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Urban domestic gardens (I): Putting small-scale plant diversity in context

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Abstract. As part of a larger survey of biodiversity in gardens in Sheffield, UK, we examined the composition and diversity of the flora in two 1-m^2 quadrats in each of 60 gardens, and compared this with floristic data from semi-natural habitats in central England and derelict urban land in Birmingham, UK. Garden quadrats contained more than twice as many taxa as those from any other habitat type. Ca. 33 % of garden plants were natives and 67 % aliens, mainly from Europe and Asia. A higher proportion of garden aliens originated from Asia and New Zealand than in the UK alien flora as a whole; 18 of the 20 most frequent plants in garden quadrats were natives, mostly common weeds. Garden quadrats showed no evidence of 'nestedness', i.e. a tendency for scarce species to be confined to the highest diversity quadrats. Conversely, species in all semi-natural and derelict land data sets were significantly nested. Compared to a range of semi-natural habitats, species richness of garden quadrats was intermediate, and strikingly similar to the richness of derelict land quadrats. Although species accumulation curves for all other habitats showed signs of saturation at 120 quadrats, gardens did not. Correlations between Sørensen similarity index and physical distance were insignificant for all habitat types, i.e. there was little evidence that physical distance played any part in structuring the composition of the quadrats in any of the data sets. However, garden quadrats were much less similar to each other than quadrats from semi-natural habitats or derelict land.

Keywords: Alien plant; Biodiversity; Urban derelict land; Urban ecology; Urban flora.

Nomenclature: Stace (1997); Wright (1984).

Introduction

England is increasingly urbanized, with 7 % of the land area covered by cities and towns with populations > 10 000 (Anon. 2000). The majority of the human population of England lives in urban areas; 80 % by this definition, with 40 % in London, the major conurbations (e.g. Birmingham, Manchester) and the larger cities (Anon. 2000). Much of this urban area is residential, and much of the residential zone consists of private domestic gardens (e.g. 23 % of Sheffield, Gaston et al. ms.).

While there is widespread recognition that private gardens are potentially of great significance for wildlife (e.g. Hammond 1974; Gilbert 1989; Owen 1991; Vickery 1995; Baines 2000; Good 2000), there has been almost no attempt to describe the composition and distribution of garden floras. Still less has there been any attempt to place garden floras in the context of semi-natural and other urban floras. A search of Web of Science™ in May 2002 for the terms 'species richness + gardens + plants' produced five records. Other searches were hardly more productive (biodiversity + gardens + plants: 11 records; private gardens: 16; domestic gardens: 12). None of the papers found were concerned, other than very indirectly, with the floras of private gardens.

We have, therefore, sought answers to the following question for a sample of private gardens in Sheffield, UK: how do garden floras compare, in terms of composition, origin and local and total richness, with the floras of other UK habitats? There is a widespread perception that garden floras consist entirely of cultivated aliens, so we particularly wished to determine to what extent they also provide a habitat for native species. Although the study applies specifically to the UK, we expect our findings to be of general relevance to temperate gardens throughout the northern hemisphere. This study constitutes part of a broader investigation (the Biodiversity of Urban Gardens in Sheffield [BUGS] project) of the resource that domestic gardens provide for biodiversity and ecosystem functioning, the factors that influence the levels of biodiversity associated with different gardens, and ways in which features of gardens can be manipulated to enhance native biodiversity (Gaston et al. ms.).

Methods

Study sites

Survey gardens were in the city of Sheffield, South Yorkshire, UK (53° 23' N, 1° 28' W). Sheffield lies in the centre of England and is largely surrounded by agricultural land, except where the urban area merges with that of Rotherham to the northeast. The administrative boundaries of the city enclose an area of more than 360 km^2, including farmland and a portion of the Peak National Park. The study was carried out in the rear gardens (hereafter called 'gardens') of 60 private, owner-occupied houses in the predominantly urbanized 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 by eye from Ordnance Survey 1 : 25 000 scale maps). The study focused on rear gardens because they form the major garden component of most properties; front gardens are frequently absent from terraced housing, while semi-detached and detached properties, especially younger ones, tend to have access and parking space for vehicles at the front of the plot.

