Scaling up from gardens: biodiversity conservation in urban environments

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As urbanisation increases globally and the natural environment becomes increasingly fragmented, the importance of urban green spaces for biodiversity conservation grows. In many countries, private gardens are a major component of urban green space and can provide considerable biodiversity benefits. Gardens and adjacent habitats form interconnected networks and a landscape ecology framework is necessary to understand the relationship between the spatial configuration of garden patches and their constituent biodiversity. A scale-dependent tension is apparent in garden management, whereby the individual garden is much smaller than the unit of management needed to retain viable populations. To overcome this, here we suggest mechanisms for encouraging 'wildlife-friendly' management of collections of gardens across scales from the neighbourhood to the city.

Urbanisation and its impacts

Urban growth is occurring at an unprecedented scale. In 2008, for the first time, >50% of the global human population lived in urban environments [1]. Much of this urbanisation is occurring in developing countries, which are predicted to harbour 80% of the urban population of the world by 2030 [1]. The developed world has already experienced an urban transition, with ~80% of people residing in towns and cities [1]. Although urban areas remain a relatively small fraction of the terrestrial surface (~4% globally), the urban ecological footprint extends beyond city boundaries and drives environmental change at local to global scales [2].

Rapid urban expansion is impacting heavily on ecological processes (Table 1). Unsurprisingly, given the scale and variety of these impacts, urbanisation is a significant factor in both current and predicted species extinctions [3]. We are also witnessing an 'extinction of experience', whereby people living in species-poor cities are increasingly disconnected from the natural world [4]. Here, we highlight the valuable role of urban green spaces in mitigating the detrimental impacts of urbanisation, and draw particular attention to the significance of private gardens within a landscape ecology framework.

Although we focus on the biodiversity benefits, urban green spaces are also important for the provision of ecosystem services and can have a positive impact on quality of life, human health and wellbeing [5,6]. They provide opportunities for people to interact with nature and are, therefore, vital in fostering a wider interest in nature conservation issues [4]. Private gardens are especially significant in the development of a personal relationship with the natural environment [7].

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Urban biodiversity: a conservation role for gardens and green spaces

With the encroachment of urban areas into rural habitats and the decrease of rural habitat quality owing to agricultural intensification [8], urban green spaces are becoming an increasingly important refuge for native biodiversity. Although urbanisation typically results in a reduction in biodiversity (Table 1), globally declining taxa can attain high densities in urban habitats. For instance, urban parks in San Francisco, USA, support higher mean abundances of bumblebees (*Bombus* spp.) than do two parks beyond the city boundary [9]. Populations of common frog *Rana temporaria* in Britain have experienced declines in rural areas but increases in urban parks and gardens [10]. Growth of experimental bumblebee *Bombus terrestris* nests was greater in suburban gardens in southern England than in agricultural habitats [11], and the density of bumblebee nests recorded in UK suburban gardens (~36 nests ha^{-1}) was comparable to that found in linear countryside habitats, such as hedgerows (20–37 nests ha^{-1}) [12].

Estimates of the areas of gardens in the urban environment vary from 16% (Stockholm, Sweden [13]), through 22–27% in the UK [14], to 36% (Dunedin, New Zealand [15]). Gardens are a major component of the total green space in many UK cities, ranging from 35% in Edinburgh to 47% in Leicester [14]. Gardens can also be an important resource in developing countries; for example, private urban patios comprise 86% of all green space in the city of León, Nicaragua [16]. The potential value of gardens for enhancing biodiversity has long been recognised, as evidenced by many popular books, television programmes and information handouts advising on 'wildlife-friendly' gardening. Initiatives to enhance the biodiversity value of gardens by conservation NGOs and governments are now commonplace in developed countries (Box 1).

Documenting garden biodiversity

Despite the growing awareness of the conservation potential of private gardens, information on wildlife gardening is supported by only limited ecological research. This is mainly because residential landscapes have long been viewed as depauperate ecosystems, where access to the system is difficult owing to fragmented private ownership.

