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Climate change and the city: Building capacity for urban adaptation

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Abstract

The significant shifts in climate variables projected for the 21st century, coupled with the observed impacts of ongoing extreme weather and climate events, ensures that adaptation to climate change is set to remain a pressing issue for urban areas over the coming decades. This volume of Progress in Planning seeks to contribute to the widening debate about how the transformation of cities to respond to the changing climate is being understood, managed and achieved. We focus particularly on spatial planning, and building the capacity of this key mechanism for responding to the adaptation imperative in urban areas. The core focus is the outcomes of a collaborative research project, EcoCities, undertaken at the University of Manchester's School of Environment and Development. EcoCities drew upon inter-disciplinary research on climate science, environmental planning and urban design working within a socio-technical framework to investigate climate change hazards, vulnerabilities and adaptation responses in the conurbation of Greater Manchester, UK. Emerging transferable learning with potential relevance for adaptation planning in other cities and urban areas is drawn out to inform this rapidly emerging international agenda. Approaches to build adaptive capacity challenge traditional approaches to environmental and spatial planning, and the role of researchers in this process, raising questions over whether appropriate governance structures are in place to develop effective responses. The cross-cutting nature of the adaptation agenda exposes the silo based approaches that drive many organisations. The development of a collaborative, sociotechnical agenda is vital if we are to meet the climate change adaptation challenge in cities.

Keywords: Climate change; Adaptation; Cities; Urban; Spatial planning

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1. Planning an urban climate change adaptation response

1.1. Climate change and the adaptation imperative

Climate change has emerged as one of the defining issues of the early 21st century. NASA's Goddard Institute for Space Studies finds that global surface temperatures in the past decade are 0.8 °C higher than the start of the 20th century, with two thirds of this warming having occurred since 1975 (Hansen, Ruedy, Sato, & Lo, 2010). Recent research confirms that the imprint of human induced climate change can be recognised in current events (Min, Zhang, Zwiers, & Hegerl, 2011; Pall et al., 2011). There is a high probability of observed trends, such as increases in heat waves and heavy precipitation events, intensifying over the 21st century (IPCC, 2007). Extreme weather and climate events are anticipated to generate significant risks to societies and ecosystems (IPCC, 2012).

The extent of future climate change depends on a number of variables including the pace of greenhouse gas emissions, deforestation rates, and the response of ecosystems to the changing climate. Alarmingly, since 1990, global emissions of greenhouse gases have increased by 45%, and by 30% since 2000 (Olivier, Janssens-Maenhout, Peters, & Wilson, 2011). Globally, emissions increased by an unprecedented 5.8% in 2010 alone (Olivier et al., 2011). Meanwhile, negotiations to deliver a supra-national climate change mitigation strategy post-Kyoto are progressing slowly, whilst at the same time the earth's capacity to naturally absorb greenhouse gas emissions is declining (Canadell et al., 2007). Hence, for scientific and geopolitical reasons, a global average surface temperature increase of around 4 °C is now thought to be a distinct possibility during the 21st century (Betts et al., 2011; Hamilton, 2010; New, Liverman, & Anderson, 2009). Reducing the risk of climate change of this magnitude will require radical social and economic shifts (Anderson & Bows, 2008; Brown, 2011; Hamilton, 2010), particularly in cities (Rosenzweig, Solecki, Hammer, & Mehrohtra, 2011). Even at the lower levels of climate change projections produced by the Intergovernmental Panel on Climate Change (IPCC) (around 2 °C warming by the end of this century), a complex series of poorly understood secondary effects on natural environments, economies and societies, locally and globally, can be expected (IPCC, 2007; USGCRP, 2009).

Adaptation to climate change in cities is a necessity. Although urban climate change adaptation is a relatively new topic, over recent years significant advances have been made in policy, practice and research on climate change adaptation more broadly, and in urban areas specifically. The Cancun Adaptation Framework, adopted in 2010 under the UN Framework Convention on Climate Change (UNFCCC), establishes that climate change adaptation must be afforded the same level of priority as mitigation to reduce greenhouse gas emissions. The Cancun Adaptation Framework also supports the development of national adaptation plans. In Europe, as of January 2013, 15 Member States have adopted national adaptation plans or strategies (European Commission, 2013a, 2013b). For example, the UK's National Adaptation Programme (Defra, 2013) outlines thematic policies and actions to address risks and exploit potential opportunities linked to the changing climate. High level strategic frameworks such as these can support adaptation planning, establishing headline climate risks and corresponding adaptation response themes. However, the European Commission reflects that, at the national level, ‘‘Much of the adaptation work undertaken to date can be summarised as awareness raising or preparing the ground for adaptation’’ (European Commission, 2013a, 2013b, p. 6).

It is a finer spatial scales that more comprehensive design and implementation of adaptation strategies, plans and actions is beginning to take hold, often in the absence of a strong national lead. Given that the impacts of climate change are experienced locally, it is understandable that certain cities are taking the initiative to develop adaptation responses in advance. Examples include coastal adaptation planning responses developed by the New York City Panel on Climate Change (Rosenzweig, Solecki, Blake, et al., 2011), London's climate change adaptation strategy (GLA, 2011) and Rotterdam's ‘Climate Proof’ adaptation programme (City of Rotterdam, 2010).

Although some cities are making progress on adaptation, with ‘global’ cities such as London and New York potentially recognising the threat that climate change poses to their economic competitiveness, adaptation is by no means firmly embedded throughout the activities of the majority of cities and urban areas. It is valuable, therefore, that research institutes and capacity building organisations are generating an increasingly a rich framework of scientific knowledge and practical insights to support the creation of adaptation responses. Examples include the UK Climate Impacts Programme and Germany's Klimzug initiative. Both are comprehensive programmes aimed at building capacity to adapt to climate change, and cover themes ranging from managing the process of developing adaptation responses, good practice case studies and stakeholder engagement. Primary research into these issues is progressing via national and supra-national research programmes, for example projects funded through the UK's Adaptation and Resilience in a Changing Climate (ARCC) programme and the European Framework Programme. At the European scale, projects including PREPARED (which looks at water and sanitation under climate change), CORFU (with a focus on flood resilience in urban areas) and SUDPLAN (which concentrates on adaptation via long term urban planning) demonstrate the richness of ongoing research and capacity building in the theme of urban adaptation.

The scope of academic engagement in this field is expanding in tandem, with urban adaptation proving to be a rich new area for research and associated publications. While and Whitehead (2013, p. 1326) identify "...a new level of empirical and intellectual scope" regarding the study of the interface between urban areas and climate change. This Progress in Planning article aims to contribute to the ever-widening debate around how cities are responding to the changing climate (see, for example, Bulkeley, 2010; Carter, 2011; Corfee-Morlot, Cochran, Hallegatte, & Teasdale, 2011; EEA, 2012; Pelling, 2011; Rosenzweig, Solecki, Hammer, et al., 2011; Whitehead, 2013).

1.2. A focus on urban adaptation

There are three reasons why cities occupy a central position in the adaptation agenda. Firstly, continued urbanisation is set to define and shape the 21st century (Graham & Marvin, 2001). While and Whitehead (2013, p. 1325) describe cities as "...the defining ecological phenomenon of the 21st century." Globally, the majority of population growth over coming decades will take place in urban areas (United Nations, 2008). Allied to this urbanisation trend, cities and urban scale governance structures are set to challenge the dominance of the nation state this century (Glaeser, 2011; Sassen, 2006). It is also notable that the move towards the knowledge-based economy has a distinct urban dimension, with innovation activity and output particularly high in large agglomerations: "Cities, therefore, seem to provide favourable surroundings for the diffusion of knowledge and its application in economic activity" (European Commission DG Regional Policy, 2011, p. 16). Coupling the prominent role of cities with observed and projected weather extremes and climate change, the pressing nature of adaptation in cities becomes apparent.

Secondly, the design of cities creates unique micro-climates that affect variables including temperature and wind (EEA, 2012; Hebbert, Jankovic, & Webb, 2011). The urban heat island effect is a key example, where cities are warmer than their surrounding hinterlands due to the complex topography and mass of buildings, replacement of pervious vegetated surfaces with impervious built surfaces and the emission of heat from anthropogenic activities (Gartland, 2008; Smith, Lindley, & Levermore, 2009). Climate change is projected to further intensify the heat island effect (Wilby, 2007). Also, sealed surfaces exacerbate flood risk due to reduced infiltration and consequent enhanced rainwater runoff (Gill, Handley, Ennos, & Pauleit, 2007). Wilbanks et al. (2007) add that within cities, development is increasingly located where exposure to climate change hazards is potentially high, for example in coastal areas, on slopes and within flood plains.

Thirdly, it is recognised that due to factors including their heavy reliance on interconnected networked infrastructure, high population densities, large numbers of poor and elderly people and major concentrations of material and cultural assets, cities are particularly threatened by climate change (Defra, 2012; EEA, 2010; Schauser et al., 2010). Social, economic and political processes, such as poor governance structures or inadequate urban design, can exacerbate climate change risks (EEA, 2012; Schauser et al., 2010).

For reasons such as these, cities often suffer from weather and climate hazards. A recent report on urban adaptation in Europe focused on heat, flooding, water scarcity and drought (EEA, 2012), which affected cities in the past and continue to do so (Carter, Connelly, Handley, & Lindley, 2012; Hebbert & Jankovic, 2013). High profile events include Europe's 2003 heat wave which impacted Paris particularly severely (Poumadère, Mays, Le Mer, & Blong, 2005), the Elbe floods of 2002 and the resulting impacts on Dresden (Kundzewicz et al., 2005) and the implications of drought conditions for Barcelona in 2008 (Martin-Ortega & Markandya, 2009). A range of other climate hazards are relevant, from sea level rise to wild fires, and there may be new and, as yet unforeseen, challenges arising from the interaction between increasingly extreme and erratic weather patterns and other socioeconomic and biophysical forces shaping the future of cities.

1.3. Urban adaptation: towards a conceptual framework

Within this article, we follow the definition of climate change adaptation promoted by the Intergovernmental

Panel on Climate Change, where adaptation concerns (IPCC, 2007):

> ...adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities.

This definition usefully emphasises that adaptation is not purely anthropocentric, that it is not solely future-oriented, and that there are potential benefits associated with adaptation. Adaptation can be both autonomous and incentivised by policy making (IPCC, 2001). Within this article we focus on the latter, concerning ourselves with the development of forward looking proactive responses.

Over recent years, the notion of 'resilience' has been increasingly associated with climate change adaptation (Leichenko, 2011). Indeed, the overall aim of the EU Strategy on adaptation to climate change (European Commission, 2013a) is noted as being to support progress towards a 'climate-resilient Europe'. Although it had its roots in ecology and notions of persistence of systems and the relationships that support them (Holling, 1973), the concept of resilience has broadened and is now applied to a diverse range of agendas and is receiving increasing attention in academia and policy (Jabareen, 2013; Pike, Dawley, & Tomaney, 2010). Wilkinson, Porter, and Colding (2010, p. 26) add that resilience now also encompasses; "...broader matters of the governance of linked social-ecological systems." The United Nations Office for Disaster Risk Reduction (UNISDR) defines resilience as (UNISDR, 2012, p. 92):

> Resilience means the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of the hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

Conceptually, adaptation is increasingly conceived of as the management of climate risk. This connects adaptation to broader perspectives urban resilience. From the perspective of a city, a shock to the urban system (which may be driven by a range of factors, climatic or otherwise) may be withstood if resilience is high, or push the system to a less favourable state (for example towards shrinkage and decline) if this is not the case. Risk assessment frameworks are emerging to support this broad approach to adaptation in urban areas, where identifying and subsequently reducing risks from extreme weather and climate hazards acts to lessen the frequency and intensity of shocks to urban systems (Lindley, Handley, Theuray, Peet, & Mcevoy, 2006; Rosenzweig, Solecki, Hammer, et al., 2011). This broadly follows the work of Ulrich Beck, which charts the progressive evolution of industrial society into a risk society, where risks are described as "... systematically caused, statistically describable and in that sense predictable types of events, which can therefore be subjected to supra-individual and political rules of recognition, compensation and avoidance" (Beck, 1992, p. 328). More recently, 'risk governance' has emerged in response (Renn, 2008). Beck (1992) differentiates between risks caused by decisions, and those that are independent of decision-making such as natural disasters. Climate change risks are often a product of an interrelation between the two; they arise where the outcomes of decisions, for example linking to the development and use of land, interact with a natural disaster, for example a storm surge, to generate negative socioeconomic impacts.

There are different interpretations of what constitutes a climate change risk assessment, and there is no universally accepted approach. We adopt an established risk-based conceptual framework to clarify central concepts that run through this article and to structure the ensuing discussion. This is important given the complexity of climate change impacts and adaptation responses, and their relationship to urban processes. The framework is contained within a report from the Urban Climate Change Research Network which emphasised that: '...a multidimensional approach to risk assessment is a prerequisite to effective urban development programmes that incorporate climate change responses' (Rosenzweig, Solecki, Hammer, et al., 2011, p. 36). Their 'urban climate change vulnerability and risk assessment framework' (Fig. 1) offers an effective means of understanding climate risks and framing the development of corresponding adaptation strategies and actions. It is underpinned by World Bank research (Mehrotra et al., 2009) and has been applied in a range of cities internationally.

The urban climate change vulnerability and risk assessment framework differs slightly from interpretations adopted by international organisations including the IPCC, for example within their special report on managing the risks of extreme events and disasters (IPCC, 2012), and the UNISDR. Nevertheless, there are also clear linkages in respect of the overarching terminology used and the underlying risk based approach. The key difference is that the urban climate change vulnerability and risk assessment framework separates out adaptive capacity from vulnerability, whereas the IPCC and UNISDR approaches integrate

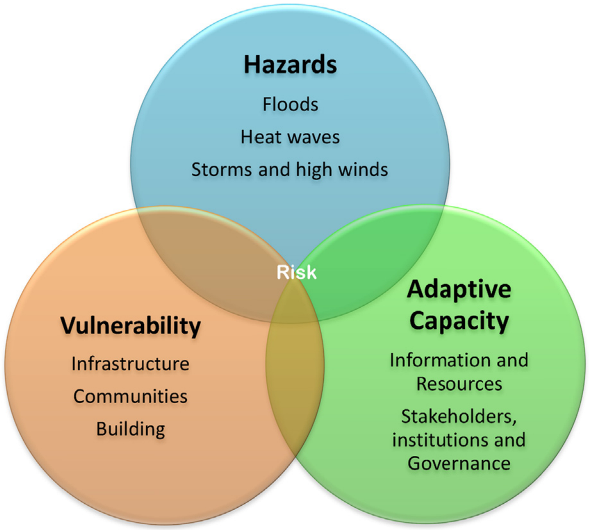

Fig. 1. Urban climate change vulnerability and risk assessment framework.
Adapted from Rosenzweig et al. (2011); after Mehrotra et al. (2009).

the two. The IPCC defines vulnerability to climate change as a function of the level of exposure and sensitivity of a system to climate change hazards, and also its adaptive capacity to moderate potential damages or take advantage of associated opportunities (IPCC, 2001). The UNISDR also does not treat adaptive capacity separately, noting that climate change risk depends on the degree of exposure and sensitivity to a hazard event (UNISDR, 2012). Nevertheless, the IPCC does acknowledge that adaptive capacity and vulnerability can be seen as separate notions (IPCC, 2012, p. 33). We see the value of separating adaptive capacity out, conceptually, particularly when trying to formulate targeted policies or assessing barriers to implementing adaptation responses, and hence apply the urban climate change vulnerability and risk assessment framework.

This framework clarifies that the level climate change risk is dependent on the extent of climate hazards, the vulnerability of different systems and receptors to hazards, and their adaptive capacity (as visualised in Fig. 1). These are the core elements of the adaptation agenda. Appreciating and assessing climate change risk involves understanding each of them. *Hazards* are the weather and climate events that a city experiences, for example floods and heat waves. Vulnerability is a more highly contested term and agreement has not been reached over its precise meaning (Alcamo & Olesen, 2012; EEA, 2012). This article sees the *vulnerability* of city residents, infrastructure and the built and natural environment as a state. Here vulnerability is intrinsically associated with people places or things, irrespective of whether they experience a hazard that could cause harm. It concerns the characteristics that underlie the 'elements at risk' or 'receptors' in a city. These encompass physical and socio-economic factors, which influence the exposure and sensitivity of elements at risk to climate change hazards. *Adaptive capacity* then refers to the ability of city governors, businesses and residents, and associated structures and systems to prepare for and moderate potential harm from climate change hazards and exploit any emerging opportunities. Reducing vulnerability and building adaptive capacity can help to reduce risk.

1.4. Building capacity for urban adaptation

Within this article, we are particularly concerned with adaptive capacity and different ways of building capacity to adapt to climate change. Adaptive capacity encompasses ability of actors to modify exposure to, absorb and recover from climate change impacts, and also to exploit new opportunities that may arise through adapting to the changing climate (Adger & Vincent, 2005, p. 400). Adaptive capacity is determined by: 'the characteristics of communities, countries and regions that influence their propensity or ability to adapt' (IPCC, 2001, p. 18). These characteristics have dimensions that are generic, and also those that are specific to particular climate change risks (Adger et al., 2007). A range of identified generic factors are presented in Table 1.

The list of factors influencing adaptive capacity can be broadly categorised into those of socio-economic and bio-physical nature. In terms of the latter, the adaptive capacity of the physical fabric of a city encompasses issues including the quality and location of physical infrastructure, such as transport networks and electricity generation and supply. From a socio-economic perspective, looking specifically at a city's population, differences in adaptive capacity are driven by variations in awareness of climate change hazards, relative mobility, socio-economic status, length of residence time or the extent of community support (Lindley et al., 2011). Governance arrangements can support responses to offset damage and enhance opportunities linked to climate change hazards, for example through developing, communicating and implementing proactive and responsive adaptation strategies and creating networks between stakeholder groups.

Mehrotra et al. (2009, p. 11) emphasise the role of governance stating that adaptive capacity is determined

Table 1
Generic factors determining adaptive capacity (drawing on Adger et al., 2007; Alberini, Chiabai, & Muehlenbachs, 2006; Brooks, Adger, & Kelly, 2005; Haddad, 2005; Mehrotra et al., 2009; Smit & Wandel, 2006; Vincent, 2007; Yohe & Tol, 2002).