Gardens were selected from a pool of 161 householders who had either volunteered, or been approached, to participate in the study. Because the sample was chosen to maximize variation in house age, garden size, and location within the urban area, it does not reflect the proportions of housing types in the city. Housing type was characterized as terraced (two or more adjoining dwellings), semi-detached (one adjoining dwelling), and detached (no adjoining dwellings); the percentages of these types were, respectively, 16 : 56 : 28 (compared to a random sample of 50 : 44 : 6 (n = 218) taken from all Sheffield gardens, Gaston et al. ms.). Properties were distributed throughout the urban area and were aged between 5 and 165 yr. Gardens ranged from 32 - 940 m^2 in area.

Recording garden characteristics

A scale plan was drawn of each garden, including the side portions of corner plots, and principal dimensions were measured to the nearest 0.5 m. The plan incorporated areas of all forms of land use, but only data on total garden area and area of cultivated borders are used here. A complete list was also made of all vascular plant taxa present in the garden.

Survey methods

All species in two 1-m^2 quadrats in each garden were identified in July 2001. The timing of the survey probably meant that some strict vernals (e.g. *Anemone blanda*) were missed, although the remains of *Hyacinthoides*, *Narcissus* and *Tulipa* spp. were still visible. Quadrats were placed at random in separate cultivated borders if possible. If there were more than two borders, the two largest were used; if there was only one border both quadrats were placed in it. In some cases, local circumstances dictated that this protocol was varied. In a few gardens, border space was so limited that all or part of one quadrat (in a single case, both quadrats) contained plants in pots or tubs. One garden was entirely lawn and here both quadrats were necessarily placed in the lawn. In completely overgrown and neglected gardens, an effort was made to locate and place quadrats in the remains of cultivated borders. Only herbs and dwarf shrubs actually rooted in the quadrats were included, although trees and large shrubs overhanging the quadrats were also noted. Nomenclature followed Stace (1997) where possible, otherwise Wright (1984). Some plants (e.g. *Primula vulgaris*, *Aquilegia vulgaris*) were allocated to the native taxon, even though many garden plants are of hybrid origin. Cultivars were not considered as separate taxa. For the majority of garden plants, plant diameters (or recommended planting distances) were obtained from Wright (1984).

Other data sources

To place garden quadrats in context, they were compared with quadrat data from two other sources. First, quadrat data were obtained from surveys of the Sheffield region described in Hodgson (1986) and Grime et al. (1988). In these surveys, identities of all higher plant species were recorded in over 10 000 1-m^2 quadrats in a 3000-km^2 area of central England. Quadrats were deliberately placed to include all the major habitat types of the region and every quadrat was allocated to one of the 32 terminal categories of a detailed hierarchical habitat classification system. For comparison with the 120 garden quadrats, habitats with at least 120 quadrats were required. From the relatively few habitat types that satisfied this criterion, four were selected: limestone grassland, acid grassland, acid woodland and scrub. From each habitat, 120 quadrats were selected at random, from a total of 128 - 240.

Second, quadrat data were obtained from a large-scale survey of urban derelict land in Birmingham, UK. Field surveys of 50 derelict land sites took place between June-September in 1998 and 1999. Sites were selected either from reconnaissance surveys in the region or from the current derelict land database of the local councils' planning teams. All vascular plants were identified in 1056 1-m^2 quadrats, chosen by random stratified sampling, varying from ten to 30 quadrats per site depending on size. Walking transects were also undertaken across the whole of each site at 5-m intervals to draw up a complete list of higher plant species present. Three independent sets of 120 quadrats were selected for analysis at random from the complete data set.

Data analysis

For each data set, the mean species accumulation curve was calculated for 100 randomly shuffled runs (Software used: Species Diversity and Richness, PISCES Conservation Ltd., UK), thus removing the effect of sample order and producing a smoothed curve. For the garden quadrats, separate accumulation curves were plotted for native and alien species. In all other data sets, aliens were in a relatively small minority and were therefore not plotted separately.

