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Research article

Urban domestic gardens (V): relationships between landcover composition, housing and landscape

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Abstract

The contribution to urban green space by private or domestic gardens in residential zones was investigated in the city of Sheffield, UK, as part of a wider study of the garden resource and its associated biodiversity. The attributes of 61 gardens, including patterns of landcover and vegetation cover, were explored in relation to housing characteristics and the nature of the surrounding landscape. The number of surrounding houses, and the areas of buildings and of roads were negatively correlated with garden area. The proportion of a housing parcel comprising garden increased with parcel size, although the proportion that was rear garden remained relatively constant. Garden size played an overwhelming role in determining garden composition: larger gardens supported more landcovers, contained greater extents of three-quarters of the recorded landcovers, and were more likely to contain trees taller than 2 m, vegetable patches, and composting sites. Unvegetated landcovers made greater proportional contributions as garden size declined. All categories of vegetation canopy increased with garden size, and large gardens supported disproportionately greater cover above 3 m. House age was a less significant factor determining garden landcover. Gardens of newer houses were more likely to occur towards the edge of the urban area, and older properties, that contained fewer hedges, possessed less canopy between 2–3 m. The extent and occurrence of different landcovers in gardens, and their consequences for wildlife, are considered for residential patches in urban areas. The implications for urban planners are discussed.

Introduction

Urbanisation is characterised by increased human population density and the development of commercial or industrial infrastructure. It is a global agent of ecological change, occurring on every continent except Antarctica, and across a wide range of biomes. Urban areas currently cover about 4% of the Earth's land surface, more than 4.71 million km^2 (UNDP, UNEP, WB and WRI 2000) – roughly equivalent to 19 times the entire area of the UK, or 0.5 times that of the USA.

Urbanisation causes wholesale transformation of the local environment: it fragments or destroys natural habitats, whilst also creating new ones; it alters regional climate, and both the quality and flow of water; it reduces net primary production; and it changes the composition of species assemblages (Sukopp and Starfinger 1999), (Kinzig and Grove 2001). Non built-up land in urban areas, often termed green space, plays a major role in buffering such changes; examples of green space are public parks, sports fields, derelict land, the edges of roads, railways, and waterways, and indigenous vegetation encapsulated by development. In addition, such landcovers and their related attributes are important to the physical and mental well-being of the large proportion of the human population that lives and works in urban areas (Niemelä 1999; Dunnett and Qasim 2000).

Given the high human populations of urban areas in the UK and some other regions, private gardens associated with residential zones (hereafter called domestic gardens) may contribute the greatest proportion of land to urban green space. Indeed, the few estimates available for U.K. cities indicate that domestic gardens comprise 19–27% of the entire urban area (Owen 1991; McCall and Doar 1997; London Biodiversity Partnership 2001; Gaston et al. in press b). Whilst data on the ecological value of domestic gardens, compared to other types of green space, are generally lacking, available evidence suggests that the former play a significant role in supporting diverse wildlife populations (e.g. Davis 1979; Owen 1991; Vickery 1995; Saville 1997). Furthermore, as the quality of the wider countryside deteriorates (Robinson and Sutherland 2002), gardens in the UK are becoming increasingly important for particular species (and almost certainly in other developed countries too) (e.g. common frog *Rana temporaria*, hedgehog *Erinaceus europaeus*, and song thrush *Turdus philomelos*; Swan and Oldham 1993; Doncaster 1994; Mason 2000).

The ecological functions provided by green spaces will depend on their configuration and composition. Regarding their configuration, an assessment of the domestic garden resource in the city of Sheffield, UK, shows that it is distributed throughout the majority of the urbanised area; that smaller gardens, due to their abundance, contribute disproportionately to the total garden area of about 33 km^2 (23% of the urban area); and that although they are relatively few, the regions of the city with proportionately greater garden area account for most of the total (Gaston et al. in press b). In short, domestic gardens can form extensive, inter-connected tracts of green space. Therefore, as for other categories of urban green space, the benefits of individual gardens probably arise from them acting as isolated patches (in the case of plants, sedentary organisms, and those with small home ranges, e.g. insect herbivores, Owen 1991, small mammals, Dickman and Doncaster 1987), as components of a landscape that includes other vegetation (for species using particular resources in gardens, e.g. hedgehogs, Rondini and Doncaster 2002; bumble bees, *Bombus* sp., Goulson et al. 2002), or as corridors through the urban matrix (e.g. birds, Fernàndez-Juricic 2000).

However, the nature of the green space provided by domestic gardens – and hence their potential benefit to wildlife – must also depend upon composition. In general terms, the landcovers of 'conventional' domestic gardens in the UK are well known (e.g. grass lawn, paved patio, and cultivated flower beds containing ornamental annual, perennial and woody plants; Hessayon and Hessayon 1973), but a quantitative description of garden landcover, and an understanding of the physical factors affecting its composition, are lacking for any major urban area. For example, while it is recognised that household size has serious repercussions for biodiversity via its effects on landcover and resource consumption (Liu et al. 2003), the consequences for the composition of domestic gardens have not been considered. Long term research in single gardens (Owen 1991; Miotk 1996), and short term studies of multiple gardens (Saville 1997), indicate that they are complex environments, supporting diverse microhabitats that result from the interplay of aspect, vegetation structure and management regime. Even simple landcovers, such as paving, may provide important substrates for certain organisms (e.g. lichens). Likewise, compost bins and heaps may have been created solely for waste disposal or recycling, yet they offer valuable and unique resources to wildlife (Curds 1985; Ødegaard and Tømmerås 2000).

Additionally, whilst the landcovers assumed to benefit wildlife in gardens are well known (e.g. beds with cultivated flowers, trees, neglected areas, and ponds; Hamilton and Owen 1992; Hill 1996; Baines 2000), the factors affecting their likelihood of occurrence are largely unknown. For example, lack of space may simply deter people from planting trees or from neglecting a portion of their garden in order that it may 'run wild'. Understanding the role of such factors is essential for assessing the contribution made by domestic gardens to green space resources.

In this paper we provide the first detailed examination of the composition of domestic gardens in the UK, and of the physical factors affecting the occurrence of particular landcovers, based on a case study in the city of Sheffield. Our aims were fivefold: first, as a preliminary goal, to provide some context about landcover at a local scale, by exploring relationships between a garden's main attributes – area and house age – and the composition of the residential landscape in that garden's immediate surroundings. It was anticipated that patterns would be discernable because, even in relatively small blocks of housing, building density should influence the configuration of surrounding landcovers. Second, to identify the presence of systematic relationships between the area of individual housing parcels and the extents of gardens within them; we predicted that larger parcels would contain greater extents of garden, but it was not clear how the proportion of garden would change with parcel size. As a complement, we checked whether housing type (defined below) and house age, which are often used as a rough guide to garden area, were reliable indicators or not. Third, the main focus of the study was to explore how landcovers and vegetation structure within rear gardens were affected by changes in garden area and house age. The present study focussed on rear gardens because they form the major garden component of most properties. Frequently, front gardens are either absent or have been converted to access and parking space for vehicles. We considered that larger rear gardens would expand the options available to garden owners, encouraging them to have a broader range of landcovers and possibly greater extents of individual landcovers, as well as different types of vegetation (e.g. larger trees). House age might also have provided a guide to the maturity of the vegetation, which would be evident in its canopy structure. However, it was uncertain whether particular landcovers would remain common to all garden sizes, and if certain landcovers or vegetation types effectively disappeared as garden area declined. Fourth, we explored how the composition and geometry of garden boundaries varied in relation to garden area and house age. We discuss the implications of the results for the role of gardens as green space and potential wildlife habitat. Our final aim was to extrapolate the findings for garden landcovers to the wider urban landscape, with reference to the UK government's plans for future house building. Up to 3.8 million extra households are likely to be needed just in England by 2021 (DETR 2000). The pressure on available land (particularly if impacts on previously undeveloped 'green field' sites are to be minimised) means that the gardens of new housing will be smaller than those of many older dwellings. Guidance on housing recommends increasing densities from the 'normal' 20–25 to 30–50 dwellings ha^{-1} (DETR 1999), and portions of many existing gardens (particularly larger ones) are likely to be built on due to pressure for 'backland' development (London Biodiversity Partnership 2001). Therefore we compared how extents of different vegetated landcovers changed under different housing density scenarios.