Generic factors determining adaptive capacity
• Income levels and equality in the distribution of income
• Availability of, access to and distribution of resources
• Availability of and access to information on climate change impacts and potential adaptation responses
• Awareness and perception of climate change risks
• Technological capacity and range of technological adaptation options available
• Environmental factors, including the availability and quality of land, water, raw materials, biodiversity, etc.
• Infrastructure quality and provision
• Organisational and institutional capacity to implement adaptation responses
• Quality and transparency of decision making processes
• Society's ability to act collectively to develop and implement adaptation responses
• Human capital (including factors such as skills and education)

by, '. . .the ability and willingness of the city's key stakeholders to cope with the adverse impacts of climate change and depends on the awareness, capacity, and willingness of the change agents'; where 'change agents' include government, the private sector and civil society. Assets associated with planning and management are central to a city's adaptive capacity (Engle, 2011; Rosenzweig, Solecki, Hammer, et al., 2011). In this respect, given its influence over urban form and function, spatial planning is a key mechanism that cities can employ to build adaptation responses and we now consider this theme, which runs through the article, in more detail.

1.5. Spatial planning: adapting the development and use of land in cities

The geographies of cities vary greatly, for example, in terms of their land cover, population characteristics, and distribution of critical, social, and transport infrastructure. Extreme weather events such surface water flooding caused by incidents of heavy rainfall and climate change impacts including sea level rise and storm surges also have a spatial footprint, although the location and extent of this footprint is subject to considerable uncertainty from event to event. This spatial variance of weather and climate events and their receptors influences how areas will be affected by climate change and shapes the distribution of risks. This is the case at a macro scale, between European regions for example (Carter et al., 2012; ESPON, 2011), and at finer scales within individual cities and neighbourhoods (Kazmierczak & Cavan, 2011; Lindley et al., 2006). Correspondingly, adaptation responses often mirror the spatial nature of climate change impacts and risks. They generally concern the district (municipal) scale or below (Agrawal, 2008; Adger, 2001), flowing through to neighbourhoods and down to the level of individual buildings (Gething, 2010; Shaw, Colley, & Connell, 2007).

Spatial planning provides a key policy lever that can be applied to the task of urban adaptation (ASC, 2010; Blanco & Alberti, 2009a, 2009b; Davoudi, Crawford, & Abid Mehmood, 2010; Wilson, 2006; Wilson & Piper, 2010). Within this article, we follow the definition of spatial planning provided by Davoudi et al. (2010, p. 14), as "...the processes through which options for the development of places are envisioned, assessed, negotiated, agreed and expressed in policy, regulatory and investment terms." This encompasses strategic spatial planning where policy, strategy and guidance are progressed, and also the processes of shaping developments (known in the UK as development control) where detailed decisions over the location and design of new buildings are taken.

Richardson, Steffen, and Liverman (2011, p. 401) stress that: '. . .mainstreaming climate change adaptation considerations into current urban development has to be a central strategy for dealing with climate change.' Looking beyond spatial planning's role in regulating the development and use of land, reasons for this include the forum it provides for stakeholder engagement and that it offers a nexus for planning much of the key infrastructure supporting cities. Other factors are its inherent focus on the future and the wide scope of issues and spatial scales that it covers (Carter & Sherriff, 2011; Wilson & Piper, 2010).

Despite these potential strengths, planning's role is underplayed in national adaptation strategies of EU countries (Greiving & Fleischhauer, 2012). The UK Government's Adaptation Sub Committee add that, in the UK, spatial planning decisions do not sufficiently incorporate consideration of climate change risks (ASC, 2010). The UK's Royal Commission on Environmental Pollution (RCEP) highlight the 'fragmented and convoluted' frameworks of legislation and policy that guide the planning system's response to climate change (RCEP, 2010, p. 46). Further, the extent to which spatial planning is recognised can often appear to be at the mercy of political predilection and, consequently, the system is continually in flux. The political dimension of planning is recognised by the RCEP; "Planning is inherently political in nature, and can never be a completely quantitative or technocratic process'' (RCEP, 2002, p. 75), with Cullingworth and Nadin (2002, p. 2) adding that; ''Politics, conflicts and disputes are at the centre of land use planning''.

The planning system's connection to short term political cycles constrains its use for achieving longer term progressive goals such as adapting to climate change. A change in the UK's government in 2010, which precipitated a comprehensive shake up of planning legislation and regulations, provides an illustrative example. The National Planning Policy Framework (NPPF) ushered in a radical shift in planning powers from Westminster downwards into local communities and neighbourhoods as part of a broader Localism Act passed in 2011, and also led to the loss of regional planning frameworks. From an adaptation standpoint, these changes to governance arrangements, coupled with local authority budget cuts and the slimming down of guidance aimed at planning authorities, present a considerable challenge to building adaptive capacity and responding to climate change risks in UK urban areas. Critics to argue that, from a strategic perspective, there is no spatial framework to coordinate development and infrastructure activity taking place between national and neighbourhood scales (Ellis, 2011, 2012). For issues including adaptation to climate change, where a tiered spatial approach addressing different themes at different spatial scales is needed, this is presents a problem. In addition, from a more local perspective, the Green Alliance (2010, p. 41) note that since the deregulation of the planning system action on climate change in local planning authorities now depends on voluntary action backed by political will; ''climate change will not be tackled with the consistency and level of ambition that is needed if national targets are to be met''.

1.6. Greater Manchester: overview and context

With the overarching context and conceptual stance of this article now established, we now turn to the location where much of the discussion focuses; Greater Manchester. The Greater Manchester conurbation is situated in the north west of England (Fig. 2). The urban core, centred on the cities of Manchester and Salford, was the first area to experience mass industrialisation in the 19th century; 'shock cities' whose damp climate and efficient commercial production of cotton fostered industrialisation at a pace hitherto never seen before (Briggs, 1963; Platt, 2005). A combination of culture and physical geography resulted in environmental degradation and social segregation that would be replicated in cities across the globe; Chicago offering one apt comparison (Platt, 2005). Manchester and its environs have long offered an illustrative case for scholars in urban planning and environmental studies (e.g. Carter, 1962; Douglas, Hodgson, & Lawson, 2002; MacKillop, 2011; Platt, 2005). We follow on from these traditions focussing on the 'city-region' (Ravetz, 2000a, 2000b) and factors relating to its response to the adaptation imperative.

Topographically, Greater Manchester rises from the lowlands of the River Mersey basin in the west to the Pennine hills in the east, which reach over 500 m. This elevation change, coupled with the prevailing westerly winds, produces a distinct precipitation gradient, increasing from west to east. This rainfall, which amounts to an average of just over 800 mm per year, is a key feature of Greater Manchester's Atlantic maritime climate. Projected changes in Greater Manchester's climate are discussed in Section 2 of this article.

Greater Manchester is the principal city of the north of England in terms of population and economic strength. It has a population approaching 2.7 million living within an area covering close to 500 square miles. Its population is projected to grow by 0.5% per year, adding 132,000 people during the 10 years to 2018 (AGMA, 2008). Over recent decades, the city-region has re-invented itself as a post-industrial city with industries including finance, media, education and business services becoming more prominent. However, the prospect of global economic decline, commodity price inflation, reductions in consumer spending and a magnification of impacts linked to government spending cuts pose potential risks to Greater Manchester's economy (Oxford Economics, 2010, p. 8).

Ongoing efforts by city governors are focused on removing brakes on growth and productivity, with the Greater Manchester Strategy (GMS) providing an overarching framework for increasing prosperity across the conurbation (AGMA, 2009). The strategy establishes a shared vision and series of strategic priorities for a range of diverse partners working across different sectors and spatial scales. A private sector dominated Greater Manchester Local Enterprise Partnership was established in 2011 to oversee the implementation of the GMS, with its central position in Greater Manchester's current decision making structure reflecting the prominence of the economic agenda in the city-region.

Another key feature of Greater Manchester's current governance arrangements is that the ten local authorities making up the conurbation (their outlines are visible in Fig. 2) have a history of voluntary collaboration. This is

Fig. 2. The ten local authorities of Greater Manchester.

organised under the auspices of the Association of Greater Manchester Authorities (AGMA), which emerged in 1986. This collaborative cross-authority model was given statutory approval in April 2011 through the creation of the Greater Manchester Combined Authority (GMCA), which has a specific remit over economic development, regeneration and transport. A strategic layer of governance sits between the national level and Greater Manchester's local authorities, which can potentially support strategic cross-authority governance approaches. With the abolition of regional spatial strategies, statutory structures such as the GMCA that sit at a scale above the local authority level are rare in the UK, with the exception of institutions such as the Greater London Authority.

Meanwhile, the role of the UK's central state has realigned so that decision making is no longer the sole jurisdiction of a hierarchical nation state. A combination of deregulation, devolution and greater European integration have brought other actors to the fore, such as business elites or single issue interest groups, to deliver on public policy objectives (Bulkeley & Betsill, 2005; Hooghe & Marks, 2001; Rhodes, 1996; Rydin, 2010). This does not mean that the role of the UK state has lessened; it engages in different modes of governance to co-ordinate the various actors and to mobilise resources in a way that gives more capacity to act at the urban scale (Bulkeley, 2012; Rydin, 2010; Stoker, 1998). Concerning adaptation to climate change in the UK, the general approach has focused on an efficient allocation of resources and a strong emphasis on supporting local and regional action (Defra, 2010). Working within this context, Greater Manchester has been able to embed the adaptation agenda within key strategic policy documents (Carter & Connelly, 2012). The importance of adaptation to climate change is highlighted within the GMS, which notes that:

> A timely shift to a low carbon economy and the challenge of adapting to a rapidly changing climate both offer opportunities to the city region. Conversely, failure to cut emissions and adapt to climate change will fundamentally undermine our economic viability and success.... Adapting to a changing climate and boosting our resilience is also integral to our future success (AGMA, 2009, p. 43).

Civic leaders in the city-region clearly recognise that future economic prosperity will depend, in part, on adapting to the changing climate. Greater Manchester's climate change strategy (AGMA, 2011) is intended to support the delivery of the climate change aspirations of the GMS. The climate change strategy demonstrates an intention to produce strategic cross-authority, cross-sector adaptation governance arrangements. The challenge is now to move beyond city-region scale high level policy and guidance frameworks, such as the Greater Manchester strategic flood risk assessment (Scott Wilson, 2008), to embed adaptation responses across the activities of organisations such as local planning authorities.

1.7. Greater Manchester as a research laboratory: the EcoCities project

Until recently, discourse amongst urban planners and academics working on climate change has been focused principally on climate change mitigation, that is reducing greenhouse gas emissions, with adaptation receiving short shrift (Næss, 2010). However, as noted above, policy, practice and research is now paying increasing attention to urban adaptation with knowledge and experience growing as a result. The EcoCities project (2008–2012) established a programme of research in this field to advance knowledge of urban adaptation and to help build capacity amongst Greater Manchester stakeholders to support nascent local activity in this area. This article is based on the outcomes of this research programme. EcoCities builds on ongoing inter-disciplinary research activity into urban climates and adaptation responses at the University of Manchester that stretches back over a decade (e.g. Lindley et al., 2006; MacKillop, 2011; White, 2010). EcoCities was developed by the University of Manchester's School of Environment and Development and funded via a charitable donation from the Manchester-based property company, Bruntwood, and the Oglesby Charitable Trust.

EcoCities drew upon inter-disciplinary research on climate science, environmental planning and urban design, working within a sociotechnical framework to investigate climate change impacts, vulnerability and adaptation responses in Greater Manchester. This sociotechnical framing of the project was central to moving the research beyond narrow and distinct debates around technological innovation and behavioural change that often characterise research on climate change and cities (Guy, 2006). Instead, by engaging in the complex and interconnected field of climate change adaptation, the research team recognised that an interdisciplinary approach is an essential element of developing and using knowledge, helping to insure against "the radical inadequacy of piecemeal approaches to our joined up world" (Bhaskar, Frank, Høyer, Næss, & Parker, 2010: vii). A further dimension of this 'joining-up' was the collaborative nature of the EcoCities project, drawing together expertise at the University, with planners and policy-makers in local authorities and the Association of Greater Manchester Authorities, in addition to partners in the private sector, notably Bruntwood and Arup. As a result, EcoCities can be viewed as a form of 'co-produced' knowledge that has been shaped by a policy imperative, or as the City itself has put it, a 'call to action'.[2]

Research methods employed by the research team during the project included down-scaling climate projections, spatial analysis with GIS, land use modelling, energy balance modelling, social network analysis, participatory workshops, Delphi survey, literature review, scenario development and semi-structured interviewing. This mixed-methods approach was key to the success of the EcoCities project in foregrounding the relational nature of climate change challenges for sustainable urban development (Rydin, 2010). It is not possible within this article to cover all of the research outcomes produced; these are included in a supporting website.[3] Instead the goal is to focus on specific aspects of the research that collectively cover different dimensions of building adaptive capacity. This article also maintains a focus on the planning system as a key element of progressive long term urban adaptation responses. This is in recognition of the central role that planning can play in equipping cities to an evolving climate future, in addition to the evident need to boost the capacity of planners to grasp this opportunity.

1.8. Article structure and contents

This article presents learning from a detailed case study of climate change impacts and adaptation in Greater Manchester, undertaken within the EcoCities project. Although the underpinning research was conducted on one city-region, the core themes and concepts explored here are shared by urban areas more generally. We believe that by following the climate

[2] http://www.manchester.gov.uk/site/scripts/download_info.php?downloadID=2929.

[3] http://www.sed.manchester.ac.uk/architecture/research/ecocities/.

change adaptation process in one conurbation, we will help to contextualise the issues internationally and highlight universal transferable good practice where appropriate. Our conclusions and recommendations are relevant to cities generally rather than being geographically specific.

Each of the following five sections of this article addresses different dimensions of adapting to climate change. Raising knowledge and awareness of current and potential future weather and climate is an important element of building capacity to deliver urban adaptation responses. Drawing on research findings from the EcoCities project undertaken by Jeremy Carter, Nigel Lawson and Gina Cavan, Section 2, written by Jeremy Carter, provides an overview of the extent of recent and projected changes to Greater Manchester's weather and climate and associated consequences. This is used to inform a discussion that is principally centred on questions concerning the use of weather and climate data by urban planners engaged in strategic and practical adaptation activity. The conceptual framework outlined above (Fig. 1) highlights that in order to assess and respond to climate change risks, vulnerability to locally prevalent hazards should be considered. Section 3 discusses vulnerability in the context of two hazards identified as posing a significant threat to Greater Manchester; the prevalent impact of flooding on different forms of infrastructure and the projected impact of high temperatures on human health. Adaptation responses are discussed, focusing on those linked to spatial planning. Section 3 draws on research undertaken by Aleksandra Kazmierczak, and was written by Aleksandra Kazmierczak, Jeremy Carter and John Handley.

Section 4 looks in detail at a specific location within Greater Manchester, the Oxford Road Corridor. This is a strategically significant site, playing a crucial employment and wealth creation role for the conurbation and the north west region of England as a whole. Written by Gina Cavan and Aleksandra Kazmierczak, and drawing on research that they undertook on this area, the potential contribution of green infrastructure as an adaptation response is explored. Modelling work assesses the implications of different green cover scenarios on surface temperatures, and the discussion considers themes linked to the implementation of adaptation responses in practice. Section 5 builds on topics emerging within Section 4 on governance and stakeholder networks, linking these to adaptive capacity. The results of a social network analysis are presented, revealing a complex, and in some cases fragile, network of actors cooperating and collaborating to different degrees across multiple scales and sectors. This section draws on research undertaken by Aleksandra Kazmierczak, Jeremy Carter and Angela Connelly, and was written by Aleksandra Kazmierczak and Angela Connelly.

In Section 6, we reflect on learning generated across the EcoCities programme to outline a range of themes linked to repositioning adaptation closer to the centre of urban policy, practice and research. The introduction and conclusions sections of this article (Sections 1 and 6) were written by Jeremy Carter, with support from the article's co-authors. Simon Guy chaired the writing team, provided specialist inputs and, with John Handley, provided strategic editorial direction across the article.

2. Looking back and projecting forwards: weather and climate data and adaptive capacity

2.1. Introduction

Knowledge of prevalent climate hazards is an important dimension of assessing climate risk (Rosenzweig, Solecki, Hammer, et al., 2011; after Mehrotra et al., 2009). This section focuses on building adaptive capacity through enhancing knowledge and awareness of weather and climate hazards. We discuss data obtained for Greater Manchester within the EcoCities project on recent trends in weather and climate and future projections. This acts as a platform to consider the potential value and associated limitations of using weather and climate data for adaptation planning at a local scale in an urban setting. Here we draw on the findings of ten interviews, eight with local authority planners, one with a local authority climate change manager and one with a planner working with the Association of Greater Manchester Authorities (AGMA).

Should planning decisions be based more upon what we already know about extremes of current climate and its impacts? Or, is it now time to look past this historic information and place greater weight on climate change projections for the coming decades? This section explores both of these questions, highlighting associated benefits and limitations of related data, and concludes that each has its value in responding to the urban adaptation imperative. Whilst the emphasis is on weather and climate data gathered for Greater Manchester, there are broader implications for urban planners more generally and these are highlighted where relevant.

Table 2
Recent trends in Greater Manchester's climate (Cavan, 2012).

Variable/time period	1961–1990	1971–2000	Absolute change between the 2 time periods
Annual mean temp	8.94 °C	9.21 °C	+0.28 °C
Summer daytime temp	18.58 °C	18.90 °C	+0.32 °C
Summer night-time temp	10.82 °C	11.03 °C	+0.21 °C
Winter daytime temp	7.10 °C	7.49 °C	+0.39 °C
Winter night-time temp	1.04 °C	1.42 °C	+0.38 °C
Annual precipitation	1072 mm	1068 mm	−4 mm
Summer precipitation	257 mm	243 mm	−14 mm
Winter precipitation	276 mm	291 mm	+15 mm

2.2. Looking back: recent trends in weather and climate and their consequences

2.2.1. Recent trends in Greater Manchester's weather and climate

In Greater Manchester, general warming across all seasons, particularly during the winter months, is matched by an emerging seasonal pattern of drier summers and wetter winters (Table 2). These observations mirror changes taking place at the regional level in north west England (Jenkins, Perry, & Prior, 2008). Allied to this work, the EcoCities project investigated the occurrence and consequences of past extreme weather and climate events across Greater Manchester (Carter & Lawson, 2011; Lawson & Carter, 2009). The research approach was based around the local climate impacts profile (LCLIP) method, which was developed by the UK Climate Impacts Programme (UKCIP) to support adaptation planning within local authorities (UKCIP, 2009). Events within Greater Manchester that caused impacts on human health and well-being, damaged urban infrastructure or severely disrupted services were identified. Since local authorities and emergency service providers do not record weather related impacts systematically, media outlets (principally local newspapers) were a key data source for this study. The associated caveat is that the local media is entirely subjective. The consistency of reporting is influenced by the existence (or lack of) other newsworthy events and levels of interest in the weather at the time. This issue has been recognised by other studies focusing similar sources (Luiijf, Nieuwenhuijs, Klaver, Van Eeten, & Cruz, 2010). A total of 377 events from 1945 to 2008 were identified, providing a strong basis for analysis. Fig. 3 records the incidence of these events over this period.

