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Urban domestic gardens (IV): the extent of the resource and its associated features

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Abstract. Domestic ('private') gardens constitute a substantial proportion of 'green space' in urban areas and hence are of potential significance for the maintenance of biodiversity in such areas. However, the size and nature of this resource and its associated features are poorly known. In this study, we provide the first detailed audit, using domestic gardens in the city of Sheffield as a model study system. Domestic gardens, the mean area of which was 151 m^2, cover approximately 33 km^2 or 23% of the predominantly urban area of the city. The smaller gardens contribute disproportionately to this total because, although individually they add little, they are large in number. Conversely, the regions of the city with proportionately more garden area contribute most to the total garden area of the city, although such regions are limited in number. Based on the findings of a telephone based survey, 14.4% of dwellings with gardens were estimated to have ponds, 26% to have nest-boxes, 29% to have compost heaps, 48% to hold trees more than 3 m tall, and 14% of dwellings were estimated to be home to one or more cats. Whilst the absolute frequency of these features is low to moderate, by extrapolation they nonetheless yield estimates for domestic gardens in Sheffield of a total of 25,200 ponds, 45,500 nest boxes, 50,750 compost heaps, 360,000 trees, and a population of 52,000 domestic cats. These results are considered in the context of the role of gardens in urban areas as habitats for wildlife and the implications for housing policy.

Introduction

Urban areas (characterised by high human population densities or significant commercial or industrial infrastructure) presently cover more than 471 million ha, or about 4% of global land area (UNDP et al. 2000). This coverage continues to grow, as a consequence of human population increase, development and social trends. Provision and management of green space (non-built-up areas) within such environments is increasingly seen as an important issue. It is fundamental to the maintenance, or restoration, of biodiversity in areas impacted by development, to the provision of ecosystem services (*sensu* Daily 1997) in urban regions, to the quality of life (including physical and mental health) for the large proportion of the human population who live in them (Niemelä 1999), and it may be significant for educating and engaging people in habitat management and conservation (Cannon 1999).

In common with many other regions, since the late 1940s there has been substantial growth in the urbanisation of England, with 7% of the land area presently covered by cities and towns of more than 10,000 people (Department of Environment, Transport and the Regions 2000a). Indeed, the majority of the human population of England lives in urban areas; 80% by this definition, with 40% distributed amongst London, the major conurbations (e.g. Birmingham, Manchester) and the larger cities (Department of Environment, Transport and the Regions 2000a).

The ecological effects of urbanisation are diverse, but include (i) alteration of habitat, including the loss and fragmentation of natural vegetation, and the creation of novel habitat types, (ii) alteration of resource flows, including reduction in net primary production, increase in regional temperature and degradation of water quality, (iii) alteration of disturbance regimes (with many habitats experiencing more frequent disturbance), and (iv) alteration of species composition (commonly comprising reductions in the richness of animal groups in areas of intense urbanisation, but sometimes increases in that of plant groups, often because of the large number of aliens) (Kinzig and Grove 2001; for empirical examples see Davis 1978; Dickman 1987; Gilbert 1989; Ruszczyk and de Araujo 1992; Jokimäki and Suhonen 1993; Rapoport 1993; Blair 1996, 1999; Blair and Launer 1997; Bolger et al. 1997; McGeoch and Chown 1997; Clergeau et al. 1998; Germaine et al. 1998; Gering and Blair 1999; Hardy and Dennis 1999; Roy et al. 1999; Sodhi et al. 1999; Jokimäki and Huhta 2000; King and Buckney 2000; Savard et al. 2000; McIntyre et al. 2001).

As might be expected from their large human populations, residential areas constitute a high proportion of urban areas. In England, and indeed the UK more generally, many of the dwellings in these zones have private gardens associated with them (henceforth termed ‘domestic gardens’, and defined as the private spaces adjacent to or surrounding dwellings, which may variously comprise lawns, ornamental and vegetable plots, ponds, paths, patios, and temporary buildings such as sheds and greenhouses). They share this characteristic with urban areas in many other regions of the world, although the form that these spaces take and the uses to which they are put varies widely. Though typically they are each small, the large numbers of domestic gardens mean that they make a substantial contribution to urban ‘green space’. However, quantitative information on green space in urban areas in the UK, and elsewhere, is generally poor and fragmented (Department for Transport, Local Government and the Regions 2001). Despite the potential size of the resource, domestic gardens are seldom included in estimates of the extent of such space, probably primarily because of a paucity of reliable information and because by their very nature these areas tend to lie outside the immediate control (and hence management requirements) of local government and administrative authorities.

There is also a scarcity of empirical data on the nature of the green space that domestic gardens comprise in urban areas, in large part because of the problems of systematically obtaining data from such a fragmented and inaccessible resource. The potential importance of domestic gardens to biodiversity, and the ways in which this biodiversity can be enhanced, have regularly been highlighted (e.g. Hammond 1974; Baines 1985; Gilbert 1989; Owen 1991; Vickery 1998; Good 2000; '[e]ven the smallest of town gardens can provide a rich and valuable sanctuary for a whole host of wildlife' – Baines 1985, p. 18). However, data on the magnitude of the potential wildlife resource that domestic gardens provide are very limited. In England, this is particularly significant at a time when Local Biodiversity Action Plans (one of the UK Government's instruments for responding to the Convention on Biological Diversity) are required to be developed, and the inclusion in these of gardens and other urban habitat types is under consideration in many counties and districts (e.g. Devon Biodiversity Partnership 1998; Essex Biodiversity Partnership 1999; Birmingham and Black Country Biodiversity Action Plan Steering Group 2000; Edinburgh Biodiversity Partnership 2000).