The work reported here is part of the 'Biodiversity of Urban Gardens in Sheffield' (BUGS) project, a broader investigation of the resource that domestic gardens provide for biodiversity and ecosystem functioning (Gaston et al. in press b), the levels of that biodiversity associated with different gardens and the factors that influence this (Thompson et al. 2003, 2004), and ways in which garden landcovers and features can be manipulated to enhance biodiversity (Gaston et al. in press a).

Methods

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 (Figure 1); it is largely surrounded by agricultural land, except where the urban area merges with that of Rotherham to the north-east. The administrative boundaries of the city enclose an area of more than 360 km^2, including farmland and a portion of the Peak District National Park. Sheffield had a long history as a market town, larger than surrounding villages, and with a distinctly urban character, but rose to prominence as a consequence of the great industrial changes that took place over the last 250 years (Hey 1998). The central town population grew from around 10,000 in 1736 to 83,000 in 1851, and 90,000 by 1901, and the urban areas spread westwards and north-westwards incorporating many more inhabitants (400,000 by 1901), such that by 1911 Sheffield was the fifth most populous city in England. In the second half of the nineteenth century, steel manufacture became the major industry, and remained so for nearly one hundred years. However, during the 1970s and 1980s, manufacturing industry be-

Figure 1. Map of the position of Sheffield in the UK.

gan to shrink drastically, the economy diversified, and by the mid-1990s two-thirds of jobs in Sheffield were in the service sector. Major areas of the city have been redeveloped under regeneration programmes, with many of the 'heavy' industrial sites (e.g. for steel manufacture) replaced by housing, or service and 'light' industries.

Residential areas in Sheffield, as in most urban areas of the UK, comprise four principal types of dwelling: blocks of apartments (many adjoining dwellings, on more than one level), 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 (Figure 2), 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 (Gaston et al. in press b), a value that is similar to a national estimate of 80% (Hessayon and Hessayon 1973). Sheffield gardens have a mean area of 173 m^2 (Gaston et al. in press b), again differing little from a national figure of 186 m^2 (Hessayon and Hessayon 1973). The common landcovers of rear gardens in Britain have changed little since those recognised by (Hessayon and Hessayon (1973) and Owen (1991): a mown lawn, cultivated beds of ornamental herbs, grasses, shrubs and trees (generally bordering the garden), paved paths and patio, boundaries composed of hedges, fences or walls, and possibly some fruit trees and bushes, a vegetable patch, a shed, and a greenhouse. Relatively recent trends are for parts of larger gardens to be sold for house building, and for garden styles to be influenced by fashion in a way previously associated with interior design (e.g. creative lighting). British gardens are generally used between spring and autumn for growing produce for eating or display, relaxation, children's play, and for exercising pets.

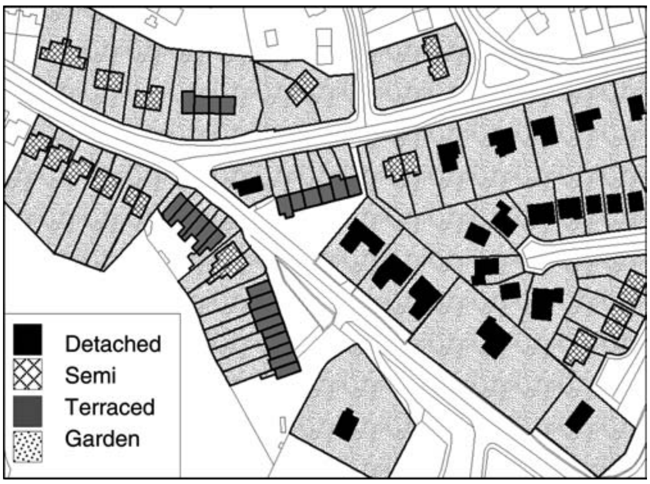

Figure 2. Examples of typical UK house types with associated garden space: detached, semi-detached and terraced dwellings in Sheffield. Thick grey lines show parcel boundaries. Property outlines were traced from Ordnance Survey Landline data (Crown Copyright Ordnance Survey. All rights reserved).

Sample gardens

The study was conducted on the gardens of private, owner-occupied dwellings (Figure 3) in 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. 1:25,000 scale maps). Sixty-one gardens were selected as a stratified sample from a convenience sample of 161 householders, derived from contacts among ancillary, clerical and academic staff at the University of Sheffield, and from members of the public at lectures or displays about the project (see Discussion about potential sources of bias). This approach was chosen due to the great difficulty in the alternative of recruiting householders at random who were both sympathetic to research being conducted in their gardens, and able to offer daytime access. 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 parcel size – and selecting values along the entire length of each axis, our method enabled us to explore the influence on landcover composition of such axes, over their full ranges of variation. By this means the results from the study could be generalised to culturally similar areas in the UK even if the distribution of parcel sizes differed. House age and parcel size were the sole information used in generating the garden sample. Blocks of apartments, generally lacking private gardens, were excluded from the study.

Recording garden characteristics

A brief guide to definitions of variables used commonly throughout the paper follows, to help avoid confusion (other variables occur later): Parcel, the private area belonging to a householder, including dwelling and garden space (measured from a GIS); Garden, calculated as the area of the parcel minus the area of the house (measured from a GIS); Rear garden, the part of a parcel's garden, behind the house, whose boundaries and landcovers were mapped on the ground; Surrounding gardens, the summed area of garden (all parcels minus their houses) within a circle of 10000 m^2 centered on the study parcel.

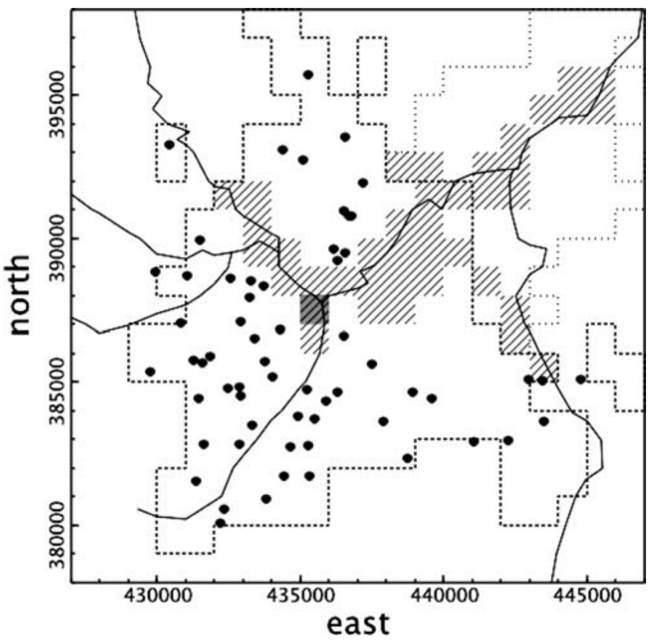

Figure 3. Map of the locations of the 61 study gardens in the predominantly urban area (heavy dashed line) of Sheffield, in relation to zones with $>50\%$ industrial / commercial use (cross-hatching), principal rivers, and the adjoining town of Rotherham to the north-east (light dashed outline). The shaded square indicates 1 km^2 of the central business district, centered on the city hall. Map axes represent distances (m) on the Ordnance Survey national grid; the map covers 20 km×20 km.