Flooding, the most frequently occurring event in Greater Manchester, was considered in greater depth (Carter & Lawson, 2011). This highlighted a clear trend towards the greater incidence of pluvial over fluvial events; that is surface water flooding events rather than overtopping of rivers and streams. Pluvial flooding is predominantly caused by short duration intense rainfall occurring locally, and results from rainfall-generated overland flow and ponding prior to associated runoff entering any watercourse, drainage system or sewer. It also occurs where excess water cannot enter the drainage network as it is full to capacity. Pluvial floods are difficult to forecast, warn against and prepare for (Falconer et al., 2009; Golding, 2009).

Across Greater Manchester, whereas 56% of identified floods were fluvial between 1945 and 1960, this figure fell to 34% between 2001 and 2008. Correspondingly, 17% of flood events were pluvial between 1945 and 1960, with this figure rising to 54% for the period 2001–2008. Several factors can be proposed to help explain this marked shift. Firstly, flood risk strategies designed to manage fluvial floods are proving successful. Secondly, development activity and urban densification is leading to more hard surfaces at the expense of green cover, making pluvial flooding more likely (Douglas et al., 2010). Finally, pluvial floods are often associated with short intense rainfall events; it could be that they are increasing in frequency

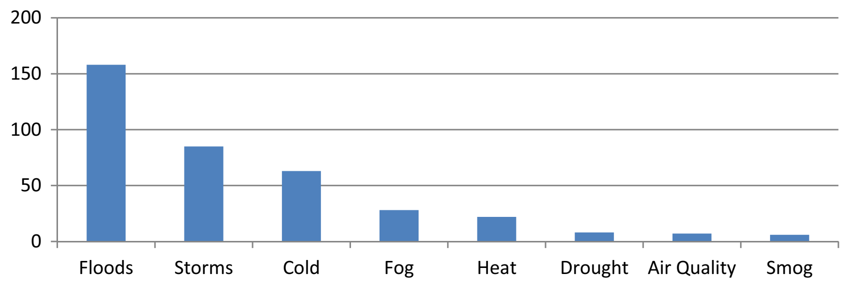

Fig. 3. Number of recorded incidence of weather and climate events across Greater Manchester (1945–2008). Based on Lawson and Carter (2009).

across Greater Manchester as a consequence of changing climate patterns. Indeed, according to the Clausius–Clapeyron relation, for every 1 °C increase in temperature, the capacity of the atmosphere to hold water increases by around 7%, with corresponding increases in volume of water deposited during heavy rainfall events (Pall, Allen, & Stone, 2007).

2.2.2. Exploring the consequences of current weather and climate extremes

Following UKCIP's LCLIP guidance (UKCIP, 2009), the EcoCities study of recent weather and climate events also looked at their headline consequences. Our interviewees often highlighted the importance of developing a better understanding of what changes in climate variables means locally, which appears important to enhance the usability of such data. One captured this sentiment, noting that: "*It's not the weather trends that people are bothered about. It is about the consequences of them.*" Another emphasised this point with reference to spatial planning: "*A planning officer won't necessarily, in looking at an application and in pre-application discussions, be thinking quite so much, if at all, about weather trends, and more about the resultant issues.*"

Impacts on critical infrastructure and health and wellbeing account for over two-thirds of recorded consequences identified by the LCLIP (Table 3). Further analysis demonstrated that between 1945 and 2008, 68% of the total recorded consequences resulted from floods and storms. This is understandable given that these are the most prevalent events hitting the city-region. For critical infrastructure, health and wellbeing and social and emergency infrastructure, floods are responsible for a greater number of consequences than any other weather and climate event. Storms emerge as the most damaging event for the natural and built environment. Extreme cold events also have prominent impacts on critical, social and emergency infrastructure. The recorded consequences of other weather and climate events feature more rarely, commensurate with their less frequent occurrence.

Pluvial flooding is highly significant for Greater Manchester, both in terms of the frequency of events and the scope of associated consequences. Over 14% of Greater Manchester's area is susceptible to pluvial flooding at the depth of over 0.1 m, and 2% is susceptible to pluvial flooding deeper than 1 m (Kazmierczak & Cavan, 2011). Adaptation to pluvial flooding would be valuable, particularly for critical infrastructure and linked networks, which support the effective functioning of the city region (Her Majesty Treasury and Infrastructure, 2010; URS Corporation Limited, 2009), and if disrupted would bring significant socio-economic implications. Acknowledging its importance locally, Section 3 of this article looks at flooding of infrastructure in greater detail.

2.2.3. On the utility of recent trends data for adaptation planning

It is increasingly apparent that climate change adaptation does not relate exclusively to action that will be taken in future decades. Recent research (Min et al., 2011; Pall et al., 2011) suggests that extreme weather and climate events occurring in Greater Manchester, such as the pluvial floods that appear to be affecting the conurbation with increasing regularity, are likely to be, in part, a reflection of the changing climate. Heywood, an area of Greater Manchester which was urbanised during the industrial revolution, is a good case in point. It did not experience floods until severe pluvial flooding occurred in 2004, and again in the summer of 2006.

Table 3
Consequences of weather and climate events on different receptors in Greater Manchester (Carter & Lawson, 2011).

Receptor type	Examples of consequences of weather/climate events on each receptor	Total number of recorded consequences (1945–2008)	% of total recorded consequences
Critical infrastructure	Impact on transport (e.g. flooding of roads, tree falls, rail and flight disruption), water supply/wastewater treatment, power cuts, telephone services	155	37.5
Health and wellbeing	Deaths, injuries and illness. Disruption to people's lives caused by flooding of properties, flooding of parks and recreation spaces, sporting events cancelled, etc.	128	31
Natural environment	Damage to trees, water pollution due to heat or contaminated storm runoff, fish kills, moorland fires, insect infestations	56	13.6
Built environment	Properties damaged by tree falls and high winds, damage to properties from flooding, lightening strikes and subsidence	54	13.1
Social and emergency infrastructure	Impacts on schools (e.g. flooding and cold weather), disruption to ambulance services, doctors' surgeries closed	20	4.8

Fig. 4. Flooding in Heywood on the 3rd August 2004.
Picture credit – Nigel Lawson.

Some 90 dwellings, many of them over 100 years old, were filled with sewage-infested water up to 90 cm in height (Douglas et al., 2010) (Fig. 4). There are other factors at stake here. Urban infill and increase in impervious surfaces, when coupled with climate change, is linked to the growth in pluvial flood events in parts of Greater Manchester (Douglas et al., 2010).

If it is accepted that the impacts of climate change are already being experienced, understanding and reducing the risk of current extremes is integral to climate change adaptation in cities. As noted by Hebbert and Jankovic (2013, p. 1345), "Cities which understand and manage their local climate have a head start in responding to global climate change." They also emphasise that the observation of extremes of weather and climate is nothing new, and trace back a long history of urban climatology, with associated planning responses in countries including Germany and Austria providing valuable lessons for contemporary urban adaptation (Hebbert & Jankovic, 2013). From a policy perspective, the Adaptation Sub-Committee (ASC), who advises the UK government on adaptation, identified two adaptation priorities, the first being to assess "...assets and institutions that are sensitive to current climate risks" (ASC, 2010, p. 2). Wilby and Dessai (2010, p. 181) describe this as a bottom-up method, noting that "Adaptation occurs by improving coping strategies or by reducing exposure to known threats." These threats will differ from place to place, and hence the value of local assessments. Further, understanding recent events provides a useful input to developing adaptation responses to future changes in weather and climate (Hallegatte, 2009), helping to reduce levels of uncertainty around the direction of future change in weather and climate, particularly over the short to medium term (Willows & Connell, 2003).

In the case of spatial planning, one of our interviewees, a planning officer, stated that regarding current weather and climate: "*You need as much robust local data as you can get your hands on to justify policies.*" Data on current weather and climate extremes, used in association with decision support tools such as the South East Climate Change Partnership's Checklist for Development (GLA, 2005) and the Town and Country Planning Association's Adaptation by Design Guide (Shaw et al., 2007), can support adaptation planning at all scales. Within Greater Manchester, particular attention has been paid to flooding. National experience of high magnitude events has focused attention locally. As noted by one planner: "*With all the news about floods across the country over the last decade, I think that has brought home to people that the risk is real...it is something that can happen so we need to take that very seriously.*" This has stimulated action at the city-region scale with the preparation of a strategic flood risk assessment (SFRA) (Scott Wilson, 2008). This SFRA provided a context for district flooding policies, which have been further informed by district-scale SFRAs, local evidence bases and associated planning guidance documents. In some areas, data on current flood risk is influencing decisions on site allocations, both in terms of the location and type of future development.

These are positive developments, as a failure to identify and respond to current events will erode capacity to meet future climate challenges. Dealing with the aftermath of present day extremes saps resources from developing longer term proactive adaptation strategies. This is particularly pertinent in an era of low GDP growth and local authority budget cuts. Cities have reduced capacity to rebound from extreme events when there is less money available to invest in a post-crisis response. Identifying and reducing known risks can guard against this situation.

Adaptation to current events is also important in the context of keeping climate change adaptation 'in the present day'. There is a danger that focusing exclusively on future climate projections will not offer the current generation enough incentive to commit time and resources to adaptation planning. Building on this point, regarding the climate data used by Greater Manchester planners to support decision making, one of our interviewees noted that "*The longer the time period, the less it is going to be looked at*". They went on to suggest that this is due to the difficulty people have in looking several decades into the future and that current funding priorities encourage a focus on present day problems, not future concerns. With a nod towards the future, one planner suggested that insights on recent trends can reinforce why policies to respond to longer term climate change should be developed.

2.2.4. The limitations of recent trends data for adaptation planning

Despite the benefits associated with identifying and then responding to data on recent trends and current extremes in weather and climate, there are issues that limit its use in a planning context. Our interviewees highlighted that these are associated with the characteristics and presentation of the data, whilst the literature points towards broader issues concerning the use of such data in an era impacted by rapid climate change.

On the data itself, our interviewees roundly agreed that for planners, the consequences of recent trends in weather and climate need to be made explicit. Ultimately, the value of the data itself is of limited use unless it can be translated into something that people can understand. Specifically, for spatial planners, it was noted that details of the implications of weather and climate extremes for different economic sectors and local authority services would be valuable. Given the scepticism around climate change in some quarters, one planner felt that taking this approach would help to build support for the agenda. Presenting the data graphically, where possible, was recommended as a route to enhancing its utility, with one planner noting that: "*People need to be able to visualise what the change means.*" Issues linked to the spatial refinement of the data were also highlighted. Several planners suggested that the value of broad scale data can be limited for some planning uses such as site allocation decisions, and that there is a need to look more closely at what extreme events mean for specific locations. Addressing these issues can help to increase the value of recent trends data for adaptation planning and capacity building.

Certain weather and climate events will not appear in the historical record for a particular location, yet they may nevertheless become more common in the future. The literature emphasises that as our climate envelope is set to shift radically, learning from and acting on historic records of extreme events sits at odds with the magnitude of future projections (Engle, 2011). As noted by Karl, Melillo, and Peterson (2009, p. 41) in reference to water resource planning in the United States, "the past century is no longer a reasonable guide to the future for water management." In this context, Milly et al. (2008) stress that the climate regime has changed to such an extent that data on past trends in precipitation in the US are no longer reflective of the current situation, let alone a future in which climate change intensifies. Further, the probability of weather extremes in the present day is enhanced by climate change, with cases including the 2000 floods in the UK and the European heatwave of 2003 (Pall et al., 2011; Stott, Stone, & Allen, 2004) suggesting that our approach to understanding extreme events must shift with the evolving climate.

Planning strategies, and associated modifications to urban form and the design of buildings and infrastructure, based solely on responding to recent trends and current threats risks committing urban areas and developments to a model unsuited to future climates. Adger et al. (2011, p. 764) agree noting that: "[adaptation] responses based on past experience can lock systems into pathways that reduce future options." An urban neighbourhood and individual developments within it will, in effect, be required to travel through various climate zones over the course of this century. To be resilient to this change, it is necessary to consider the potential implications of the changing climate in more detail and use this knowledge within planning and design. It is to this issue that the discussion now turns.

2.3. Projecting forwards: future weather and climate

Whilst insights into the incidence and consequences of recent weather and climate variability can provide a catalyst for action, the UK's Adaptation Sub Committee recommends that reviewing recent events should act as a precursor to an assessment of future climate change impacts (ASC, 2010, 2011). This is particularly relevant to spatial planning, which influences urban development locations, practices and processes that have long term implications.

Given that climate change projections can vary considerably depending on location, even in a relatively small country such as England (Murphy et al., 2009), local scale data is especially valuable for adaptation planning. However, this is not always available at the city scale (Carter et al., 2012). Projections for Greater Manchester were produced within the EcoCities project using the UK Climate Impacts Programme 'weather generator' (see Cavan, 2010 for a full description of the method). Table 4 summarises the projected changes in climate variables across three distinct zones of Greater

Table 4
Summary of changes from the baseline for key climate variables under the high and low emissions scenarios for the 2050s (Cavan, 2010).

Climate variable (changes from the baseline)	Zone[a]	Low emissions scenario Probability level			High emissions scenario Probability level		
		10th	50th	90th	10th	50th	90th
Annual mean temperature (°C)	MB	1.4	1.9	2.9	1.8	2.4	3.6
	PF	1.4	1.9	2.9	1.8	2.5	3.6
	PU	1.4	1.9	2.9	1.8	2.4	3.6
Summer mean daily maximum temperature (°C)	MB	1.1	2.5	4.3	1.4	2.9	5.6
	PF	0.9	2.4	4.1	1.4	3.0	5.5
	PU	1.1	2.5	4.2	1.5	3.0	5.7
Warmest day in summer (°C)	MB	1.3	2.6	4.6	1.5	3.1	6.0
	PF	1.1	2.6	4.3	1.6	3.4	6.0
	PU	1.2	3.0	4.7	1.6	3.4	5.9
Summer mean daily minimum temperature (°C)	MB	0.9	1.7	2.9	1.3	2.1	4.0
	PF	1.0	1.8	3.0	1.2	2.3	4.0
	PU	1.1	1.8	3.0	1.2	2.3	4.0
Warmest night in summer (°C)	MB	0.9	1.8	3.6	1.3	2.6	4.4
	PF	1.1	2.0	3.4	1.3	2.6	4.6
	PU	1.0	2.0	3.5	1.4	2.6	4.4
Winter mean daily minimum temperature (°C)	MB	0.9	1.9	3.3	1.7	2.4	3.9
	PF	1.0	1.9	3.2	1.8	2.5	3.9
	PU	0.9	1.9	3.4	1.7	2.4	3.9
Coldest night in winter (°C)	MB	0.6	1.9	3.3	1.3	2.4	3.5
	PF	1.2	2.0	3.3	1.7	2.4	3.8
	PU	0.8	2.0	3.7	1.4	2.6	3.7
Annual mean precipitation	MB	−6	0	9	−5	2	9
	PF	−5	3	12	−4	5	13
	PU	−4	3	13	−3	4	12
Summer mean precipitation (%)	MB	5	−15	−29	−5	−20	−36
	PF	15	−12	−26	0	−20	−36
	PU	13	−13	−27	−2	−21	−36
Wettest day in summer (%)	MB	−13	1	18	−15	0	19
	PF	−12	7	31	−17	2	25
	PU	−14	5	27	−20	−3	20
Winter mean precipitation (%)	MB	−3	9	23	0	14	28
	PF	−2	10	23	1	16	36
	PU	−4	9	22	3	16	33
Wettest day in winter (%)	MB	−6	7	18	1	11	31
	PF	−1	11	22	2	15	38
	PU	−1	10	25	2	14	31

[a]MB, Mersey basin; PF, Pennine Fringe; PU, Pennine Upland.

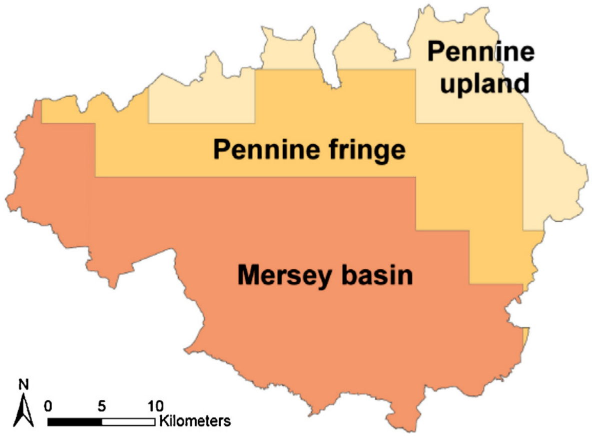

Fig. 5. Three climate zones across Greater Manchester (Cavan, 2010).

Manchester, which were identified through statistical analysis of climate and topographic characteristics (see Fig. 5), and for two different emissions scenarios. The 10, 50 and 90% probability levels included in Table 4 can be interpreted as:

- 10% probability level: unlikely to be less than.
- 50% probability level: as likely as not.
- 90% probability level: unlikely to be greater than.

The following thresholds were found to be indicative of weather-related consequences occurring which have, in the past, affected human health and well-being, caused damage to urban infrastructure or severely disrupted services in Greater Manchester (Smith & Lawson, 2012):

- Days where the maximum daily temperature is greater than or equal to 29.2 °C.
- Days where precipitation exceeds 38 mm.
- Days where snowfall amounts to greater than or equal to 6 cm.
- Maximum wind gusts greater than or equal to 60 knots.