The few studies that have examined the role of domestic gardens for maintaining biodiversity in urban areas provide evidence that their potential value may be considerable. These include intensive investigations of the biodiversity of individual gardens (e.g. Owen 1991; Miotk 1996), investigations of the occurrence of particular taxa in one or more gardens (e.g. Barnes and Weil 1944, 1945; Morley 1944; Guichard and Yarrow 1948; Barnes 1949; Tutin 1973; Mathias 1975; Davis 1978, 1979; Dickman 1987; Rapoport 1993; Vickery 1995; Bailey et al. 1998), and investigations of the occurrence of multiple taxa across numbers of gardens (e.g. Saville 1997; Association of Croydon Conservation Societies 1998). Contrary to earlier assertions that domestic gardens were akin to biological deserts (Elton 1966), these studies have revealed the occurrence of a surprisingly high diversity of species in gardens, including those in urban settings, and the occurrence of some species of particular conservation concern. Indeed, a substantial fraction of species on the UK lists of some major taxonomic groups have been recorded in individual domestic gardens, *albeit* some of these were transient visitors (e.g. Hammond 1974; Davis 1978; Owen 1991; Vickery 1995). There is growing evidence that species that have suffered declines in the wider countryside (most notably in farmland) are found in significant numbers in urban areas, and particularly in domestic gardens (e.g. common frog *Rana temporaria* L., song thrush *Turdus philomelos* C.L. Brehm, hedgehog *Erinaceus europaeus* L.; e.g. Gregory and Baillie 1998; Mason 2000). Urban populations of some species may even act as important sources of immigrant individuals to populations in other environments.

This evidence, in combination with the inevitability of continued urban development, indicates the importance of developing a much better empirical understanding of the nature and role of urban gardens as part of the provision of green space in towns and cities in the UK and elsewhere. In this context, the Biodiversity in Urban Gardens in Sheffield (BUGS) project is using the city of Sheffield, UK as a model study system to address three main questions. First, what is the size and composition of the resource that domestic gardens provide for biodiversity and ecosystem functioning? Second, what are the factors that influence the levels of biodiversity associated with different gardens (Thompson et al. 2003, 2004)? Third, are there simple manipulations of the features of gardens that can enhance the native biodiversity associated with them (and particularly breeding populations) within a reasonably short time frame (Gaston et al. 2004)? Sheffield provides a useful study system to address such issues, because it (i) has a well-established history of urbanisation, resulting in developments of a wide diversity of types and ages (Hey 1998), (ii) is a substantial size, with a human population of approximately half a million individuals (531,000 in 1998), (iii) has clear non-urban boundaries on three sides, giving rise to clear gradients of urbanisation, from heavily built environments to rural ones, and (iv) has a flora and fauna that have been studied by local natural historians for many decades, *albeit* predominantly outside domestic gardens, providing a wealth of background information (e.g. Zasada and Smith 1981; Hornbuckle and Herringshaw 1985; Whiteley 1985, 1992, 1997; Shaw 1988; Richards 1995).

In this paper, we address the first of the three questions posed above for the city of Sheffield. The outcome is the first detailed audit of the size of the domestic garden resource of a substantial urban area and of the occurrence of important ecological features within that resource.

Methods

The city of Sheffield, South Yorkshire (53°23′N, 1°28′W) lies central to England (Figure 1a). The administrative boundaries of the city extend over a region of more than 360 km^2 (Sheffield City Council 1991). This includes substantial areas of the Peak National Park and farmland (Table 1). We limited considerations to the smaller predominantly urbanised area, in which nearly all of the human population live (Figure 1b). To the east this is principally defined by the boundaries of Sheffield and the neighbouring borough of Rotherham, to the south by the Derbyshire/South Yorkshire county boundary, and to the north and west by the demarcation between 1×1 km cells having more or less than 25% coverage by residential and industrial zones (as judged by eye from Ordnance Survey 1:25,000 scale maps). This area has an extent of approximately 143 km^2.

Within this area, we obtained information on a number of basic features of gardens of relevance to biodiversity from two sources: direct measurement from maps, and a telephone survey.

Measurement from maps: garden areas

The areas of domestic gardens in Sheffield were measured in two ways, both employing digital versions of Ordnance Survey Plus (1:1250) maps (500×500 m tiles) imported to ArcView GIS (Environmental Systems Research Institute, Inc.).

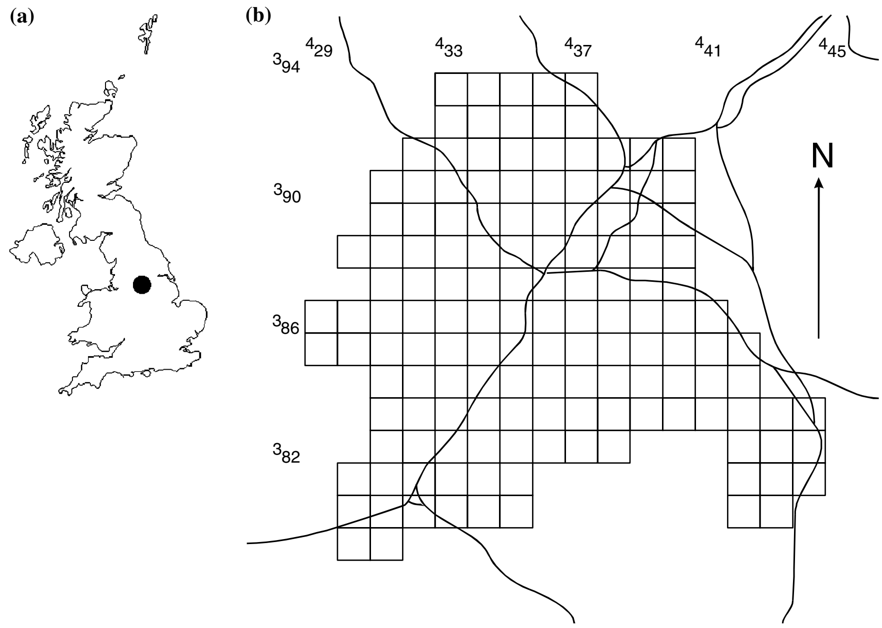

Figure 1. (a) The approximate position of the city of Sheffield within the UK, and (b) the extent of urbanised Sheffield, as indicated by the 1 km northings and eastings of the Ordnance Survey (OS) grid (100 km square SK), with the railway network indicated for reference.

Table 1. The extent of some major habitat types in the City of Sheffield (Sheffield City Council, 1991).