Rear gardens were surveyed between July and September 2000. Principal dimensions were measured to the nearest 0.5 m, and a scale plan was drawn of each garden, including the side portions of corner parcels. The areas of rear gardens ranged from 32–940 m^2 and the ages of their associated properties ranged from 5–165 years. The plan incorporated boundaries (and their construction), buildings within the rear garden, and all forms of landcover, of which 22 were recognised: lawn (grass cut more than once per month during the growing season); uncut grass; cultivated flower bed; uncultivated/neglected ground; vegetable patch; gravel; paths (made of hard and loose surfaces, or grass); patio (all terraces paved in stone or similar hard surfaces, other than paths); roofed patio; shed; garage (originally intended for storing a vehicle); greenhouse (glasshouse for plants); pond; decking (terraces made from wooden boards); chicken enclosure; compost bin (closed) and compost heap (open); ornamental fountain; internal walls; and hedging (plants forming a boundary; species were identified with nomenclature following Stace 1997). The part of the rear garden perimeter abutting other parcels, and forming a boundary, was termed Exposed garden perimeter. The areas of each type of landcover, and the lengths of linear landcovers, were estimated from the plan. Vegetation structure, including tree canopies but omitting lawn, was measured by mapping the area covered by a canopy in the following height classes: <0.5, 0.5–1, 1–2, 2–3, and >3 m. Ground areas that were overlapped by several canopy classes contributed to the total for each of those classes. The number of trees taller than 2 m was also recorded (this height class was chosen because it had been used in a related study in the project). Distance to the centre of the nearest 1 km×1 km cell having less than 25% coverage by residential or industrial zones (as judged by eye from Ordnance Survey 1:25,000 scale maps) was assessed as a measure of distance to an urban edge. Parcels were located between 0.46 and 4.73 km from an urban edge.

Garden measurements using a Geographic Information System (GIS)

Parcel area and garden area were measured for each parcel using Ordnance Survey digital 'Landline Plus' (1:1250) maps, imported to an ArcView GIS (Environmental Systems Research Institute, Inc.). Some variables for landcover surrounding each parcel were also created, measured for a circular area of 10000 m^2 (1 ha) centred on each parcel: number of houses (where more than half of the area of a house was covered), area of roads, area of buildings (both dwellings and non-residential buildings), and area of surrounding gardens. The number of houses was not a direct measure of the local housing density because the sample area may have included non-residential landcovers. The area of land not in the former categories was also measured, and termed unclassified, because more detailed landcover types could not be reliably interpreted (including e.g. farmland, recreational space, and semi-natural vegetation).

Analyses

Context: general housing characteristics

We set the context of gardens in the local built environment by looking at relationships between total garden area, house age, and the surrounding landcover variables, and total garden area and parcel size. These were examined through linear correlations, as the approach does not assume any causal links, appropriate here for simply exploring patterns among the variables. For the same reason, no attempt was made to account statistically for covariation, although it is readily acknowledged that variables were likely to be intercorrelated, and such relationships are discussed; e.g. housing density and the area of buildings. As for all the analyses, we chose not to try to control for the number of comparisons because the conceptual and methodological uncertainties with techniques for doing this would have resulted in arbitrary judgements as to how to apply such corrections (Moran 2003). Variation in rear garden area and house age were analysed in relation to housing type by one-way ANOVA to check the assumptions that housing type provides a reliable guide to rear garden size, and possibly house age.

Landcover in gardens

Landcover richness in gardens was analysed in relation to garden area and house age by simple linear regressions. The probability of individual landcovers occurring in gardens in relation to garden area and house age were analysed by logistic regression, using a binomial response and logit link function. The influence of garden area on the extents of individual landcovers was examined by simple linear regression. The data were analysed in two ways: the first dataset contained all gardens even if a landcover was absent from a proportion of these (i.e. the landcover had a logical minimum of zero). By this approach, the regression coefficients for data including zeros could be generalised to garden samples where the proportion of gardens containing the landcover was unknown. Second, the dataset was analysed with only those gardens containing a particular landcover (i.e. omitting zero values), since the factors determining whether a landcover exists in a garden may be different from those affecting its size, e.g. owners may or may not choose to have a pond in their garden for reasons of child safety, but where a pond is present, garden area may dictate its size; thus the effect of garden area could be contingent upon the choice to have a landcover or not. Changes in the proportional contributions of landcovers in relation to garden area and house age were also analysed by simple linear regression. Since area and age had significant effects on the proportion of hard paths, this landcover was reanalysed by multiple regression, incorporating area and age as independent variables.

Vertical structure of vegetation

To test the effects of garden area and house age, number of trees above 2 m high, and length of hedging on the extent of canopy vegetation, these factors were analysed by multiple regression for each of the five canopy height classes (omitting number of trees and hedge length from the analyses of canopy classes <0.5 and 0.5–1 m), as well as the summed classes. Simple linear regression was used to see how the proportional contributions of different canopy classes were related to garden area and house age.

Garden shape and properties of the boundary

To investigate whether properties of garden boundaries varied systematically with garden area or house age, simple linear regression was used to analyse: garden dimensions in relation to garden area; proportional boundary composition in relation to garden area and house age; and length of hedging in relation to garden area. The probability of presence of hedging in gardens in relation to house age was analysed by logistic regression.

Changes in vegetated landcovers under different housing density scenarios

We estimated areas of vegetated landcovers for residential parcels at housing densities of 10, 20, 30 and 40 houses ha^{-1}, based on the relationships (using data with zero values) between individual $\log_{10}$ landcover extents and $\log_{10}$ garden area from the sample of 61 gardens (see section Landcover in gardens). The garden area at each density was derived from the relationship between $\log_{10}$ rear garden size and $\log_{10}$ number of houses in the surrounding 1 ha; all the gardens at a given housing density were assumed to be of identical size. By a similar method we estimated the frequency of occurrence of landcovers for residential parcels, based on the frequency of occurrence in the sample of 61 gardens. The estimates for the number of trees and vegetable patches, using data without zero values, were corrected for the number of gardens likely to possess these features at each garden size (see section Landcover in gardens).

All analyses were carried out in SAS (release 8.01, SAS Institute Inc., Cary, NC, USA). The values of areas of gardens and their internal landcovers, of GIS-derived variables, lengths of internal walls and hedges, and proportions were, when necessary, logarithmically or arcsine-square root transformed either to linearise relationships or to homogenise variances and normalise residuals.

Results

Context: general housing characteristics

Individual garden area was weakly positively correlated with the total area of gardens in the surrounding environment ($r = 0.33$, $n = 61$, $p < 0.01$), but negatively related to the number of houses ($r = -0.68$, $n = 61$, $p < 0.001$), the area of buildings ($r = -0.60$, $n = 61$, $p < 0.001$), and the area of roads ($r = -0.28$, $n = 61$, $p < 0.05$). Housing density would explain these relationships between an individual garden's area and its surrounding landcovers: large parcels would tend to be surrounded by other large parcels, thus containing fewer houses. Consequently the number of houses might also be expected to be related to many aspects of the residential environment. It was indeed strongly correlated with the total area of buildings ($r = 0.81$, $n = 61$, $p < 0.001$), but not with the total areas of roads ($r = 0.08$, $n = 61$, $p = 0.514$) or with total area of surrounding gardens ($r = 0$, $n = 61$, $p = 0.980$). The latter result is unexpected, but may be due to the scale at which landcovers were measured. Note that the number of houses was an indirect measure of housing density, since the 1 ha sample area also contained non-residential landcovers. Therefore, while sample areas with many houses may have had relatively little total garden area (i.e. high density), areas with few houses may also have had little total garden area simply because they were coincident with non-residential landcover (rather than being low density housing with a large total garden area). This is supported by a lower number of houses being weakly correlated with a larger area of unclassified land ($r = -0.28$, $n = 61$, $p < 0.05$). Individual garden area was unrelated to: position in the city on easterly or northerly axes, altitude, distance to the edge of the urbanised area, or with the amount of unclassified land (generally not built on) in the surroundings.

Rear garden area was strongly related to house parcel size ($r = 0.91$, $n = 61$, $p < 0.001$). However, the proportion of the parcel which was rear garden did not vary systematically with parcel size ($r = 0.09$, $n = 61$, $p = 0.494$). This result contrasts with the response of total garden area (parcel area – house area, estimated from the GIS) to parcel size, whereby the proportion of garden increased non-linearly with parcel size (Figure 4). The reason that proportional total garden area, but not proportion of rear garden area, increased with parcel size is due to the addition of front garden space and the relatively slow rate of increase in house area (the regression slopes of house and total garden areas with parcel size are 0.36 and 1.21 respectively).