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Table 1. Impacts of urbanisation on habitat and the resulting biological effects

Impact of urbanisation on habitat	Biological effects	Refs
Habitat loss, fragmentation and disturbance	Reduced species richness and evenness resulting in biotic homogenisation	[92]
	Peaked species richness at intermediate levels of urbanisation, particularly for birds and plants	
Import of species for human landscaping	Domination of floras by exotic species, causing increased species richness relative to rural areas, but decreased native plant diversity	
	Invasion of species to surrounding semi-natural habitats	[48,93]
Increased air temperatures and altered atmospheric chemistry (i.e. elevated CO_2, NO_x, aerosols, metals and ozone)	Altered nutrient cycling, primary production and plant growth	[94,95]
Increase in impervious surfaces alters hydrology of urban watersheds	Decreased biodiversity, high nutrient loadings and elevated primary production produce an 'urban stream syndrome'	[2]
Altered productivity, competition and predation	Shifts in trophic structure and food-web dynamics	[96]
Altered environmental conditions (e.g. increased ambient sound)	Local adaptation and evolution caused by behavioural, morphological and genetic responses to novel selective pressures (e.g. noise necessitating changes in bird song)	[97–99]

Early investigations of suburban habitats did not attempt to gain access to private properties and involved comparisons between residential and natural areas (e.g. [17]), between suburban neighbourhoods differing in age, vegetation characteristics and location (e.g. [18]) and along urban–rural residential gradients (e.g. [19]). The majority of private garden research has been undertaken in developed countries and began with long-term studies of single gardens (e.g. [20,21]). Short-term studies of multiple gardens have now been undertaken in various locations, most notably the Biodiversity in Urban Gardens in Sheffield project (BUGS), which involved floral and faunal sampling of 61 gardens in Sheffield, UK, and was followed by floral surveys of 276 gardens in five further UK cities (BUGS 2) (reviewed in [22]). Similar short-term studies of the biodiversity of urban gardens have been carried out in North America [23,24], and are now emerging in tropical developing cities [25–27]. Long-term studies of multiple gardens have also been undertaken, focusing on national and continental trends in garden use by birds (e.g. [28,29]).

Key findings from this range of garden studies are that, in addition to the high cultivated floral diversity, the three-dimensional structure (i.e. complexity) of garden vegetation is an important predictor of vertebrate [25,30,31] and invertebrate abundance and diversity [32,33]. Planting and management by humans is the overwhelming influence on garden vegetation, as evidenced by the similarity in plant species richness and composition in gardens across five contrasting UK cities [34].

Gardens and their management create considerable habitat; in UK gardens, there are estimated to be a total of 28.7 million trees, at least 4.7 million nest boxes and up to 3.5 million ponds [35]. Although the effectiveness of such habitat creation for increasing biodiversity was found to be variable when tested experimentally [36], the wide provision of resources displays the public enthusiasm towards wildlife gardening. Indeed, a questionnaire survey across five UK cities found that significant numbers of households participate in some form of wildlife gardening and/or management, with bird feeding the most popular activity [37]. A total of 12.6 million (48%) of UK households feed wild birds [35], and such levels of supplementary feeding can influence avian abundance at regional scales [38].

Negative impacts of urban biodiversity

The presence of a diverse biota in private gardens, coupled with considerable enthusiasm for 'wildlife-friendly' management, means that urban green spaces could be viewed as a panacea for biodiversity conservation in human-modified environments. Yet the converse is often true, with urban areas providing a real threat to native biodiversity. Urbanisation can accelerate the transmission of wildlife diseases [39], and gardens are also the source of a major predator: the domestic cat. The density of cats in urban areas of Britain has been estimated to be at least 132 cats km^{-2} [40], and the mean predation rate calculated at 21 prey $cat^{-1}\,y^{-1}$ [41]. The

Box 1. Existing garden conservation strategies

The management of private gardens lies largely outside direct government control and, therefore, various strategies exist for incentivising homeowners into 'wildlife-friendly' gardening activities. Initiatives by conservation NGOs are now commonplace in developed countries; for instance, the USA National Audubon Society's 'Audubon at Home' project offers participants the chance to take the 'Healthy Yard Pledge' and commit to several management principles (http://www.audubon.org/bird/at_home/). In the UK, the Royal Society for the Protection of Birds' (RSPB) 'Homes for Wildlife' scheme encouraged >25 000 people to undertake >300 000 tailored management actions in their homes and gardens in its first year of operation (http://www.rspb.org.uk/hfw/). Several conservation charities provide advice and incentives for individuals or communities to 'certify' their gardens or neighbourhoods as wildlife habitats. The USA National Wildlife Federation Backyard Habitat Certification Scheme is particularly popular and currently includes >100 000 certified backyards (http://www.nwf.org/backyard/).