	Area (ha)
Woodland	2675
Scrub	2226
Grassland and herbaceous	10856
Arable	430
Heathland, moorland and bog	8659
Gardens and allotments	5509

First, 250 dwellings were identified at random across the city (from a total of > 220,000) using the current British Telecom telephone directory for Sheffield North and Central (British Telecommunications 2000). This covers the vast majority of Sheffield as defined above, as far east as OS easting 441000 (88% of the 500 × 500 m Land-Line Plus tiles). The position of the dwellings chosen was located on the appropriate 500 × 500 m Land-Line Plus tile, and the ground areas of the dwellings and of their associated gardens (if any, and summing front and back where these were distinct) were each determined, along with the grid references of the mid-points of the dwellings. This procedure should sample gardens in approximate proportion to the frequency with which those of different size, age, type, etc. occur across the city as a whole.

Second, seventy 500 × 500 m Land-Line Plus tiles covering the Sheffield area were selected at random (from a total of c.550), within each such tile a 100 ×100 m quadrat was placed approximately centrally, and the summed areas of the gardens and the number of dwellings within this quadrat were determined. This samples the total area of gardens in proportion to the frequency with which gardens occupy different proportions of ground area across the city.

In both these approaches the estimates of garden area do not distinguish the different kinds of use to which this area has been put and may include significant proportions that have been paved or concreted over, or are covered by temporary structures (garden sheds, greenhouses, etc).

Telephone survey: garden features

A number of general surveys gathered information on the occurrence in domestic gardens of features of particular significance to wildlife (e.g. ponds, nest boxes), and/or the occurrence of species or species groups (e.g. Association of Croydon Conservation Societies 1998; Bailey et al. 1998; Good 2000; London Wildlife Trust 2001). Almost invariably these have been based on collecting responses to requests for information made in the media (magazines, newspapers, television, radio). They suffer from the problem of being highly non-random in their coverage. Exposure to the appropriate medium, and willingness to respond to such appeals for information, are unlikely to be independent of people's interests and activities in relation to wildlife, gardening and conservation.

To obtain a less biased picture of the occurrence of selected features in domestic gardens in Sheffield, we conducted a random telephone survey of households across the city. Dwellings were again identified at random from the current British Telecom telephone directory (this lists stationary but not mobile phones) for Sheffield North and Central, with just five of those for which responses were obtained lying outside of the region from which garden areas were determined.

Telephone calls were made, by the same individual, between 11-00 and 19-00 h, and a standard set of questions were asked. Repeat calls to a given number were made, at different times of day, if previous calls went unanswered. The survey continued until responses had been obtained for 250 dwellings. This is a markedly smaller sample size than obtained by some previous broad surveys of garden features (see references above), but it is difficult to conceive of a means of reducing the bias in responses without such a trade-off or the investment of much greater resources. Possible biases remaining in a telephone survey, which could conceivably be correlated with garden features (perhaps because of covariance with socio-economic factors), include whether dwellings do or do not possess a telephone, whether telephone numbers for dwellings are listed in the directory, the availability/willingness of occupants to answer telephone calls, and the willingness or otherwise of occupants to respond to the questions posed.

The questions asked in the telephone survey were specifically designed to be non-intrusive. Householders were asked whether they had a garden, and the number of domestic cats *Felis catus* that they owned. If they had a garden, they were asked whether this contained a pond, a bird nest-box, and/or a compost heap, and also the number of trees in the garden more than 3 metres tall, whether $<1/4$, 1/4…1/2, 1/2…3/4 or $>3/4$ of the garden was covered by lawn, and whether in the Summer the occupants worked in the garden, on average, more than once a week, about once a week, or less than once a week.

Results and discussion

Garden sizes, and total garden area

Of the 250 randomly selected dwellings, 87% had gardens, slightly more than the 80% of households in Britain cited by, the now somewhat outdated, Hessayon and Hessayon (1973). Garden size varied between 0 and 1073 m^2. The frequency distribution of sizes was strongly right skewed, with, including zeros, a mean of 151 m^2 (SE 8.8) and a median of 139.7 m^2 (Figure 2). Large gardens were relatively infrequent, and the smallest gardens were the most common. Possible bias in the mean area due to small sample size was checked for by repeatedly resampling the data and estimating mean garden sizes from

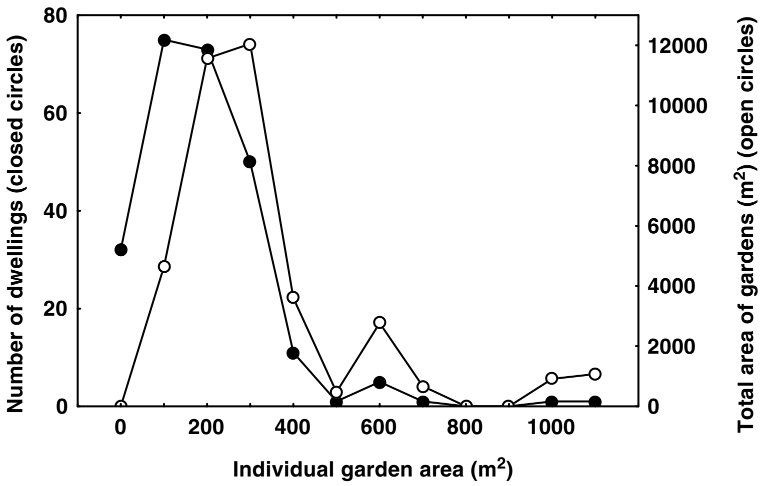

Figure 2. The area of the domestic gardens (m^2) of each of 250 randomly selected dwellings in Sheffield. Figures on the *x*-axis are upper bounds.

random samples of different numbers of gardens, but no systematic effect of sample size on mean garden size was evident above c.150 gardens (K.J.G. et al. unpubl. analyses).

Summing the area of gardens within different classes of garden size (0, 1–100 m^2, 101–200 m^2...) reveals the contribution of these different classes to overall garden area (Figure 2). Small gardens comprise the bulk of this total because of their large number, whilst large gardens contribute rather little because they are scarce. There was only a weak relationship between garden size and the ground area of the dwelling, however: garden size declined from detached (no adjoining dwellings) to semi-detached (one adjoining dwelling) to terraced houses (two or more adjoining dwellings; Figure 3; Kruskal–Wallis test: $\chi^2 = 79.93$, df = 2, $p < 0.001$; log-transformed areas: detached = 2.56 ($\pm$0.26), semi-detached = 2.31 ($\pm$0.17), terraced = 1.93 ($\pm$0.26)), and detached houses were larger than semi-detached and terraced (Kruskal–Wallis test: $\chi^2 = 13.91$, df = 2, $p < 0.01$; log-transformed areas: detached = 1.95 ($\pm$0.13 SD), semi-detached = 1.67 ($\pm$0.10), terraced = 1.65 ($\pm$0.10)).

