-quarters of gardens (Fig. 2(b)). Thus alien families were sub-

Table 1 – The species occurring in more than half of the 61 gardens in Sheffield, UK

Species	Status	No. of gardens	Location
Taraxacum officinale agg.	Native	58	Lawns
Epilobium montanum	Native	56	
Poa trivialis	Native	55	Lawns
Lolium perenne	Native	51	Lawns
Holcus lanatus	Native	51	Lawns
Festuca rubra	Native	49	Lawns
Poa annua	Native	48	Lawns
Rubus fruticosus	Native	46	
Ranunculus repens	Native	45	
Hedera helix	Native	44	
Senecio jacobaea	Native	44	
Lonicera periclymenum	Native	43	
Trifolium repens	Native	43	Lawns
Agrostis stolonifera	Native	43	Lawns
Poa pratensis	Native	42	Lawns
Cardamine hirsuta	Native	40	
Buddleja davidii	Alien	40	
Primula × polyantha		40	
Aquilegia vulgaris	Native	40	
Agrostis capillaris	Native	39	Lawns
Digitalis purpurea	Native	38	
Crocosmia × crocosmiiflora	Alien	37	
Lavandula angustifolia	Alien	37	
Geum urbanum	Native	37	
Sambucus nigra	Native	34	
Rumex obtusifolius	Native	34	
Ligustrum ovalifolium	Alien	32	
Fraxinus excelsior	Native	32	
Myosotis sylvatica	Native	31	
Salvia officinalis	Alien	31	
Viola riviniana	Native	31	

Species growing mainly in lawns are indicated.

stantially more restricted in their occupancy of gardens compared to natives (*G*-test of independence, $G = 14.6$, $p < 0.001$).

Although alien families comprised about one third of family richness in gardens, relatively few plants (only 96 species: 9.0%) belonged to alien families (ignoring the 98 unidentified species whose family could not be designated). Consequently, most alien families (32, 61.5%) were represented by a single species (Fig. 3), whereas just 22 native families (23.4%) contained singletons. Native and alien families contained on average (±SD) 10.3 ± 16.6 and 1.8 ± 1.5 species (median 4 and 1 species), respectively. A relatively small number of native families contained most of the species: Asteraceae, Rosaceae, Scrophulariaceae and Poaceae, each holding more than 50 species, together contributed one quarter of the garden flora (24.8%); and the top 10 families contributed nearly half (506 species, 43.4%; Table 2). In contrast, no alien family contained more than 10 species (Table 2).

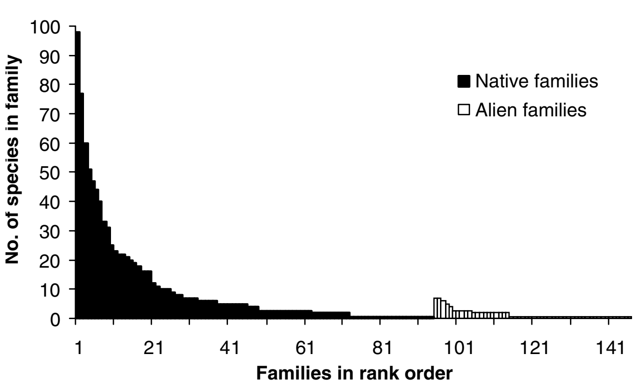

Fig. 3 – The frequency distribution of vascular plant species occurring in 96 native and 52 alien families, recorded from 61 urban gardens in Sheffield, UK.

As alien species dominated the garden flora, and relatively few came from alien families, it follows that aliens contributed substantially to the membership of native families. Twelve families native to Britain were represented entirely by alien species in the garden sample; another 23 native families comprised only natives. Fifty-nine families were mixtures, of which only 15 (25.4%) were less than 50% aliens. The proportion of a native family comprising aliens was not related to the number of species in Sheffield gardens occurring in that family (for families with at least three species, proportions arcsine square-root transformed: $F_{1,60} = 0.839$, $r^2 = 0.014$, n.s.).