The recognition of gardens within government nature conservation strategies is also growing. An increasing number of cities are producing documents aimed at protecting garden biodiversity, particularly in the UK (e.g. the London private gardens action plan; http://www.lbp.org.uk/londonhabspp.html#gardens), but also elsewhere, (e.g. Adelaide, South Australia; http://www.backyards4wildlife.com.au/).

Homeowners now provide a valuable source of fieldworkers for research organisations by collecting scientific data in their own backyards. The popularity of public 'gardenwatch' initiatives, such as the RSPB Big Garden Birdwatch (http://www.rspb.org.uk/birdwatch/) and the British Trust for Ornithology Garden BirdWatch (http://www.bto.org/gbw/) in the UK, and Project FeederWatch in the USA and Canada (http://www.birds.cornell.edu/pfw/), underlines the importance of gardens for raising awareness about biodiversity and the public understanding of science. Not only have these garden data revealed important population trends (e.g. [28]), but this 'citizen science' movement also has huge potential for enhancing urban environments by coordinating public management actions to produce cumulative positive impacts on biodiversity [81].

impact of cat predation and associated sub-lethal, indirect effects on urban bird populations gives, therefore, particular cause for concern [40,42].

The total plant-species richness recorded in 267 gardens in five UK cities (1056 species) exceeded that recorded in other urban and semi-natural habitats [34]. However, much of this increased diversity is the result of landscaping and gardening practices that import and maintain exotic species at artificially high densities. For example, ~70% of the UK garden flora is exotic in origin [34]. The impact of exotic vegetation on higher trophic levels within the residential ecosystem remains an area of debate. A study of six pairs of gardens within a suburban area of Pennsylvania, USA, found that native planting significantly increased the bird and butterfly diversity as compared to conventionally managed non-native gardens [43], matching findings of earlier studies from Australia [30,44]. These results are supported by research in experimental gardens showing that exotic plants are little utilised by native pollinating insects [45]. By contrast, the abundance and diversity of various invertebrate species captured in gardens in Sheffield, UK, was rarely related to native plant species richness, indicating that 'wildlife-friendly' gardens need not be dominated by native planting.

The impact of exotic plants on other garden organisms notwithstanding, private gardens are a focal point for the spread of exotic or non-local plants to surrounding natural communities [46,47], especially in a warming climate [48]. Invasive exotic species that have already escaped from gardens have caused major economic and conservation impacts throughout the world. For example, dense stands of exotic knotweeds *Fallopia* spp. have replaced natural vegetation in riparian habitats in Europe, resulting in decreased plant and invertebrate diversity [49].

Landscape ecology in the urban environment

During recent decades, research in urban environments has embraced the ecology-of-cities paradigm: an interdisciplinary approach that views urban landscapes as socio-ecological systems within which humans and their social institutions are integrated with the environment [50]. Implicit in the ecology-of-cities framework is that the provision of ecosystem services relies on the spatial arrangement of habitat patches at the city scale (particularly the patch size, connectivity and heterogeneity, Box 2) [51]. Understanding urban environments, therefore, requires a landscape ecology perspective [52].

Cities are characterised by habitat patches that are small, fragmented and isolated. Consequently, the standard positive relationships between species richness, area and connectivity are especially pertinent in urban ecosystems. For instance, Evans *et al.* [53] reviewed 72 studies of the habitat influences on urban avifaunas, and concluded that larger habitat patches support larger and more stable bird populations. Similar results apply for a range of other taxa occupying urban environments, such as amphibians [54], mammals [55] and carabid beetles [56]. The importance of habitat connectivity has also been demonstrated in the urban landscape; for example, for birds in wooded streets [57] and mammals in habitat fragments [55].