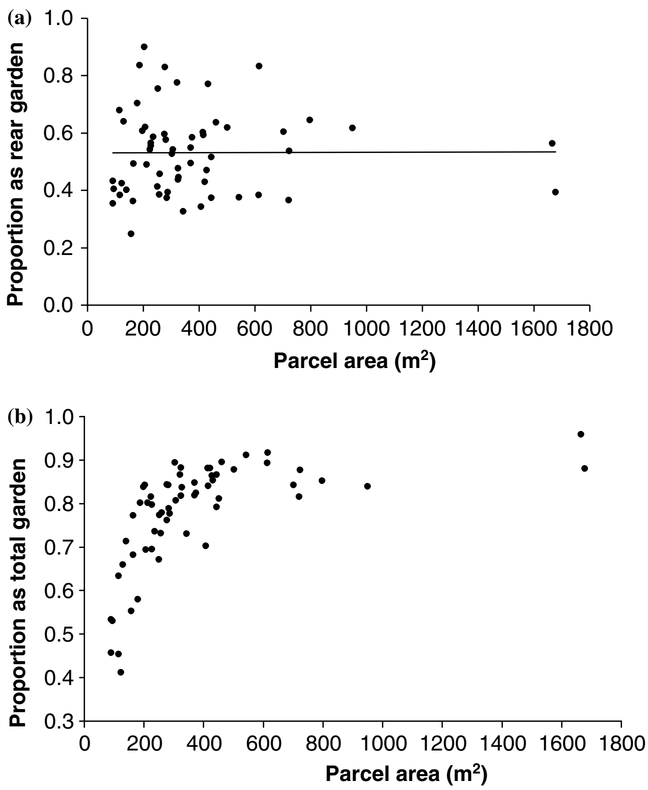

Figure 4. The relationship between a) rear garden area (measured on the ground), as a proportion of parcel area, and parcel area ($F_{1,58} = 0.02$, $p > 0.05$, $r^2 = 0$), and b) total garden area (calculated from the GIS), as a proportion of parcel area, and parcel area ($F_{1,59} = 35.7$, $p < 0.001$, $r^2 = 0.52$).

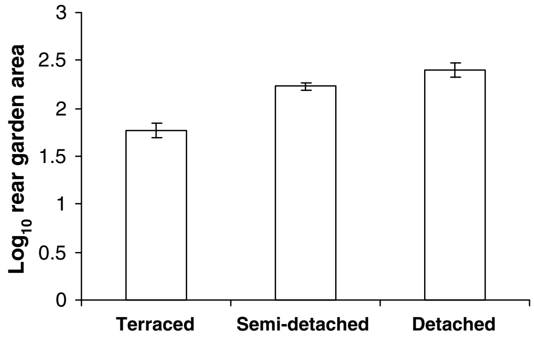

Figure 5. The relationship between housing type and rear garden area.

Variation in rear garden area was related to housing type: gardens of terraced houses were significantly smaller than those of detached and semi-detached houses (ANOVA: $F_{2,58} = 20.41$, $p < 0.001$, Fig. 5). Terraced houses, with smaller gardens, were on average older than other house types (ANOVA: $F_{2,58} = 14.67$, $p < 0.001$; terraced mean ± S.E. = 105 years ± 3.9; semi-detached: 65.3 ± 5.4; detached: 39.7 ± 8.4), resulting in a weak, negative relationship between garden area and house age ($r = -0.26$, $n = 61$, $p < 0.05$).

Newer houses occurred closer to the edge of the urbanised area ($r = 0.52$, $n = 61$, $p < 0.001$), with evidence of a tendency for newer houses to lie to the east of the city ($r = -0.24$, $n = 61$, $p = 0.057$); no relationship existed with position on a northerly axis or with altitude. Older houses were surrounded by a greater area of road ($r = 0.30$, $n = 61$, $p < 0.05$); perhaps because such houses tended to be terraced, and smaller areas of front garden space and more compact housing rows (Figure 2) allowed more road in the immediate vicinity. Otherwise house age was unrelated to the areas of other landcovers (gardens, buildings, unclassified land), or to the number of houses.

Landcover in gardens

The majority of gardens possessed a mown lawn, patio, cultivated flower bed for ornamental plants, hard paths, trees > 2 m high, and internal walls of stone or brick construction. This description closely resembles one for conventional gardens in Britain (Hessayon and Hessayon 1973). The number of landcover types per garden (termed landcover richness) ranged from 2 to 15, with a mean of 8.90 (SD ± 2.70), and a median of 9 for all gardens. Landcover richness was positively related to garden area (Figure 6) but not to house age ($F_{1,59} = 0.89$, $p = 0.35$, $r^2 = 0.015$).

The observation that landcover richness increased with garden area is borne out by the occurrence of some individual landcovers: trees more than 2 m high, vegetable patches, and composting (heaps and bins combined) were more likely to be found as garden size increased (Figure 7); non-significant trends for the same relationship existed for mown lawns (logistic

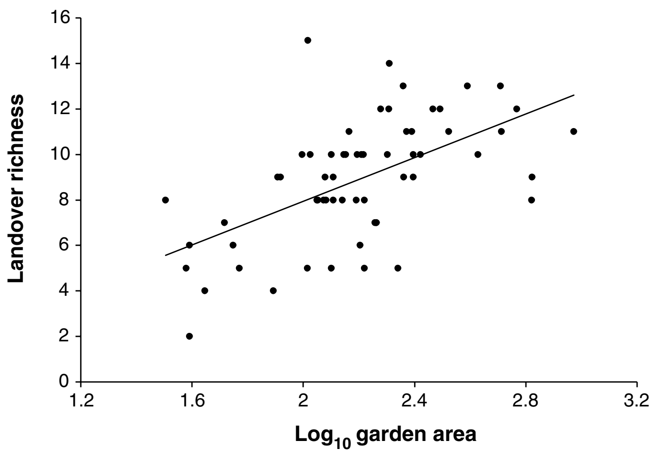

Figure 6. The relationship between landcover richness and garden area ($F_{1,59} = 28.4$, $p < 0.001$, $r^2 = 0.32$).