Semi-detached dwellings contribute disproportionately to the total garden area, compared with detached and terraced, because despite having smaller gardens than detached houses they are more numerous, and despite being slightly less numerous than terraced houses they have larger gardens (proportional contribution to overall garden area: detached, 0.15 (n = 13); semi-detached, 0.58 (96); terraced, 0.29 (109)). There was no relationship between the area of a garden and the distance of that garden from the edge of the city (Figure 4). The lack of a simple pattern is not surprising, given that whilst

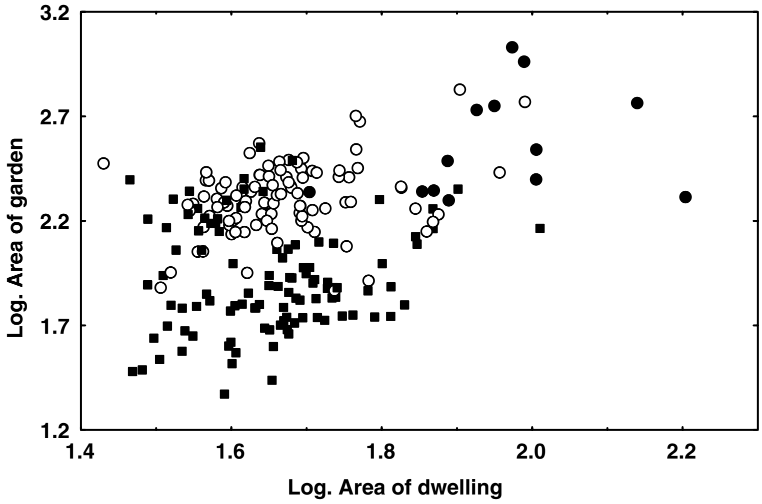

Figure 3. The relationship between the ground area of dwellings with gardens (m^2) and the area of those gardens (m^2) (Spearman Rank correlation $r_s = 0.240$, n = 218, $p < 0.001$). Closed circles, detached dwellings; Open circles, semi-detached dwellings; Squares, terraced dwellings.

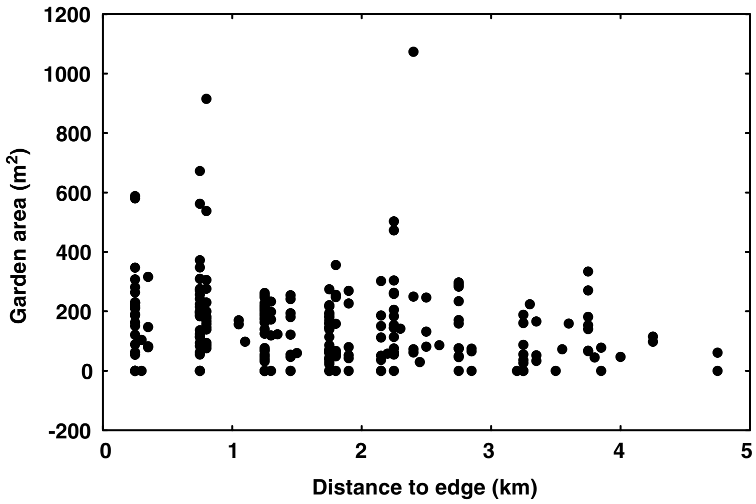

Figure 4. Relationship between the distance (km) of a sample garden to the edge of the city of Sheffield (to the nearest 250 m), as defined in Figure 1, and the area of that garden (m^2).

Sheffield is bounded on the west by the open country of the Peak National Park, on the east it essentially forms a continuous urbanised conurbation with the city of Rotherham. However, there is still some suggestion that large gardens do not occur at longer distances from the city limits (Figure 4).

Hessayon and Hessayon (1973) give a mean area for gardens in Britain of 186 m^2, although this almost certainly does not include zero values. This is not dissimilar from the figure of 173 m^2 for Sheffield when zero values are excluded. Rapoport (1993), reporting the results of surveys of the numbers of cultivated plants and weeds in gardens, gives garden areas of 11.9 ± 25.7 m^2 (mean $\pm$ SD) for London (n = 65), 55.3 ± 86 m^2 for Gdansk (n = 7), 40.8 ± 16.1 m^2 for Warsaw (n = 9), 17.4 ± 6.2 m^2 for Szczecin (n = 8), 115.4 ± 259.9 m^2 for six cities in Poland (n = 34), 35.8 ± 54.4 m^2 for Mexico City (n = 19), and 53.4 ± 133.3 m^2 for Buenos Aires (n = 21). It is not clear how representative these samples are in each case, nor whether they have been measured in a strictly comparable fashion, but they are typically much smaller than those for Sheffield.

The frequency distribution of the overall domestic garden areas of the random seventy 100 × 100 m quadrats was strongly right skewed (Figure 5). However, quadrats with intermediate to large areas of gardens contribute disproportionately to the overall garden area (Figure 5). There was no simple relationship between the area of garden in a quadrat and the distance of that quadrat from the edge of the city, although there was a tendency for the maximum area to decline away from the edge (Figure 6). It seems likely that the decline in maximum garden area away from the edge of the city is associated with the historical pattern of decline in environmental quality from

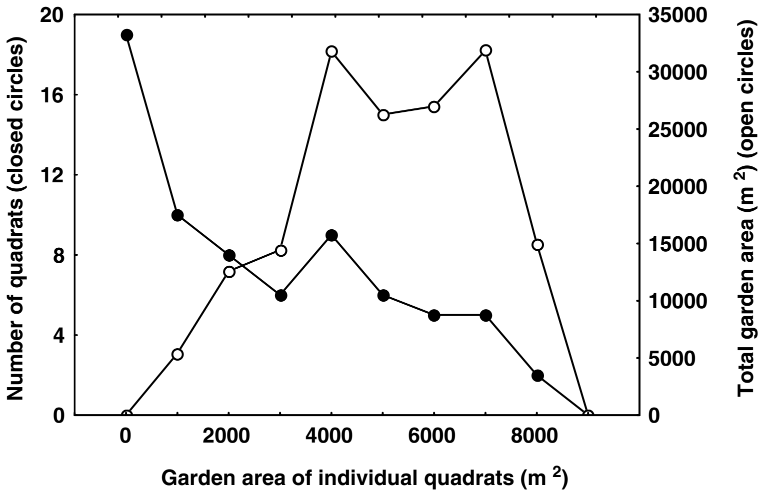

Figure 5. The area of garden (m^2) in each of seventy 100 × 100 m quadrats in the centres of 500 × 500 m tiles chosen randomly from those covering Sheffield. Figures on the *x*-axis are upper bounds.