These thresholds are, of course, only indicative. Many flood events happened when daily precipitation at Greater Manchester's Ringway meteorological station was in the region of 25–30 mm and even lower (Lawson & Carter, 2009). Nevertheless, this thresholds study can support efforts to understand how the changing climate might affect the conurbation. Looking at the threat of extreme events (90th percentile probability) for the 2050s high emissions scenario, there may be as much as

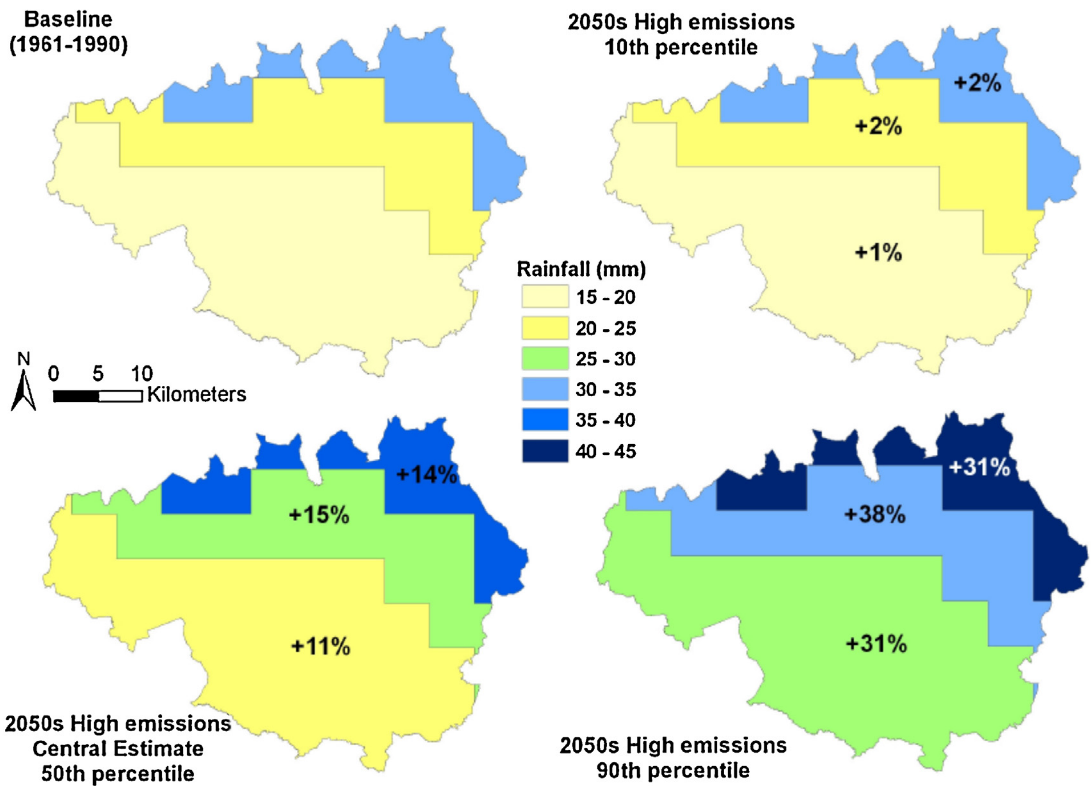

Fig. 6. Wettest day in winter across Greater Manchester for the baseline and 2050s high emissions scenario (Cavan, 2010).

31% more rainfall on the wettest day in winter in the Pennine Upland area compared to the baseline period, which equates to over 40 mm more rain (Fig. 6). This increase alone exceeds the 38 mm of rainfall per day threshold at which significant disruption has been caused in the past. This suggests that flooding events could become more common, although preventative adaptation responses such as increasing green cover and the provision of sustainable drainage systems would moderate this risk.

Research from the United States, Australia and Europe demonstrates the deadly consequences of heat stress (Poumadère et al., 2005; Robine et al., 2008). In temperate regions such as the UK, severe but infrequent temperature fluctuations are associated with increases in weather-related mortality (McGeehin & Mirabelli, 2001). The Heatwave Plan for England places threshold temperatures for heat waves in north west England at 30 °C for two days with the intervening night not falling below 15 °C (NHS, 2009). Currently, temperatures in Greater Manchester rarely reach these heights (Cavan, 2010). However, under the high emissions scenario for the 2050s, the central estimate is for a 3.1–3.4 °C increase in the warmest day in summer from the 1961 to 1990 baseline, although this figure rises to 6 °C at the 90th percentile probability level (Fig. 7). Given that the warmest day in summer is currently between 25 and 27 °C (Cavan, 2010), it appears that the heat wave threshold is set to be exceeded more frequently. The risk of heat stress for human health is considered in greater detail in Section 3 of this article.

2.3.1. On the utility of future projections for adaptation planning

In common with data on recent trends in weather and climate, future projections offer benefits to adaptation planning. They also carry certain limitations. We draw on relevant literature and themes emerging from our interviews to look more closely at these issues in the context of spatial planning.

2.3.1.1. Future climate projections: potential benefits for adaptation planning. Greater Manchester's spatial planning community is increasingly working with future climate projections data to inform decision making. According to our interviewees, key applications include the use of data to build the evidence base underpinning planning policies, to support the development of planning guidance documents, to inform site allocation decisions (such as future housing developments) and to influence

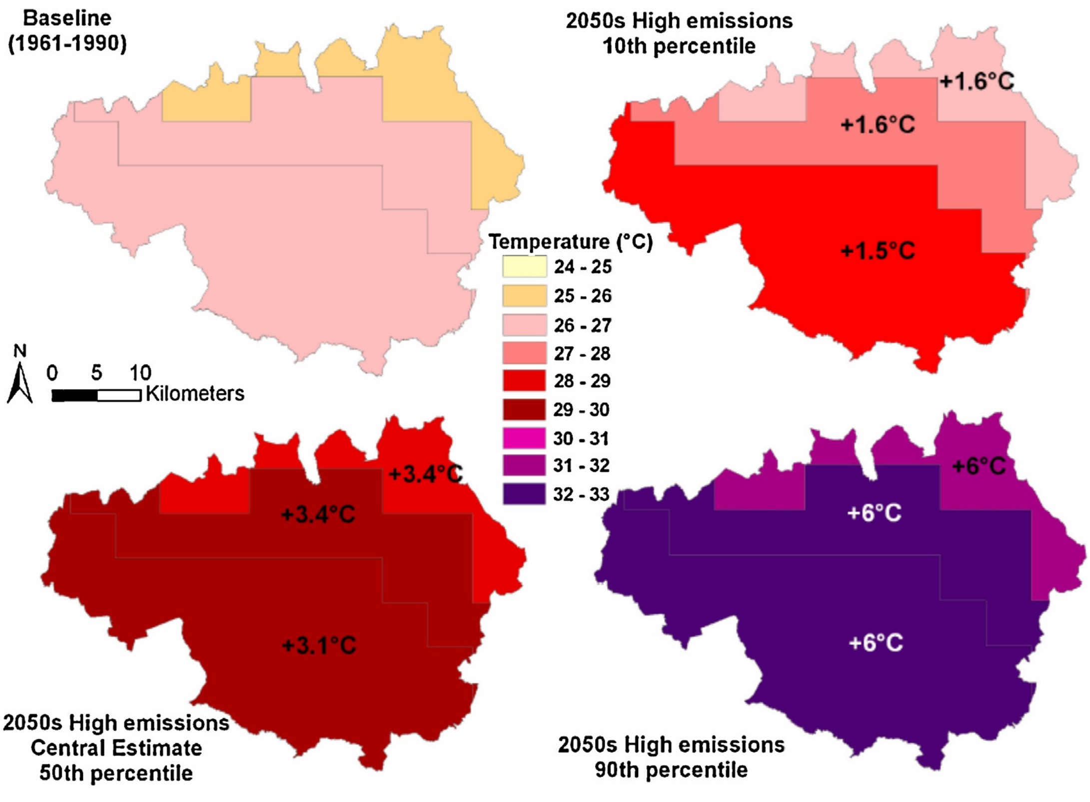

Fig. 7. Temperature of the warmest day in summer across Greater Manchester for the baseline and 2050s high emissions scenario (Cavan, 2010).

the outcome of individual planning applications (for example securing commitment for urban greening measures). Additional uses include providing a foundation for climate change strategies (which have emerged at the city region and district level) and informing the sustainability appraisal of emerging plans. Projections data is also enhancing understanding of climate change amongst decision makers and elected members, which is building support for action not only on adaptation responses but also for carbon reduction strategies. Where planners are not currently applying projections data in these various ways, they generally anticipate doing so in the future.

Our interviews established that, in most cases, planners have used available data to consider the implications of local climate change impacts on local services and agendas. However, one planner recognised that impacts beyond the city-region's boundaries will influence planning policy locally. The impact of rising sea levels on low lying high quality coastal agricultural land in other parts of England was identified by this interviewee, who stated that as a result, in their district, "*The need to protect and maximise the utilisation of higher grade agricultural land is going to become an increasing priority.*" It was suggested that increased weight will be placed in their forthcoming spatial plan on protecting this resource, which may in turn influence decisions over the allocation of housing and employment land. This broader geographical perception of climate change impacts is valuable, and although limited at present, should be encouraged to enhance climate change decision making.

Looking beyond the practical experience of planners in Greater Manchester, the literature reveals benefits associated with utilising climate projections data. These relate to acknowledging and responding to the pace and intensity of projected climate change, which will shift patterns of historic risks (Willows & Connell, 2003). Drawing on the example of water management, Milly et al. (2008, p. 573) note that addressing climate issues has been based around the principle of 'stationarity' describing this as "...the idea that natural systems fluctuate within an unchanging envelope of variability..." They go onto argue that as a result of climate change, "stationarity is dead" and "cannot be revived" Milly et al. (2008, p. 573). The basic assumption that decisions can be taken on the basis of a continuation of past climate conditions is no longer valid (National Research Council, 2009), and hence spatial planners engaged in responding to climate change in cities should pay more attention to future projections.

Via the outputs of academic research projects, planners in Greater Manchester have access to climate projections at a level of spatial refinement and comprehensiveness available to only a relatively small number of cities globally. In theory, this builds local capacity for urban adaptation. However, Wilby and Dessai (2010) contest that whilst climate change models have been successful in demonstrating the need to reduce greenhouse gas emissions, they have been less helpful in supporting adaptation decisions. Confirming this assertion, a study of the application of UK climate change scenarios found that they supported awareness raising and the need to adapt, yet were held back from greater use within policy and decision making by issues including their inherent uncertainty (Gawith, Street, Westaway, & Steynor, 2009); "...the level of confidence which could be placed in the scenario information was not sufficient to justify major adaptation decisions" (Gawith et al., 2009, p. 119). Lemos, Kirchhoff, and Ramprasad (2012, p. 789) emphasise that climate science data must shift from being "useful to usable."

2.3.1.2. Future climate projections: potential limitations for adaptation planning. Although Greater Manchester's planners are using future climate projections data to positive ends, particularly in terms of developing high level strategies and raising awareness of the adaptation imperative, there are practical limitations in the data that are constraining its wider contribution to building adaptive capacity. Lemos et al. (2012, p. 729) identify a "persistent gap" between the production of climate knowledge and its use in practice. In Greater Manchester, our interviews established that limiting factors relate, in part, to the presentation of the data. As noted by one planner, the projections data "*...is not presented in a way that planners can get the gist of it. It might have the detail in terms of the actual empirical or scientific evidence but what it doesn't have necessarily is the presentation for somebody to see what that means.*"

A key theme repeated by the interviewees was that planners (and other key groups including the public and politicians) do not understand the implications of climate change. As noted by a climate change manager, "*One of the problems is translating the data into everyday speak, into something that people can find tangible.*" Simpler messages are needed with an accompanying narrative to explain what climate change means locally. One officer noted that the core messages; "*...cannot always be relied upon to be passed through the filter of one officer or even one team.*" The data needs to be presented in a way that others can take the key messages on board more readily and progress related actions, particularly those in senior positions. Table 4 exemplifies this point. Climate change projections for Greater Manchester are strong from a scientific perspective, presenting different variables, probabilities and scenarios, yet this is not what planners appear to need to make progress.

Our interviews revealed that, in common with the data on recent trends, there is a need to offer more detail on the potential consequences of projected climate change. This was perceived as important at this juncture in Greater Manchester, with one planner noting; "*Within the core strategy is has been accepted that there are going to be these changes to the climate. So it is not the specific evidence that we now need...it is more what does that mean for development that might come forward.*" Several of our interviewees emphasised that data on the financial implications of climate change and extreme weather projections would be valuable. The simple fact, as noted by one planner, is that, "*Whenever you start talking about the impacts of climate change people always ask what are the costs of it...we live in a capitalist structure that is at the mercy of the economy.*"

In the majority of cases, the individuals we interviewed believed that more finely detailed spatial climate data would be useful, and could support judgements on issues such as what climate change means for specific development locations and the infrastructure needed to support them. Caution must nevertheless be exercised, as highly detailed projections can lead to poor decisions if the data is misinterpreted or not used correctly (Dessai, Hulme, Lempert, & Pielke, 2009). In addition, finer downscaling of does not offer any additional confidence in the resulting outputs (Wilby & Dessai, 2010). This is because the underlying emissions scenarios are based on estimations of greenhouse gas levels under different socio-economic futures, the directions of which are uncertain. Further, uncertainties magnify from the consideration of future emissions, through the various stages of assessing climate change impacts, to the effectiveness of adaptation options (Ranger et al., 2010). Dessai et al. (2009, p. 111) note that climate change projections are affected by 'fundamental, irreducible uncertainties'. They suggest that the prospect for lessening these through future scientific effort is limited, emphasising that additional research may in fact increase uncertainties as it has done in the field of climate sensitivity.

Despite the uncertainty associated with future projections, the need to adapt to climate change has been broadly accepted by decision makers at the city-region and district scale in Greater Manchester. In addition to the Greater Manchester Climate Change Strategy, a number of district-scale spatial plans include adaptation policies. Hence, uncertainty has not been a barrier to placing adaptation on the agenda and informing strategic policy making in this respect. However, it may influence the success of efforts to take adaptation from policy to practice. Regarding flooding, and the complexity of this particular issue, one planner noted that; "*We are already finding it difficult to understand what the implications are at this moment in time without even trying to factor in climate change. We have uncertainty to start off with, and then we are building uncertainty on top the uncertainty.*"

Commenting on the implications of uncertainty for developing adaptation responses, one planner noted that; "This makes it more difficult for us to determine what the appropriate policy response is ... that in turn makes it more difficult to convince other stakeholders that this is something that we need to take very seriously." It also makes it harder to be clear on costs linked to adaptation responses and therefore to enforce actions, with one planner citing the example of raising floor levels in developments which will depend on projected flood risk levels that can vary. Another raised this issue, noting that data on flood risk in Greater Manchester is constantly changing with different consultants and models producing different outcomes; "That constant change of the modelling work and the outputs that come from it does mean that people are reluctant to believe a lot of this and certainly it makes them very wary of the likely accuracy of it." This highlights the issue of 'model uncertainty' which is recognised in the literature (Christensen, Goodess, Harris, & Watkiss, 2011). Despite this, it appears that decision makers must ultimately accept and learn to work with climate uncertainty. As noted by one of our interviewees, "You accept that information, data and intelligence gets better over time...I don't really see that there is a major problem because we have what we have."

2.4. Broadening beyond climate and weather data – integrating vulnerability within adaptation planning

The key issues raised by this section, which are of relevance to cities and urban areas across the world, concern the use of weather and climate data to inform the development of adaptation responses. We have considered the data available for Greater Manchester and aimed to understand more about the utility of this data within a spatial planning context and how it can be used to build capacity to adapt. Weather and climate hazard data, relating to both recent trends and potential future scenarios, has a place in proactive adaptation planning. Despite their inherent uncertainties, future climate projections do emphasise that attention must be directed towards reducing associated risks across different sectors and spatial scales.

It is useful to remember, however, that the urban climate change vulnerability and risk assessment framework underpinning this article (Fig. 1) emphasises that reducing climate risk is about more than gaining insights into current and potential future weather and climate hazards. The vulnerability of receptors – that is their susceptibility to harm from hazards – is also a relevant consideration (Rosenzweig, Solecki, Hammer, et al., 2011). Indeed, Wilby and Dessai (2010, p. 181) suggest that "...significant progress can be made in the majority of cases without climate change projections", clarifying that this perspective is not anti-climate science but is pro-adaptation in a practical sense. The following section takes on the issue of vulnerability to climate change from the perspective of two pertinent issues for Greater Manchester that have been raised above; flooding of infrastructure and the effect of excess heat on vulnerable populations.

3. Assessing and reducing vulnerability to climate change

3.1. Introduction

The previous section advocates that for effective adaptation, decision makers should develop responses to both recent trends in weather and climate and future projections. However, accessing data on climate hazards alone is not sufficient for cities to address risks associated with climate change and weather extremes. Indeed, urban climate risk results from a combination of interconnected themes relating to climate change hazards, vulnerabilities and adaptive capacities in urban systems (Rosenzweig, Solecki, Hammer, et al., 2011); accessing data on all of these themes is essential to understand risks faced by cities and to effectively plan adaptation responses. This section builds on knowledge of Greater Manchester's past extreme weather events and future climate projections discussed in the previous section, considering this in the context of the characteristics of the city-region's urban system. Possible adaptation responses to prevalent and emerging impacts, focusing on those relating to spatial planning, are also identified and discussed. In doing so, this section provides an insight into how the planning system can contribute to the reduction of climate risks in urban areas.

Within this section we focus on moderating climate change risk through assessing and acting to reduce vulnerability to weather and climate hazards. Conceptually, we take vulnerability to encompass the physical exposure and inherent sensitivity of a receptor (for example people or infrastructure); in essence the extent to which a receptor is likely to come into contact with a hazard and, if it does, the degree to which it is susceptible to harm from it. From the perspective of spatial planners, through following this broad approach a range of options are available to reduce vulnerability and hence to lessen risk from weather extremes and climate change. These can focus on reducing exposure, for example by preparing strategic spatial plans to steer development away from exposed locations. Planners can also modify public spaces to incorporate adaptation responses, such as increasing the provision of green infrastructure (Shaw et al., 2007) which makes spaces more conducive to walking and cycling (see Section 4 for a discussion of such an approach in a city centre location), thus delivering important co-benefits.