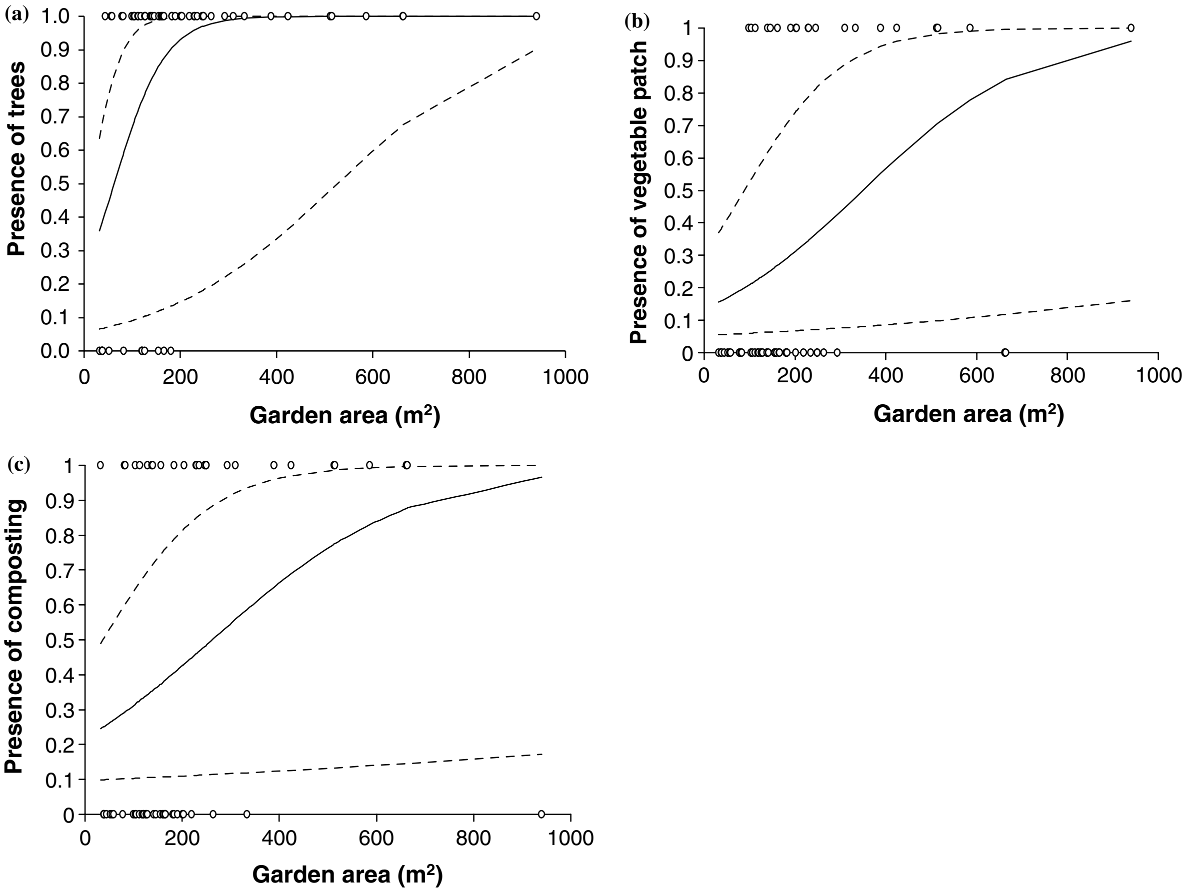

Figure 7. The relationships (analysed by logistic regression) between a) the presence of trees >2 m high and garden area (χ^2 = 7.56, $p<0.01$); b) the presence of vegetable patches and garden area (χ^2 = 6.59, $p<0.05$); and c) the presence of composting (heaps and bins combined) and garden area (χ^2 = 5.30, $p<0.05$). Open circles – observed values, solid line – predicted values, dashed lines show lower and upper 95% confidence limits.

regression: $\chi^2 = 2.61$, $p = 0.105$), uncultivated areas ($\chi^2 = 3.27$, $p = 0.070$), compost heaps ($\chi^2 = 2.78$, $p = 0.095$), and internal walls ($\chi^2 = 2.50$, $p = 0.113$). Therefore garden area partly determines the availability of particular landcovers, and consequently the presence of potential habitat for wildlife, e.g. composting sites may be the only source of warm, decaying vegetation used as a breeding site by certain flies. The presence of hedges (see under boundary characteristics below) was the only landcover of gardens to be related to house age.

Besides the effect of garden area on landcover availability, the extents of particular garden landcovers may affect their suitability for wildlife, e.g. pond size could determine whether unfrozen refuges remain during winter. Here garden area also exerts an effect. The quantities of 13 out of 17 landcover types, frequent enough to be analysed, were positively related to garden area (Table 1), but none were related to house age.

Additionally, the proportional contributions of different landcovers are relevant when considering the amount of potential resource across a block of gardens, especially when such blocks comprise parcels of similar size. The instances in which the proportion of landcover was related to garden area were, unsurprisingly, mainly for buildings or objects which maintained a relatively constant absolute size, and whose contribution to area was therefore negatively related to garden size (Figure 8): compost bins ($F_{1,13} = 35.8$, $p<0.001$, $r^2 = 0.73$), sheds ($F_{1,33} = 5.53$, $p<0.05$, $r^2 = 0.14$), greenhouses ($F_{1,13} = 14.8$, $p<0.01$,

Table 1. The types of landcover recorded in 61 domestic gardens in Sheffield: the ranges in percentage cover of rear garden area; the no. of gardens in which they occur (N); and the variation explained in regressions of the area ($\log_{10}(x+1)$) of individual landcovers on $\log_{10}$ garden area (where a landcover was recorded in more than five gardens).

Landcover	Range in % cover	N	r^2	
			Excl. zero values	Incl. zero values
Cultivated flower bed	1.1–59.3	59	0.48***	0.50***
Patio	2.4–64.1	56	0.24***	0.14**
Hard path	0.8–38.4	53	0.20***	0.30***
Mown lawn	4.4–85.1	52	0.62***	0.56***
Trees > 2 m high (number)	–	61	0.52***	0.52***
Internal walls (length, m)	–	44	0.44***	0.30***
Uncultivated/neglected	0.5–85.8	39	0.30***	0.26***
Sheds	0.8–17.5	37	0.20**	0.11**
Pond	0.4–5.8	30	0.31***	0.10*
Vegetable patch	0.4–25.0	20	0.05	0.12**
Unmown lawn	0.5–30.5	18	0.48**	0.13**
Compost heap	0.3–2.3	17	0.30*	0.12**
Compost bin	0.2–1.6	15	0.58***	0.06
Greenhouse	0.8–5.8	15	0.02	0.09*
Loose path	1.6–25.6	14	0.18	0.04
Garages	3.3–18.1	14	0.08	0
Grass path	1.6–7.0	16	0.74**	0.03
Gravel	2.7–12.5	3	–	–
Wooden decking	1.0–3.1	3	–	–
Ornamental fountain	0.6	1	–	–
Roofed patio	15.6	1	–	–
Chicken enclosure	10.9	1	–	–

In the cases of trees and internal walls, regression coefficients were derived respectively from the regressions of $\log_{10}$ (No. of trees + 1) on $\log_{10}$ garden area, and length and $\log_{10}$ garden area. * $p<0.05$, ** $p<0.01$, and *** $p<0.001$.

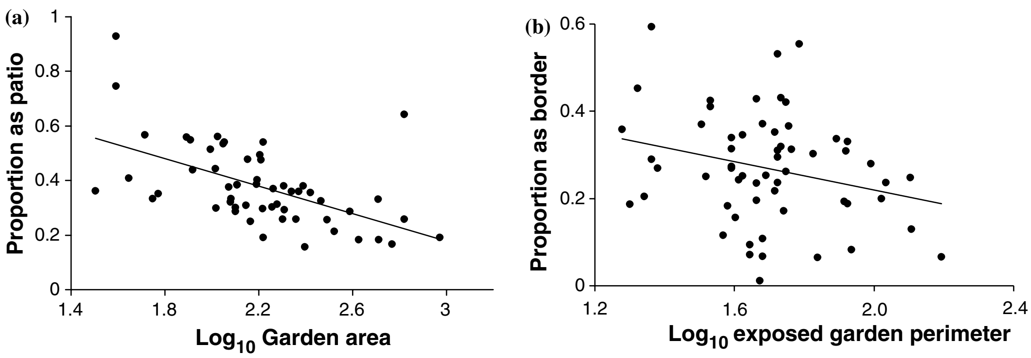

Figure 8. Examples of the relationships between proportional contributions of different landcover types and measures of garden size: (a) patios as a proportion of garden area (arcsine square-root transformed) vs. garden area, and (b) flower bed as a proportion of garden area vs. length of exposed perimeter.

$r^2 = 0.53$), patios (arcsine square-root transformed, $F_{1,54} = 23.8$, $p<0.001$, $r^2 = 0.31$), garages ($F_{1,12} = 21.9$, $p<0.001$, $r^2 = 0.65$) and hard paths (see below).

The only measure of proportional vegetated space to be related to area, albeit indirectly, was for cultivated flower bed. The latter was weakly, negatively related to the exposed garden perimeter ($F_{1,57} = 4.2$, $p<0.05$, $r^2 = 0.07$, Figure 8b), which is closely related to garden size (see below). This relationship arose because flower beds are normally situated along the boundaries of a garden, rather than as 'islands' surrounded by other landcover. Therefore, as gardens became smaller, and the ratio of perimeter to area increased (see below), flower beds should have occupied relatively greater space.