Box 2. Urban landscape ecology tools

Inherent in landscape ecology are concepts such as patch size, scale (Box 3), fragmentation (the breaking up of patches into smaller parcels), connectivity (the degree to which habitat is spatially continuous or functionally connected), and spatial heterogeneity (the uneven distribution of patches across a landscape). The importance of these concepts vary among taxa as a function of body size, resource requirements and dispersal abilities. The heart of the methodology of landscape ecology is classification and pattern analysis, and the unique application of these methods in the urban environment is summarised below.

Urban classification systems

Urban classification is undertaken at different spatial scales. At fine spatial scales, cities comprise a complex mosaic of built and vegetated patches, and land-cover classification systems have been developed that capture this fine-grained landscape heterogeneity (e.g. [100]). These classification systems benefit from advances in remote-sensing technology (i.e. satellite imagery and digital aerial photography), which enable analysis at increasingly fine resolutions. For example, Mathieu *et al.* [15] used automated techniques to identify >90% of gardens from other land covers in Dunedin, New Zealand, based on high-resolution Ikonos satellite imagery. These remote-sensing approaches are now being used to help predict patterns of species richness in urban environments (e.g. [101]).

Pattern analysis

Quantifying patterns is a prerequisite to understanding the link between patch structure and ecological processes. An array of landscape metrics, or indices, has been developed for this purpose and their application has been facilitated by the use of Geographic Information System technology. The effects of urban development patterns on ecosystem function are increasingly well documented (e.g. [51]). A popular framework for exploring variation in urban landscape patterns is the gradient paradigm, whereby the effects of biophysical changes along a gradient from rural hinterland to urban centre are examined. Combining the gradient approach with the computation of landscape metrics has revealed that, along a gradient of increasing urbanisation, patch density generally increases whereas patch size and landscape connectivity decrease (e.g. [102]). Over 200 empirical studies have used gradient analysis as a tool for assessing the impacts of urbanisation on the distribution of organisms (reviewed in [103]). However, the development of landscape metrics offers a new and unexplored opportunity for explicitly quantifying the effects of urban landscape structure on ecosystem function and biodiversity.

An area of debate in urban ecosystems (as in agricultural systems) is the relative importance of local (i.e. garden)-scale versus landscape (i.e. city)-scale factors in determining biodiversity. The consensus from avian research is that local factors are more important than regional ones in explaining avian species richness in urban landscapes ([53] and references therein). However, most existing avian studies have been undertaken within large urban habitat patches, such as parks, which are larger than a typical garden. Furthermore, research from other taxa suggests that the heterogeneity of the surrounding landscape is significant. For example, the retention of butterfly and burnet species in grassland reserves within the city of Prague, Czech Republic, was attributed, in part, to the diverse mosaic of gardens, parks and green spaces in the urban landscape surrounding the reserves [58].

A useful parallel exists between urban and agricultural ecosystems. Both cities and farmed landscapes are highly modified by human activities and are comprised of nested subsets of patches spanning several spatial scales. Early conservation management in farmland ecology was

Box 3. Why does scale matter?

Different taxa will perceive and respond to landscape structure at many spatial scales, depending on a range of parameters, such as body size and life-history characteristics [60], life stage (e.g. sessile versus mobile life-stages; dispersing young) and season (e.g. birds defend a smaller home range when breeding than when foraging more widely in winter).

The scale of sampling can confound ecological patterns. For example, there might be negative or positive relationships between human population density and biodiversity depending on the study extent considered: negative at fine scales (where high building density precludes natural habitats) and positive at large scales (where both humans and wildlife tend to occupy productive areas and not live in deserts) [104].

Borgstrom *et al.* [105] contend that 'scale mismatches' are prevalent in urban ecosystems, whereby the scale of management does not match the scale of ecological patterns and processes. For some taxa (e.g. soil organisms), a viable population can exist within a garden. Yet many of the large and/or mobile taxa, that provide important ecosystem services, such as pollination and seed dispersal, operate at broader scales than the individual garden (i.e. groups of gardens and adjacent urban green spaces). To take into account the scale dependencies of many taxa properly, it is likely that research and management at multiple spatial scales is needed [106,107].

directed at the field scale, but it is now widely accepted that farmland biodiversity depends on the creation and maintenance of habitat heterogeneity at multiple spatial scales [8]. Given that individual gardens are much smaller than individual fields, it follows that there is an even larger disparity in residential landscapes between the existing scale of management and the scale necessary to retain viable populations of most taxa (Box 3). Maximising habitat heterogeneity at the correct scale, such that individual gardens complement the resources available in the surrounding landscape, should likewise maximise the biodiversity of urban ecosystems.

