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Manchester – The role of urban domestic gardens in climate adaptation and resilience

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Introduction

Cities are particularly vulnerable to warming temperatures and the increasing incidence of extreme weather events, prompting action by governments and policy makers to deliver solutions to improve urban resilience to climate impacts and protect the health and wellbeing of city dwellers (Rosenzweig et al., 2018). It is well-known that urban green infrastructure (GI) - the interconnected network of vegetation and water in cities – contributes to the health of a city and influences urban climate. Urban GI can help to moderate microclimate through cooling through evapotranspiration, shading, and storing less heat than built surfaces, and mitigate flooding through intercepting and capturing rainfall, reducing the rate and volume of surface water runoff (Gill et al., 2007; Bowler et al., 2010). Urban GI therefore offers potential to aid urban resilience in adapting cities to climate change. Accordingly, it has received increasing interest in environmental planning and policymaking (Carter et al., 2014). GI provides a wide range of other ecosystem services (ES) (a concept linking the functioning of ecosystems to human benefits), in addition to climate regulation. Importantly, there is a strong association between GI and health – since GI not only reduces climate-related health hazards such as heat-related deaths, but also improves physical and mental health and wellbeing (Lindley et al., 2019).

Domestic gardens offer a valuable source of GI within an urbanised environment (Gaston et al., 2005; Davies et al., 2009; Cameron et al., 2012). They are important patches of greenspace that can provide connectivity between larger areas of green spaces (parks, recreation grounds, etc.), therefore improving provision of urban ES. Whilst, individually, one domestic garden may appear insignificant, collectively domestic gardens can comprise over one third of a city's surface area (Mathieu et al., 2007), and become more important as a GI resource as urbanisation increases (Loram et al., 2011). Domestic gardens provide diverse ES which benefit urban residents through both active and passive engagement (Lin et al., 2017). Health and wellbeing benefits, such as restorative benefits, depend both upon the resident interacting with the physical space and characteristics of the garden, in terms of vegetation, design, size, etc. (Lin et al., 2017). Some ecosystem services are also gained via passive means, such as climate regulation, whereby benefits extend beyond the immediate garden parcel to influencing climate at the neighbourhood scale. Differences in both form and management of domestic gardens will significantly affect the ES provision (Cameron et al., 2012).

Despite their importance as an urban GI resource, domestic gardens have received comparably little attention to public green spaces, and thus, there is a lack of data and reliable information about the quantity and quality of GI provision by domestic gardens (Cameron et al., 2012), not least regarding their contribution to a city's climate resilience. Furthermore, the lack of regulation of domestic gardens means that homeowners can alter garden composition how they choose, with local government having little control over existing gardens. As a result, policymakers and planners perceive domestic gardens as a particularly challenging issue to influence. Changes to garden composition can have significant implications for ES provision. For example, conversion of front gardens to hard surfaces, housing extensions, infilling, and adding impervious surfaces such as paths, whilst a gradual process, could result in significant loss of total garden resource. Such changes in garden composition reduce resilience to climate change, which highlights the need to engage citizens, in order to stimulate positive outcomes that aid climate resilience. With growing urban densification, domestic gardens are perceived increasingly as a luxury and thus there is a need to better understand private gardens and their role in ES provision (Cameron et al., 2012) to support effective environmental policy and planning practice.

This chapter presents the outcomes of a co-produced project at the science-policy-practice interface that aimed to improve understanding of domestic gardens in a large city and the ES they provide, with a particular focus upon the benefits that enhance climate resilience. The research aimed to embed new knowledge in user organisations to illustrate the benefits of urban gardens for reducing climate risks in order to facilitate improvements in spatial planning and installation of GI. Whilst the project's aim was primarily focused upon generating new knowledge to inform GI planning, the need to involve citizens was clear in order to implement adaptation solutions. Accordingly, the methodology incorporated a citizen science element to both gather data and as an educational tool. The project was carried out in Manchester, UK, led by Manchester Metropolitan University and University of Leicester with public (Manchester City Council), private (Southway Housing Trust) and third sector (Manchester City of Trees and Lancashire Wildlife Trust) organisations as partners.

Study area

Manchester, UK, is a post-industrial city with a growing population of 541,263 people (2016 mid-year estimate) within an area of 115.6 Km^2 (Manchester City Council, 2017). Manchester experiences a warm temperate fully humid climate, with warm summers (Cfb) and mild winter temperatures (Kottek et al., 2006). Manchester's daytime air temperature UHI is around 3°C (night-time, 5°C) in summer (Smith et al., 2011), and the city is especially vulnerable to extreme weather events, including flooding and warm temperatures (Smith et al., 2011; Kazmierczak & Cavan, 2011; Smith et al., 2015; Carter et al., 2014). The Indices of Deprivation in 2015 ranked Manchester as 5 out of 326 local authorities in England, where 1 is the most deprived, confirming that it has one of the highest proportions of deprived neighbourhoods in England (DCLG, 2015). This profile of high deprivation increases vulnerability of populations to extreme weather events, and affects the capacity of the city's population to prepare for, respond to, and recover from, climate-related extreme events (Kazmierczak & Cavan, 2011).

Green and blue infrastructure is a core component of Manchester City Council's long-term plan for delivering a green, sustainable, healthy and liveable city throughout the 21st Century. The Manchester Strategy, overseen by stakeholders and developed through extensive consultation with residents, businesses and partner organisations, sets out a long-term vision for Manchester's future, with five key priorities to realise: a thriving and sustainable city; a highly skilled city; a progressive and equitable city; a liveable and low-carbon city; and, a connected city (Manchester City Council, 2016). Several key plans support this strategy, relating to themes such as local development, transport, ageing, and poverty. Of key interest here is the Manchester Green and Blue Infrastructure Strategy (MGBIS) 2015-2025, the policy document for guiding GI planning in the city. The MGBIS and accompanying Implementation Plan outlines how stakeholders will work together to improve Manchester's GI (Manchester City Council, 2015). This recognises the valuable role of GI in delivering environmental and social benefits to the city, creating attractive, successful neighbourhoods, and encouraging business investment (Manchester City Council, 2015).