3.3. *Species richness in individual gardens*

The 61 surveyed gardens contained between 41 and 264 species (mean ± 1 SD = 112.4 ± 50.0 species, median = 98 species). Although natives comprised only 30% of the total recorded species, natives experienced less turnover between gardens than aliens (see above), so that individual gardens contained on average 45.2% natives (range 23.3–87.8%). Importantly, this proportion did not change in relation to garden size ($F_{1,59} = 0.19$, $r^2 = 0.003$, n.s.), therefore large gardens were no different from small ones in terms of the proportion of natives they supported. Further, the richness of native and alien species was correlated within gardens ($r = 0.68$, $n = 61$, $p < 0.001$). Although alien species dominated the flora of each garden, only a small proportion of these aliens belonged to alien families (as seen across the entire garden flora, above), and on average 50% of the alien species also belonged to native genera. Thus most aliens in gardens had close affinities, at the family level, to native species: gardens contained on average 93.2% (range 78.6–100%) species from native families.

Garden area was the only factor, among a range of variables related to the dwelling and the surrounding environment, that was significantly related to species richness ($F_{1,59} = 26.3$, $r^2 = 0.30$, $p < 0.001$; Fig. 4(a)). When exploring this relationship further regarding status, garden area exerted a weaker influence on aliens ($F_{1,59} = 10.0$, $r^2 = 0.15$, $p < 0.01$; Fig. 4(b)) compared to natives ($F_{1,59} = 41.5$, $r^2 = 0.41$, $p < 0.001$; Fig. 4(c)). However, if those natives largely confined to lawns were excluded then the explained variation in native richness declined substantially ($F_{1,59} = 23.7$, $r^2 = 0.29$, $p < 0.001$; Fig. 4(d)). This is because garden area influences lawn area (Smith et al., 2005), which in turn is positively related to plant richness in lawns (Thompson et al., 2004). The slopes of the species–area relationships were similar, at around 0.30–0.35, regardless of status. The shallowness of the slopes meant that, as garden size increased, species density (total no. of species divided by garden area) declined (Fig. 5). Therefore,

Table 2 – The 10 alien and native plant families containing the most species, in 61 gardens in Sheffield, UK

Alien families	No. of species	% of flora	Native families	No. of species	% of flora
Berberidaceae	7	0.66	Asteraceae	98	9.18
Myrtaceae	7	0.66	Rosaceae	77	7.21
Hydrangeaceae	6	0.56	Scrophulariaceae	60	5.62
Rutaceae	5	0.47	Poaceae	51	4.78
Magnoliaceae	4	0.37	Liliaceae	47	4.40
Agavaceae	3	0.28	Lamiaceae	44	4.12
Bignoniaceae	3	0.28	Brassicaceae	40	3.75
Buddlejaceae	3	0.28	Fabaceae	33	3.09
Paeoniaceae	3	0.28	Ranunculaceae	31	2.90
Vitaceae	3	0.28	Caryophyllaceae	25	2.34
Cumulative total	44	4.12		506	47.4

The percentage contributed by each family to the entire garden flora is calculated from the 1067 species where the family was known.