Prospectus for the future

The small, but growing, body of research on garden biodiversity has focused largely on individual gardens. A fruitful next step would be to extend a landscape ecology framework to the study and management of gardens, in effect by treating groups of gardens not as independent units but instead as patches of interconnected habitat within the residential ecosystem. To make this work requires collaboration between ecologists and social scientists, urban planners and householders.

Scaling up from gardens

Previous research shows that the species–area relationship is applicable at the scale of the individual garden. Garden size is positively related to land-cover heterogeneity (including the number of trees and ponds) [59], plant species richness [34] and avian species richness [29,30]. Garden size does not consistently correlate with invertebrate species richness or abundance, although other garden-scale factors, such as vegetation structure, are important [32,33]. These findings have led to conclusions that the design and management of individual gardens are paramount, at least for the conservation of native avian species (e.g. [30]).

However, we suggest that treating the single garden as an independent patch (and thus prioritising management initiatives at the individual garden scale) is problematic. Problems arise as ecological processes depend on spatial scale (Box 3) and, therefore, the appropriate scale of management will be taxon dependent. Given that birds are capable of foraging across large scales, management at a local scale can create good foraging conditions and give rise to the finding that local-scale factors are most significant. However, birds utilise resources from the wider landscape. For instance, Hostetler and Holling [60] showed that most birds in US cities are able to exploit urban tree patches at broad scales from 0.2–85 km^2. Likewise, Chamberlain *et al.* [61] concluded that the likelihood of many bird species occurring in UK gardens is related to the surrounding habitat, rather than on within-garden habitat features. Similarly, mobile invertebrate taxa will utilise urban green space at broader scales than the individual garden. For example, Smith *et al.* [32,33] examined the influence of landscape factors on invertebrate diversity and abundance by quantifying the land use in a 1-ha area surrounding 61 study gardens in Sheffield, UK and found correlations between landscape variables and the species richness and abundance of mobile invertebrate taxa including beetles, bees and wasps.

To test explicitly for the influence of local and landscape effects, it is necessary to sample at multiple spatial scales [62]. This will involve simultaneously sampling several gardens that are located within the same landscape but that differ in local characteristics such as size and vegetation structure. In other words, the patch comprising of a group of adjacent gardens becomes the sampling unit, with individual gardens the sampling points within the patch. Although such a sampling design is constrained by access to multiple gardens, it remains the only adequate way of assessing the relative influence of garden versus landscape factors.

The emerging literature on the role of gardens for enhancing native biodiversity has somewhat overlooked the need to coordinate garden management within the surrounding landscape. Recent work has begun to recognise the importance of considering groups of gardens at a coarser scale, especially for supporting avian diversity. An interconnected network of mature and structurally diverse gardens has been recommended for supporting bird populations in Madrid, Spain [63] and Melbourne, Australia [64]. Sympathetically managed garden networks are also significant in the provision of ecological connectivity. For instance, planting native vegetation has been advocated in gardens adjacent to creeks in New South Wales, Australia, to enhance habitat connectivity by extending the width of riparian corridors [65]. Similarly, a connectivity analysis by Rudd *et al.* [66] demonstrated that garden habitats are vital in providing functional connectivity between urban green spaces in Greater Vancouver, Canada.

The relationship between private gardens and urban green space is further evident in the concept of 'ecological land-use complementation', which outlines how urban habitats could interact synergistically to support biodiversity when clustered together [67]. Indeed, the presence of adjacent gardens can increase the species richness of urban parks [68]. These results suggest a role for urban planning whereby if private gardens and other green spaces can be spatially arranged to maximise total habitat patch area and minimise isolation, this will result in benefits to urban biodiversity. This is particularly relevant to new developments, but planning consent for the conversion of gardens to new buildings and driveways ('land grabbing') will also influence patch size and spatial patterns.