In order to reduce sensitivity, planners can provide frameworks for developers which encourage them to incorporate adaptation responses in new developments, for example concerning the use of building materials that can reduce the sensitivity of housing developments to water damage in the event of a flood. Also, reducing the sensitivity of receptors to hazards through strategic spatial planning will often involve more indirect interventions. Examples include improving access to public transport options to increase the mobility of sensitive groups, hence facilitating movement away from locations exposed to high temperatures in heat wave events. Planning tools, such as Environmental Impact Assessment and Strategic Environmental Assessment, also have a potentially important role to play in strengthening the approach of individual projects, and the content of planning documents, in the context of reducing vulnerability through raising awareness of related themes during project design and strategic planning. These tools, in addition to other adaptation responses, can be seen as part of a suite of responses that planners can apply to the task of reducing vulnerability to support urban adaptation.

This section is based around two thematic case studies exploring the themes of assessing and reducing vulnerability to weather and climate hazards. The first focuses on a current threat; flooding of infrastructure. The previous section identifies flooding as the most frequent climate hazard currently facing Greater Manchester, and established that impacts of this hazard on critical infrastructure are a particular challenge. The second case study looks at the implications of high temperatures for people, an impact that climate change projections for the city-region indicate will become more commonplace over the coming decades. These cases offer insights into prevalent impacts and options for related adaptation responses, which can potentially guide resourcing decisions both for planners in Greater Manchester and for other urban areas responding to the adaptation imperative. The methods and concepts applied can inform research approaches in this field.

3.2. *Flooding and infrastructure*

Critical infrastructure (e.g. energy generation and supply, communications, transport, water supply and waste water collection and treatment), emergency infrastructure (e.g. hospitals, fire stations) and social infrastructure (e.g. schools, doctors surgeries), are key to the functioning of modern society. Infrastructure can be crucial in responding to extreme weather events in a manner that minimises losses of human life, health and property. Emergency services are lifelines for people exposed to extreme weather events, and in the aftermath, health centres are important sources of relief (Cutter, Boruff, & Shirley, 2003). The vital role of infrastructure is emphasised when it is damaged or when its functions are hindered. In order to perform their normal functions, or to help in responding or recovering from extreme weather events, all types of infrastructure should be resilient to climate change and extreme weather.

It is widely recognised that flooding is a major threat to infrastructure (Highways Agency, 2011; Network Rail, 2011; Royal Academy of Engineering, 2011). This has been recognised by the UK government, and the Adaptation Reporting Power conferred by the Climate Change Act (2008) ensures that 91 major organisations responsible for key aspects of national infrastructure (such as utilities or transport) now have to explain how they will adapt to projected changes in climate. The national Climate Change Risk Assessment (Defra, the Scottish Government, the Welsh Government and the Department of the Environment Northern Ireland, 2012), identified flooding as the greatest climate risk in the UK. The Institute for Civil Engineers (ICE) (2011) recognised river flooding as a major threat to water and electricity supply, sewage treatment plants and reservoirs. Intense precipitation and flooding can damage transport infrastructure through subsidence and accelerated deterioration of concrete, disrupt railway services, and structurally damage bridges. NHBC (2007) NHBC Foundation (2007) lists flood damage to buildings as second only to fires in terms of economic losses. Looking to the future, related impacts are projected to magnify; the inland flood component of insurance premiums could increase by around 21% across Great Britain, assuming a global temperature rise of 4 °C (ABI, 2009). The previous section indicates that flooding also looks to be the most significant risk for Greater Manchester.

3.2.1. *Vulnerability of infrastructure in Greater Manchester*

In Greater Manchester, floods are responsible for a greater number of impacts on infrastructure than any other weather and climate event. A study of recent extreme weather events identified that floods caused 40% of all related consequences for critical infrastructure and 70% of consequences for social and emergency infrastructure (Carter & Lawson, 2011). Kazmierczak and Kenny (2011) investigated the extent to which different types of infrastructure are potentially exposed to fluvial and pluvial flooding in Greater Manchester. This involved the use of GIS to overlay spatial data on the location of different types of infrastructure onto maps demonstrating the extent of exposure to fluvial and pluvial flooding across Greater Manchester (which are displayed in Figs. 8 and 9). The results are presented in Table 5. The study established, for example, that a considerable proportion of electricity substations are located within areas where surface water flooding may exceed 1 m depth and within the 1 in 100 year flood zone. In the event of extensive heavy rainfall in Greater Manchester, electricity and water provision could be seriously affected by flooding (having knock-on effects on other types of infrastructure, e.g. transport and social infrastructure) if flood proofing measures, such as bunds around electricity sub-stations, at the site level are absent. Further, the flooding of waste and water management installations may cause contamination of flood waters with risk to health.

Considering transport infrastructure specifically, the road network, in particular motorways, appears disproportionately exposed to surface water flooding (compared to the overall percentage of Greater Manchester's area threatened by this type of flooding). However, the remaining roads appear less exposed, potentially providing relief routes. Whilst a high number of motorway junctions appear exposed, many are likely to be raised well above ground level, leading to differential patterns of vulnerability. This demonstrates

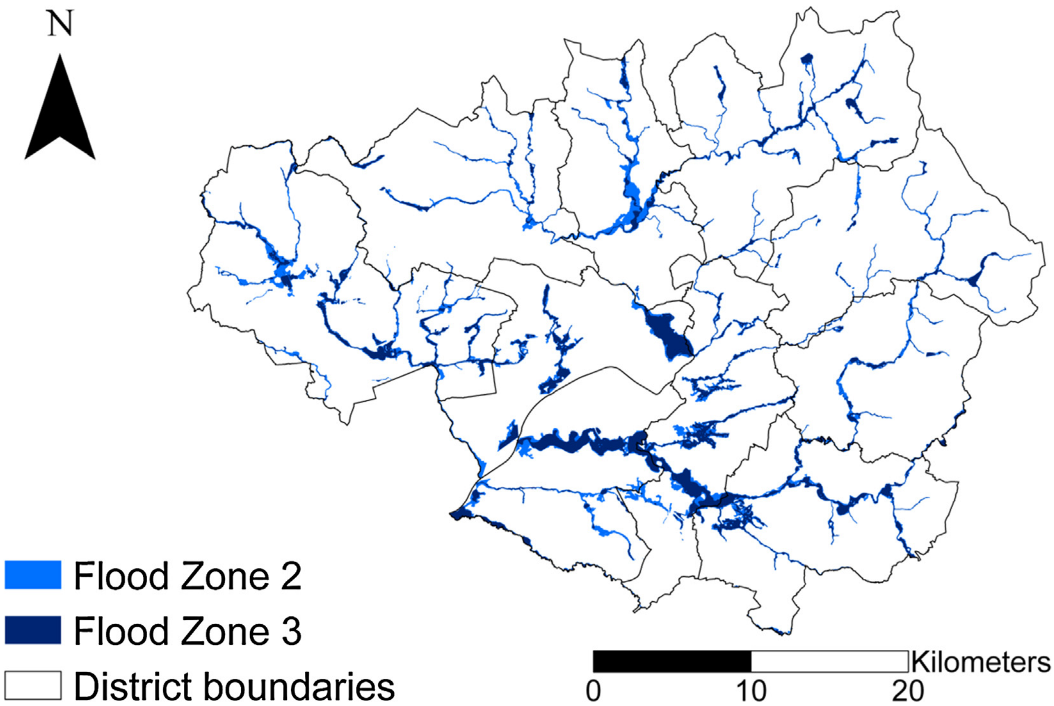

Fig. 8. Flood Zones 2 and 3 in Greater Manchester. Based on Environment Agency data. Base map is © Crown Copyright/database right (2009). An Ordnance Survey/EDINA supplied service.

the difference between potential and actual exposure, and the corresponding need to 'ground truth' vulnerability assessments of this type to establish the extent of features that can moderate exposure to hazards. In addition to the motorways, the Metrolink (light rail) network crossing the city-region appears particularly exposed to surface water flooding. In the case of transport infrastructure, the impact of flooding will not be limited to structural damage to road surfaces, rail tracks or stations. There will also be important implications for issues including the functioning of emergency services and school access. The case of the city of Carlisle in north west England, which was hit by floods in 2005 inundating the city's fire and police station and impairing the emergency response, provides a good example of this threat. Carlisle's fire and police stations have since been relocated.

Regarding emergency infrastructure, the analysis established that the accident and emergency units and hospitals in Greater Manchester display a low level of potential exposure to potential flooding, although access routes may nevertheless be affected. The proportion of police stations potentially exposed to surface water flooding roughly reflects the total proportion of areas at risk in Greater Manchester, and the number of fire stations potentially exposed sits at a higher level. As the proportion of social infrastructure exposed to flooding is relatively low, this type of infrastructure may continue to function during floods, as well as providing shelter or information points for those affected by flooding. To determine which locations can provide such services, in addition to conurbation scale screening of this type, localised neighbourhood scale analysis is also required to assess the impacts of climate change on key infrastructure networks and systems within different areas of the conurbation.

3.2.2. Adapting infrastructure to future risks

From the perspective of strategic spatial planning, a key principle for lowering future flood risk, as communicated in the National Planning Policy Framework (NPPF) (CLG, 2012), is to direct development (including infrastructure) away from areas at highest risk (i.e. Flood Zones 2 and 3). In addition, Strategic Flood Risk Assessments (SFRA) can support the development of policies locally to manage flood risk from all sources, and advises where development should be avoided and where it should be flood proofed. In Greater Manchester, the ten local authorities are situated within a common watershed, the Mersey basin. A Greater Manchester SFRA was undertaken collaboratively to provide consistent and integrated flood risk advice for strategic planning and development

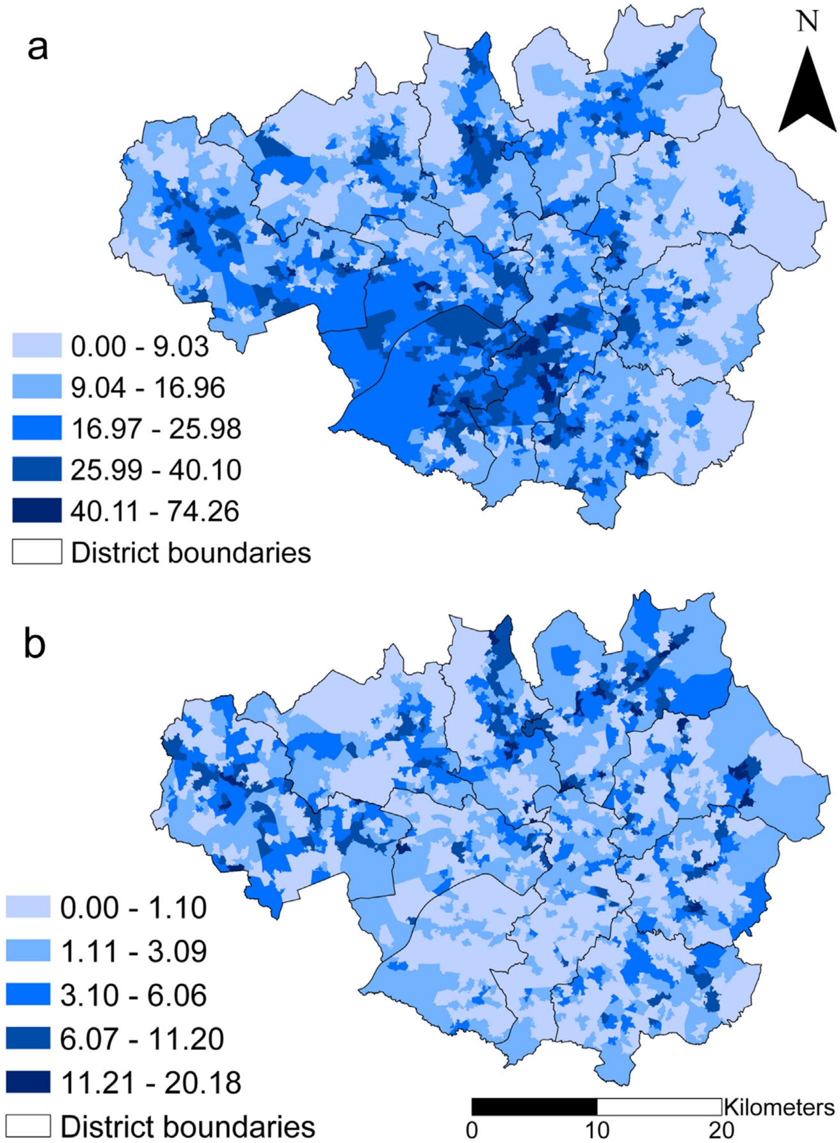

Fig. 9. Proportion of Lower Super Output Areas[1] threatened by surface water flooding: (a) surface water flooding exceeding 0.1 m depth; (b) surface water flooding exceeding 1 m depth. Classes (rounded figures) have been calculated using natural breaks. Based on Environment Agency data. Base map is © Crown Copyright/database right (2009). An Ordnance Survey/EDINA supplied service. [1]Lower Super Output Areas (LSOA) are compact areas of homogenous socio-economic characteristics constrained by the boundaries of the electoral wards used by the Office of National Statistics to report small area statistics across England and Wales. LSOAs contain on average a population of around 1500 people (circa 600 households), and a minimum population of 1000 residents (400 households) (ONS, 2008). There are 1646 LSOAs in Greater Manchester.

control across local authority boundaries that are hydrologically connected (Scott Wilson, 2008). The importance of collaborative approaches such as this, involving a range of actors actively working on adaptation issues, is discussed further in Section 5.

In addition to strategic spatial planning policies, planners working within the development control process can help to ensure that development taking place in areas at potential risk from flooding is properly flood proofed, whilst recognising that new buildings in potentially exposed locations can lower storage capacity and increase flood risk for others. The NPPF identifies this conflict and emphasizes the importance of making development that is necessary in high risk zones safe, without increasing flood risk elsewhere. The NPPF implicitly recognises that development will continue to take place in areas at risk of flooding, and that it is the responsibility of planners not to exclude

Table 5
Percentage of different types of infrastructure located in the flood risk areas.

Type of infrastructure	Surface water flooding (depth)[a]		River flooding[b]		Combined area at risk of flooding (surface water and river)
	>1 m	>0.1 m	FZ3	FZ2	
Critical infrastructure					
Telephone exchanges	2.9	17.7	2.9	4.4	22.1
Communications and masts	1.7	16.5	4.4	6.7	20.1
Hazardous substance installations	4.5	34.8	6.7	15.7	39.3
Water storage and treatment	72.6	98.6	58.9	63.0	100
Waste management and landfills	24.2	87.9	18.2	21.2	87.9
Electricity substations	16.7	83.3	16.7	41.7	83.3
Transport infrastructure					
Metrolink stations	0	18.9	5.4	8.1	17.0
Metrolink network (km)	27.4	80.6	5.5	18.0	81.1
Train stations	12.00	34.0	1.0	4.0	39.0
Rail network (km)	1.0	33.6	3.8	7.2	40.4
Motorway junctions	13.7	52.9	5.9	13.7	58.8
Motorways (km)	30.5	83.1	16.9	21.0	86.2
Total road network	4.6	43.1	6.0	8.64	45.1
Emergency infrastructure					
Fire stations	2.4	28.6	4.8	7.2	32.6
Police stations	1.7	16.7	1.7	5.0	20.0
Hospitals	1.0	5.0	2.0	3.0	8.0
Ambulance stations	0	12.5	0	6.25	15.6
A&E Units	0	0	5.0	5.0	5.0
Social infrastructure					
Community centres	0	9.9	1.4	2.8	11.3
Leisure centres	0	22.9	4.2	9.3	25.0
Educational establishments	0.9	11.5	2.4	4.3	20.5
Nurseries and early years	1.3	12.3	3.6	5.5	15.3
Children's homes	0.0	8.3	4.2	4.2	12.5
Homeless shelters	0	7.1	7.1	7.1	12.5
Residential care homes	0.2	9.4	2.2	3.8	11.7
GP surgeries	1.3	14.0	3.5	5.3	23.7

[a] Based on the geospatial map of Areas Susceptible to Surface Water Flooding 2009 (produced by JBA Consulting and licensed by the Environment Agency for emergency planning purposes). The map is based on the Digital Terrain Model (5 m × 5 m resolution) and was produced by simulating a 1 in 200 year event for a 6.5 h rainfall event. As such rainfall would overwhelm even the most modern drainage system, any impact from the drainage system can be ignored and is not accounted for in the model (GeoStore, n.d.).
[b] Flood Zone 2 (FZ2) equals medium risk (i.e. probability of a flood event in a 100–1000 years) and Flood Zone 3 (FZ3) is high risk (i.e. the probability is higher than 1:100).

this development but to reduce the extent of flood risk to new and existing developments in the catchment. Taking forward this approach in Greater Manchester, Salford City Council's (2008) *Planning Guidance: Flood Risk and Development* suggests providing a safety margin for the floor height of new development in flood risk areas, accommodating even highly unlikely events. It also requires that new development in flood zones should not result in a net loss of flood storage capacity, which presents opportunities for the creation of Sustainable Drainage Systems (SUDS), understood here as systems that encourage water storage and infiltration. Such requirements should ideally be expanded to infrastructure installations.

In addition, planners have a role in encouraging property-level flood protection measures through attaching them as planning conditions to new developments. Property-level flood protection measures can be classified into those that increase resistance and those that improve resilience (Defra, 2008). These approaches broadly connect to reducing exposure and sensitivity respectively. Resistance measures can be temporary or permanent, and are designed to keep water out of buildings by sealing potential water entry points

(Bowker, 2002); in effect reducing exposure to flooding events. Resilience measures aim to minimise damage to buildings, including the interior and furnishings, in the event that water enters the premises, thereby facilitating the quickest possible recovery (Bowker, 2002; Pitt, 2008); in effect reducing the sensitivity of receptors of flooding events. Resistance and resilience measures are suitable for both residential and commercial buildings and installations, and the Environment Agency also recommends their use for infrastructure such as electricity substations (McBain, Wilkes, & Retter, 2010). However, there is little information about available options and their effectiveness, and absence of building regulations on the provision of resistance and resilience measures is a significant barrier to their use. It is recommended that building regulations should be revised to address this gap (Pitt, 2008).

Looking beyond buildings and infrastructure installations, planners have a role to play in place shaping and modifying urban landscapes with adaptation to flooding in mind. Green infrastructure performs important adaptation functions in this respect, through reducing runoff rates and volumes (Gill et al., 2007). Spatial planning can contribute to the gradual reinstatement of green open spaces, which together with wetland and woodland enhancement throughout catchments can help to reduce surface water runoff, hence reducing fluvial and pluvial flood risk. Planning for green infrastructure as an adaptation measure is promoted by the NPPF, in particular where new development has to be brought forward in areas at risk of flooding (CLG, 2012).