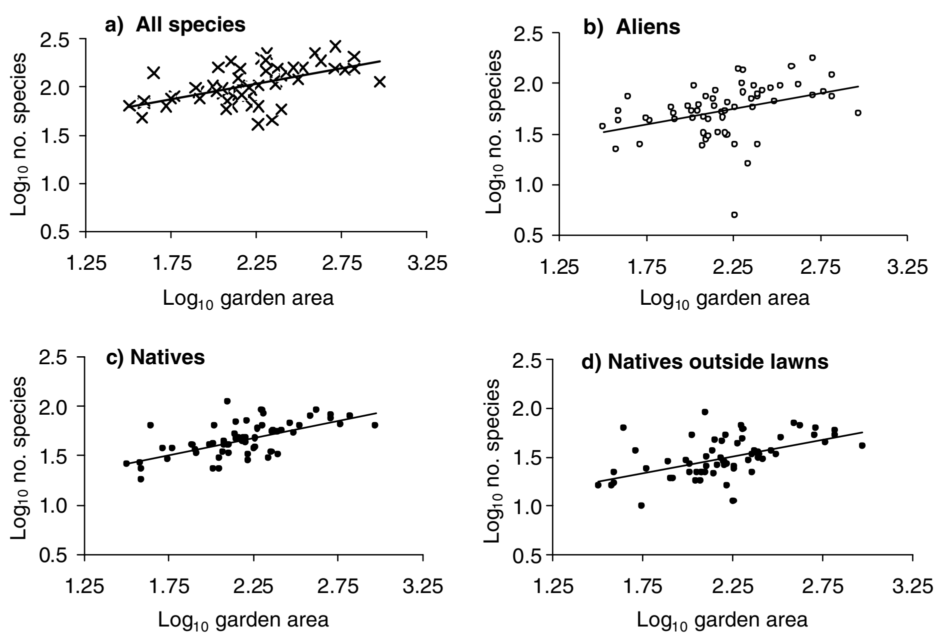

Fig. 4 – The relationship between garden area and the species richness of plants in 61 urban gardens, Sheffield, UK, for (a) all species, $y = 0.321x + 1.309$; (b) aliens, $y = 0.309x + 1.052$; (c) natives, $y = 0.346x + 0.902$; and (d) natives not confined to lawns, $y = 0.343x + 0.738$.

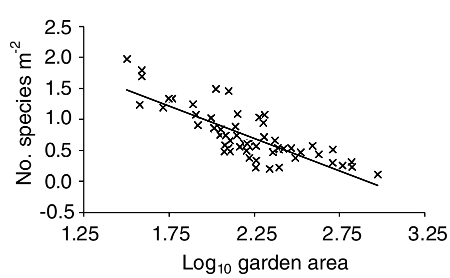

Fig. 5 – The relationship between species density and garden area ($y = -1.0521x + 3.0638$) in the flora of 61 urban gardens, Sheffield, UK.

larger gardens contained fewer species per unit area. Doubling garden size resulted in a 24.9% increase in the average number of species.

3.4. *Family richness*

A mean (±1 SD) of 43.7 ± 13.2 plant families (range 18–75 families) was recorded from the 61 survey gardens. A consequence of high turnover in alien species between gardens and of the relatively small number of species in each alien family was that individual gardens were largely composed of native families: a mean of 86.2% (range 68.1–100%). On average, gardens contained 37.3 ± 10.4 native and 6.4 ± 4.0 alien families.

As for species richness, garden area explained a substantial proportion of the variation in family richness in gardens (all families: $F_{1,59} = 18.1$, $r^2 = 0.23$, $p < 0.001$; Fig. 6(a)). Again, less variation in alien richness ($F_{1,59} = 8.97$, $r^2 = 0.13$, $p < 0.01$) was explained compared to natives ($F_{1,59} = 19.0$, $r^2 = 0.24$, $p < 0.001$; Fig. 6(b)). One property resulting from the relationships of species richness and family richness with garden area was the strong positive correlation between the two measures