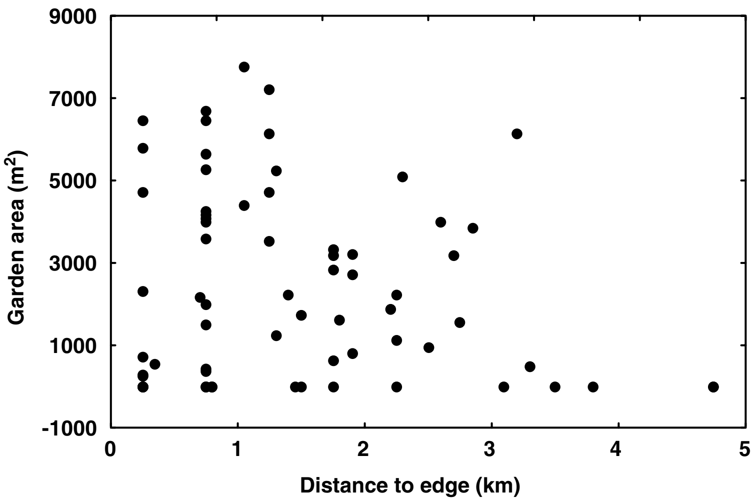

Figure 6. Relationship between the distance of a sample quadrat (km) to the edge of the city of Sheffield, as defined in Figure 1, and the area of garden in that quadrat (m^2).

west to east across the city (Knox 1976), and the consequent tendency for the wealthy to build houses on the urban fringe to the west (Hey 1998).

The mean garden area within the quadrats was 2347 m^2, and the median value was 1806 m^2. Again, possible bias in the mean area due to small sample size was checked for by repeatedly resampling the data and estimating mean garden area from random samples of different numbers of gardens, but no systematic effect of sample size on mean garden size was evident above c.40 quadrats (K.J.G. et al. unpubl. analyses). The mean and median equate, respectively, to approximately 23 and 18% of quadrat area. With an overall area to the city of 143 km^2, this gives a total garden area for Sheffield of 33.6 km^2. This is somewhat smaller than the figure of 5509 ha (55.09 km^2) for 'gardens and allotments' given in the Sheffield Nature Conservation Strategy (Table 1; Sheffield City Council 1991). However, as well as being derived for a substantially larger overall region (see Methods), the latter figure includes maintained landscapes around offices, factories, and residential buildings including many areas that would not constitute domestic gardens as used here, as well as the substantial areas of allotments around the city.

In the 1991 Census the human population of Sheffield was distributed amongst 220,790 dwellings. A simple calculation, using this value and the mean garden size from the 250 randomly selected dwellings (151 m^2), yields an estimated garden area of 33.3 km^2 (23.3% of Sheffield), remarkably close to the figure based on quadrats. The estimate can be refined a little. Of the 220,790 dwellings, 11.4% were detached houses, 35.5% were semi-detached houses, 32.2% were terraced houses, and 19.1% were flats (the small balance comprised various forms of converted accommodation and shared dwellings). If we assume that all detached, semi-detached and terraced houses have associated domestic gardens (plainly some houses do not, but some flats do), this gives an estimate of about 175,000 dwellings with such gardens. The mean size of the gardens of those of the 250 randomly selected dwellings that had a garden was 173 m^2. This gives an overall area of 30.3 km^2 (21.2% of Sheffield), much the same figure as with the simpler method.

The sole strictly comparable figure of which we are aware for other cities, in Britain or elsewhere, is one for Nottingham (R.N.E. Blake pers. comm.). Here, a detailed analysis of land use in 1991 provided an estimated area for domestic gardens of 16.9 km^2, or 22.6% of area of the city (including buildings, roads etc). 'Rural' land classes (woodland, roughland, water, arable land, pasture) comprised 13.95% of the area of the city, and if these were excluded the proportion covered by domestic gardens rose to 26.2%. Though the methodologies by which they were achieved in each case are not given, Owen (1991) quotes an estimate that 27.6% of the area of the city of Leicester is covered by gardens, McCall and Doar (1997) quote an estimate of 19% for the city of Edinburgh, and the London Biodiversity Partnership (2001) give an estimate of 20% of Greater London. The figure for Sheffield of 21–23% falls within this range.

Garden features

For only 44 of the dwellings to which calls were made in the telephone survey did the occupants refuse to participate (15% of the contacts made, ignoring failure of calls to be answered, and telephone numbers that were not recognised). A number of these refusals were because the timing of the calls was inconvenient (and an offer to repeat the call was not accepted), and in other cases the call was terminated before its purpose could be conveyed to the recipient. Of the 250 dwellings for which the survey was completed, 223 had associated gardens (89.2%; the others were almost exclusively flats).

Ponds

The creation of ponds has regularly been advocated as a means of enhancing domestic gardens as a biodiversity resource, as a response to the decline of such environments in the wider countryside, and more particularly as a means of maintaining regional populations of some amphibian species (e.g. Prestt et al. 1974; Baines 1985; Fry and Lonsdale 1991; Sheffield City Council 1991). Thirty-two (14.4%, SE 2.4%) of the dwellings surveyed that had gardens contained ponds. Extrapolating to the estimated 175,000 domestic gardens in Sheffield, this gives a total of 25,200 ponds in the city, a density of about 176 km^{-2}. In terms of numbers of ponds, meaningful comparisons with other areas are difficult because most garden ponds are much smaller than the standing waters that would be recognised as ponds in wider surveys; e.g. Countryside Survey 2000 defines a pond as being between 0.25 and 2 ha in area, and on this basis estimates there to be about 1.7 lowland ponds per ha in England (excluding urban and garden ponds; Haines-Young et al. 2000). If we assume that garden ponds, on average, have an area of 2.5 m^2 (mean = 2.53 m^2 [$\pm$1.96 SD] for a sample of 37 such ponds; a visual estimate suggests this is also the middle of the range of sizes of pre-formed pond liners available in a selection of garden centres) this suggests an area of standing water of 6.3 ha. Although the total area is small, it is fragmented into many tiny patches and very widely distributed. And although garden ponds individually are generally small, they differ from natural, or semi-natural standing waters of an equivalent size in that most garden ponds probably contain water all the year round, and are actively maintained to prevent succession, whereas natural patches of water of this area will tend to be seasonal, and relatively short lived. In this sense, garden ponds may play a role equivalent to natural ponds of a rather larger size, although the substantial turnover in garden ponds (resulting from changes in house occupancy and ownership, and fashions in garden management), the frequent presence of fish, and the regular cleaning of some ponds, may perhaps reduce the likelihood of establishment of well-developed pond assemblages and the occurrence of some groups of species.