One overlooked type of green space is domestic gardens. In suburban areas, where the majority of the population lives, they are the predominant green space resource (Gill et al., 2007, 2008). It is estimated that private gardens form nearly 18% Greater Manchester's area (Kazmierczak & Cavan, 2011), which through reducing surface water runoff have a significant potential role in enhancing the adaptive capacity of urban areas (Gill et al., 2007). However, this resource is declining as a result of 'garden-grabbing' by developers and paving over of gardens by individual homeowners. Pauleit et al. (2005) observed a 5% loss in vegetation in Merseyside between 1975 and 2000, mainly due to infill densification of urban areas. A similar study in Leeds reached the same conclusion (Perry and Nawaz, 2008). Although recent policies in the UK excluding gardens from the definition of previously developed land may slow this trend (CLG, 2012), private homeowners still have the freedom within planning legislation to manage their garden as they choose. While the paving over of gardens attracts little attention due to the small scale of each change, cumulatively it can have far-reaching consequences. Land use change, coupled with increasing rainfall intensity, magnifies the threat of surface water flooding and there is a need for planning solutions to protect private gardens and the adaptation functions that they provide to urban areas, particularly on sandy soils where infiltration and storage capacity is most effective (Gill et al., 2007; White, 2008).

3.3. People and high temperatures

3.3.1. The distributional impacts of heat waves

Extreme and prolonged heat causes negative health effects for people, with dehydration, hyperthermia and heat stroke being the most common causes of death (McGeehin and Mirabelli, 2001). However, high temperatures do not affect all people in the same way. Some are more susceptible to harm than others as their level of sensitivity to heat stress is higher. Factors affecting sensitivity to high temperatures and heat waves include personal characteristics and living arrangements. A range of physiological characteristics and diseases influence sensitivity to heat (Kovats et al., 2004; NHS, 2009; Semenza et al., 1999). Children and the elderly are particularly sensitive due to physiological and mobility issues (McGeehin & Mirabelli, 2001). Older people have been the most numerous victims of heat waves (Canouï-Poitrine et al., 2006; Hajat et al., 2006; NHS, 2009; Semenza et al., 1996; Wilhelmi, de Sherbinin, & Hayden, 2004). People living on their own tend to be more vulnerable (McGeehin & Mirabelli, 2001). Studies have shown that 92% of the victims of the 2003 heat wave in France lived alone (Poumadère et al., 2005), and that during the 1995 heat wave in Chicago social contact or social care significantly decreased the risk of death of the most vulnerable (Semenza et al., 1996). However, in 2003, two-thirds of the excess deaths among the elderly in France took place in retirement homes and care homes (Kovats & Ebi, 2006; Poumadère et al., 2005), highlighting that factors including the quality of care provided and built environment characteristics also play an important role.

Alongside health, age and living arrangements, low income levels appear to effect temperature-related mortality (Kovats & Ebi, 2006). Also, the fear of crime in poorer neighbourhoods may discourage people from opening windows for ventilation, particularly at night time (Lindley et al., 2011). In addition, individuals unable to speak or read the official language may be particularly vulnerable to extreme weather events (McGeehin & Mirabelli, 2001), where access to information on associated risks in other languages is lacking. Cultural differences may also hamper the acceptance of support from emergency services (Thrush et al., 2005). Consequently, alongside knowledge of climate hazards, awareness of levels, types and distribution of vulnerability is increasingly seen as a crucial factor in reducing climate risk (McEntire, 2005; Rosenzweig, Solecki, Hammer, et al., 2011).

Kazmierczak and Cavan (2011) investigated the vulnerability of communities in Greater Manchester to extreme weather events. This centred on analysing indicators related to factors that affect sensitivity to climate hazards, such as those listed above, using census data and Indices of Multiple Deprivation. Four primary aspects of sensitivity were identified: (1) poverty and poor health, (2) diverse, dense and transient communities; and high proportions of (3) children or (4) elderly in the population. Mapping these factors established that poorer and more diverse communities tend to concentrate in the urban core of Manchester, Salford and around other town centres in the conurbation, although there are pockets of material deprivation in outlying locations. High proportions of the elderly and children are associated with suburban locations (Fig. 10).

The exposure of vulnerable people to climate change hazards is affected, in part, by the characteristics of the area that they live in. In particular, urban green space is important for reducing temperatures, via direct shading and cooling through evapotranspiration, and because it stores and re-radiates less heat than built surfaces (Armson et al., 2012; Gill et al., 2007; Hall et al., 2012). The effect of green space cover on surface temperatures has been demonstrated by research based in Greater Manchester. In town centres and areas of retail or industry (20% green space cover), modelled surface temperatures reached 31.2 °C on a hot summer day. Conversely, in woodlands (98% green space cover) and medium density housing areas (50% green space cover), modelled surface temperatures were much lower, 18.4 and 24.0 °C respectively (Gill et al., 2007). These findings provide an indication of Greater Manchester's urban heat island (UHI), which was modelled within the SCORCHIO research programme

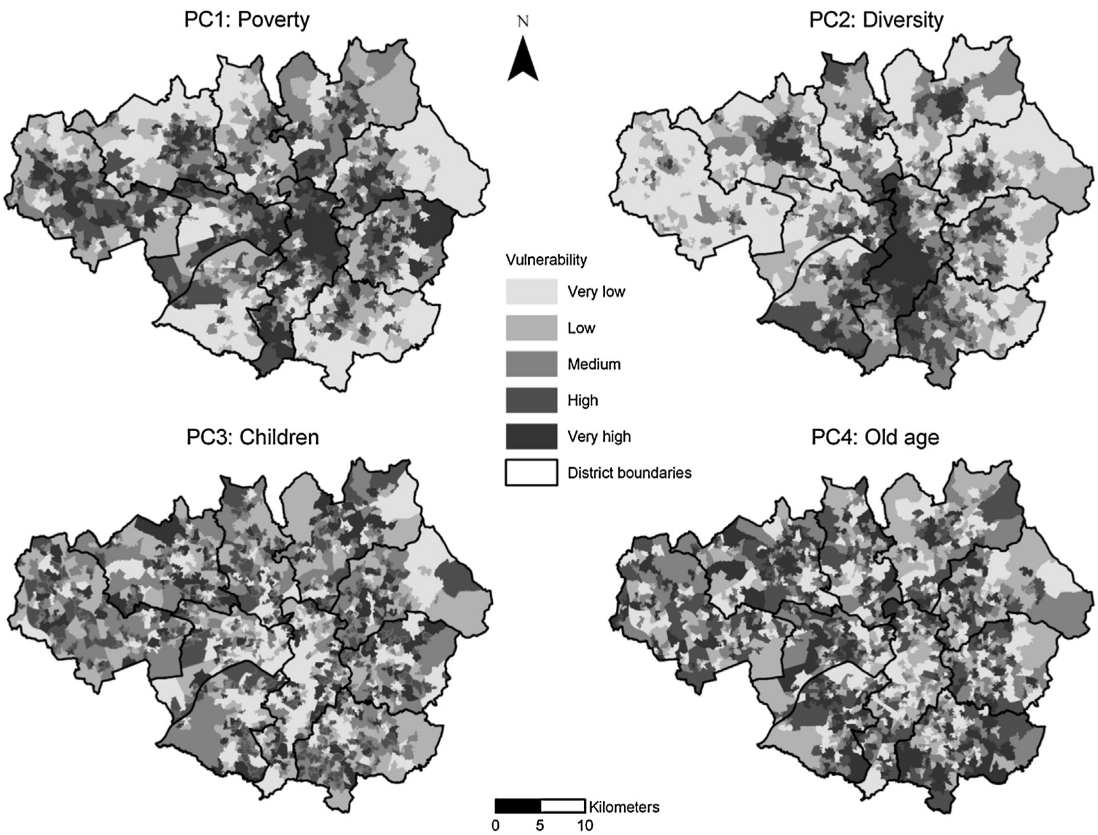

Fig. 10. Spatial distribution of different aspects of vulnerability of people and communities in GM.[1] (Kazmierczak & Cavan, 2011). [1]The analysis of vulnerability is carried out for the territorial unit of Lower Super Output Areas (LSOA).

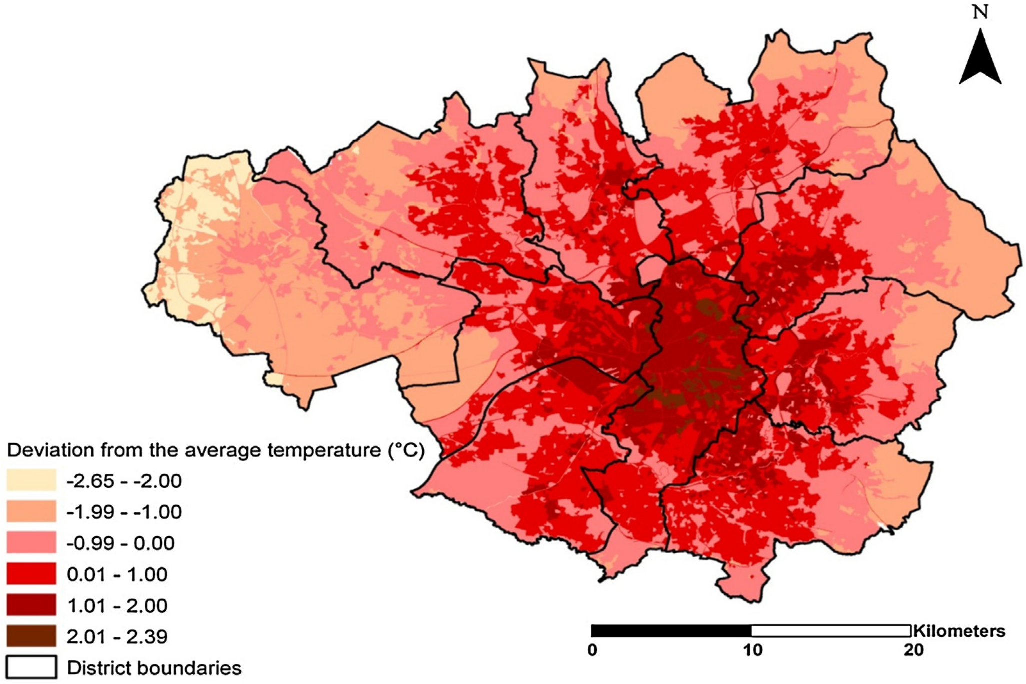

Fig. 11. The extent and intensity of the UHI in Greater Manchester: the deviation of surface temperatures from the average surface temperature in Greater Manchester (Smith et al., 2011). Base map is Crown Copyright/database right (2009). An Ordnance Survey/EDINA supplied service.

(Fig. 11) (Smith, Webb, Levermore, Lindley, & Beswick, 2011). These findings clarify that as a result of issues linked to land cover and the UHI, dense built-up urban environments will be most exposed to high temperatures during heat waves. Modelling of surface temperatures in relation to land cover to inform adaptation decisions is discussed in more detail in Section 4 of this issue.

Analysis of spatial associations between the extent of the UHI and the distribution of diverse communities and those suffering from material deprivation and poor health revealed a positive correlation, with these groups linked to areas of higher UHI intensity (Fig. 12). Further, these groups were negatively associated with the proportion of green space (and hence the cooling function that this resource provides) in their immediate

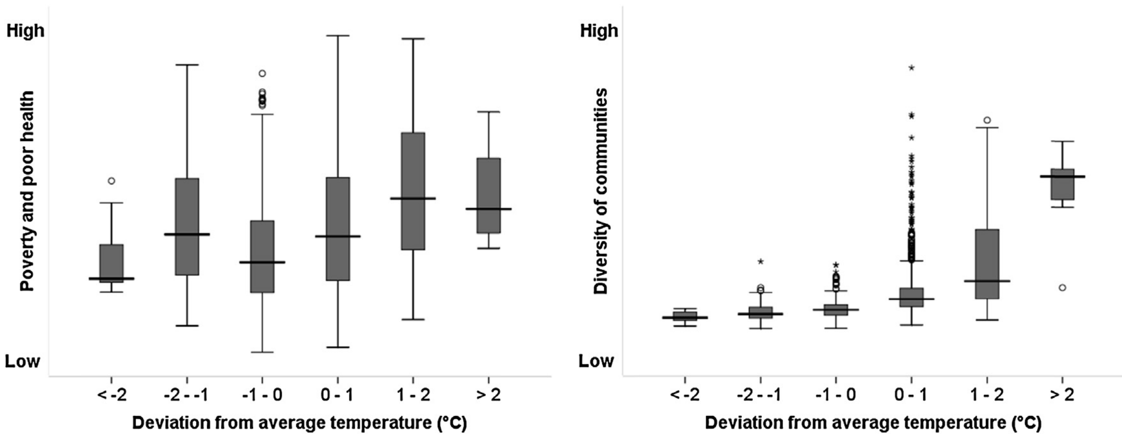

Fig. 12. The associations between the different aspects of vulnerability of communities and the intensity of urban heat island (Kazmierczak, 2012a, 2012b).

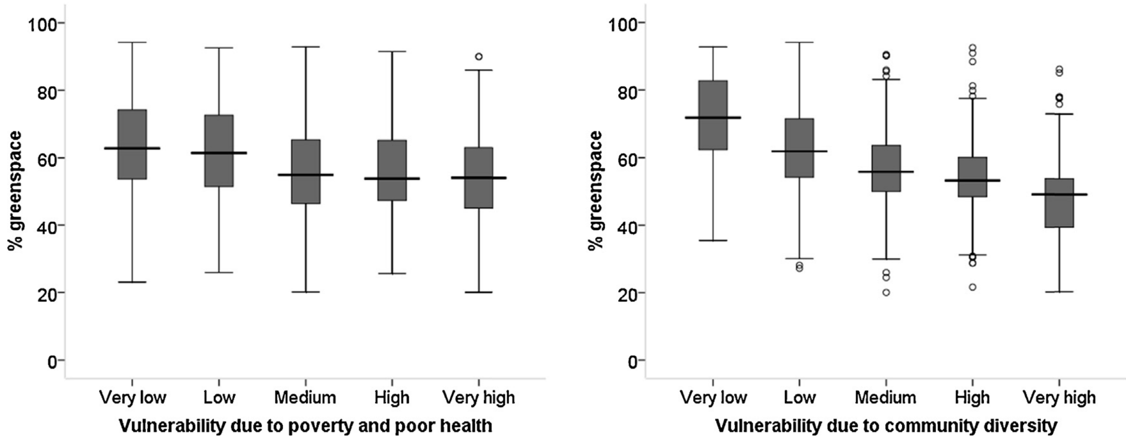

Fig. 13. Percentage of green space in Lower Super Output Areas occupied by communities of different vulnerability (Kazmierczak, 2012a, 2012b).

neighbourhood (Fig. 13). However, the analysis showed communities sensitive to heat stress due to a high proportion of elderly in the population tend to be found in locations that are less exposed to the UHI (Kazmierczak, 2012a, 2012b).

It is also valuable to understand the exposure of social infrastructure – including hospitals, GP surgeries, residential care homes, homeless shelters, nurseries and educational establishments – to high temperatures (Fig. 14). An analysis of the distribution of these facilities demonstrated that the majority are located in places where the temperature is elevated, in comparison to the average surface temperatures in the conurbation, due to the UHI effect (Kazmierczak, 2012a, 2012b). Climate change is projected to intensify the UHI (Wilby, 2007). This suggests that, in order to reduce the exposure of social infrastructure to heat stress (which serve vulnerable populations during heat wave events), adaptations to the buildings and their surrounding landscapes are required. Adaptation responses to risks associated with high temperatures, where spatial planning can play an important role, are considered below.

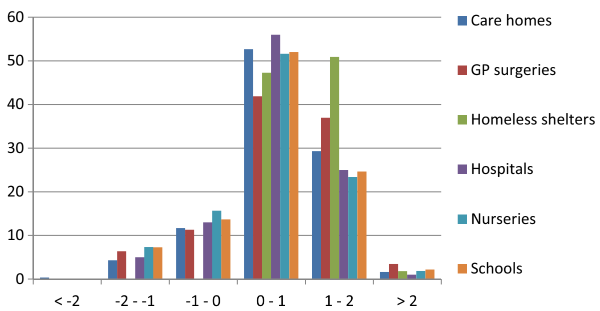

Fig. 14. Social infrastructure and UHI effect. Based on Kazmierczak (2012a, 2012b).

3.3.2. *Adapting the conurbation to heat waves*

The Heat Wave Plan for England (NHS, 2009), whilst including some anticipatory actions, focuses predominantly on the role of health and social care services in raising awareness of risks relating to severe hot weather. The development and implementation of longer term spatial planning policies and actions has, to date, received much less attention revealing a gap in planning practice in this respect. It may be that the relative lack of experience of heat stress in the UK and city-regions such as Greater Manchester has contributed to this implementation gap. Nonetheless, the Heat Wave Plan for England (NHS, 2009) observes that green spaces are important for creating cool environments and greening of urban areas, particularly via tree planting, is recommended.

Spatial analysis of factors including the location of vulnerable communities, the UHI and green space resources can support more effective and targeted planning decisions and actions to reduce the risk of heat stress in line with the recommendations of the Heat Wave Plan for England. Currently, the spatial distribution of green space across the conurbation is unequal, and many green spaces are characterised by poor or nonexistent access (Kazmierczak et al., 2010a). The Accessible Natural Green Space Standard (ANGSt), promoted by Natural England (English Nature, 2003), which recommends that no one should live further than 300 m from the nearest accessible, natural green space could be considered. Adhering to the standard could be achieved by turning brownfields into accessible green spaces to enhance provision in vulnerable areas, and spatial planning has a clear role to play here. According to National Land Use Database data, there are more than 2200 brownfield sites in Greater Manchester, occupying an area of 4200 ha, or 3.3% of the conurbation. The majority is located in urbanised areas, and thus within the UHI (Kazmierczak, 2012a, 2012b). If transformed into green spaces, these areas could provide a valuable cooling function. However, less than 15% of sites are planned as open space, much of which is outside Greater Manchester's UHI, which limits the potential for a large-scale urban greening via this route (Kazmierczak, 2012a, 2012b). Nevertheless, the potential does exist for spatial plans, supported by relevant policy and guidance, to designate brownfield land in urban areas as open space.