The MGBIS undertook an initial stocktake of Manchester's GI resources and estimated that GI covers 58% of the land area of the city, including five river valleys, three canals, over 160 parks, street trees, woodland, private gardens and other areas of natural environment (Manchester City Council, 2015). This assessment, based upon OS Mastermap datasets, was limited in its representation of domestic gardens, since it was unable to distinguish between land surface cover types within a garden, and assumed gardens are completely GI. Since land surface cover in urban areas is a major driver of the provision of climate regulating and other ecosystem services, and gardens comprise 20 per cent of the land area in the city, resulting environmental models that estimate the provision of, for example, cooling potential and runoff retention, will be inaccurate. This data gap will overestimate the amount of GI in a given area, thus, the need to enhance existing GI will be underestimated, affecting delivery of GI solutions. Furthermore, since the distribution of gardens varies across Manchester (Fig. 1), environmental model outputs will not have a uniform error across the city.

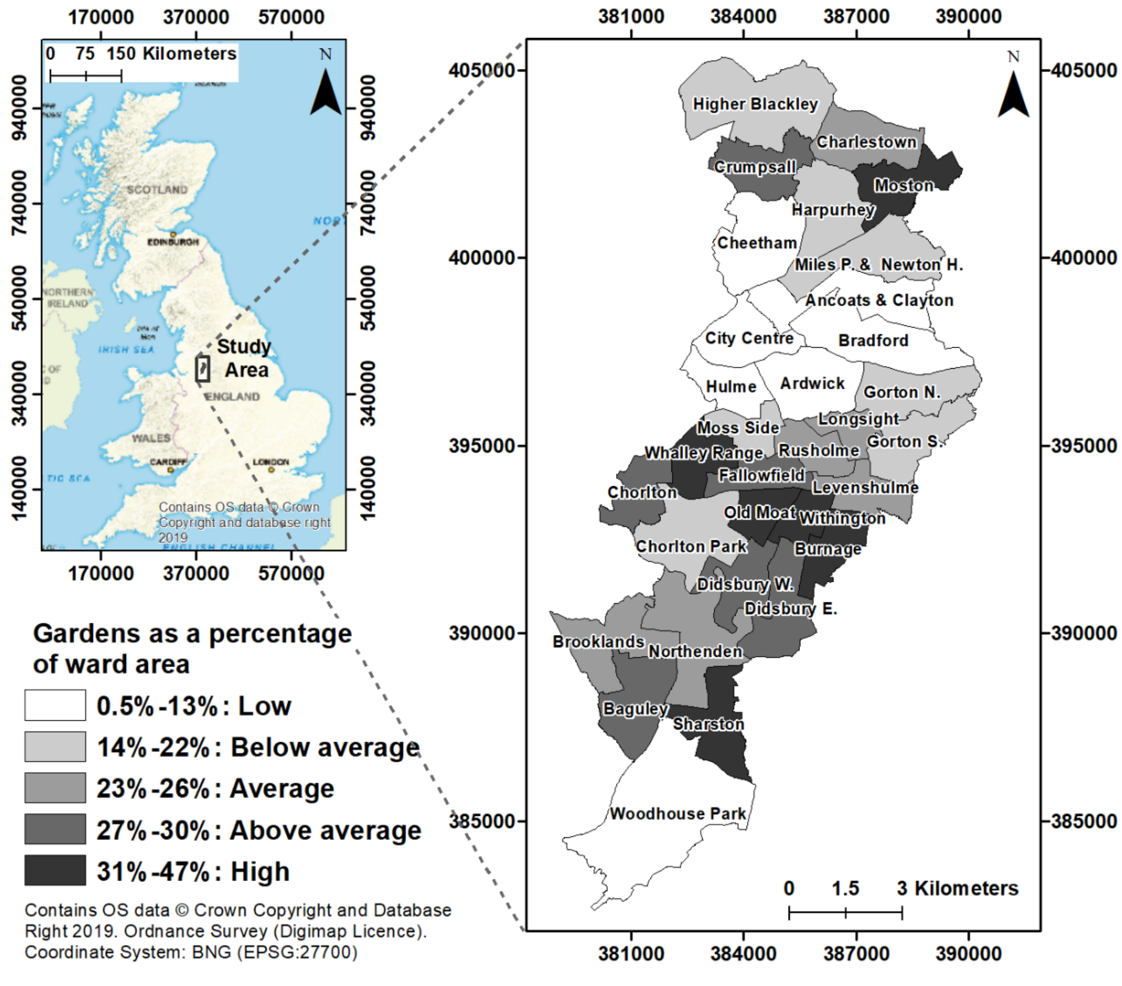

Figure 1: The case study area of Manchester, UK, showing gardens as a percentage of ward area

Manchester comprises 226,640 households of which approximately 68% is private stock (owner occupied and private rented), with the remainder owned by Local Authority or Registered Social Landlords (Housing Associations) (Manchester City Council, 2018). Manchester has a large proportion of apartments (26.6%) and terrace housing (36.0%), in comparison to the national averages, and a low amount of detached housing (4.3%) (AGMA, 2010). There are 156,573 gardens, which comprise over one fifth (20.4%, 23.6 Km^2) of the total land area of Manchester, and garden coverage (as a proportion of total land cover) varies considerably across the city, between 0.5% in the City Centre ward to 47% in suburban areas (Figure 1). Given the extensive terrace housing, many gardens in the city are small spaces, with 22.52% of gardens having a footprint of less than 50 square metres.

Establishing the baseline: Fine resolution mapping of garden green infrastructure

Vegetation has an important influence on urban climate. At the micro-scale, vegetation type and structure are important for influencing climate regulating services. For example, grasses mitigate runoff completely, and trees reduce runoff by 60%, in comparison to tarmac surfaces (Armson et al., 2013). Regarding cooling functions, mature parkland trees reduce radiant temperatures by 5-7°C, whilst grasses have very little effect on reducing radiant temperatures (Armson et al., 2012). An understanding of the mix of land surface cover types within gardens is therefore needed. This lack of data on the land surface cover in gardens necessitated the collection of a detailed dataset in order to understand the contribution of gardens to climate resilience on a city-scale.

Obtaining detailed land surface cover information for gardens is challenging due to the small scale and heterogeneity in land cover across gardens. Local knowledge from citizens can be a useful resource in crowdsourcing information, and has been found to be valuable in previous studies related to garden green infrastructure, for example, to gather data on garden use and maintenance (Loram et al., 2011; Lin et al., 2017) as well as in other disciplinary areas, including climate and atmospheric sciences (Muller et al., 2015). Using crowd-sourced information for accurate characterisation of garden composition, however, has not been previously attempted. Further benefits of working with local communities to create a garden database include the exchange of knowledge between local residents, scientists, and stakeholders.

To obtain fine-scale high quality information on urban gardens, a novel methodology was employed, which combined citizen science with high resolution image analysis. This involved two steps: firstly, designing and implementing an online citizen science survey (CSS) tool to capture quantitative data relating to garden composition, and secondly, classification of high resolution optical imagery to verify and extend the CSS results. This combined approach enabled an assessment of the quality of citizen science data. A summary of the methodology is presented below, and full details are provided in Baker et al. (2018).