We examined the 'nestedness' of all our data sets using software available from the Field Museum, Chicago, US (http://www.fmnh.org/research_collections/zoology/nested.htm). This software calculates the 'temperature' (signal to noise) of nestedness order within a species presence-absence matrix (Atmar & Patterson 1993). In a perfectly nested data set, once the quadrats have been ranked in terms of species richness, the set of species in any quadrat will be a perfect subset of all the species in the quadrats that precede it in the matrix. Such a data set will have a 'temperature' of zero. Theoretically, a completely disordered matrix will have a 'temperature' of 100°, but in practice, depending on matrix size, occupancy and rectangularity, the 'temperature' of a random matrix is often much less than this. To test if our data were significantly different from random, a Monte Carlo test was conducted, in which each matrix was randomized 50 × and the 'temperature' of the random data compared with that of the original matrix. Urban derelict land quadrats were analysed in blocks of 120, but the garden quadrats were first split into two blocks of 60 (one from each garden) and these blocks were analysed separately.

To examine the effect of spatial proximity on the species composition of quadrats, physical distances between every pair of quadrats in each data set were calculated from six figure UK national grid references. A Sørensen similarity index was then calculated between the species composition of every pair of quadrats. The correlation between each physical distance matrix and similarity index matrix was then examined by a Mantel test (Manly 1997).

Results

The garden quadrats contained 438 taxa, of which ca. 33% (149) were British natives, while ca. 67% (289) were aliens. It was not possible to allocate species to 'planted' and 'volunteer' categories, since many species can be in different categories in different gardens, or even different parts of the same garden. The aliens were overwhelmingly from Europe and Asia, with significant minorities from North and South America, New Zealand and South America, while a few were of garden origin. Comparison with the origins of all UK aliens (M.J. Crawley unpubl.) suggests that, relative to their frequency among all aliens, New Zealand and Asia (particularly Japan) are disproportionately likely to give rise to garden plants, while the reverse is true for Europe and North America (Fig. 1). Assuming that plants are circular in plan, mean area of individual garden herbs and dwarf shrubs was 0.22 m^2. However, the distribution of plant sizes was bimodal, with two distinct peaks at 0.07 m^2 and 0.28 m^2 (22 % and 20 % of the total, respectively).

Most of the 20 most frequent species in garden quadrats were native or alien weeds (Table 1). Some were natives that have mostly found their own way into gardens (e.g. *Digitalis purpurea*, *Geranium robertianum*) and are now tolerated by gardeners to varying degrees, while others were natives (e.g. *Aquilegia vulgaris*, *Meconopsis cambrica*) or aliens (e.g. *Alchemilla mollis*) that were probably originally planted, but are now largely self-sown. Both *Fraxinus excelsior* and *Hedera helix* were frequent as wind- or bird-sown seedlings, respectively.

Mean number (± s.e.) of native and alien species per quadrat differed only slightly: native 5.5 ± 0.26; alien 5.3 ± 0.23; numbers of natives and aliens in individual

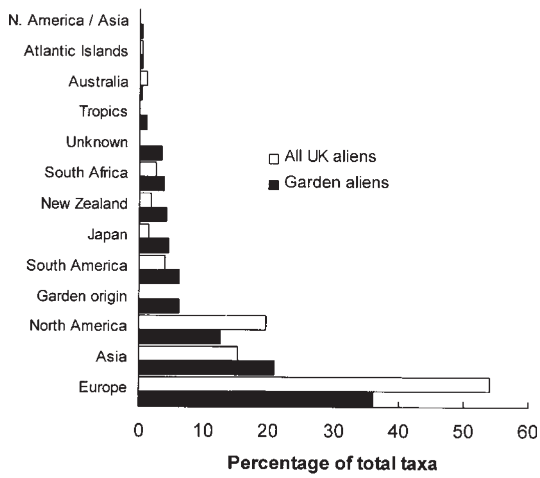

Fig. 1. The origins of the 289 alien taxa recorded in 120 1-m^2 quadrats in 60 private gardens in Sheffield, UK, compared to origins of all UK alien taxa.

Table 1. The 20 most frequent taxa in 120 1-m^2 quadrats in 60 private gardens in Sheffield, UK.