In addition, activating private land owners to participate in greening initiatives is recommended. Mechanisms in development control requiring that a certain proportion of land plots is vegetated, such as the Biotope Area Factor, could be applied to new developments or redevelopments. This approach was developed in Berlin (Kazmierczak & Carter, 2010) and then adopted in other cities including Malmö, Sweden (Kruuse, 2010). However, in high density neighbourhoods where exposure to heat stress is highest, space available for greening may be limited. According to Hall et al. (2012) in high density housing in Greater Manchester, planting could potentially increase tree cover by between 2.8 and 5.3%, which would have a minimal impact on maximum surface temperatures in these areas. Smaller scale green infrastructure measures such as green roofs could be recommended for high-density areas (Kazmierczak & Carter, 2010; Shaw et al., 2007). The use of green spaces as a possible adaptation option in Manchester city centre is discussed in Section 4.

Since we spend much of our time in buildings (Lader et al., 2006), building design strategies are an important dimension of urban adaptation responses. These involve modifications to the built environment to promote passive cooling, such as shading and improved insulation (Hacker et al., 2005; Hacker & Holmes, 2007). Looking at the residential sector, Porritt et al. (2010) have modelled the temperatures inside a house with the use of different anti-overheating adaptation strategies, finding external wall insulation, external window shutters and internal wall insulation to be particularly effective interventions. It is apparent that such measures can also reduce exposure to low winter temperatures, hence adding climate change mitigation benefits. Despite the existence of such solutions and research into their relative effectiveness, at present, the UK has no standards relating to reducing the risk of overheating in domestic building regulations, which should be addressed in the future to promote adaptation action (Zero Carbon Hub and the NHBC Foundation, 2010).

3.4. Reducing vulnerability to climate hazards via spatial planning

This section has explored vulnerability to two types of climate risks and related spatial planning responses in a Greater Manchester context; the prevalent risk of flooding to infrastructure and the future risk of heat stress to vulnerable populations. The research shows that in Greater Manchester, the proportion of infrastructure potentially exposed to flooding is considerable. Widespread flooding could threaten serious disruption to transport networks and flooding of different types of infrastructure may result in risks to human health and well-being. As extreme rainfall and flooding events are projected to become more frequent, significant changes in planning policy and building regulations are needed, which could support the climate-proofing of existing infrastructure and future developments. Through promoting responses such as the protection and enhancement of green spaces and encouraging sensitive building location and design, planners can help to ensure that where future urban development does occur, the exposure of sensitive receptors in the urban system to climate change hazards is not increased.

Looking towards a future where high temperatures and resulting heat stress are projected to become more common, there is a clear environmental injustice in relation to diverse and poorer communities in Greater Manchester. Here, the greater sensitivity of the inner-city and urban communities is combined with their enhanced levels of exposure to higher temperatures. There is a need for spatially targeted adaptation responses focusing on vulnerable neighbourhoods. Although climate change projections suggest that it will be some time until heat stress becomes a common feature of life in Greater Manchester, the long time scales needed to implement adaptation responses, such as those linking to the provision of green space and the modification of urban form, call for an early precautionary response particularly where vulnerable communities are involved. Further, as demonstrated by the 2003 European heat wave event, the risk of which was increased by climate change (Stott et al., 2004), isolated extreme events such as this present a major challenge at this stage of limited preparedness for related consequences. A precautionary approach would dictate a departure from current policy and governance responses to extreme weather events. In the case of flooding, these have essentially been reactive (White, 2010), rather than having the foresight that the analysis of future climate change projections within Section 2 suggests is needed. There is also a particular need to develop adaptation responses to climate events that are difficult to forecast, such as pluvial flooding and heat waves.

This section of the article has highlighted the complex interplay between built, natural and human systems that results in vulnerability to extreme weather and climate change. The adaptation implications need to be tackled holistically rather than through a sector-based approach. Interdependencies between different types of infrastructure, or different locations in terms of hydrological links, stress the importance of actors working together across sectors and scales to respond to current and potential future weather and climate risks. Also, some solutions mentioned in this section require the intervention of national rather than local scale authorities (e.g. changes to building regulations), which highlights the value of multi-level collaboration on climate change adaptation. These issues are explored in more detail in Section 5 of this article which explores issues concerning the adaptation functions of green spaces in Manchester city centre, looking at the Oxford Road Corridor area. It also examines factors influencing the implementation of related adaptation measures in this strategic location, which is central to the future growth and development of Greater Manchester.

4. Urban greening for climate change adaptation: challenges and opportunities for building adaptive capacity

4.1. Introduction

Climate change impacts associated with increases in temperature are exacerbated in urban areas by the Urban Heat Island (UHI) effect, which can result in temperature differences of up to 7 °C between large cities and their surrounding rural areas (Wilby, 2003). The UHI effect exacerbates the risks to urban populations associated with high temperatures (Wilson et al., 2008) and impacts on infrastructure (URS Corporation Limited, 2009). Providing cooling in the urban environment is a high priority for urban planners and designers (Smith & Levermore, 2008). Design tools for adapting cities to heat stress include those linked to vegetation, water, built form and material (Kleerekoper et al., 2012). Of these adaptation responses, we focus specifically on using vegetation to cool the urban environment.

Urban green space is important for reducing temperatures, via its functions such as cooling through evapotranspiration, storing and reradiating less heat than built surfaces, and through direct shading (Gill, 2006). Therefore, increasing green space, especially in densely built-up areas is considered to be a valuable adaptation response. Urban greening also contributes to creating attractive urban centres, essential for economic growth. Good quality places with attractive parks and natural surroundings tend to attract investment and skilled workers, improve an areas' competitiveness as a business location and can enhance property values (CABE, 2004a; Crompton, 2007; Dunse et al., 2007; Wolf, 2003).

Urban planners have a key role to play in creating and maintaining attractive and liveable cities, particularly given the challenges of a changing climate. Kleerekoper et al. (2012) note that to encourage policymakers to work with design principles for reducing the UHI effect and threat of heat stress, quantitative information is required on the extent of heat accumulation, acceptable levels of heat, and measures to address heat accumulation. This knowledge builds capacity to take appropriate action to address this issue. Whilst recent peer-reviewed literature has addressed such questions (e.g. Armson et al., 2012; Gill et al., 2007), it can be difficult to transfer the knowledge into an easily accessible format for stakeholders to utilise. Challenges relate to understanding vulnerability locally, and individuals need to be supported in appreciating the relevance of research for communities and industries, in order to be able to assess local capacity to adapt (Roberts, 2012). Further, frameworks for successful adaptation action need to be comprehensive, prioritised, and time based, recognising the life-cycle of planning, building and infrastructure (Roberts, 2012).

There are additional barriers affecting local capacity to adapt cities due to the high density of urban centres and restricted opportunities for new development. Planners, therefore, may have a limited scope to deliver adaptation actions in city centres, and need to work together with building and land owners to deliver local action. A collaborative approach to adaptation is thus also required at the local scale. City centres in the UK have been the focus of collaborative management approaches for over two decades. The Town Centre Management (TCM) approach emerged in the 1990s as a response to external factors and the need to revitalise city centres. Warnaby, Alexander, and Medway (1998, pp. 17–18) described TCM as, "the search for competitive advantage through the maintenance and/or strategic development of both public and private areas and interests within town centres, initiated and undertaken by stakeholders drawn from a combination of the public, private and voluntary sectors''. This resonates well with the role of urban greening in improving the attractiveness of city centres whilst also bringing adaptation benefits.

This section discusses a case study of a partnership of stakeholders and landowners established to progress a key economic development area in Manchester. Modelling of the influence of future changes in climate and land cover on local surface temperatures is presented. It then discusses the partnership's perceptions of these changes, and the barriers and opportunities regarding implementing design strategies focussed on increasing vegetation. The case study area is the Oxford Road Corridor (''The Corridor''), which extends south from Manchester city centre and covers approximately 2.7 km^2. The Corridor is a strategically important economic development area, containing 12% of the city's workforce and generating £2.8 billion annually (Corridor Manchester, no date). The area supports a wide range of cultural attractions and over 40% of the activity of The Corridor is knowledge intensive. The Corridor's envisaged growth is to be propelled by educational and health institutions, who have committed to a £1 billion investment programme. The core principles of The Corridor Partnership (Table 6), are identified in a Strategic Development Framework. This focuses on maximising the opportunities arising from current and planned development and predicted economic growth along The Corridor, and supporting growth through improvements in infrastructure. Emphasis is also placed on improving environmental quality, and creating a sustainable greener public realm to encourage walking, cycling and use of public transport, and to strengthen demand for retail and leisure (Manchester City South Partnership, 2009).

Table 6
Organisations forming the Corridor Partnership Board (in July 2010).

Sector	Organisation
Public	Manchester City Council North West Development Agency Central Manchester University Hospitals NHS Foundation Trust
Quasi-public and third sector	University of Manchester Manchester Metropolitan University Cornerhouse (centre for contemporary visual arts and film)
Private sector	Manchester Science Park ARUP Bruntwood
Other	Chief Executive of the Corridor

4.2. Methodology

The research underpinning this section consisted of two parts. Firstly, a scenario-driven approach was used to investigate the impact of climate change and different land surface cover scenarios on localised surface temperatures – considered as an effective indicator for modelling energy exchange in the urban environment (Whitford et al., 2001; Gill et al., 2007). This required the following stages to be completed:

(a) Assessment of the current land surface cover characteristics of The Corridor: Aerial photograph interpretation and Ordnance Survey MasterMap data was used to map and categorise land surface cover types.
(b) Identification of possible future land cover scenarios: Interpretation of aerial photography enabled identification of surfaces that could potentially be greened in the future. These included flat roofs; car parks, courtyards and other large sealed surfaces; and roads where street trees could be planted. Three future development scenarios associated with different amounts of green cover in The Corridor were created. These included: business as usual (maintaining current proportions of greenspace); high development (greenspace significantly reduced); and deep green (greenspace significantly increased).
(c) Analysis of climate change projections for The Corridor: Information was synthesised from the latest climate change projections, using the Weather Generator (Jones et al., 2009).
(d) Modelling current and future surface temperatures in The Corridor: An energy exchange model (Gill, 2006; Tso, Chan, & Hashim, 1990, 1991) was run under the three development scenarios. The impact of climate change on surface temperatures was incorporated through input of the latest climate change projections information. The model was run for 1961–1990 and 2050s high emissions scenarios (IPCC A1FI scenario) (for further information, see Kazmierczak et al., 2010b).

Secondly, a series of structured interviews were carried out with the Corridor Partnership Board (Table 6), during September–October 2010. The aims were to transfer the knowledge gained through the scenario

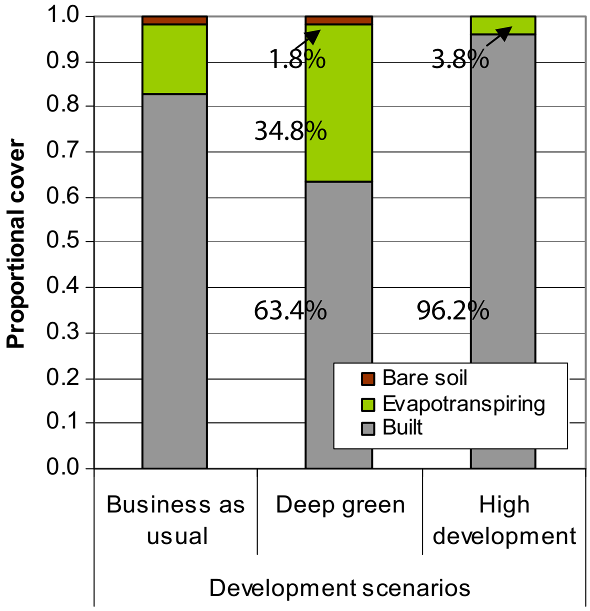

Fig. 15. Land surface cover under the three future scenarios of The Corridor.

modelling exercise, ascertain the stakeholder perceptions of the research results, discuss localised vulnerabilities, and consider barriers and opportunities associated with implementing the deep green scenario in practice. The interviews followed a presentation of the research results to the Partnership Board on the 27th July 2010. We present these barriers and opportunities in the framework of a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis. SWOT analysis is an important decision support tool, commonly used to systematically analyse strategic situations (Gao & Peng, 2011). In total, thirteen members of the Corridor Board were interviewed. The questionnaires were audio-recorded, transcribed and coded using NVivo software.

4.3. Current and future land surface cover in The Corridor

Analysis of the current land surface cover in The Corridor revealed that 83% of the area is built up. Evapotranspiring surfaces form 15% of the area, of which approximately 7.5% are trees and 6.8% grass. Green space is currently not a prominent feature of the area, with most of the vegetation contained within two parks, small areas of grass and a few street trees. Aerial photograph analysis revealed that there are 161 flat roofs within The Corridor (8.2% of the area), and large sealed surfaces (excluding roads) and carparks (7.9% of the area) that could be greened. Formal green space which could not be developed without significant amendments to the open space regulations in Manchester, covered around 3% of the area. This information enabled the creation of three hypothetical development scenarios:

- *Business as usual* –assumes that the future ratio of green space to buildings and roads remains the same as the current situation;
- *Deep green scenario* – assumes that all flat roofs are greened by 100%, large sealed surfaces and carparks are greened by 50%, and trees are planted along roads and streets (resulting in greening of these surfaces by 30%); and,
- *High development scenario* – assumes that all green space and bare soil, with the exception of formal parks and open water, are replaced by buildings or other impervious surfaces.

The resulting land surface cover characteristics associated with each scenario are shown in Fig. 15. Whilst green and blue space cover increases by 130% under the deep green scenario, the high development

Fig. 16. Simulated development scenarios from aerial photograph interpretation. Base map is © Crown Copyright/database right (2010). An Ordnance Survey/EDINA supplied service.

indicates coverage four times less than the current provision. Fig. 16 provides a visual simulation of these different scenarios.

4.4. Modelling future surface temperatures in The Corridor under different development scenarios

Climate projections for the 2050s (2040–2069) high emissions scenario generated for The Corridor area suggest that there will be a significant increase in temperatures across all seasons. The mean summer temperature is likely to increase from the baseline of 1961 to 1990 by 1.6–4.7 °C. Warming is greatest during the daytime in summer, reflected by the projected increase in the summer mean daily maximum temperature, which is unlikely to increase by less than 1.7 °C and more than 5.4 °C.

Results from the energy exchange model indicate that the business as usual and high development scenarios result in increased surface temperatures in The Corridor compared to the 1961–1990 period (Fig. 17). The business as usual scenario illustrates that climate change alone will increase the baseline surface temperature experienced approximately two days per summer by between 1.1 and 3.7 °C. The high development scenario projects surface temperatures to increase by around 5.6–9.2 °C. In contrast, provision of additional green space under the deep green scenario reduces surface temperatures by between 3 and 4.9 °C under the high emissions scenario. Thus, even with increasing air temperatures resulting from climate change, provision of a considerable amount of green space decreases surface temperatures in relation to the baseline climate conditions.

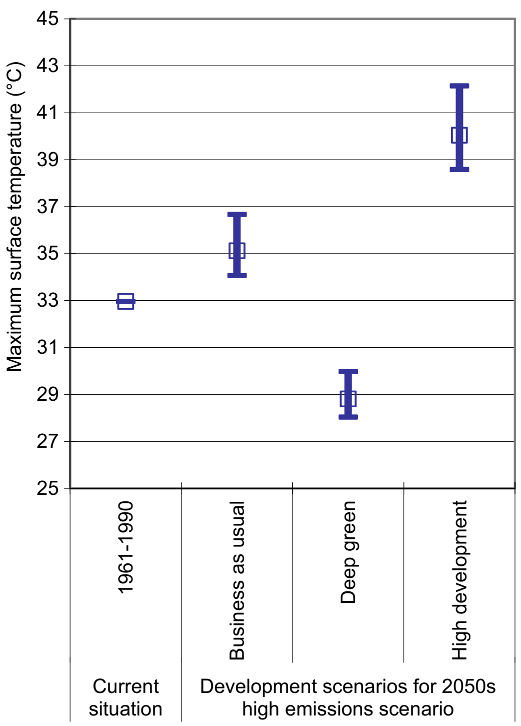

Fig. 17. Impact of development scenarios on maximum surface temperatures for the 98th percentile summer day for the 2050s high emissions scenario.

4.5. Knowledge transfer and investigating barriers and opportunities for realising the scenarios in practice

We now outline the responses from interviews with the Corridor Partnership Board members.

4.5.1. Perceptions of climate change projections and modelling results

The EcoCities research on The Corridor area presented to the Corridor Partnership Board enabled consideration of localised vulnerability and personal relevancy – essential components for committing organisations to local adaptation action (Roberts, 2012). Responses from interviews revealed that presentation of the research results increased the participants' awareness of climate change and the issues and problems associated with it, for example:

> Interviewee 12: ‘‘I knew that it was going to get warmer, but I hadn't quite appreciated the research indicating how much warmer.''

> Interviewee 5: ‘‘I think it was a seminal moment at the presentation. Actually, I think it was a bit of a trigger point to start thinking about climate change, design of buildings, greening, and [how to] join that together.''

The majority of the respondents considered increased temperatures significant, mainly due to the density of development and the number of workers in The Corridor. However, one interviewee described the impact as ‘‘not dramatic, but noticeable'', and another observed that higher temperatures could be manageable, as in many hot countries ‘‘people can work under these conditions, and can adapt to these conditions if they don't start with the mind-set of the average European''.