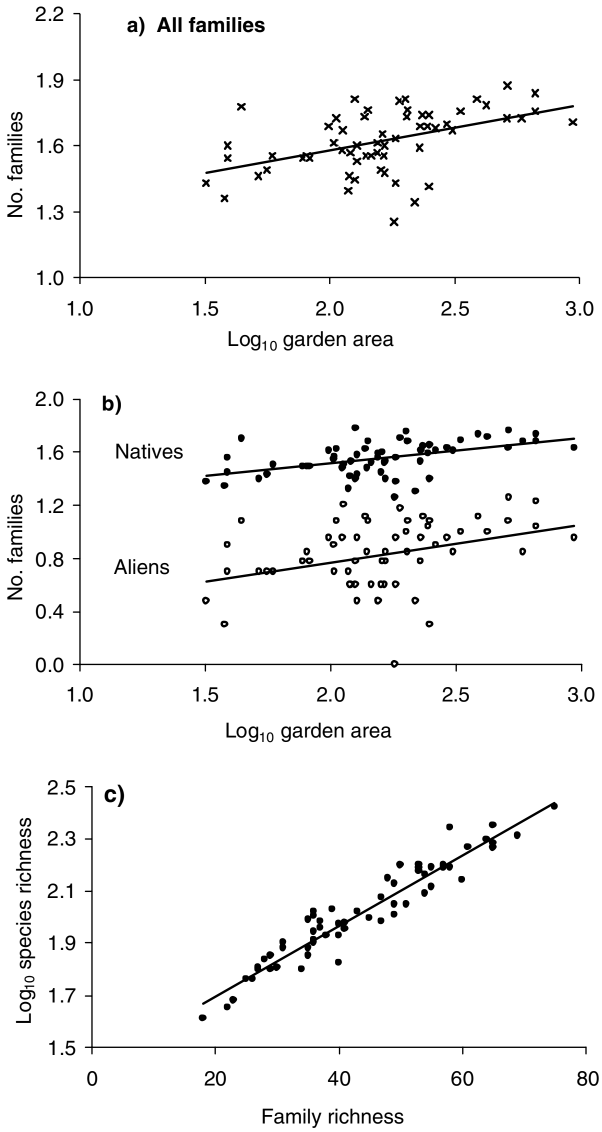

Fig. 6 – The relationships between (a) garden area and the richness of all plant families ($y = 0.208x + 1.162$); (b) garden area and the richness of aliens ($y = 0.287x + 0.193$) and natives ($y = 0.193x + 1.130$); and (c) species and family richness ($y = 0.014x + 1.428$) in 61 urban gardens, Sheffield, UK.

of richness (Fig. 6(c)). Thus family richness was a reliable predictor of species richness in the Sheffield garden sample.

3.5. *Composition by growth form*

The garden flora comprised 108 annuals (10.1%), 673 biennial/perennials (63.1%), 195 shrubs (18.3%), and 90 trees (8.4%). Generally, aliens and natives were represented in these different growth forms in proportion to their occurrence across the entire garden dataset. However, there were 30% more alien shrubs than would have been expected by chance (176 instead of 134, *G*-test of independence with Williams' correction: $G_{adj} = 44.03$, $p < 0.001$; Fig. 7). This observation is matched by the fact that the top 10 native families were wholly or largely herbaceous, yet the top 10 alien families were mostly woody (see above, Table 2).

4. Discussion

4.1. *Species richness of the garden flora*

The present study showed that the domestic garden flora of Sheffield was very rich, with 1166 species recorded from just 61 gardens, a combined area of 12,700 m^2 or 0.0127 km^2. This total exceeded the maximum number of species (1107) recorded outside cultivation in any 10×10 km^2 in Britain and Ireland (Preston et al., 2002). It also roughly equalled the entire richness of the uncultivated alien and native flora recorded for the Sheffield region: 1140 species over an area of 900 km^2 (Shaw, 1988); yet the garden flora had not reached saturation. Had we sampled more sites the garden flora would undoubtedly have continued to grow, in a large part due to aliens, with a theoretical maximum set by the pool of species available from local nurseries and by mail-order. Such a pool is certainly global in extent; one estimate of the size of the pool is the approximately 14,000 species available from nurseries registered with the Royal Horticultural Society (Macaulay et al., 2002).

There are few other studies with which to compare the size of the Sheffield garden flora. A study of 16 urban and rural private gardens in Lothian region, Scotland, revealed about 830 species in a combined area of 15,600 m^2 (Saville, 1997), although lawn plants were omitted and average garden size was much greater. The data nevertheless suggest that garden floras throughout the UK are similar in the order of magnitude of plant richness. In contrast, just 750 species were recorded in about 55,000 m^2 from 400 gardens in Mexico City (Díaz-Betancourt et al., 1987).