The CSS tool, promoted as *My Back Yard*, was co-designed with the project partners, and open for completion for 6 months (July 2016 - December 2016). The CSS required respondents to estimate the proportional cover of ten common garden land surface cover types (buildings, hard impervious, hard pervious, bare soil, trees, shrubs, mown grass, cut grass, cultivated and water), required for environmental modelling in order to account for the ecological processes of varying land cover types. In addition, the CSS performed as a public engagement tool to enable learning about the role of urban gardens in climate regulation. On completion of the survey, respondents received feedback on their results and how they compare with other responses from their neighbourhood. Specific guidance on ways to improve their garden to aid climate resilience was provided and respondents could then pledge their support to implementing adaptation solutions, committing to make positive changes to their own garden. The survey was open to anyone with a UK residential postcode, however, results presented are responses collected for Manchester residents only. Over one thousand useable responses to the survey were received, with a good diversity of gardens captured, in terms of both size and amount of garden GI (Baker et al., 2018).

Image analysis was required to validate and extend the CSS database, by categorising broad surface cover types for all digitised garden parcels in Manchester. Validation was important to provide an accuracy of CSS garden land surface cover estimations, and extension was needed to quantify garden surface coverage beyond the gardens reported by the CSS respondents. Validation of the CSS land surface estimations revealed a mean accuracy of 76.63% (s = 15.24%), demonstrating that citizens are able to provide valid estimates of garden surface coverage proportions. High Resolution True-colour Aerial Imagery (TAI) (spatial scale 0.125 m) was used for the object based image analysis, to classify seven land surface cover categories for all garden parcels in the city, which achieved an overall classification accuracy of 82%. CSS land surface estimations were then extrapolated, to provide the proportional coverage of ten garden land surface cover types (buildings, hard impervious surfaces, hard pervious surfaces, bare soil, trees, shrubs, mown grass, rough grass, cultivated land, water) for every garden parcel in the city.

The resulting dataset quantifies the proportion of ten land surface cover types in all gardens across the city. This reveals that the proportion of GI in an average Manchester garden is 50.23% (Table 1). Average garden land surface cover proportions vary considerably between wards, with GI in an average garden varying between 15.44% (lowest, Hulme ward) to 52.74% (highest, Burnage ward) (Figure 2). Furthermore, it is evident that there are differences in the provision of different types of GI, with tree cover in an average garden varying greatly between 2.15% (lowest, Moss Side ward), to 25.52% (highest, Didsbury East), highlighting the increased quality of GI in some wards, since trees provide increased climate regulation benefits (Figure 2).

Garden land surface cover type	***Proportion (%)***
Buildings	1.32
Hard Impervious	33.77
Hard Pervious	9.53
Bare Soil	5.15
Trees	16.54
Shrubs	9.19
Mown Grass	14.46
Rough Grass	1.97
Cultivated	7.62
Water	0.45
Total green infrastructure (GI)	50.23

Table 1: Average proportional land surface cover across Manchester's gardens. Total GI is the sum of trees, shrubs, mown grass, rough grass, cultivated & water.

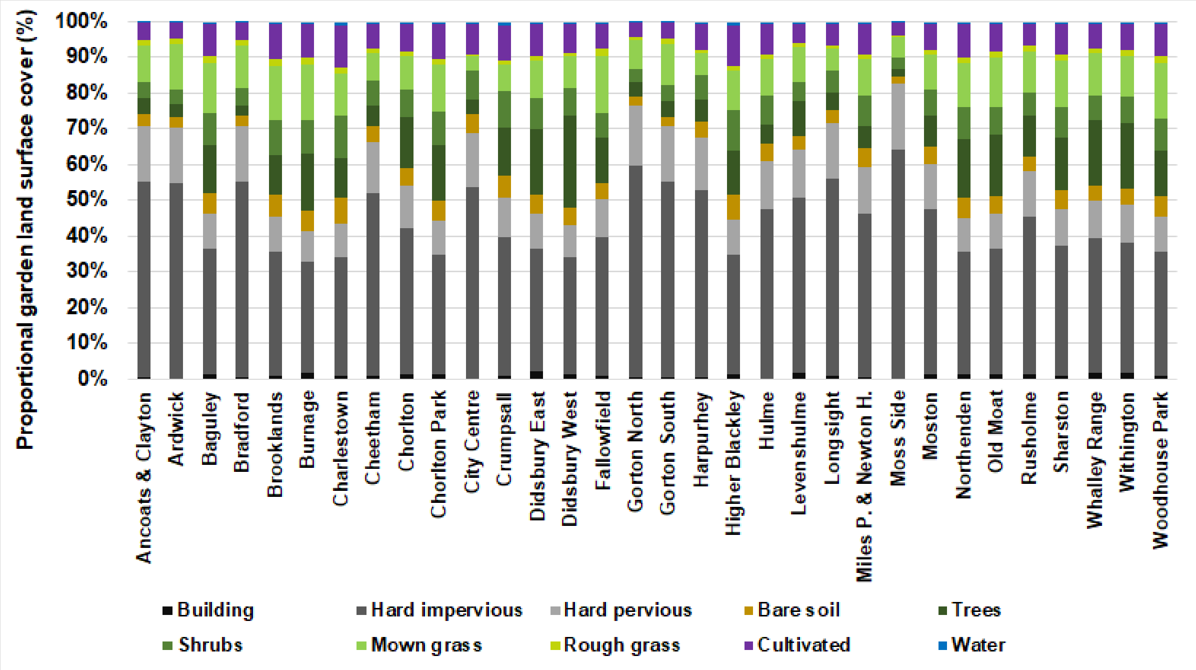

Figure 2: Proportional garden land surface cover for the average garden in each ward

Combining garden GI with public green space datasets (from Ordnance Survey) reveals that Manchester has a total of 49.0% GI - almost 10% less than previously estimated, since gardens were assumed to be completely comprised of green space. This means that over one fifth (20.94%) of Manchester's GI is contained within domestic gardens, for which city residents are responsible for maintaining and protecting.

Spatial variation in garden GI between wards is also evident, varying between 0.2% (lowest, City Centre) and 27% (highest, Burnage) (Figure 3a). Results reveal that whilst the wards with the greatest proportion of garden space to ward area (including Old Moat, Withington, and Burnage, Figure 1) still have the highest proportion of garden GI, they experience a significant reduction. For example, in Burnage, domestic gardens cover 47.2% of the ward area, but garden GI cover is only 27% of the ward area, with the remaining proportion (20.2%) comprising other land surface cover types including buildings, hard surfaces and bare soil. This demonstrates that gardens are not performing as well as they could be in delivering GI.