Gardens as socio-ecological constructs

A suite of socio-economic characteristics have been shown to influence garden management directly and, hence, the heterogeneity of urban landscapes [69–74] (Figure 1). Given that these socio-economic factors drive vegetation complexity, which underpins species richness and abundance, we can expect cultural and social factors to influence patterns of urban biodiversity [75]. Indeed, several studies have found correlations between human socio-economic status and urban bird populations (e.g. [38,76,77]). It is therefore apparent that just as many garden organisms do not operate at the scale of the individual garden, many socio-economic processes operate at scales beyond the individual household. For example, Zmyslony and Gagnon [78] describe a neighbour 'mimicry' effect in the planting and landscaping of front gardens in Vancouver, Canada, whereby gardens in a given vicinity are more likely to be similar to each other than to those in a different street or neighbourhood (but see [79]). A key challenge is to maximise vegetation complexity throughout the residential ecosystem in the face of prevailing social norms or across areas where social resources are lacking for 'wildlife-friendly' garden management (e.g. time, money, information, etc).

Beyond the neighbourhood scale, there is also a need to better integrate the design and management of private gardens into city-wide biodiversity strategies. This approach is complicated by the hierarchical structure of residential landscapes: the individual garden is the scale at which householders manage their land, but the size and configuration of interconnected garden patches is under the control of urban planners and housing developers. To ensure coordinated management at multiple scales throughout the garden hierarchy, collaboration and communication between a range of stakeholders across all sectors of society and academia is required (Figure 1).