4.2. *Composition by aliens and natives*

Of the 750 species in Mexico City, 70% were alien – virtually the same percentage as found in the Sheffield garden flora. Similarly, the well-studied flora of one Leicestershire garden contained 60% alien species (Owen, 1991). These data indicate that domestic gardens probably exceed any equivalent area of uncultivated habitat in Britain for both the number of alien species and the proportion of the flora comprising aliens. At a national scale, the maximum number of aliens recorded in any 10×10 km^2 in Britain and Ireland is 422; and less than 1% (35 out of 3859) of squares in Britain and Ireland are composed of more than 25% neophytes (those aliens introduced since 1500) (Preston et al., 2002). The latter figures are unlikely to be solely due to natives having been recorded more thoroughly than aliens. Considering that domestic gardens probably comprise the largest areas of urban greenspace (Gaston et al., in press), they very likely form the largest source of alien plant species for potential colonisation of uncultivated habitats.

4.3. *Implications of garden plants for floras outside gardens*

Horticultural plants have exerted a huge influence as invasive species worldwide: in the USA, 85% of woody invasive plants were originally introduced for horticulture (Reichard and White, 2001), while 66% of the entire naturalised Australian

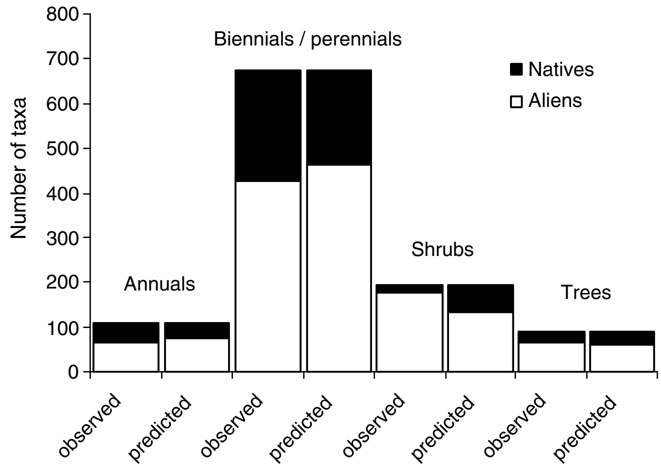

Fig. 7 – The observed and expected contributions of alien and native taxa to different growth forms in the garden flora of 61 urban gardens, Sheffield, UK.

flora derives from this source (Groves et al., 2005). In Britain, garden plants form 75% of the 100 most widespread aliens in Berkshire (Crawley, 2005), and 64% of the plants alien to Scotland (Welch et al., 2001).

It is probable that garden plants will continue to make a large contribution to change in the British flora, as they have in the past (Preston et al., 2002). While the proportion of introduced plants leading to severe problems in the UK may be low, at 0.11% (data for angiosperms, Williamson, 1996, p. 35), estimates of the number of future invasive horticultural species need to consider the rate of introduction of new species. Since 1997, 38,650 new plants have been made available through nurseries (averaging 4831 per year; J. Cubey, pers. comm.). Critically, however, it is unclear what proportion of these introductions are species, cultivars or varieties, and how many are new to the British garden flora (as opposed to new to the list, begun in 1987).

In addition, another factor influencing invasions – the number of individuals that are introduced – remains poorly known. Although the number of species sold through 30 or more nurseries has risen by almost 4 times since 1997 (J. Cubey, pers. comm.), it remains less than 3% of the total, i.e., the availability of most plants is low. Similarly, a large proportion of the Sheffield garden flora was rare, particularly aliens: 42% of species occurred only once, and 79% of these were aliens. Consequently, while gardens contain many alien species, the opportunities for the large majority to colonise outside gardens may be relatively few.