Combining the new garden GI data with all other GI in the ward (e.g. public parks) reveals that total ward GI varies between 13.65% (lowest, City Centre) to 73.36% (highest, Higher Blackley) (Figure 3b). Of the total GI in a ward, domestic gardens contribute between 1.34% (lowest, City Centre) to 62.41% (highest, Burnage) of the GI. These large spatial variations in GI quantity and type will affect the spatial provision of climate regulating services, as discussed in the next section.

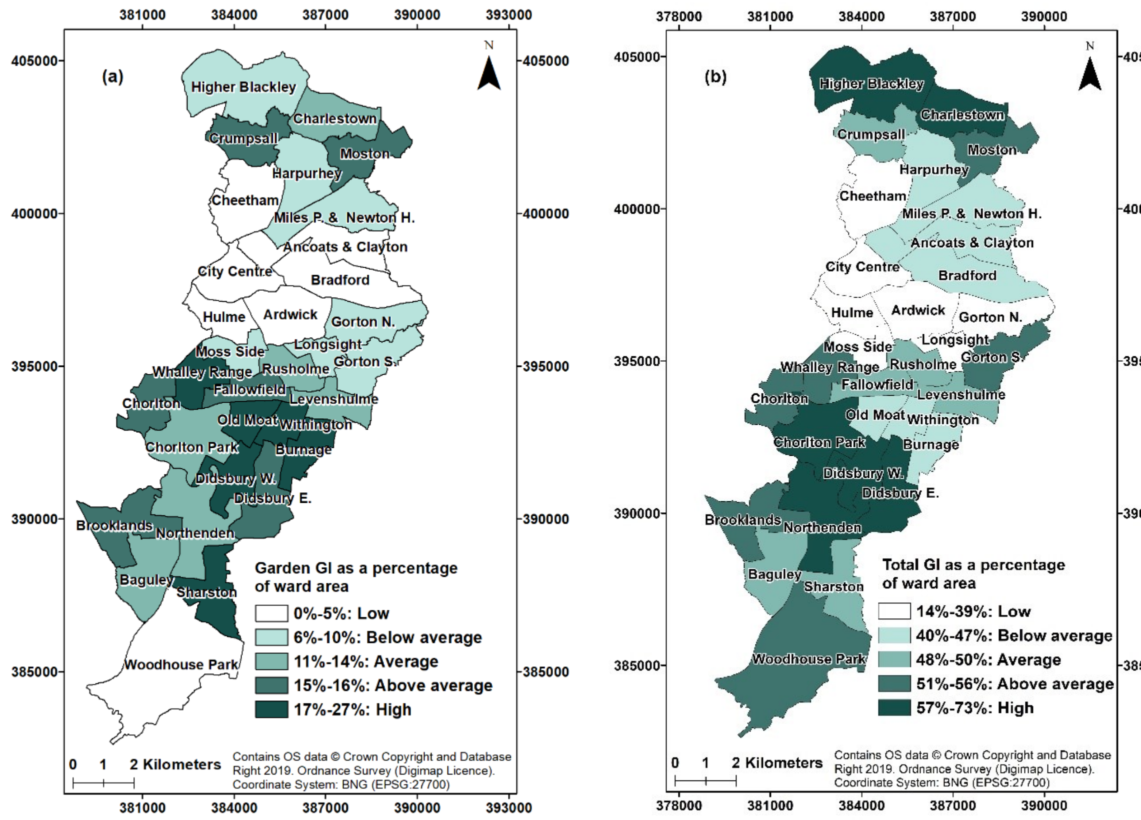

Figure 3: (a) Garden GI as a percentage of ward area, (b) total GI as a percentage of ward area

The contribution of domestic gardens to climate regulation

Environmental modelling was undertaken to estimate and map the cooling potential and runoff attenuation functions of GI, to indicate benefits related to reduced risks from heat waves and flooding. Risks of heat waves and flooding were identified as priority climate risks by the project partners and a wider group of stakeholders forming the Manchester Green and Blue Infrastructure Strategy Group.

The cooling potential of domestic gardens was assessed using an urban energy exchange model, which produces outputs of maximum surface temperature expected during the two hottest days in summer (98^{th} percentile) for a specified study area (Gill et al., 2007; Carter et al., 2012; Cavan et al., 2014). Runoff attenuation was assessed using a model based upon the US Soil Conservation Service approach (Gill et al., 2007), providing the percentage of rainfall that becomes surface runoff for a given amount of daily rainfall, in this case the 99th percentile daily winter rainfall (assuming normal soil moisture conditions). Both models were available within an online decision-support tool (the 'STAR Tools'), which have been applied to cities in the UK, Europe and Africa, and used by policymakers, researchers, and green infrastructure professionals to guide planning and policy (The Mersey Forest and University of Manchester, 2011).

The STAR tools were run for the electoral wards administrative unit (32 in total) to demonstrate how land cover change influences climate risks across the city. Whilst ward boundaries do not reflect climatic or environmental processes, these were the preferred spatial unit for the project partners, since electoral wards are the spatial units used to elect local government councillors , and thus have importance for local planning policy. Wards vary in size and population, with the national average around 5500 people per ward. Baseline and future climate projections data was available from the UK Climate Projections 2009, the most up-to-date high resolution climate information for the UK at the time. Climate data for 1961-1990 baseline time period and 2050s High emissions scenario (2050H) 90% probability level (to represent the maximum amount of change) were selected, where the High emissions is equivalent to the IPCC A1FI scenario (Murphy et al., 2009). Four scenarios were run to demonstrate the contribution of gardens to climate regulation (Table 2).

Table 2: Description of the four scenarios for assessing cooling potential and runoff attenuation

Scenario	**Description**
Baseline I	1961-90 climate with the assumption that gardens are completely green space
Baseline II	1961-90 climate with more accurate garden greenspace data
Future I	2050s high emissions scenario (90% probability level) with more accurate garden greenspace data
Future II	2050s high emissions scenario (90% probability level) with the assumption that gardens are completely green space

Results demonstrate that because gardens are comprised of heterogeneous land surfaces, wards experience higher maximum surface temperatures (between 0.1 to 4 degrees Celsius; Figure 4) and higher surface runoff (between 0-6 per cent; Figure 5) than they would if gardens were wholly green space. Differences are most pronounced in the wards that have a higher proportion of gardens to ward area, in particular, Burnage, Old Moat and Withington (with garden areas comprising 47.26%, 46.49%, and 39.62% of the ward respectively). As previously demonstrated, domestic gardens contain a significant amount of the city's green space, and thus, make an important contribution to climate regulation.