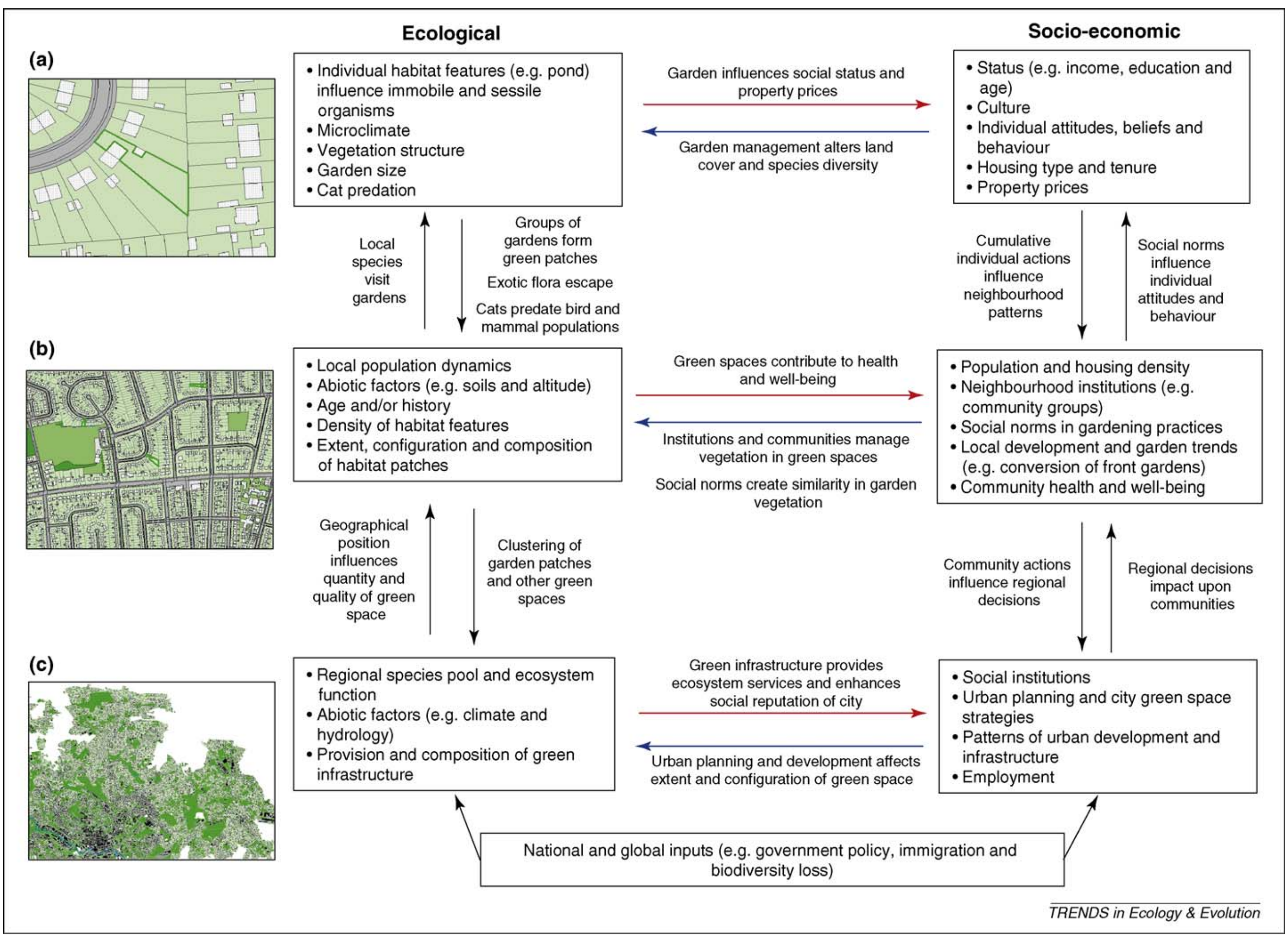

Figure 1. Gardens as socio-ecological constructs. A conceptual framework showing the key ecological and socio-economic components impacting on private gardens at multiple spatial scales. We identify a nested hierarchy in garden management that spans three scales: **(a)** the individual garden or household; **(b)** the neighbourhood or garden 'patch'; and **(c)** the city or landscape scale. In reality, many of the ecological and socio-economic factors can act at more than one scale along this continuum (e.g. vegetation structure or social status) and interactions exist between scales to illustrate feedbacks within the garden ecosystem (black arrows). Ecological factors influence socio-economic factors through the provision of ecosystem services and economic and health benefits (red arrows). Socio-economic factors influence ecological conditions via human decision-making and subsequent management (blue arrows). Research and management is necessary at multiple scales to maximise the utility of private gardens for native biodiversity conservation.

Incentivising householders into 'wildlife-friendly' gardening

To target conservation resources at a meaningful scale, we must explore mechanisms for encouraging multi-scale, complementary 'wildlife-friendly' management of gardens and adjacent green spaces. We are currently witnessing a paradigm shift in biodiversity conservation, away from the establishment and maintenance of protected nature reserves towards community-based conservation [80]. Yet, the general public remains inexperienced in biodiversity management and the resulting lack of coordination among private householders can result in the 'tyranny of small decisions', whereby the cumulative outcome of many garden-scale management decisions is detrimental to native biodiversity in residential landscapes [81].

Options for incentivising householders into wildlife-friendly gardening fall into two broad categories: (i) top-down, financial incentives or regulation; and (ii) bottom-up, community-lead initiatives. Top-down incentives might include tax reductions or government grants for sympathetic management (e.g. for building a pond or creating a compost heap), as per financial incentives offered successfully to households for the installation of renewable energy technologies [82]. Top-down approaches can also be implemented for wildlife conservation purposes, with tax incentives and subsidies an increasingly popular tool for imposing the US Endangered Species Act on private land [83]. Planning regulation can also be a top-down approach, such as declining applications for new development on existing gardens, or enabling protection of hedgerows or trees. Indeed, the absence of front garden uniformity in Hobart, Tasmania, lead Kirkpatrick et al. [79] to suggest that voluntary mechanisms for improving the conservation value of private gardens are unlikely to spread by social diffusion. Instead they argue that top-down regulation and economic penalties will be required.

Although top-down incentives can produce pro-environmental behaviour, they often fail to change underlying values and attitudes [84] and fail to understand the motivations of gardeners [85]. The garden evokes strong feelings of ownership and sense of place [7], and is the perfect setting for generating meaningful connections with nature that will increase emotional involvement and uphold long-term pro-environmental behaviour. Moreover, gardeners tend to have a greater ecological knowledge than do managers of urban green spaces [86]. At the neighbourhood scale, householders often form organisations, such as residents' associations or horticultural societies. These community organisations have been viewed as local 'stewards' and can be targeted for participatory techniques that engage groups of gardeners in managing their land more sympathetically and synergistically for wildlife [13].