Concerning composition of the garden flora by growth form, the flora comprised nearly two-thirds biennial or perennial plants, roughly equal (and small) proportions of annuals and trees, and approximately one fifth shrubs. A disproportionate number of these shrubs were aliens. This supports the view (Crawley et al., 1996) that the disproportionate number of certain life-forms (shrubs and geophytes) in the naturalised, alien flora of Britain is due to their over-representation in the garden flora. Geophytes (plants that over-season underground, e.g., bulbs) were not analysed in the present study because of difficulties in categorising many garden perennials. Nevertheless, the evidence for shrubs implies that garden plants naturalise at random with respect to growth form.

4.4. *Plant richness in individual gardens*

Understanding how plant richness varies at the individual garden level is important for predicting how floras are likely to respond to changing trends in housing density. Garden size accounted for about a third of the variation in total species richness across gardens. However, the slope of the relationship was shallow, so that large increases in garden size resulted in only moderate changes in the size of the flora; and these increments became smaller at larger garden sizes. As rare plants are as likely to occur in low – as compared to high-richness gardens (i.e., garden floras are not nested, Thompson et al., 2003), then species turnover at different housing densities would be similar. Consequently, on average, rear gardens in an area of high density housing will contain more species than in an equivalent area of low density dwellings (larger properties would nevertheless support many more species in front gardens, which are often absent from smaller properties; Smith et al., 2005).

Garden area had a considerably stronger effect on natives ($r^2 = 0.29$) than on aliens ($r^2 = 0.15$), even when natives in lawns were ignored; such a result is likely due to garden owners exerting a greater influence over aliens compared to natives. Level of interest in gardening is probably the most important factor in determining individual garden richness, and the proportion of planted species would be a direct indication of a gardener's interest. However, a substantial proportion of species could have been planted or have occurred spontaneously – even within the same garden, and to have measured this would have required too many resources. It was nevertheless clear that gardeners could create very rich floras in walled yards, while households apparently lacking time or interest could possess large gardens with relatively few plants. Another component of a gardener's interest likely to influence species richness is their tolerance towards volunteer species; such plants could be treated as welcome additions to the flora or as weeds. Again, the ratio of planted to volunteer species may have indicated the level of acceptance of the spontaneous flora. This may be one reason that none of the measured environmental variables around gardens, or the intensity of garden management, entered the model for species richness: effects may only have been apparent on the spontaneous flora (e.g., the influence of nearby green space as a source of native species).

4.5. *Implications of the composition of the garden flora for biodiversity*

In contrast to the result for species, the garden flora contained mostly native families, and in total it contained three-quarters of the families recorded outside cultivation in Britain. Most alien families occurred in few gardens, whereas native families were much more widespread. This was reflected in family membership: less than 10% of species belonged to alien families, most alien families were represented by singletons, and the top 10 native families accounted for nearly half of the flora. On average, 87% of alien plants in a garden belonged to native families and 50% to native genera; overall, 93% of a garden's species came from native families. This affinity with the native flora is perhaps also reflected in the predominance of European or Mediterranean species among the garden aliens; these comprised 31% of the total (R.M. Smith unpublished data, but much the same as recorded for data from quadrats, Thompson et al., 2003).

Together, these results suggest that garden floras may offer many more resources to wildlife than is implied by their species composition. Incidentally, the groups of plants that were generally missing from gardens – aquatic families, and those with specialised life histories – also support disproportionately few herbivores (Ward and Spalding, 1993). One negative aspect of the relatedness between garden and uncultivated floras is the potential for ornamental plants and their trade pathways to act, respectively, as reservoirs and routes of transmission for infectious plant diseases (e.g., *Rhododendron* and *Viburnum* spp. probably being the principal hosts of certain *Phytophthora* spp. in the UK (Defra, 2005)).

The potential value of garden plants to herbivores will depend on how specific are the requirements of a particular group. Substantial minorities of British herbivorous insect families accept hosts across the same plant family, e.g., sawflies, 23%; thrips, 22%; psyllids 21%; and aphids 18% (Hodkinson and Hughes, 1982), so these portions could potentially adapt to most alien species. Although the above insect families range from 47% to 79% in the proportion of their members which feed on a single plant genus, on average 50% of the alien species in individual gardens also belonged to native genera.