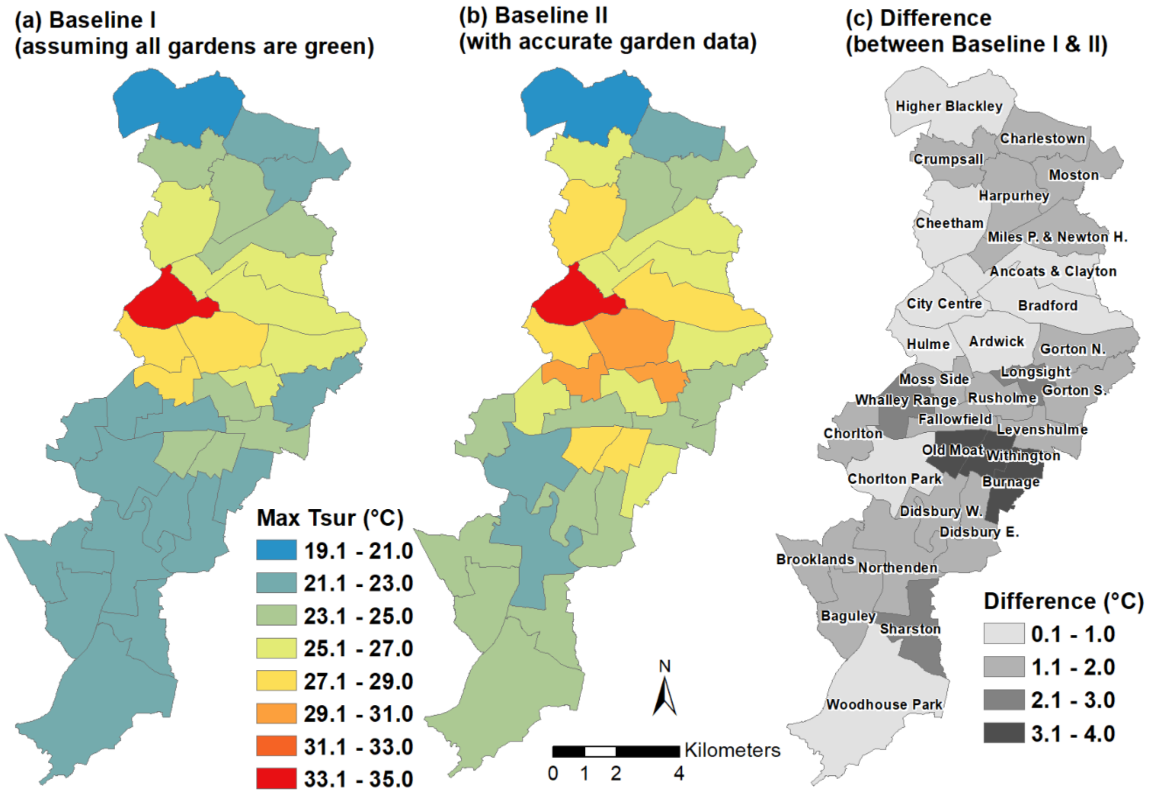

Figure 4: Modelled maximum surface temperatures for (a) Baseline I scenario (b) Baseline II scenario (c) Difference between Baseline I and Baseline II scenarios

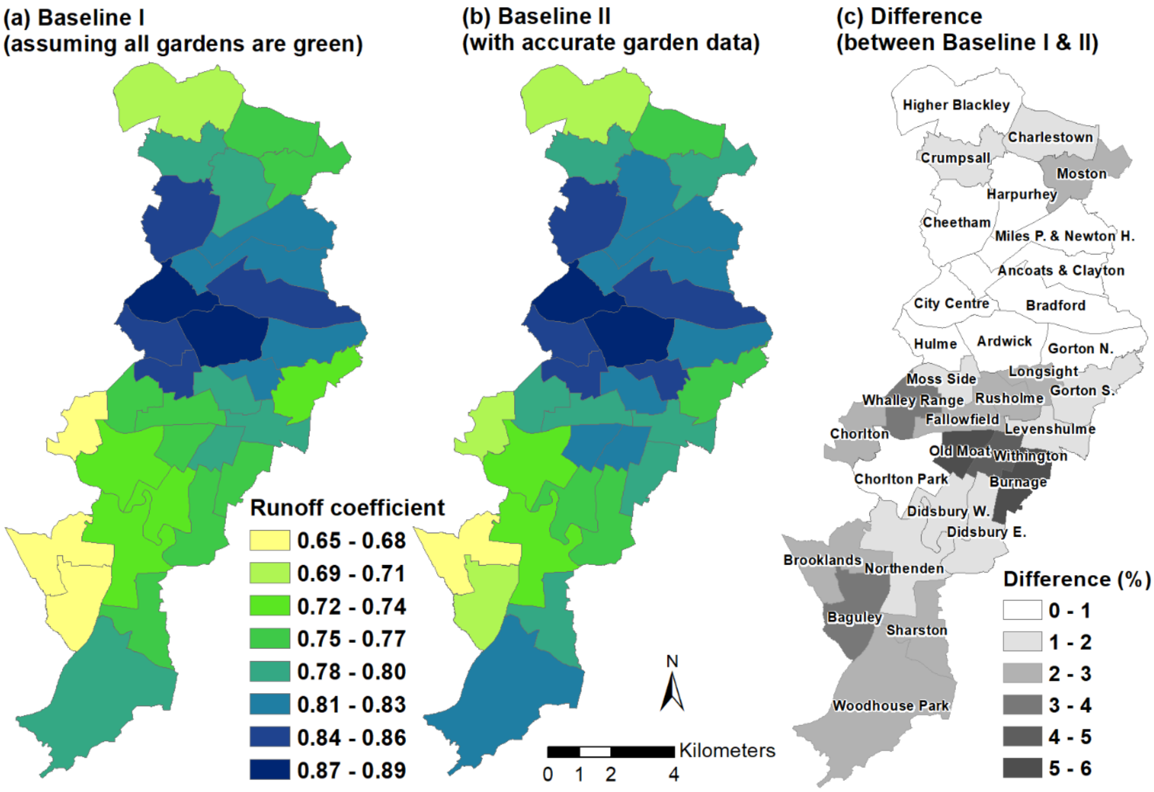

Figure 5: Modelled surface runoff coefficient (where a coefficient of 1 is complete runoff) for (a) Baseline I scenario (b) Baseline II scenario (c) Difference between Baseline I and Baseline II scenarios.