Species	Status	no. of records
Epilobium montanum	Native	34
Taraxacum officinale agg.	Native	32
Geum urbanum	Native	19
Aquilegia vulgaris	Native	18
Festuca rubra	Native	18
Ranunculus repens	Native	18
Cardamine hirsuta	Native	16
Elytrigia repens	Native	16
Primula vulgaris	Native	16
Holcus lanatus	Native	15
Rubus fruticosus	Native	15
Alchemilla mollis	Alien	13
Fraxinus excelsior	Native	13
Poa trivialis	Native	13
Digitalis purpurea	Native	12
Geranium robertianum	Native	12
Crocosmia × crocosmiiflora	Alien	11
Epilobium ciliatum	Alien	11
Hedera helix	Native	11
Meconopsis cambrica	Native	11

quadrats were not related ($r = 0.026$, $n = 120$, $p = 0.78$). Regressions of total number of species and numbers of aliens and natives separately against garden area or total border area were not significant, i.e. there was no tendency for quadrat richness to increase with garden area or border area, although total vascular plant species richness of gardens was strongly correlated with garden area (unpubl.). Total quadrat richness and number of native species were also not related to the total number of species in the garden. However, alien quadrat richness was positively correlated with total garden richness, although the proportion of variation explained was small ($r^2 = 0.08$; $n = 60$; $p < 0.001$).

The garden quadrats contained more than twice as many species as any other community, while acid grassland predictably contained very few species (Table 2). The three random samples of derelict land were very similar to each other and to limestone grassland in total richness. Gardens had much the largest proportion of species (almost half) represented by a single record, and a disproportionately large fraction of these infrequent species (74 %) were aliens. Gardens also had the smallest maximum number of records for any individual species, while acid grassland had the highest. Although garden quadrat richness was slightly more variable, coefficients of variation of garden and derelict land quadrats were similar, while the semi-natural quadrats were all more variable, particularly acid woodland and scrub (Table 2).

The garden quadrats showed no evidence of 'nestedness', i.e. a tendency for scarce species to be confined to the highest diversity quadrats. In neither set of garden quadrats was nestedness significantly different from that of a random matrix with the same occupancy (i.e. 'temperature' of actual data < 2 standard deviations from random mean in both cases; Table 3). Conversely, species in all semi-natural and derelict land data sets were significantly nested (> 2 standard deviations from random mean in every case).

The complete urban derelict land data set (from 1056 quadrats) contained 297 taxa, of which 101 were also found in the Sheffield garden quadrats. These included many of the most abundant species in both data sets. Sixteen of the species in Table 1 were also in the Birmingham data set, while 17 of the most abundant species in Birmingham were also in Sheffield gardens.

Patterns of total richness were not reflected in species richness at the quadrat scale. Acid grassland, acid woodland and scrub quadrats had low diversity, while limestone grassland quadrats were much the most diverse. Gardens and urban derelict land were intermediate and remarkably similar to each other, the most and least diverse differing by only 0.5 spec. m^{-2} (Fig. 2).

Not surprisingly, given the much larger total number of species, the species accumulation curve for garden quadrats was quite different from that for any other habitat (Fig. 3). An examination of the curves suggests this was almost entirely a consequence of the large number of alien (mostly planted) species in gardens; the curve for native garden species was parallel to the curve for derelict land. The curves for the semi-natural plant communities mostly reflected their differences in total

Table 2. A comparison of some features of the floras of Sheffield gardens and five other UK habitat types. Each row of the table is based on 120 1-m^2 quadrats.

	Total no. of spp.	% of spp. occurring 1 ×	Max no. of records for 1 spec.	CV of species richness (%)
Acid grassland	49	24.5	111	37.2
Acid woodland	106	34.0	44	64.4
Derelict land 1	169	34.3	68	29.3
Derelict land 2	176	31.8	73	31.2
Derelict land 3	166	38.6	67	30.8
Gardens	438	48.6	34	36.4
Limestone grassland	179	20.1	97	43.3
Scrub	137	27.7	44	68.0

Table 3. Nestedness of all studied data sets, expressed as the 'temperature' (signal to noise) of nestedness order within a species presence-absence matrix. A perfectly nested data set will have a 'temperature' of zero. Each matrix was randomized 50 × and the temperature of the random data shown, together with its standard deviation. For urban derelict land and semi-natural habitats, $n = 120$, but the garden quadrats were analysed in two blocks of 60 (one from each garden). For further details of methods, see Text.