Of all the garden landcovers, the proportion of hard paths was the only one related to house age as well as garden area (multiple regression, $F_{2,52} = 10.1$: area: $p < 0.05$, $r^2_{adj} = 0.08$; age: $p < 0.01$, $r^2_{adj} = 0.18$; but see boundary walls also, below).

Vertical structure of vegetation

The vegetation canopy is a component of habitat structure not captured in other measures of landcover. As might be expected, total canopy vegetation cover (i.e. summed across the five height classes between 0 and > 3 m) increased both with garden area and the number of trees taller than 2 m, yet it was unrelated to house age (Table 2, Figure 9). While trees in gardens were the principal source of tall vegetation, it was not clear whether the number of trees accounted for its extent, since single mature trees often possessed disproportionately large canopies; furthermore, shrubs also grew as high as small trees. In individual analyses of the vegetation height classes 2–3 and > 3 m (Table 2), the effect of trees was indeed greatest for canopy > 3 m high. It is likely that garden area also plays a direct role in influencing canopy above 3 m because large tree species are more likely to be grown in large gardens; large canopies tend not to be tolerated close to houses (i.e. particularly those with small gardens) because they cut out light and falling trees or branches may also pose a risk of damage. Additionally, canopy > 3 m formed a larger proportion of total cover as the number of trees increased ($F_{1,58} = 38.9$, $p < 0.001$, $r^2 = 0.40$). In contrast, the area of canopy at 2–3 m was more strongly influenced by the length of hedging in gardens, as well as being positively related to house age (Table 2, Figure 9). All other vegetation height categories – between 0 and 2 m – were related to area only (Table 2); they reflected the strong relationships between garden area and the areas of different landcovers, since the herbs and shrubs which comprised the lower canopy categories were principally recorded from cultivated flower beds.

Garden shape and properties of the boundary

Gardens were generally rectangular in shape, with the majority of their lengths being longer than their widths; there was no relationship between the ratio of length to width and garden size (excluding those gardens with markedly irregular perimeters, e.g. 'L' shaped rear gardens of corner parcels; $F_{1,47} = 2.07$, $p > 0.05$, $r^2 = 0.04$). Exposed perimeter increased with garden area (Figure 10a), while the exposed perimeter: area ratio was negatively related to garden area (Figure 10b), so that smaller gardens had a greater proportion of their area exposed to edge. However, the 'permeability' of gardens is also likely to be determined by boundary characteristics. Virtually all types of hedges and fences probably permit movement by invertebrates, and small vertebrates, at ground level. Mortared walls, though, would be expected to create a barrier to any organism unable, or unwilling, to climb them. The proportion of the

Table 2. The relationships between vegetation canopy classes ($\log_{10}$ transformed) and garden characteristics, based on multiple regression models for individual classes (where non-significant terms were removed from final models).

Model term		House age	$\log_{10}$ Garden area	$\log_{10}$ No. trees	$\log_{10}$ Hedge length
Canopy class	d.f.				
< 0.5 m	1, 58	ns	0.48 ***	–	–
0.5–1 m	1, 52	ns	0.49 ***	–	–
1–2 m	1, 52	ns	0.44 ***	ns	ns
2–3 m	3, 46	0.12 **	ns	0.05 *	0.27 ***
> 3 m	2, 47	ns	0.27 **	0.39 **	ns
Total canopy cover	2, 58	ns	0.59 ***	0.27 ***	ns

'Total canopy cover' sums all height classes. Cells show r^2 or partial r^2; cells with dashes indicate terms not fitted in original model. ns = not significant, * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

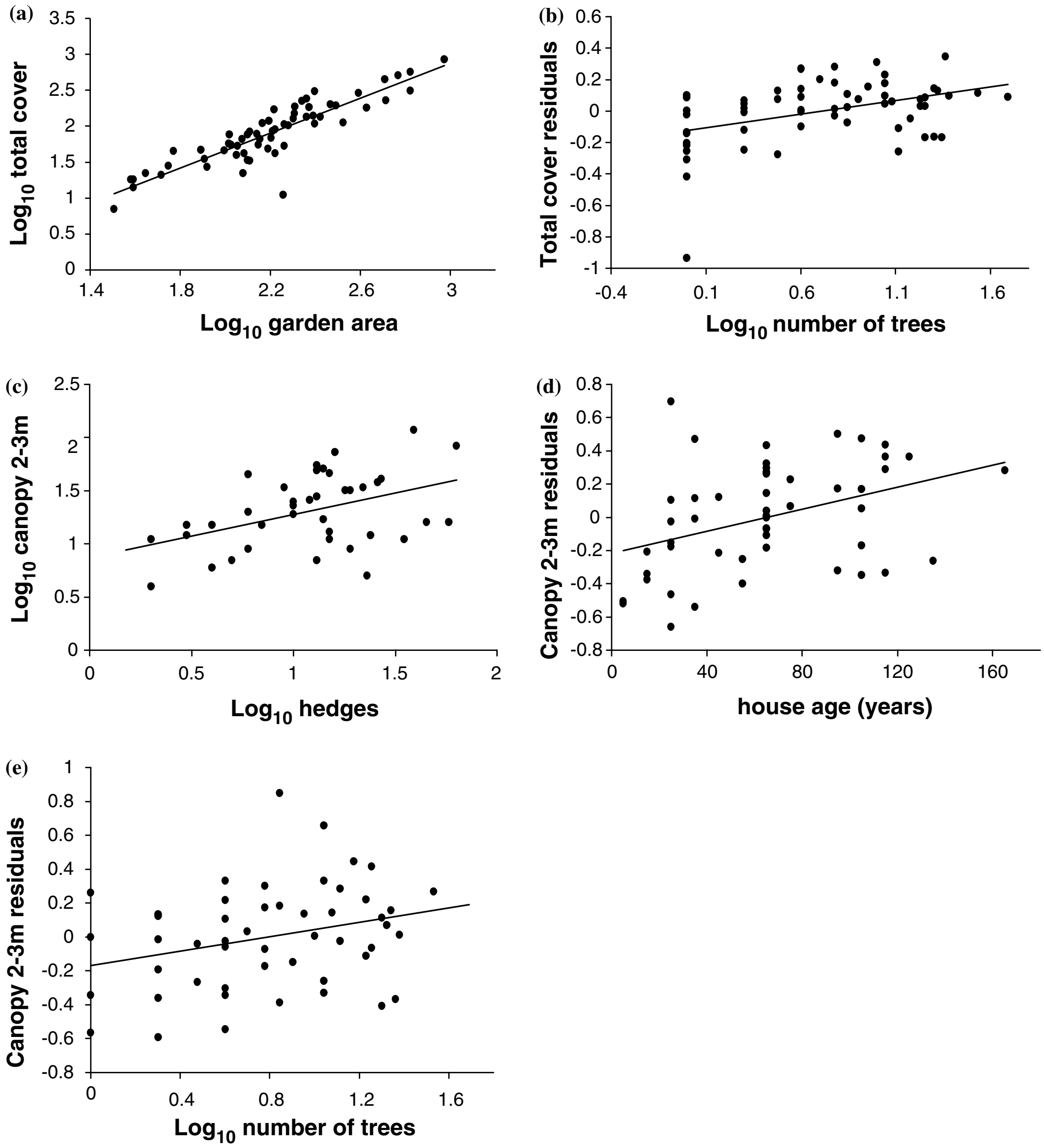

Figure 9. The relationships between (a) total canopy cover and garden area, (b) total canopy cover and number of trees (y axis shows residuals from regression model of cover against garden area), (c) canopy at 2–3 m and length of hedging, (d) canopy at 2–3 m with house age, and (e) canopy at 2–3 m with number of trees. Y axes for (d) and (e) are residuals from models of canopy at 2–3 m fitted with length of hedging and number of trees/house age respectively (residuals used for figures only).

boundary comprising such walls increased with house age ($F_{1,59}$ = 23.3, $p > 0.001$, r^2 = 0.28). In contrast, the presence of hedges was negatively related to house age (Figure 10c).