Future climate projections were run to demonstrate potential future change and the impact of greening gardens on climate regulation. Figures 6 and 7 show ward level results for the modelled maximum surface temperatures and surface runoff, respectively. This highlights the impact of garden greenspace in the future, as the difference between Future I scenario (future climate with accurate garden greenspace) and Future II scenario (future climate with gardens wholly greenspace). Greening gardens would reduce ward surface temperatures in future by between -0.1 to -4.2 degrees Celsius (M = -1.7°C; s = 1.0°C). It is evident that for six wards (Burnage, Whalley Range, Sharston, Withington, Old Moat and Longsight), greening gardens could mitigate the increased risk of heat wave events due to climate change on the neighbourhood, since the temperatures under the Future II scenario falls below Baseline II scenario (Figure 6). These wards have a high proportion of gardens to ward area, (between 24.93% to 47.26%), therefore, complete greening of gardens in these wards has a significant impact upon reducing future heat wave risks. Greening gardens could reduce future ward surface runoff by up to -4.0% (M = -1.0%; s = 1.0%), and in three wards (Withington, Old Moat, Burnage) this could mitigate the increased risk of surface runoff due to future climate change on the neighbourhood (Figure 7). These three wards have the highest proportion of gardens to ward area (over 39%, Figure 1). These reductions are of significant value, since UK meteorological records show that the 10 warmest years have all occurred since 2002 and extreme rainfall events have increased over the past 50 years (Kendon et al., 2019). This highlights the need for urgent action to protect vulnerable GI (which includes gardens) in urban areas.

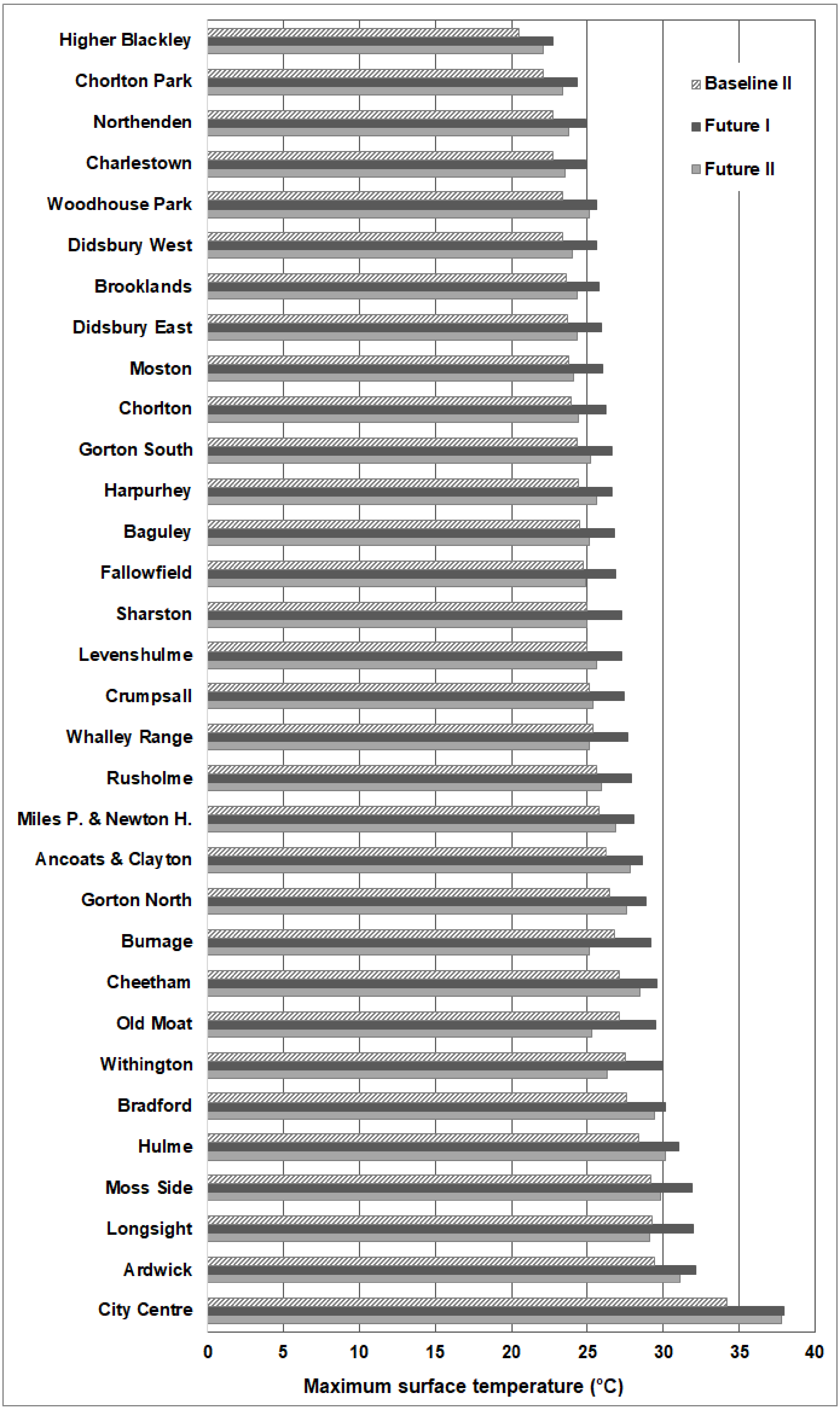

Figure 6: Ward level modelled maximum surface temperature for baseline and future scenarios