	'Temperature' of actual data	'Temperature' of random data (50 runs)	SD of random data
Limestone grassland	14.34	54.32	1.09
Acid grassland	10.52	46.21	1.95
Scrub	4.90	21.33	0.77
Acid woodland	4.77	18.73	0.86
Derelict 1	11.07	27.86	0.77
Derelict 2	9.86	26.66	0.59
Derelict 3	10.62	27.08	0.7
Gardens 1	12.87	12.32	0.72
Gardens 2	13.41	12.38	0.62

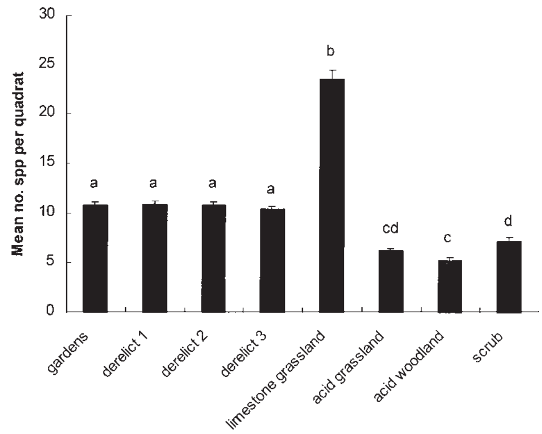

Fig. 2. Mean numbers of species recorded in 120 1-m^2 quadrats from 60 private gardens in Sheffield, UK, four semi-natural UK habitats and three random samples of the flora of urban derelict land in Birmingham, UK. Bars with the same letter are not significantly different at $p < 0.05$ (one-way ANOVA and Tukey HSD test). Error bars are standard errors.

and quadrat richness. Thus, the limestone grassland curve was steeper near the origin, reflecting the high local richness of this community.

For native and naturalized alien species, number of garden quadrats occupied was regressed against national range, defined as the number of 10 km × 10 km grid squares (hectads) occupied by a species in the British Isles. The relationship was positive and significant, but accounted for very little of the variance in the relationship ($r^2 = 0.06$; $n = 132$; $p = 0.002$). A number of species are relatively uncommon in the wild, but abundantly planted (and frequently self-seeding) in gardens, e.g. *Aquilegia vulgaris*, *Meconopsis cambrica*, *Geranium sanguineum*. Equally, many otherwise very common species occurred only rarely in the garden quadrats, e.g. *Filipendula ulmaria*, *Centaurea nigra*, *Deschampsia cespitosa*, *Anthriscus sylvestris*, *Stellaria holostea* and *Medicago lupulina*.

Correlations between the Sørensen similarity index and physical distance were negative for all eight data sets, i.e. distant quadrats were less similar than those that were closer together, but values of Mantel *r* were all

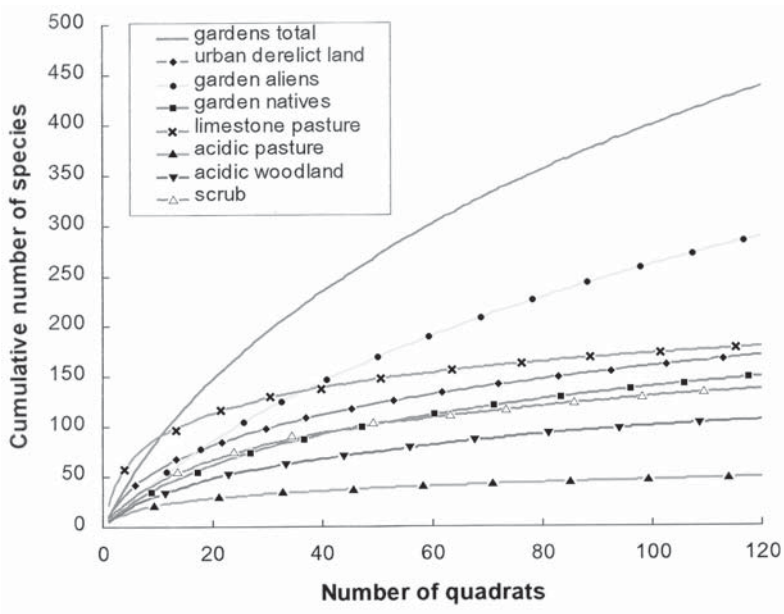

Fig. 3. Species accumulation curves for 120 1-m^2 quadrats from 60 private gardens in Sheffield, UK, four semi-natural UK habitats and three random samples of the flora of urban derelict land in Birmingham, UK. The three derelict land curves were very similar and therefore a single mean curve is plotted. Curves are based on 100 randomly shuffled runs.