Nest boxes

Twenty-six percent (SE 2.4%) of the dwellings in Sheffield surveyed that had gardens also had nest-boxes, with a weak tendency for gardens with ponds also to have nest-boxes ($\chi^2 = 4.47$, df = 1, $p < 0.05$). Extrapolating to the estimated 175,000 domestic gardens in Sheffield, gives a total of 45,500 nest boxes in the city, or a density of 318 km^{-2}.

Newton (1998) collates the findings of 46 studies of the effects of nest-box provision or the blockage of natural holes on the breeding density of bird species, almost all of which provided evidence that nest-sites limited this density. None of these studies were conducted in urban environments. However, a paucity of secure nesting sites seems particularly likely in such areas (particularly because of a lack of natural cavities; Marzluff et al. 1998), *albeit* it remains unknown whether this places a greater constraint on numbers than, say, food availability or predation.

Compost heaps

Twenty-nine percent (SE 3.0%) of the dwellings surveyed that had gardens had compost heaps, with again a significant tendency for gardens with ponds also to have compost heaps ($\chi^2 = 13.29$, df = 1, $p < 0.001$). Extrapolating to the estimated 175,000 domestic gardens in Sheffield, gives a total of 50,750 compost heaps in the city. As well as perhaps reflecting a commitment on the part of householders to an element of recycling, and reducing the use of peat-based 'composts' in gardening, compost heaps are also recognised as providing a habitat for many species of invertebrate not found elsewhere in garden environments (*albeit* including numbers of aliens; e.g. Hammond 1974; Curds 1985; Ødegaard and Tømmerås 2000).

The significance of compost heaps for the flow of materials in the urban ecosystem is not known. However, according to the DEFRA National Food Survey (http://www.defra.gov.uk/esg/Work_htm/Notices/nfs_hfc.pdf), the average Briton consumes about 2.2 kg (fresh weight) of fresh fruit and vegetables per week. This is the amount that actually enters the house, and it seems reasonable to assume that about a quarter is waste, in the form of potato peelings, apple cores, banana skins etc (K.J.G. et al. pers. obs.). Thus a household of two would accumulate over 1 kg of waste every week from kitchen sources alone, while garden waste (e.g. weeds and lawn clippings) is probably at least the same again (see later). If we therefore assume that at least 2 kg of waste material is added to each of these heaps per week, and that all 'made' compost is used on the source, or other, gardens, then these account for the processing of 5278 metric tonnes of material per annum. This is a tonnage that the city refuse services would otherwise have to handle and much of which would be disposed of by incineration (for which in large quantities such material poses a particular problem, risking extinguishing the incinerator, or lowering the temperatures at which material is burnt and thus risking increases in potentially toxic emissions) and the rest by landfill; the Sheffield incinerator plant handles c.120,000 metric tonnes (c.50%) of the city's refuse per annum (M. Pilling pers. comm.). If all dwellings in the city with domestic gardens each disposed of 2 kg of waste material per week to a compost heap, this would result in the recycling of 18,200 metric tonnes of material per annum.

Trees

Forty-eight percent of the dwellings in Sheffield surveyed that had gardens held trees of more than 10 ft (3 m) tall, most containing a very small number (Figure 7), and giving an overall total of 460 such trees. This is an underestimate, because where people had many trees in their gardens, and did not know the precise number, they were asked to put a lower bound on how many there were. Extrapolating to the 175,000 domestic gardens, again, this gives an estimate of about 360,000 trees of more than 10 ft tall in these environments across Sheffield. However, this figure should be treated cautiously because of its dependence on the high proportion of the overall number of trees that resided in just a few of the sample gardens (Figure 7); it seems likely that with a larger sample size, gardens containing different numbers of trees would contribute approximately equally to the overall total, with the larger numbers of gardens with fewer trees balancing the smaller numbers of gardens with many trees.

Bolund and Hunhammar (1999) list street trees as contributing to a number of ecosystem services in urban areas, including air filtering, micro-climate regulation, and noise reduction. Urban trees more generally have been argued to benefit urban climate in relation to heat, air movement, and humidity, and to adsorb airborne particles and fix CO_2 (Attwell 2000). Importantly, trees in domestic gardens are probably less susceptible to many of the insults to other urban trees, such as root damage from excavation for maintenance of services (e.g. water pipes, cables), physical damage from vehicle collision, lack of water because of hard surfaces, and exposure to vehicle emissions. Trees in gardens may also serve as important habitats for biodiversity (species richness of some

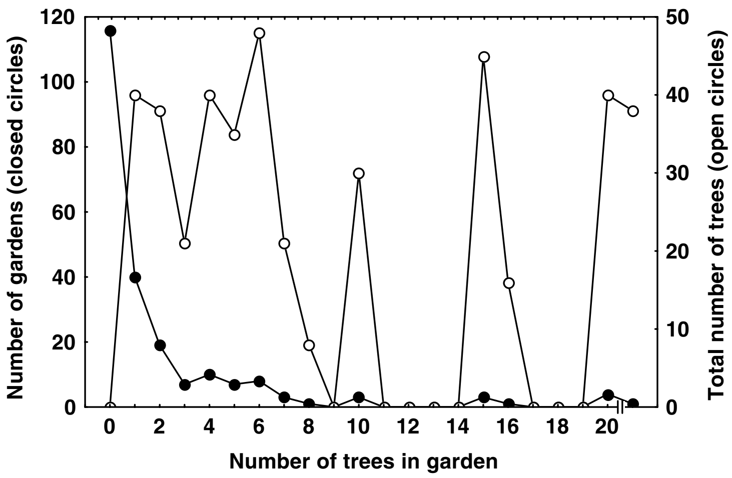

Figure 7. The number of sampled gardens with different numbers of trees more than 10 ft (3 m) high, and the total number of trees contained within all of those gardens that have a particular number of trees.