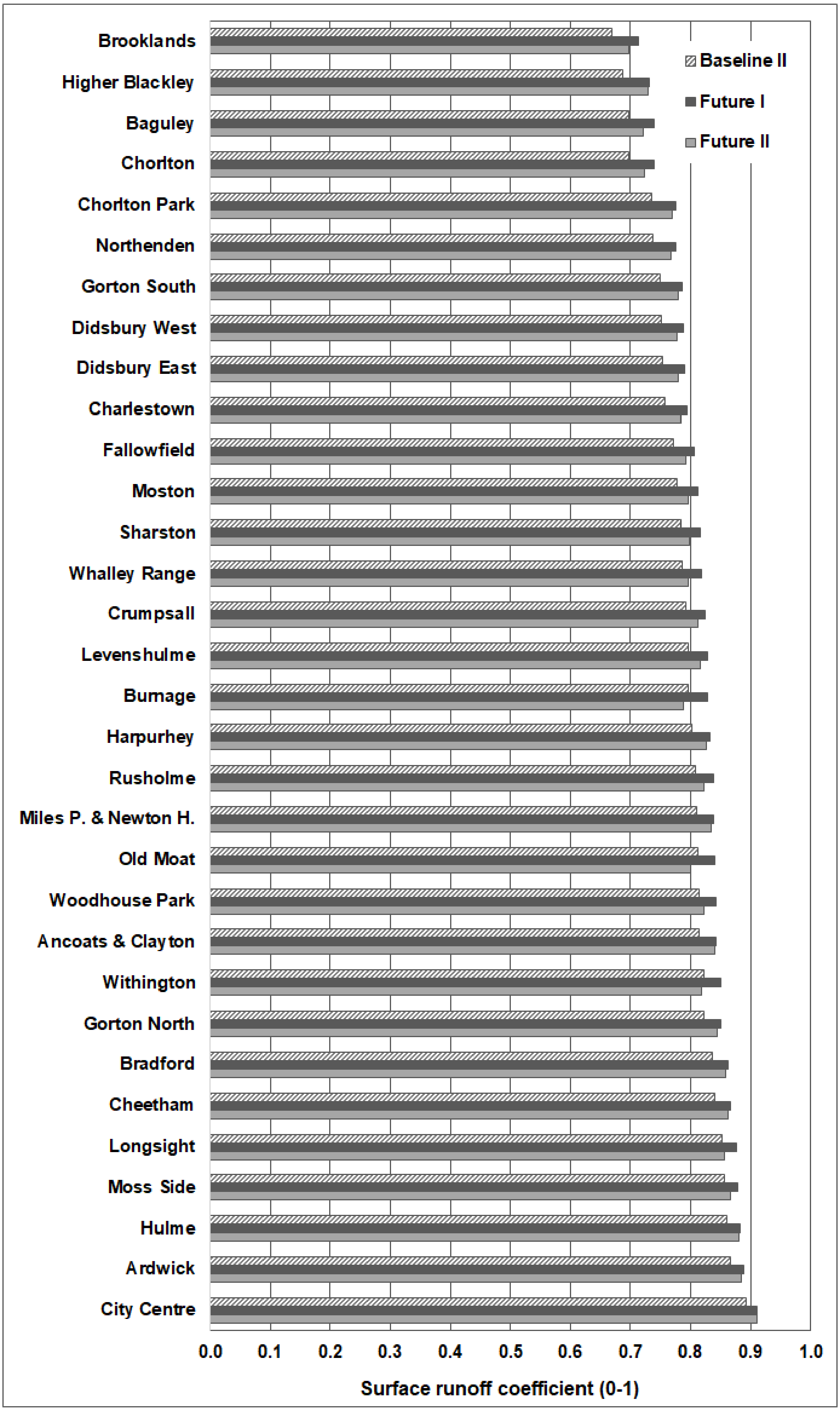

Figure 7: Ward level surface runoff for baseline and future scenarios

Engaging citizens to encourage positive action in gardens

Whilst the primary focus of the CSS was to gather data on the proportion of garden land surface cover types across the city, this also acted as a useful educational tool to engage citizens about gardens and their importance for delivering ecosystem services, in particular, climate regulation and biodiversity. As outlined above, over 20% of Manchester's GI is contained within domestic gardens, which city residents are responsible for maintaining. Since these are private spaces subject to limited planning control, engagement of city residents is key to halting loss of garden GI, and positive action is needed to increase garden GI. These changes (either positive or negative) will have a direct and measureable effect on the city's climate resilience.

On completion of the CSS, respondents received simple information about why their gardens are important for enhancing the city's climate resilience and biodiversity, and were given guidance on actions that could improve their garden. Respondents could then pledge their support to implementing adaptation solutions, committing to make positive changes to their own garden. Over 700 pledges were received, including:

- 252 respondents pledged to plant a variety of plant types in their garden to enhance wildlife;
- 228 respondents pledged to use drought resistant plants in their garden and to collect water;
- 150 respondents pledged to plant trees for shade to reduce heat wave impacts and improve air quality; and,
- 119 respondents pledged to replace the hard surfaces in their garden with green space to reduce surface water flooding.

A follow-up survey was emailed to the CSS respondents one year later to understand if the pledges had translated into action. For those who pledged to implement an action, completion rates were high, varying between 84.5% to 94.8%, depending upon the specific pledge and associated action. For example, completion rates for the action to replace hard surfaces with green space were lower, likely reflecting that such changes are more challenging and costly to implement. Further research into the barriers and enablers to action is ongoing to support delivery of the action plan, presented in the next section.

Influencing policy and practice: An action plan to increase green space in Manchester's gardens

An action plan was co-developed with the four project partner organisations - Manchester City Council, Lancashire Wildlife Trust, Southway Housing Trust, and City of Trees. These organisations all have an interest in gardens and are able to influence planning policy and practical projects in green spaces across Manchester. The action plan was created using the Delphi technique (Curtis, 2004; Okoli & Pawlowski, 2004), an iterative process where partners discuss issues and arrive at a consensus, culminating in a shared action plan which could be embedded into existing policy and delivery mechanisms. Three iterative discussions took place to co-develop the action plan, these involved:

1) Project partners identifying and discussing their existing priorities relating to GI interventions and associated delivery mechanisms in order to reach a consensus on their mutual and positively reinforcing priorities and delivery mechanisms for GI interventions;
2) Project partners reaching a consensus on the potential of the GI spatial database to facilitate integration of priorities and delivery mechanisms and on a common evaluation of the potential to pool mechanisms for delivering mutual priorities in GI interventions; and,
3) Project partners agreeing a common action plan for GI interventions that strengthen the functionality of ecosystems in areas of GI need.

Through the three iterative discussions, the final aim of the action plan was agreed to *encourage a cultural change in the way that people appreciate the benefits of their gardens*. Project partners committed to achieving this aim by (i) working in partnership; (ii) pooling delivery mechanisms; and, (iii) delivering the actions for improving green space and wildlife in gardens.

The action plan included key actions for each organisation, which bring together and complement existing activities that the project partners undertake to improve green space in gardens as well as creating the groundwork for future garden projects. Each action included a delivery mechanism, targeted areas where the action was needed (based on the spatial analysis presented), the partners involved (including collaborations beyond the project), timescales for delivery, and delivery mechanisms. There were six key themed actions, shown in Table 3, together with some specific examples and delivery mechanisms from the action plan.