small (ranging from – 0.056 to – 0.177) and none was significant. Thus there was little evidence that physical distance played any part in structuring the composition of the quadrats in any of the data sets. However, garden quadrats were much less similar to each other (mean Sørensen index 0.05) than quadrats from semi-natural habitats (mean index 0.15-0.49) or derelict land (mean index 0.20-0.21).

Discussion

The results confirm the overwhelming effect of scale when considering questions of species diversity. Collectively, garden quadrats contained many more species than any other community type, yet diversity at the quadrat scale was not unusually high. Similarly, small-scale richness of garden and derelict land quadrats was identical, yet the total species pools were very different. The garden quadrats contained 438 species, yet even 1056 derelict land quadrats contained only 297 species. In fact a more extensive survey of the Birmingham derelict land sites, involving walking transects across the whole of each site at 5-m intervals and noting all species seen, revealed only 382 species. The astonishing total richness of the garden quadrats is almost certainly a reflection of two factors. First, there is a very large pool of plants available to gardeners – the current *Royal Horticultural Society Plant Finder* (Macaulay et al. 2002) lists over 70 000 taxa (ca. 14 000 distinct species) available from UK nurseries.

Second, owing to active management and maintenance by gardeners, garden plants have a highly ‘unnatural’ ability to persist at remarkably low population sizes. Another unusual feature of gardens, relative to semi-natural habitats, is that gardens are much less homogeneous, i.e. individual gardens may be largely open, grassy or deeply shaded, while larger gardens may contain all these habitats. However, gardens share this property with urban derelict land, yet in most respects derelict land is very similar to semi-natural habitats (e.g. Tables 2 and 3; Fig. 3), implying that management and the size of the species pool are the key unique features of gardens.

Fig. 3 suggests that 120 quadrats is more than enough to detect the great majority of species ordinarily encountered in semi-natural habitats, in other words that these habitats contain relatively well-defined plant communities (Rodwell 1991, 1992). Differences in total richness between these communities are largely a reflection of the species pool available in the British flora, which is strongly correlated with pH (Grime 2001). By contrast, Fig. 3 shows that 120 quadrats were not enough to detect the whole urban derelict land community, and we know that 120 quadrats detected less than half the species present on the derelict land sites. This probably reflects the fact that the derelict land sites were of widely varying structure and successional age, and that plant communities of open land are generally rather less well-defined than those of grassland and woodland (Rodwell 2000). Native plants of gardens behaved very much like those of derelict land, while the species accumulation curve for garden quadrats showed no sign of approaching saturation (Fig. 3).

Many other unusual features of garden quadrats probably arise directly from the active maintenance by gardeners of many rare species at low population densities. For example, garden quadrats showed no evidence of nestedness, i.e. rare species were as likely to be found in species-poor as in species-rich quadrats. Nestedness appears to be a typical feature of semi-natural habitats (e.g. Pärtel et al. 2001). Other symptoms of the same phenomenon were the very high proportion of species in gardens, most of them aliens, represented by a single record, and that garden quadrats were much less similar to each other than were those from other habitat types.