Tailoring wildlife gardening advice to the landscape context

Several successful garden-scale NGO projects and more research-focused biodiversity recording schemes are testament to the potential for bottom-up community participation projects (Box 1). However, maximising the conservation benefit or ecosystem function of a particular garden requires tailoring 'wildlife-friendly' gardening practice to the context as the ecology of any small area depends on the wider landscape. The idea that entire gardens, or groups thereof, could be managed collectively as 'habitat gardens' has been posited before (e.g. [22,87]), but there has been little exploration of how such schemes would work in practice.

As a simplistic example, many cities will already have planning documents or green space strategies that promote the creation and maintenance of green infrastructure, such as habitat corridors or stepping stones. Such plans could be structured according to the creation of 'habitat zones', within which the management of urban green spaces encourages the coverage of a specific habitat type, such as woodland or wetland. The mosaic of different habitat zones within a city and its rural hinterland will ensure that habitat heterogeneity is provided at the landscape scale. Householders, community groups, NGOs and housing developers operating within each habitat zone could then be given tailored wildlife-gardening advice. Such integration of biodiversity conservation with urban planning is exemplified by the 'Zonation' conservation planning tool implemented in Melbourne, Australia, which incorporates landscape context and species-specific connectivity requirements to identify priority areas for the protection of threatened species [88].

The gardens and green spaces of new housing developments offer particularly fruitful opportunities for the creation of tailored habitat gardens comprised of native planting of local provenance. Given appropriate education and support (e.g. from a local ecologist), residents are likely to take pride in being involved in such a scheme, and might even be supportive of more radical proposals, such as the 'Cats Indoors!' campaign sponsored by the American Bird Conservancy (http://www.abcbirds.org/abcprograms/policy/cats/). Such pride in one's own patch is apparent in existing social norms, whereby the desire to conform to a suburban ideal (known as the 'ecology of prestige' [69]) results in strong similarities in garden structure within a neighbourhood. Warren *et al.* [89] imagine that if the same social processes can be harnessed to develop a conservation ethos, then neighbours might compete over the creation of wildlife habitat rather than the maintenance of weed-free biological deserts (i.e. lawns).

Concluding remarks

In a context of rapid urbanisation, biodiversity conservation within towns and cities has a significant role in minimising both the extinction of species and the extinction of the human experience of wildlife. Although parks and reserves remain the focus of urban nature conservation, private gardens offer an extensive, unique and undervalued resource for enhancing urban biodiversity. Gardens are significant habitats in their own right, and improve connectivity by functioning as corridors or by enlarging the size of other urban habitats. It is therefore imperative that gardens are not viewed as separate entities at the individual scale, but instead managed collectively as interconnected patches or networks of green space acting at multiple spatial scales across the urban landscape. Yet little is known on the ideal size or configuration of these garden patches, and quantifying the patch structure through the application of landscape ecology tools will further our understanding of residential ecosystems. Several key research questions emerge:

(i) What is the optimal garden patch size and configuration for different taxa in the residential landscape? Given the different scale dependencies of different taxa, could the patch size and configuration optimal for one taxon (e.g. birds) also accommodate other taxa whose requirements occur at a finer scale? How much does the optimal patch size and configuration differ across suburbs depending on the management of individual gardens (e.g. vegetation structure, bird feeding, application of chemicals, etc.)?

(ii) Given that the optimal garden patch will comprise a group of adjacent gardens, what mechanisms exist for the creation and maintenance of 'habitat gardens' that transcend the boundaries of the individual plot? What are the social drivers behind garden management decisions and how do we reverse social norms that reinforce the detrimental management of private gardens?

(iii) Given that most urban residents live in developing countries where private green spaces within cities are often lacking, how can we best design cityscapes and engage communities in the developing world to maximise urban biodiversity globally? Can urban agriculture provide both increased food security and biodiversity conservation benefits in cities worldwide?

Answering such questions will inform the planning of residential developments and reveal the optimal scale at which to focus conservation initiatives that seek to harmonise the cumulative management actions of householders and communities. This will involve new trans-disciplinary partnerships [90] that are increasingly being successfully implemented in rural settings [91]. If the bigger ecological question is how to enhance native urban biodiversity through green space management, then the solutions lie in realigning the scale at which land-use decisions are made and ecological processes occur. Undertaking private garden research and management at the appropriate scale would be an instructive next step in finding such a solution.

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