The action plan was published as a short briefing document for a general audience (Figure 8), supported by an online spatial database of the key mapped outputs, and has already stimulated a follow-on campaign, My Wild City, a collaboration between Lancashire Wildlife Trust and Manchester City Council funded by Esme Fairburn Foundation. My Wild City is a four year project that aims to inspire and engage city residents into getting involved in practical actions in their gardens, parks and wildlife corridors, and develop a new 10-year biodiversity strategy for the city.

Table 3: An overview of the Action Plan, outlining the six key themed actions, delivery mechanisms, and specific examples.

Types of actions	Delivery mechanisms	Examples
Promote actions that increase green space and wildlife in gardens	Citizen science Data collection & analysis Events Information packs Lobbying On the ground projects Public promotion	• The Wildlife Trust campaigns including 'My Wild City' and 'My Wild Garden'. • Engaging Manchester in national campaigns including Britain in Bloom and Grow Wild Awards. • City of Trees' Heritage Trees project, an online citizen science database of peoples' stories, memories and photographs of local heritage trees.
Undertake practical garden related improvement projects	Events On the ground projects	• Community Greening projects, food growing projects such as 'Real Food Wythenshawe', and tree planting initiatives.
Engage in garden related policy development	Lobbying	• Update the Manchester GI strategy in light of new garden data • Establish RPs green infrastructure group
Undertake research on gardens	Data collection & analysis Citizen science On the ground projects	• Ongoing collaborative green infrastructure research • Spatial mapping of the connectivity of garden corridors
Provide training and practical skills relating to gardens	On the ground projects Events Information packs	• The 'green streets' projects involving grants for groups or organisations for innovative urban forestry projects, training on tree planting and tree management skills. • Training on wildlife identification and recording in gardens
Promote the value of gardens	Citizen science Events Information packs	• A species recording campaign led by Lancashire Wildlife Trust

LANCASHIRE WILDLIFE TRUST
ACTIONS TO IMPROVE GREEN SPACE AND WILDLIFE IN GARDENS

Wards	Actions to improve gardens	Delivery mechanism	Partners	Timescale
All wards	Promote actions to improve wildlife in gardens	LWT website, social media, promotion materials	LWT	2018
All wards	Promote actions to improve wildlife in gardens	Guidance, info & resource pack (hard pack)	LWT	2017–2018
All wards	Promote actions to improve wildlife in gardens	Guidance, info & resource pack (online pack)	LWT	2017
All wards	Promote the value of indicator species in gardens	Species recording campaign	LWT	2017
City Centre	Promote the value of biodiversity and gardens in particular	Festival on gardens and biodiversity organisation	LWT, MCC	2018
City Centre	Promote actions to improve wildlife in gardens	Festival on gardens and biodiversity workshops	LWT, MCC	2018
All wards	Citizen science mapping of actions to improve wildlife in gardens	LWT website new interactive map tool	LWT	2018
All wards	Training wildlife identification and recording in gardens	Species recording campaign	LWT	2018
Targeted wards	Research on spatial mapping of the connectivity of garden corridors	GIS analysis to identify garden corridors	LWT, students, universities	2018
Targeted wards	Research on wildlife and other values of garden corridors	Student projects, partner projects	LWT, students, universities	2017

LWT: Lancashire Wildlife Trust; **MCC:** Manchester City Council

Figure 8: The MBY Action Plan, illustrating Lancashire Wildlife Trust's actions and delivery mechanisms, available to download at www.mmu.ac.uk/mybackyard

To maximise impact of the action plan, partners agreed that it should be embedded within the existing local policy context. Whilst there is no specific planning policy for domestic gardens, they are included in the Manchester Green and Blue Infrastructure Strategy (MGBIS), which complements strategic objectives of the Manchester Strategy and Manchester Climate Change Strategy. The action plan will be delivered through the Manchester Green Infrastructure Strategy Group, an informal partnership of public, private, and third sector organisations, of which all the project team are members. The Strategy Group meets four times per year to provide updates and review progress on delivery. The MGBIS is due to be updated in 2020/21, which will include the updated evidence documented here, together with priority actions and delivery mechanisms highlighted. Embedding this new evidence within the existing policy framework will ensure that progress on actions are appropriately monitored and reported.

Conclusions

Urban green infrastructure (GI) is a well-known solution to enhance resilience to climate hazards. In this context the quantity and spatial distribution of GI has been researched in relation to creating cool islands, moderating urban heat islands and reducing surface water runoff, mitigating flooding. In order to understand the impact of GI in moderating climatic extreme events, environmental models require detailed information relating to urban GI type, structure, and height, since the functionality of different GI types (e.g. mown grass, rough grass, shrubs, trees) is variable in its influence upon urban micro-climate. Whilst comprehensive geospatial datasets exist for GI in public spaces, there is less information about privately owned domestic gardens, which make up a large area of cities, and are assumed to contain a significant proportion of GI. The lack of data regarding the land surface cover in gardens necessitates the collection of a detailed dataset in order to enhance understanding of the contribution of gardens to climate resilience on a city-scale, and provide knowledge to inform spatial planning and policy making. This project applied a novel approach, combining citizen science with remote sensing analysis, within a collaborative project partnership of universities, private and third sector organisations, which culminated in an action plan to increase green space and enhance wildlife in domestic gardens across Manchester.

In Manchester, domestic gardens comprise over one fifth (20.4%, 23.6 km^2) of the total land area of the city. Gardens, however, are not comprised wholly of green space, and the proportion of GI in an average Manchester garden is 50.23%. At the city scale, this means that Manchester has a total of 49.0% GI - almost 10% less than previous estimations which assumed gardens were completely comprised of green space.

Environmental modelling was conducted to quantify and map climate regulation services including cooling potential and runoff attenuation under different scenarios. This demonstrates that greening gardens could be the solution to reducing future risk of heat wave events and surface water flooding, particularly in neighbourhoods with a high proportion of gardens to ward area. Since city residents are responsible for maintaining and protecting private domestic gardens, such actions, necessitate the engagement of citizens within a receptive policy environment. To begin to achieve this ambition, an action plan was co-developed with project partner organisations who are able to influence planning policy and practical projects in green spaces across Manchester. Embedding the action plan within the existing policy framework is beneficial since this will ensure that progress on actions are appropriately monitored and reported in the future.

The online survey tool and results are transferable to other cities and demonstrates how citizen science within a science-policy-practice project framework can provide the basis for shared learning to improve the resilience of the urban environment to climate change. Finally, it is clear that cross-disciplinary collaborations among scientists, planners, government, non-governmental organizations, the private sector, and the general public, are required to address the challenges that lie ahead for cities as healthy environments.

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