The extreme dissimilarity of garden quadrats, and the low population sizes of many garden plants, may have interesting consequences for the herbivores and pathogens that exploit them. Although commonly grown garden plants are attacked by many specialist species (e.g. lily beetle, *Lilioceris lilii*, pear midge, *Contarinia pyrivora*, camellia gall, *Exobasidium camelliae*), low population density alone may be enough to protect many species from discovery. That is, many garden plants may have low apparency, *sensu* Feeny (1976) and Rhoades & Cates (1976). On the other hand, some species that are uncommon in the wild, but frequently cultivated, might be more susceptible to attack in gardens. For example, no *Lepidoptera* larvae are recorded on *Potentilla fruticosa* in the wild in the UK (Leather 1986), yet at least nine moth species exploited this plant in a single Leicestershire garden (Owen 1991). Alien status alone, even if coupled with low taxonomic similarity to the native flora, is certainly not enough to prevent common garden plants from being attacked by native herbivores; in the same Leicestershire garden, *Buddleja davidii* was consumed by the larvae of 18 moth species (Owen 1991).

Local richness of garden and derelict land quadrats is surprisingly similar, given (a) the very large difference in total species pools and (b) that presumably different processes determine the richness of the two types of quadrat. The composition and richness of derelict land is determined by the normal processes of colonization, competition and extinction, while gardens are arguably under direct human control. The results here clearly suggest that this control may be more apparent than real.

The most frequent species in garden quadrats were either weeds or cultivated plants that behave rather like weeds, suggesting that gardens and derelict land may have quite a lot in common. In fact some gardens *are* effectively derelict, while some derelict land is derived from former gardens, although this applies to only a small proportion of sites in both our data sets. Nevertheless, it seems likely that if attempts by gardeners to maintain a rather low species density also result in a significant area of bare ground, opportunist colonists will quickly fill the available space, either by seed (e.g. *Epilobium montanum, Taraxacum officinale, Aquilegia vulgaris*, *Alchemilla mollis*) or by clonal expansion (e.g. *Ranunculus repens*, *Elytrigia repens*, *Crocosmia crocosmiiflora*). While this may account for much of the convergence in local richness between derelict land and gardens, we must also consider the possibility that the typical dimensions of herbaceous garden plants, perhaps allied to aesthetic considerations, dictate a richness of ca. 10 spec. m^{-2}. A 'typical' garden plant in our sample occupied an area of 0.22 m^2, so a mean quadrat richness of ca. 10 spec. m^{-2} is unexpectedly high. This is consistent with the suggestion that a substantial part of the diversity of individual garden quadrats is accounted for by the opportunist species listed in Table 1. Many of these species were typically present as seedlings or isolated shoots, contributing very little to quadrat cover or biomass. Local richness is also strongly influenced by the choice of growth form – low-richness quadrats contained a high proportion of trees, shrubs and large herbaceous species such as *Paeonia officinalis* or *Phormium tenax*.

The origins of garden aliens and of the UK alien flora as a whole clearly suggests different roles for chance and deliberate introduction in the two floras. The UK alien flora is dominated by plants from Europe, many of them introduced accidentally (Clement & Foster 1994). More distant locations, particularly Japan and New Zealand, are proportionately much more likely to be the origins of garden aliens, most of them deliberately introduced (Fig. 1).

There was little evidence that the most frequent native and naturalized species in gardens were also the most frequent in the country generally. This is not unexpected, since gardens provide conditions that are really rather different from those of any other common habitat. Gardens also seem to provide a refuge for some native species that are relatively uncommon in the wider countryside. There was also no evidence that garden communities were structured by their spatial proximity to other gardens, which again is not surprising. Slightly more surprising was the finding that none of the other communities examined showed any evidence of such spatial structure.

In conclusion, garden floras show remarkable levels of floristic diversity. Mooney (1988) assembled species richness data for 0.1 ha sample areas of a variety of plant communities. The highest diversities were in the wet tropics (ca. 200 spp., trees only), but several communities from Mediterranean climates achieved > 100 spp. Crawley (1997) considered that a 0.1 ha plot in Israel, with > 250 spp., might hold the world record. In this study we found 438 spp. in a total area of 0.012 ha. Admittedly, this small area was sampled from 60 different gardens, but the extremely low floristic similarity between garden quadrats suggests that high levels of diversity are achieved in individual gardens. Over a 12-yr period, Jennifer Owen's Leicester garden (area 0.074 ha) had a mean of 240 spp., 59 % of them alien (Owen 1991). The world record for plant diversity remains unknown, but is almost certainly held by a garden somewhere.