groups of invertebrates and vertebrates in urban areas is an increasing function of the volume of existing vegetation; e.g. Dickman 1987; Ruszczyk and de Araujo 1992; Jokimäki and Suhonen 1993; Savard et al. 2000), including the provision of nesting sites for birds that are better protected from feline predators (see below; London Wildlife Trust 2001). In addition, garden trees may themselves embody significant biodiversity, in including varieties that have disappeared or been severely reduced in abundance in the wider countryside, often as result of changing agricultural practices (e.g. old varieties of fruit trees).

Cities vary markedly in tree cover, depending on their climate, age, history and preferred types of construction (Nowak et al. 1996). A substantially higher percentage (86%) of gardens in a survey for London were recorded as having at least one tree of over 3 m in height than for Sheffield. However, this work was based on responses to a postal survey, for which returns seem likely to be strongly biased to those with an interest in wildlife and perhaps a wildlife-friendly garden (London Wildlife Trust 2001). McCall and Doar (1997) quote an estimate that 84% of trees in the city of Edinburgh occur in private gardens. In Sheffield the proportion is likely to be lower, particularly given the occurrence of a substantial tract of ancient woodland (Ecclesall Woods; Whiteley 1990) within the limits of the city.

Lawns

Of the dwellings in Sheffield surveyed that had gardens, 21.4% each had less than a quarter coverage by lawn, 12.3% had more than a quarter coverage but less than a half, 25% had more than a half coverage but less than three-quarters, and 41.4% had more than three-quarters coverage. Thus clearly a substantial proportion of garden area is lawn for most of the gardens (see also Attwell 2000). Taking the midpoints of these size classes, and assuming no relationship between garden area and the proportion that is lawn (see Smith et al. ms), gives an estimate of about 60% (19.5 km^2) of the total area of domestic gardens in Sheffield is lawn (or about 13.7% of the city). This is not dissimilar to the figure of 50% given for gardens across Britain by Hessayon and Hessayon (1973), although the basis of this estimate is not provided. Indeed, lawns, of one form or another, contribute substantially to urban green space (Attwell 2000).

This area of lawn produces a substantial tonnage of material for disposal, although the actual quantity is difficult to estimate, since individual lawns vary greatly in productivity. However, we can attempt to place some limits on the likely quantity. An English Premiership football pitch, well watered, heavily fertilised and mown three times a week, might produce up to 1.5 kg m^{-2} of clippings per week (D. Moore, STRI, pers. comm.). It seems unlikely that any domestic lawn would approach this productivity. At the opposite extreme, an unfertilised upland grassland at Sourhope Research Station (MLURI, Scotland), dominated by *Agrostis* and *Festuca* spp. and mown once a month, produces about 0.09 kg wet weight of clippings per m^2 per week (G. Burt-Smith pers. comm.). It seems reasonable to assume that the productivity of the typical domestic lawn lies near the lower end of this range. One such lawn in Sheffield, at 250 m elevation, not fertilized, and mown once every 3–5 weeks in 2001 produced 0.11 kg m^{-2} $week^{-1}$ of clippings (P.H.W., unpubl. data). If, conservatively, we assume an average yield of 0.1 kg m^{-2} $week^{-1}$, Sheffield's domestic lawns produce a total of 39,000 metric tonnes of material for disposal over a 20 week growing season. A proportion of this material is processed through compost heaps, but much is disposed through the refuse system; note that the tonnage of lawn clippings alone is a substantial proportion of the waste handled annually by the Sheffield incinerator (see above).

Although potentially significant for some groups (e.g. fungi; Bond 1981), 'well maintained' lawns are typically relatively sterile environments for biodiversity in domestic gardens, particularly when contrasted with herbaceous beds and other garden vegetation. However, Bolund and Hunhammar (1999) list lawns and parks as contributing to a number of ecosystem services in urban areas, including air filtering, micro-climate regulation, noise reduction and rainwater drainage. Of these, rainwater drainage seems likely to constitute the most important contribution of lawns in domestic gardens (particularly in areas where impervious surface sealing is substantial; Pauleit and Duhme 2000), indeed gardens in general may play a critical role in the development of sustainable drainage systems. Lawns may also be significant in building soils in urban areas, which are often a much depleted resource.

Cats

Of the 250 randomly selected dwellings, 14% were home to one or more domestic cats, with a grand total of 60 cats, or 0.24 (SE 0.04) cats per dwelling. This gives an estimated total for the Sheffield region of about 52,000 individuals (which does not include the population of feral cats in the city). The number of households in England in mid-1999 was estimated to be 20.743 million (Department of Environment, Transport and the Regions 2000b). If these all had a similar number of cats, on average, as the households of Sheffield, there would be approximately 5 million domestic cats. This would not seem greatly at odds with widely quoted estimates for the UK as a whole (not just England) of around 8 million individuals (an increase of more than 1 million over the 1990 figure; Pet Food Manufacturers' Association 2000).

Information on the density of domestic cats in urban areas is scant (Liberg and Sandell 1988; Bradshaw 1992; Barratt 1997a). An estimate of crude density (*sensu* Gaston 1994), averaging the number of cats by the area of the city, gives 363.6 cats/km^2 or 3.64 cats/ha in Sheffield. This contrasts with a figure of 6.6 cats/ha quoted by Bradshaw (1992) for a 25 ha suburban study site in the city of Manchester, but a difference of this magnitude could readily be accounted for by the inclusion in the Sheffield figure of non-residential areas.