Although garden area and perimeter were closely correlated, the length of hedges was related better to the exposed perimeter of the garden ($F_{1,42}$ = 23.7, $p > 0.001$, r^2 = 0.36) – perhaps unsurprising, since hedges are generally grown as a boundary between adjacent parcels. Among gardens with hedges (where more than one hedge could have occurred in a single garden), 50% of gardens contained privet, *Ligustrum ovalifolium* Hassk., 32% non-native conifers (cross *Cupressocyparis* Dallim. or *Chamaecyparis* Spach. species), 14% beech, *Fagus sylvatica* L., 4% hawthorn,

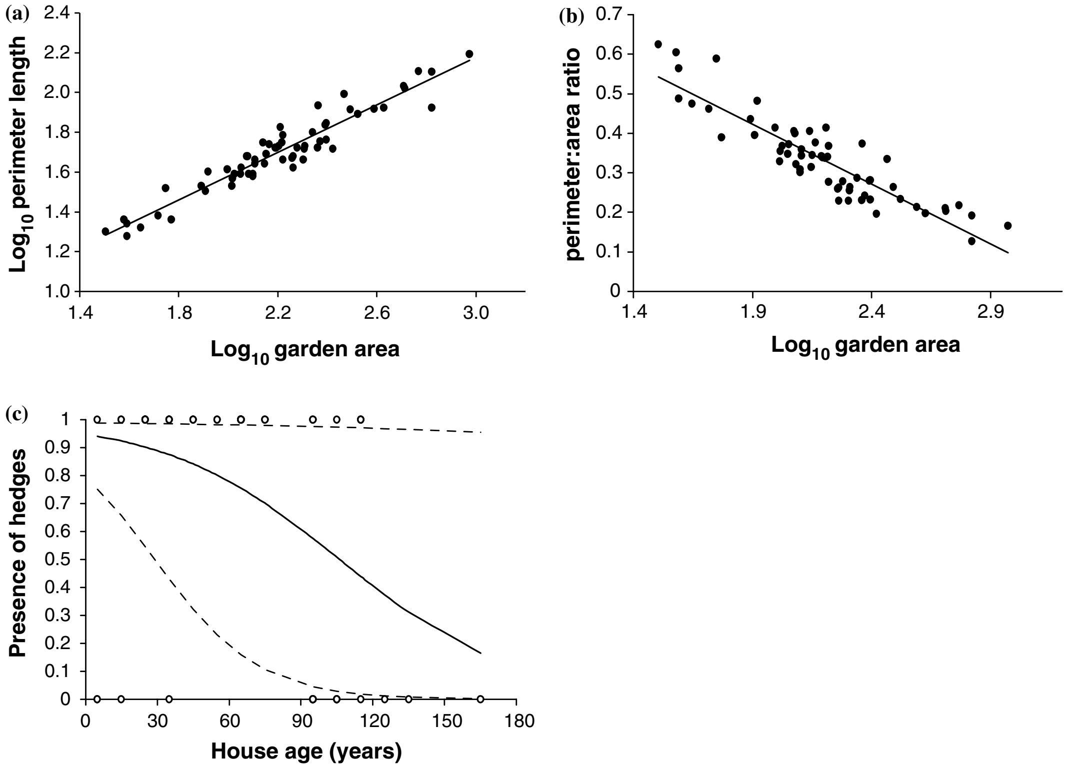

Figure 10. The relationships of (a) exposed garden perimeter to garden area ($F_{1,59}$ = 614.8, $p < 0.001$, r^2 = 0.91), (b) exposed garden perimeter: area ratio to garden area ($F_{1,59}$ = 243.8, $p < 0.001$, r^2 = 0.81) and (c) the presence of hedges and house age (logistic regression: χ^2 = 8.14, $p < 0.01$). Closed circles – observed values, open circles – predicted values, dashed lines show lower and upper 95% confidence limits.

Crataegus monogyna Jacq., and 2% cherry laurel, *Prunus laurocerasus* L. Eighty-two per cent of hedges were composed of a single plant species. This supports the view that hedges are planted principally to demarcate boundaries, rather than as specific wildlife habitats where plant diversity is encouraged (e.g. Baines 2000). Of eight mixed hedges, only two were known to have been established with wildlife in mind.

Changes in vegetated landcovers under different housing density scenarios

Figure 11 gives an impression of the changes in the extents of different vegetated landcovers in rear gardens in Sheffield, under different housing density scenarios. It suggests that if housing density was to rise, changes in the extents of different landcovers, at the scale of a hectare, would be inconsistent. Although the areas of most garden landcovers were positively related with garden size (Table 1), the slopes of the relationships were shallow enough to be offset by changes in housing density. Thus when the number of gardens was considered, denser housing could actually support a slightly greater total extent of certain landcovers (but not forgetting that parcels at lower densities would also possess front garden space, and thus greater garden area overall). This was the case for total vegetation canopy cover, cultivated flower beds, unmown lawn, vegetable patches, and compost heaps. The areas of mown lawn and uncultivated ground declined with increasing density. When the decreased likelihood of trees occurring in smaller gardens was accounted for, trees were slightly more abundant in regions of lower housing density (125, 121, 119 and 118 trees in 1 ha at housing densities of 10, 20, 30 and 40 houses ha^{-1}, respectively). Similarly, when the lower likelihood of vegetable patches occurring in smaller gardens was accounted for, the differences between housing densities were small.

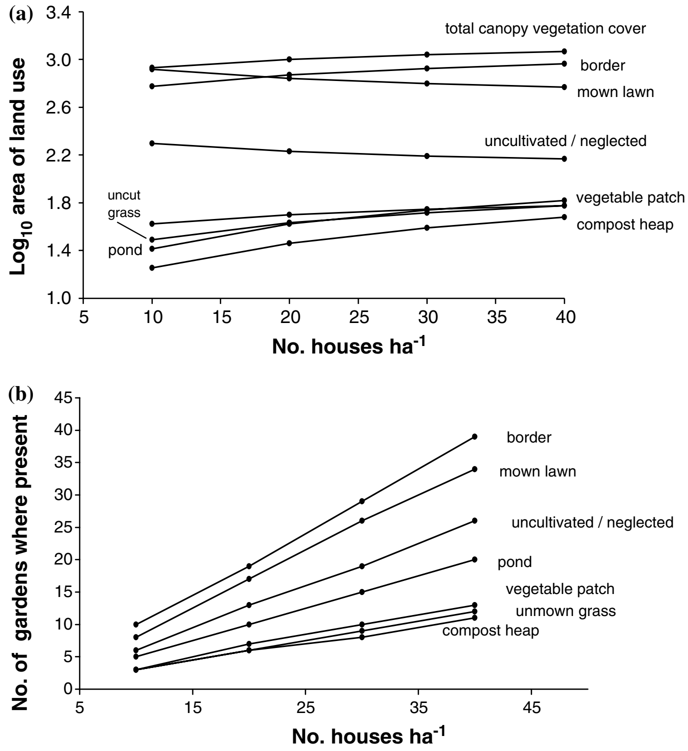

Figure 11. Estimated values for vegetated landcovers in residential parcels in Sheffield, at housing densities of 10, 20, 30 and 40 houses ha^{-1}, based on relationships from the sample of 61 gardens: (a) areas of landcovers and (b) frequency of occurrence of landcovers. Error bars are omitted for clarity.

Discussion

Our need to work intensively in gardens for all the components of the BUGS project meant that survey gardens were drawn from owner-occupiers who were either relatively interested in their gardens or sympathetic to the presence of university researchers (but not necessarily motivated by their gardens). Our sample possessed relatively more large (detached) houses, and fewer small (terraced) ones: terraced, semi-detached and detached houses comprised 16, 56, and 28% of the sample respectively, compared to 50, 44, and 6% occurring in a random sample ($n = 218$) of Sheffield gardens (Gaston et al. in press b). Thus the results of the study need to be interpreted in this context. Nevertheless, it is also clear that a substantial majority of U.K. residents invests time and interest in the garden: a random survey of Sheffield garden owners indicated that more than 75% enjoyed their garden environment, while less than 10% valued nothing about their garden (Dunnett and Qasim 2000). Nationally, nearly 80% of households with gardens take action to encourage wildlife in the garden (DEFRA 2003). Our experience also revealed that owners' interest in the project, or wildlife issues, did not necessarily match effort spent on the garden, due to constraints on time such as young children or a busy job. We therefore believe that our approach allowed us to survey the full range of variation in interest and creativity one might expect to encounter in a random sample (and possibly more): from gardens used daily to those largely untouched for 10 years; from gardens including wildlife meadows and ponds to those with nothing but a lawn. Further, our sample contained the full span of garden sizes as found in a random sample (Dunnett and Qasim 2000), which permitted us fully to investigate landcover in relation to garden area.