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References

Anon. 2000. *Our towns and cities: the future – delivering an urban renaissance*. Department of Environment Transport & the Regions, London, UK. http://www.detr.gov.uk/regeneration/policies/ourtowns/cm4911/index.htm.

Atmar, W. & Patterson, B.D. 1993. The measure of order and disorder in the distribution of species in fragmented habitat. *Oecologia* 96: 373-382.

Baines, C. 2000. *How to make a wildlife garden*. Frances Lincoln, London, UK.

Clement, E.J. & Foster, M.C. 1994. *Alien plants of the British Isles*. Botanical Society of the British Isles, London, UK.

Crawley, M.J. 1997. Biodiversity. In: Crawley, M.J. (ed.) *Plant Ecology*, pp. 595-632. Blackwell, Oxford, UK.

Feeny, P. 1976. Plant apparency and chemical defense. In: Wallace, J.W. & Mansell, R.I. (eds.) *Biochemical interactions between plants and insects*, pp. 1-40. Plenum Press, New York, NY.

Gilbert, O.L. 1989. *The ecology of urban habitats*. Chapman & Hall, London, UK.

Good, R. 2000. The value of gardening for wildlife: what contribution does it make to conservation? *Br. Wildlife* 12: 77-84.

Grime, J.P. 2001. *Plant strategies, vegetation processes and ecosystem properties*. Wiley, Chichester, UK.

Grime, J.P., Hodgson, J.G. & Hunt, R. 1988. *Comparative*

plant ecology: A functional approach to common British plants. Unwin Hyman, London, UK.
Hammond, P.M. 1974. Changes in the British Coleopterous fauna. In: Hawksworth, D.L. (ed.) *The changing flora and fauna of Britain*, pp. 323-369. Academic Press, London, UK.
Hodgson, J.G. 1986. Commonness and rarity in plants with special reference to the Sheffield flora. I. The identity, distribution and habitat characteristics of the common and rare species. *Biol. Conserv*. 36: 199-252.
Leather, S.R. 1986. Insect species richness of the British Rosaceae – the importance of host range, plant architecture, age of establishment, taxonomic isolation and species area relationships. *J. Anim. Ecol*. 55: 841-860.
Macaulay, D., Buchanan, N., Burton, R. & Murphy, M. 2002. *RHS Plant finder 2002-2003*. Dorling Kindersley, London, UK.
Manly, B.J.F. 1997. *Randomization, bootstrap and Monte Carlo methods in Biology*. 2nd ed. Chapman & Hall, London, UK.
Mooney, H.A. 1988. Lessons from Mediterranean-Chilean regions. In: Wilson, E.O. (ed.) *Biodiversity*, pp. 157-165. National Academy Press, Washington, DC.
Owen, J. 1991. *The ecology of a garden: The first fifteen years*. Cambridge University Press, Cambridge, UK.
Pärtel, M., Moora, M. & Zobel, M. 2001. Variation in species richness within and between calcareous (alvar) grassland stands: the role of core and satellite species. *Plant Ecol*. 157: 203-211.
Rhoades, D.F. & Cates, R.G. 1976. Toward a general theory of plant anti-herbivore chemistry. In: Wallace, J.W. & Mansell, R.I. (eds.) *Biochemical interactions between plants and insects*, pp. 168-213. Plenum Press, New York, NY.
Rodwell, J.S. (ed.) 1991. *British plant communities. Vol. 1, Woodlands and scrub*. Cambridge University Press, Cambridge, UK.
Rodwell, J.S. (ed.) 1992. *British plant communities. Vol. 3, Grasslands and montane communities*. Cambridge University Press, Cambridge, UK.
Rodwell, J.S. (ed.) 2000. *British plant pommunities. Vol. 5, Maritime communities and vegetation of open habitats*. Cambridge University Press, Cambridge, UK.
Stace, C.A. 1997. *New Flora of the British Isles*. 2nd. ed. Cambridge University Press, Cambridge, UK.
Vickery, M.L. 1995. Gardens: the neglected habitat. In: Pullin, A.S. (ed.) *Ecology and conservation of butterflies*, pp. 123-134. Chapman & Hall, London, UK.
Wright, M. 1984. *The complete handbook of garden plants*. Michael Joseph, London, UK.

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