A related property of the garden flora was the close relationship between species and family richness in gardens. Since 76% of British herbivorous insects are restricted to single families (based on an analysis of about 50,000 insect–host records, where host breadth within families was not specified; Ward and Spalding, 1993), then gardeners who planted more species in their gardens would have tended to enhance the range of opportunities across families too. This may be true even for plant families composed entirely of aliens in gardens, as was the case for nearly 13% of native families in the Sheffield gardens. The value of alien species, in the absence of native hosts, has been demonstrated for the urban butterfly fauna in California, where 40% of species have no known native hosts (Shapiro, 2002).

Direct evidence of the relative values of native or alien plants for garden wildlife, in terms of herbivory, is sparse and equivocal. Moths may use alien plant hosts as often as native ones in gardens, although widespread polyphagous species benefit disproportionately (Owen, 1991). The richness of leaf-miners, which tend to be specialised herbivores, is related to the richness of native plant taxa in a garden (Smith et al., in press b). Many angiosperm-feeding moths have crossed a relatively wide taxonomic gap by adapting to exotic gymnosperms (conifers) in plantations (Fraser and Lawton, 1994). This indicates that elements of the native fauna will often succeed on aliens in gardens (e.g., on buddleia, Buddlejaceae; Owen and Whiteway, 1980).

Whatever the suitability of native and alien plants in gardens, whether they are used will also depend on their accessibility to herbivore populations. While rare native plants may effectively extend their ranges when planted in gardens, this activity is of questionable wider conservation value if plants do not interact with their natural assemblages of associated herbivores, parasites and predators. For example, when broom *Cytisus scoparius* occurs as an alien it acquires an equal abundance of generalist herbivores, but fewer specialist species, compared to in its native range (Memmott et al., 2000). Even if natural habitat occurs nearby, native plants may fail to recruit their associated specialist faunas in garden environments (Kuschel, 1990). Further, although the Sheffield gardens contained 45% native species, species unique to lawns comprised a large fraction of such natives – about one third on average (Thompson et al., 2004). Therefore, the value of native lawn species may be limited unless associated faunas can tolerate the typically intense management regimes of lawns. Without doubt, alien garden plants can influence the distributions of both indigenous and non-native fauna, either by providing alternative hosts (e.g., *Thera juniperata* on junipers (*Juniperus* spp.) (Ward, 1977)) or by acting as the means of establishment (e.g., the moths *Phyllonorycter leucographella* on firethorn (*Pyracantha* spp.) (Emmet, 1989); and *Argyresthia* spp. on cypresses (Cupressaceae) (Agassiz, 2004)).

5. Conclusions

The present study shows that plant assemblages in urban domestic gardens in the UK are dominated by alien species. However, most of these aliens are scarce, and aliens have closer taxonomic affinities with natives than is often perceived. Thus a large proportion of the plants in domestic gardens may potentially interact with native herbivores. Advisors on wildlife gardening often recognise that alien plants can be important sources of fruit, pollen and nectar, informed by research (e.g., Prŷs-Jones and Corbet, 1991, p. 91; French et al., 2005). However, natives are almost exclusively recommended as food plants (e.g., Baines, 2000; RSPB, 2005; English Nature, 2003; The Wildlife Trusts/RHS, 2005). A critical assessment of the relative values of alien and native plants to herbivores would strengthen the evidence base for wildlife gardening advice; as well as understanding better the possible impact of a changing national flora on biodiversity.

The behaviour of garden owners is likely to be a much stronger factor than garden size in determining floral richness. Therefore, if recommendations for building at higher density (from <30 to 30–50 dwellings ha^{-1} (DETR, 2000)) cause gardens to become smaller in the UK, this need not cause substantial changes in plant species richness. Gardens of all sizes have the potential to be useful for wildlife, since both planting and, importantly, management decisions depend heavily on the owner. Such decisions are influenced by education, fashion, and advice.

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