The principal conclusion from this study is that rear garden size plays an overwhelming role in determining the internal composition of domestic gardens in the UK, and hence the provision of potential resources for wildlife. The role of garden size was significant because it affected garden resources in multiple ways: (1) larger gardens supported more landcovers; (2) specific landcovers – the number of trees above 2 m, vegetable patches, and compost heaps or bins – were more likely to occur in large gardens; and (3) the extents of more than three-quarters of the landcovers recorded in gardens, as well as vegetation cover, increased with garden area.

With declining garden size, those landcovers expected to maintain a relatively constant absolute size across gardens acquire greater importance (e.g. patios, sheds and greenhouses), and they do so at the expense of both vegetated landcover and landcover richness. Only the proportion of cultivated flower bed increased weakly as garden size reduced. This means that larger gardens should enhance the opportunities for colonisation by wildlife, if the number of substrates and management regimes correlate positively with the number of colonists (Owen 1991; Miotk 1996; Saville 1997). However, neither the species richness nor the abundance of invertebrates were related to garden size in the Sheffield study gardens (Smith et al. ms.).

The size of resource patches in the garden is also likely to be a critical factor, determining both the suitability of microclimate and the habitat heterogeneity required by organisms with complex life cycles (e.g. as in ponds, and compost heaps and bins). In the current study, the majority of landcovers declined in extent in smaller gardens. For example, ponds ranged between 0.25 and 8 m^2 in area; the smallest were ceramic sinks, which were likely to be unsuitable for colonisation by many animals, in terms of area and depth. Indeed, (Swan and Oldham 1993) report that, of all the widespread species of British amphibian (frog *Rana temporaria*, toad *Bufo bufo*, smooth newt *Triturus vulgaris*, palmate newt *Triturus helveticus*, great crested newt *Triturus cristatus*), only frogs and smooth newts were as likely to breed in small ponds as large ones, and that all species bar the frog occurred less frequently in ponds shallower than 50 cm.

In the context of ecosystem services (*sensu* Daily 1997), small parcels provide proportionately lower total garden area (i.e. green space), even if the proportional contribution of rear gardens to parcel area does not decline. Therefore, despite small parcels continuing to support types of garden activity that may be special to rear gardens (e.g. neglected vegetation), they form substantially greater hard or 'sealed' surfaces compared to residential zones with large parcels. As a result, one might predict that small parcels divert relatively more precipitation into the drainage system, away from groundwater and vegetation, and raise local temperatures relative to more vegetated areas (Sukopp and Starfinger 1999; Kinzig and Grove 2001).

Another way in which small parcels individually contribute less to ecosystem services is via vegetation structure. They support smaller extents of nearly all canopy classes. Large gardens, through their relationship with the number of trees, possess disproportionately greater canopy cover above 3 m in height. Vegetation structure is a vital aspect of green space, moderating local climate and reducing airborne pollution and noise (Bolund and Hunhammar 1999). Also, in urban environments the species richness of certain taxa is enhanced by increasing vegetation volume (Dickman 1987; Savard et al. 2000). House age is a less important mediator of garden vegetation, exerting opposing forces on vegetation structure: older properties have fewer hedges, resulting in less canopy at 2–3 m, although this is partially counter-balanced because older gardens also possess more canopy at 2–3 m derived from flower beds.

House age is a much less significant factor influencing garden characteristics overall. Patterns of house building dictate a tendency for newer properties to occur towards the edge of Sheffield; and that smaller parcels with terraced housing, which were built in the second and first halves of the 19th and 20th centuries respectively, fall into the older age classes. Only the effects on vegetation structure mentioned above are of further relevance to wildlife.

The influence of garden landcovers at wider scales

Once the composition of gardens is understood in relation to housing density, it is necessary to consider the effect of such composition at larger scales – at scales over hundreds of square metres, coinciding with blocks of relatively uniform styles and ages of housing. The scenarios examining how vegetated landcovers in rear gardens would change at different housing densities in Sheffield indicated that responses would be variable. Many landcovers in rear gardens were more extensive, and more frequent, in higher density housing. Therefore, assuming the similarity of residential zones in Sheffield to other parts of the country, the response of rear garden composition to housing density in England will be subtle. How limiting landcover availability would be for animals and plants, at the landscape scale, will depend partly upon their mobility. For example, birds from agricultural land seasonally exploit resources in gardens (Cannon 2000). Any organism mobile enough to exploit a set of gardens may be more successful in using suitable landcovers in areas of high housing density, where distances between non-adjacent gardens are reduced. Nevertheless, individual garden landcovers will be smaller and more fragmented at higher housing density. Coupled with the reduced permeability of small, old gardens, this could pose particular problems for the population persistence of sessile organisms. Furthermore, the loss of landcover types from smaller gardens is not random: trees more than 2 m high, vegetable patches, and composting (probably rating as relatively useful to wildlife) are all less likely to occur.

In addition to domestic gardens, other types of green space will also play important roles depending on their distribution and extent. Clear differences are to be expected between the naturally developing vegetation that occurs in encapsulated habitat fragments, on derelict sites, or along corridors compared to heavily managed sites such as recreation fields and parks. The analysis of habitat or resource fragments, be they host plants (Denys and Schmidt 1998), encapsulated semi-natural vegetation (Soulé et al. 1988, Miyashita et al. 1998) or other green space (Jokimäki 1999), has emphasised the roles of isolation and fragment area on species assemblages in towns and cities. These assemblages are considered scarce in the surrounding urban matrix, and therefore governed by extinction and colonisation processes at the scale of the patch. Such research points to a potential dichotomy in the species pools that urban areas support - those reliant on natural vegetation, and pools that are maintained by artificial environments, but with varying degrees of overlap. Changes in the species richness and abundance of lizard assemblages have already been documented over a small range in housing density in Tucson, Arizona, although these may have been driven more by the availability of native vegetation than by garden landcovers (and housing density was low compared to the UK, at <5 houses ha^{-1}; Germaine and Wakeling 2001). The failure of native plants to recruit their associated specialist faunas in garden environments (Kuschel 1990), despite native vegetation being nearby, is further evidence that garden landcovers support assemblages different from other types of green space. However, the relative importance of gardens compared to other landcovers needs to be explored more fully.

Policy implications

A trend for the size of households and families to decline, and thus for the number of households to rise at a faster rate than population size, has caused pressure for a substantial increase in house building globally (Liu et al. 2003). In countries where dwellings in towns and cities are built with gardens, urban planners have the opportunity positively to influence biodiversity. By considering the quality of residential environments in terms of human health and nature, planners can also address the goals for sustainable human settlements, under Agenda 21 of the U.N. Conference on the Environment and Development (UNDSD 2003). From one culture to another, the ways in which U.K. citizens use domestic garden space are certain to differ. Yet the two components of a garden's potential value to wildlife – landcover availability and extent – both vary systematically with garden size. This means that housing density is likely to play a crucial role in determining the composition of the local (or regional) garden resource, and hence the way that urban gardens function as green space in the U.K. In other countries the influence of housing density will of course depend on specific relationships between particular landcovers and garden size, for which data are currently lacking. It is nevertheless essential that decision-makers should possess clear objectives for enhancing the potential of domestic gardens for wildlife, in the light of future building policies, if such gardens are to play an effective role in urban green space.

Acknowledgements

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