Much attention has been directed to the potential impact of domestic cats on wildlife, particularly birds and small mammals (Matheson 1944; Churcher and Lawton 1987; May 1988; Bradshaw 1992; Mitchell and Beck 1992; Carss 1995;

Barratt 1997b, 1998). With reference to urban areas the discussion has become highly polarised, with claims that cats exert either high or minimal levels of predation, and with equally divergent conclusions as to the consequent need for control of cat numbers (Proulx 1988; Fitzgerald 1990; Jarvis 1990; Mitchell and Beck 1992). Estimates of high mortality of birds and mammals as a result of domestic cats predominantly seem to result from extrapolations from non-urban situations, and there is some evidence that per capita kill rates are a good deal lower in urban areas. However, the ability to 'hunt' without actually being dependent on prey capture to sustain this activity creates the potential for cats to act as mediating species in a form of apparent competition (*sensu* Holt 1977; Holt and Lawton 1994) where the subsidy provided by cat food has a negative effect on garden wildlife upon which cats feed. Further, and perhaps more importantly, there could be significant impact of domestic cats through acting as a deterrent to birds and small mammals from occupying gardens, in addition to any direct effect from the mortality that they exert.

Investment in garden management

Of the dwellings in Sheffield sampled in the telephone survey that had gardens, the occupants of 40.5% worked in those gardens more than once a week, 34.2% did so about once a week, and 25.2% did so less than once a week. The period of work is not known, but if we assume conservatively an hour on each occasion, with 40.5% doing this twice a week, 34.2% once a week and 25.2% once every two weeks, this gives an average of 1.28 h $week^{-1}$ per garden. Assuming this to be constant over 45 weeks in the year (in fact it is likely to be more in summer and less in winter) then this suggests about 10 million hours work is invested in gardens in Sheffield per annum, which if 'costed' as labour at £4 per hour (close to the national minimum wage) is £40 million per annum, or £12,121 ha^{-1} y^{-1}.

This level of time investment must make domestic gardens some of the most intensively managed areas of land. The sums spent on this management are immense. In the UK, nationally for the period July 1999 to June 2000, the retail market for garden products was valued at £2.62 billion, with 60% of households spending money on their gardens and an average spend of £183 (about 1% of household expenditure; Horticultural Trades Association Garden Industry Monitor unpublished). Although, given income levels, average expenditure is probably a little lower in the Sheffield region, applying these figures gives a spend for the city of £19.2 million per annum.

Policy implications

Whilst urban areas in the UK vary widely in their structure and history, there is little reason to believe that the findings documented here are atypical. Sheffield is not an especially 'green' city (as evidenced from the few data available for other cities, see above), indeed the degree of urbanisation of parts exceeds that found in the many cities which have experienced less intensive episodes of industrialisation. Thus, there is little doubt that domestic gardens contribute substantially to urban green space, and that this contribution should not lightly be ignored in auditing the provision of such space in urban areas, in determining the benefits that the space provides, or in considering how this space can best be managed to maximise those benefits.

In the past, such neglect of the importance of domestic gardens to urban green space has been common place. For example, the identification of so-called 'green corridors' for the movement of fauna through urban areas has often been based solely on public spaces (e.g. Sheffield City Council 1991). This is perhaps understandable when considered simply from the perspective of local government and administrative authorities, which can exercise only limited control over existing domestic gardens (although through planning controls they can exert considerable influence over the form of future spaces of this kind). However, even then it needs to be remembered that much of the effectiveness of public spaces rests on domestic gardens lying in their vicinity, which may enhance their capacity to provide ecosystem services, and to maintain populations of some wild species.

Looking beyond issues of governmental and administrative control, the great extent of urban domestic gardens, and the large numbers of important ecological features found within them, constitute a challenge and an opportunity. The challenge is that these resources must be fundamental to the maintenance of biodiversity and to the provision of ecosystem services within urban areas. As such, if this maintenance and provision are to be continued, changes to the structure of the domestic garden resource will have to be evaluated carefully. Predominantly as a consequence of social changes, particularly a trend for the size of households and families to decline and thus the number of households to rise at a faster rate than the (relatively stable) population size, there is pressure for substantial increases in the housing stock in England (Department of Environment, Transport and the Regions 2000a). There are likely to be up to 3.8 million extra households to be accommodated in England by 2021 (Department of Environment, Transport and the Regions 2000a). If 3.8 million new homes were to be built at the prevailing mean density for new development, they would cover an area larger than that of Greater London (Department of Environment, Transport and the Regions 2000a).

Increases in the overall area of domestic gardens are likely to result from the expansion of residential areas at the expense of agricultural land ('green field' sites) and derelict land ('brown field' sites). Conversely, decreases in the overall area of domestic gardens are likely to result from pressure for 'backland' development, building on existing garden areas, and a trend for loss of front gardens to off-street parking (London Biodiversity Partnership 2001). The net outcome of these opposing trends will vary geographically, but in existing urban areas (such as Sheffield) the balance seems likely to fall in the direction of a net reduction in the total area of domestic gardens, or perhaps a small increase, because of the significant constraints posed if the green belt is to be maintained and because of on-going backland development. The average size of gardens will almost certainly decline, both because the pressure on available land means that new gardens will be smaller than those of older dwellings (guidance on housing recommends increasing residential densities from the 'normal' 20–25 to 30–50 dwellings/ha; Department of Environment, Transport and the Regions 1999), and because of reductions in the sizes of existing gardens. This increased fragmentation of the overall garden area may have important effects if the 'patchiness' of the garden resource influences its role in the maintenance of biodiversity and ecosystem processes in urban areas. These might occur if, for example, the likelihood of occurrence or the proportional area of specific habitats do not scale directly with garden size (e.g. some habitat types, such as unkempt areas, only occur in larger gardens), or if, as seems likely, the form and intensity of disturbance and management are less suitable in smaller gardens.

In the face of such demands for housing, these broad trends may be difficult to oppose. However, domestic gardens also offer a tremendous opportunity to enhance further the maintenance of biodiversity and the provision of ecosystem services in urban areas. Whilst, for example, the overall numbers of ponds, nest boxes, trees and the like in domestic gardens in Sheffield are impressive (in some cases exceeding their densities in the wider countryside), these still result from the provision of such resources by only a relatively small to moderate proportion of householders. Encouraging their wider provision, and perhaps the redirection toward 'wildlife gardening' of even a small proportion of the huge sums spent annually on garden maintenance, could have substantial effects. Here, the subdivided nature of the domestic garden resource may in some respects be a benefit rather than a disadvantage, in as much as it spreads the demands on individual garden owners thinly, and reduces reliance on the actions of a few individuals.

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