The research results also prompted observations that increasing temperatures may result in conflicts between climate change adaptation and mitigation strategies (aiming to reduce greenhouse gas emissions),

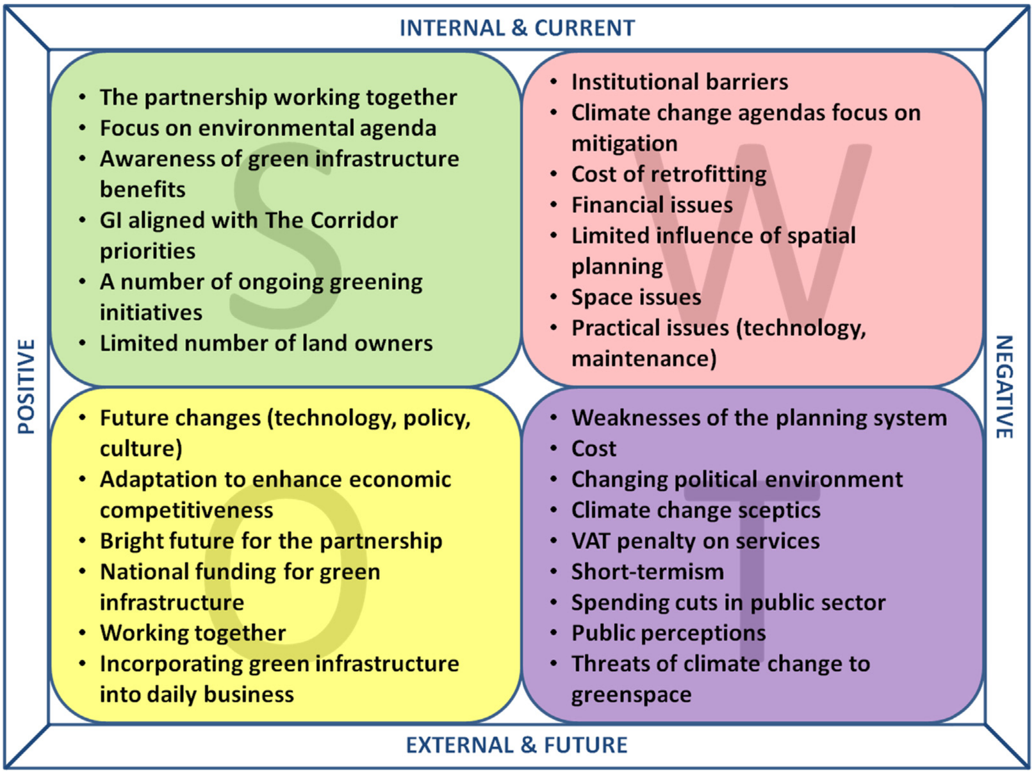

Fig. 18. SWOT analysis for achieving the deep green scenario.

which may also impact on the way that we use our cities:

> Interviewee 10: "The temperature changes would cause a significant change in the working environment, so we all fit air conditioning or something similar which is going to add to energy consumption, so we are in a vicious circle then."

> Interviewee 3: "30 degrees – it's like Phoenix, Arizona. They cope, but they cope by having expensive air conditioning and people don't go out much during the day"

This suggests that effective adaptation requires looking beyond technological solutions, and finding measures which do not exacerbate climate change in the long term.

4.5.2. Challenges and opportunities for achieving the deep green scenario

The Corridor Partnership Board members were asked to consider issues relating to the opportunities and barriers to implementing the deep green scenario (e.g. additional urban greening through planting trees) both in The Corridor and within their organisations. We focus here on the deep green scenario because the research results helped the Board members to visualise the extent of greening that would be required on the ground to achieve this scenario for The Corridor area. Fig. 18 summarises the key strengths, weaknesses, opportunities and threats related to achieving the deep green scenario. Strengths and weaknesses focus on the current situation within The Corridor itself, whilst the opportunities and threats relate to external influences and future possibilities. Whilst these results relate to specific issues and actions in The Corridor area, many issues highlighted are generic and transferable to other contexts where stakeholders are working to implement a strong adaptation response.

4.5.2.1. Strengths. Strengths are current factors that support the delivery of the deep green scenario and internal to the Corridor Partnership Board. They are factors that the Board members have direct control over. Here, a key strength is that the Partnership organisations are working well together, evidenced by members of the Corridor Board recognising that a common approach to adaptation strategies is the necessary way forward:

> Interviewee 2: ‘‘One of reasons the partnership was created was to recognise that there needed to be a shared vision around The Corridor from each of the parties, that we are all going achieve a lot more by working together than apart’’.

The interviews revealed that the organisations all have climate change strategies that solely focus on mitigation. This illustrates that adaptation to climate change is far less advanced in policy and practice than mitigation (Næss, 2010). However, the organisations are currently responding to the Manchester City Council climate change action plan (Manchester City Council, 2009) and a major strength is that they increasingly recognise the need for adaptation.

> Interviewee 4: ‘‘(. . .) when you presented this, the penny dropped that whilst at the same time as trying to reduce our carbon we do need to now start to think about how we make our buildings, and how we address the issue in the buildings and around the buildings as well’’.

The small number of landowners in the area was considered a strength that could enable a partnership approach to implementing adaptation responses, working towards a coherent strategy. Peer pressure within the partnership was also seen as an important driving factor with the potential to motivate effective collective action on adaptation:

> Interviewee 13: ‘‘If you want to be part of the clan then you have to be seen doing it this way’’.

The Partnership's Strategic Development Framework (Manchester City South Partnership, 2009) and commitment to greening The Corridor is illustrated by various projects and initiatives, including greening the university campuses and a new green roof on the art gallery. Board members particularly recognise the benefits of green infrastructure for quality of place and strengthening the economy, such as promoting a competitive advantage over other locations, with one Board member stating that:

> Interviewee 13: ‘‘One of the distinguishing features of this part of the city might be that from being a fairly arid urban environment it becomes very green and certainly it is being promoted for that as one of the core values of what we are trying to do. I think that could be quite a selling point in the distinguishing factor in the future’’.

Finally, the physical environment in The Corridor was considered helpful, as whilst green space is currently limited, there are some brownfield sites that could be greened to support adaptation goals:

> Interviewee 7: ‘‘there are also some bleak areas that could be developed and the city council needs, from the planning perspective, to earmark those bleak areas for green spaces’’.

These strengths highlight the importance of different stakeholders working together on cross-sectoral issues, such as managing the city centre. The ability to act collectively to develop and implement adaptation responses is a key factor in building adaptive capacity. Partnerships of local authorities and other stakeholders have previously been identified as important drivers for adaptive actions in cities around the world (Bulkeley et al., 2009; Clean Air Partnership, 2007; Tanner et al., 2009; Wilson, 2006). Section 5 discusses the collaborative approaches to adaptation in more detail and on a wider scale. The importance of the commitment and leadership of local authorities' such as through the provision of appropriate strategies, has been recognised in other research investigating the factors enabling adaptation in cities (CAG Consultants, 2009; Clean Air Partnership, 2007). Board members emphasised the multifunctional benefits of green infrastructure in cities, suggesting that related adaptation responses can be implemented in association with other solutions, instead of being the main driver for urban greening initiatives. This has occurred in other cities around the world, where adaptation goals were achieved as a result of initiatives targeting quality of place, biodiversity or energy saving (Kazmierczak & Carter, 2010).

4.5.2.2. Weaknesses. Weaknesses are current issues that act as limiting factors to the achievement of the objective to deliver the deep green scenario. These factors are internal and the Board has control over these issues to some extent. In the current economic climate, providing upfront investment for green infrastructure was considered difficult. In addition, uncertainty about the economic benefits of green infrastructure, and the perception that green infrastructure is not a necessity in comparison to other spending needs, were seen as obstacles to justifying investments. The long payback time of related adaptation responses, in particular green roofs, was considered to be another financial obstacle:

> Interviewee 9: ‘‘It is about upfront capital investment and in difficult times it is very hard to justify that.’’

> Interviewee 8: ‘‘I don't think that they [green spaces] are... absolutely business critical. I don't think

people are going to die or businesses are going to fail if you are not going to do them."

The Board members established that there are limited opportunities for working collectively on common investment approaches to deliver greening solutions, due to the individual character of organisational finance and governance structures and associated time-frames in the partnership institutions. In addition, the Board members recognised that the planning system has a limited influence over the provision of green space in The Corridor, due to large areas being already developed or in private ownership (relating to the earlier discussion of brownfield sites).

Further, the Corridor Partnership does not possess planning powers which could be used to enforce implementation of the green scenario. Thus, planning policies developed and implemented by Manchester City Council are crucial. Finally, other weaknesses identified by the Board as limiting the implementation of green space adaptation options included maintenance issues e.g. the negative impact of trees on utilities, technical difficulties hindering widespread construction of green roofs, and grass being impractical due to the need for frequent mowing and sensitivity to heavy use, drought and prolonged rainfall.

These recognised weaknesses emphasise the importance of building a business case for green infrastructure. This has been partly achieved by initiatives such as the Natural Economy North West project, which collated evidence on the value of green infrastructure (Ecotec, 2008) and mechanisms for calculating the economic value of green spaces (Kingston, Cahill, Handley, Tzoulas, & James, 2008). Examples of the measured economic benefits for retail, property prices and attracting and retaining businesses (CABE, 2004a; Crompton, 2007; Dunse et al., 2007; Wolf, 2003) also provide a strong argument for green infrastructure to be firmly embedded in city planning and management. Nevertheless, more case studies are needed on the value of green space. This can be achieved through the 'living laboratory' model of research, already employed in The Corridor in relation to the role of trees and green roofs in moderating the urban environment (Evans & Andrew Karvonen, 2011; MacKillop, 2011).

The limited power of the Partnership to influence land use and land cover suggest the need for a more formal strategic approach to planning and management in The Corridor. This would also allow the partners to work in a concerted way and overcome problems associated with different investment and governance timeframes. Following established models could empower the Partnership. In addition, with the spread of Business Improvement Districts (BIDs) in England, partnerships of local authorities with businesses may become more widespread in the future (Carmona & de Magalhaes, 2006). Learning from good practice in established partnership models could progress greening and adaptation agendas.

4.5.2.3. Opportunities. Opportunities can be interpreted as positive factors external to the Corridor Board, which, if exploited, could help with the delivery of adaptation responses to achieve the deep green scenario. Here, the main opportunity concerns the strong involvement of city planners on the Board in the future. For example, in the future Section 106 Planning Agreements could help reinforce greening, involving local authorities negotiating with developers to improve the public realm (Carmona & de Magalhaes, 2006).

In addition, the existence of planners on the Partnership Board could progress the development of city policies needed to enforce the green scenario. The role of large public institutions as exemplars for implementing good practice was emphasised by our interviewees, again stressing the clear need for leadership from local authorities, but also giving more responsibility to other landowners in the area to implement adaptation actions. Further, emerging national initiatives such as the Green Investment Bank which provides funds for environmental and sustainability initiatives could offer support to urban greening initiatives.

The Board members recognised that changes in cultural and work patterns may provide opportunities for greening The Corridor. Whilst the current high level of car dependence perpetuates the need for car parks and wide roads, transport improvement schemes encouraging greater use of public transport and technological changes and improved ICT infrastructure may boost home-working. In the long term, this could open space up for greening. This implies the need to consider not only future climate but also long-term societal changes in order to plan effective adaptation responses. This has been explored in the EcoCities project through development of future socio-economic scenarios for Greater Manchester (Carter, 2012).

Another opportunity was seen in the exchange of experiences on delivering green spaces for climate change adaptation in urban areas – both within The Corridor, and via knowledge transfer at the international level. Learning from others is one of the main success factors of urban adaptation strategies (Tanner et al., 2009), and participation in knowledge exchange initiatives is recommended in the future. One Board member noted:

> Interviewee 7: ‘‘I am impressed about the way their [Spanish] plazas are organised, their public spaces, their play spaces, how they care for and protect them, and keep up the standards (. . .). We do have to copy other European cities to develop these open spaces’’.

Finally, some mechanisms for implementing green space measures in developments were identified by the Board as potential opportunities if they could be established. These included planning greening alongside the maintenance and development of infrastructure and buildings, and the inclusion of requirements for greening into the process of tendering for development partners. Another type of solution that could be recommended for the future is enhancing contribution of the private sector entities to the public realm through sponsorship schemes, such as those used in the BID model (Carmona & de Magalhaes, 2006).

Analysis of the opportunities suggests that there is a need for stronger regulations and financial mechanisms encouraging the provision of green space in city centre areas. In particular, incorporating green spaces within existing developments is needed. International examples include the city of Basel, where subsidies were provided by the city for green roofs funded through an Energy Saving Fund which took a proportion of energy bills in the city (Kazmierczak & Carter, 2010). In the UK, establishment of the Green Investment Bank (Aldersgate Group, 2010) supporting energy efficiency initiatives could offer similar support. This would help to solve issues associated with requirements for upfront investment.

There are also international examples of city-level regulations specifying thresholds of green space provision in redevelopment projects, such as the Biotope Area Factor (BAF) in Berlin (Kazmierczak & Carter, 2010). Whilst, according to the Corridor Board, options for local authorities to develop and implement local regulations or incentive schemes for expanding green space are limited as such issues are regulated centrally, currently there are more opportunities than ever for Manchester to consider establishing similar approaches. The formalisation of the Greater Manchester Combined Authority in statute presents greater powers to the city-region in driving its economic growth; Manchester is the first city-region in the UK to be handed the freedom to reinvest its own national tax revenues under the Government's ‘City Deal’. In addition, the Greater Manchester Investment Framework[4] offers the potential to make the best use of funding from central government, Europe, and the private sector, to drive economic growth locally. Higher levels of autonomy and availability of funds for physical development and low carbon projects offer new opportunities to develop green infrastructure. These opportunities need to be supported by local level regulations and initiatives. Here, the Greater Manchester Green Infrastructure Framework (AGMA, 2011), and local authority Supplementary Planning Documents on green roofs (AGMA, 2011), can help to progress greening initiatives. The spatial planning system needs to continue developing techniques and policies such as these, which consider both quantity and functionality of green space, to encourage pro-active adaptation responses.

4.5.2.4. Threats. Threats are external factors that impede the ability of the Corridor Board to deliver adaptation responses linked to achieving the deep green scenario. Despite the emergence of new mechanisms for funding public realm improvements, our interviewees saw the dominance of economic and development aims in the planning system as a major threat. These agendas tend to dominate planning priorities at the expense of other concerns. Regarding this point, one Board member noted:

> Interviewee 5: ‘‘Planning and development at the moment are very much driven by the economic benefits that investment brings, and certainly the city council, its thinking, is very strongly about economic regeneration and development and wealth creation’’.

Since the completion of the interviews, there has been a significant change in the UK planning system (see sections 1 and 5). The recently implemented National Planning Policy Framework (CLG, 2012) strongly endorses economic growth and development. However, it also emphasises the importance of green infrastructure as an adaptation measure, yet mainly in the context of new development in areas at risk of climate change impacts. Hence it does not provide a strong push for retrofitting green spaces in existing developments. In addition, the on-going programme of public sector spending cuts in the UK was viewed as a potential threat. This may have a direct impact via the

[4] http://www.agma.gov.uk/cms_media/files/detail_gm_investment_framework_independent_advisory_panelv2.pdf?static=1.

removal of green infrastructure in redevelopment schemes as the 'non-critical' element:

> Interviewee 13: I can see quite a possibility, the amount of funding in the [transport change] scheme to be squeezed, and what could be squeezed out is green space and tree planting.

Further, the green infrastructure and sustainability teams in Greater Manchester's local authorities have experienced major redundancies (see Section 5) due to spending cuts, reducing their capacity to champion greening schemes. Moreover, Carmona and de Magalhaes (2006) indicate that even before resources became restricted, very few local authorities possessed departments dedicated to holistic public space management. More typically, public spaces were either managed within a much larger department incorporating many non-public space functions, or in much smaller units that separate different public space types and their management (Carmona & de Magalheas, 2006). This far from ideal system of planning and management of green spaces in local authorities, further undermined by on-going budget cuts, calls for new modes in green space planning and management. Collaborative approaches engaging stakeholders from public, private and third sectors and local communities appear necessary (Dempsey, Burton, & Mathers, 2012), and here the Corridor Partnership is well-positioned to take on the role of place-shaping organisation in the city centre context.

People's life choices and perceptions were viewed as a potentially significant threat to the progression of the adaptation agenda, in particular, greening urban areas. Our interviewees noted that a proportion of the population remains sceptical about climate change adaptation and also reflected on the lack of appreciation of public greenery in British cities.

The literature presents a more optimistic picture of people's attitudes to green spaces and urban greening. Parks are the most frequently used public service (CABE, 2010), with urban parks in England receiving 2.6 billion visits a year (Dunnett, Swanwick, & Woolley, 2002). The majority of people believe that green spaces improve their quality of life (90%) and physical and mental well-being (74%) (CABE, 2004b). This strongly suggests that vegetation and green spaces would be appreciated by citizens living and working in The Corridor.

The issue of maintaining the functionality of green space in the future, with additional pressures from the changing climate, was considered to be a threat to the success of the deep green scenario. One Board member noted that:

> Interviewee 6: ''It may be more difficult to maintain urban green spaces with the same level of functionality that they have, so you may get more situations when the grass gets browned off, or if the trees get heat-stresses, then you may get premature leaf drop and things like that''.

This emphasises the importance of understanding the potential impacts of climate change on green space for successful planning and management. For example, consideration needs to be given to the species of trees that would be able to withstand more extreme weather in the future (Rosenzweig et al., 2006) and which trees provide the most cooling benefits (Armson et al., 2012). This can be achieved by extending university research from the current focus on the role of vegetation in managing the urban climate to the impacts of climate on vegetation, and ensuring knowledge is transferred to organisations responsible for managing the public realm.

4.6. Conclusions

This study suggest that an increase in green space within The Corridor, within the framework dictated by existing development patterns, could significantly ameliorate rising temperatures associated with climate change and the urban heat island effect. Factors including an increase in human thermal comfort and quality of life, and a decrease in a number of days when artificial cooling is required (hence reducing energy bills), could be significant incentives for land owners and developers to invest in green spaces within their developments.

The potential realisation of the deep green scenario was discussed with the Corridor Partnership Board. Results suggest that there is a good chance for implementation of some elements of this land cover scenario: the partners all perceive climate change to be a significant issue, there are some foundations in the existing development strategy, positive perceptions of the benefits of green space, and an array of examples of on-going and planned initiatives of enhancement of green space that the Board appear willing to learn from.

Spatial planning remains a crucial influence on the future implementation of the deep green scenario. The promotion of green infrastructure at the national level through the National Planning Policy framework (CLG, 2012), and in the city region through the Green Infrastructure Framework (AGMA, 2011) provides an additional push for achieving this scenario. However, characteristics of the Oxford Road Corridor, including the low proportion of public land awaiting development and the relatively low number of landowners in the area, indicate that the main focus of the greening strategies should be on retrofitting the existing environment, rather than developing new areas through spatial planning. The partnership is well-positioned to deliver greening via this approach if provided with a stronger mandate to guide the redevelopment and management of the public realm and buildings in the area. Carmona and de Magalhaes (2006) observe that the involvement of local businesses in partnerships covering public spaces is increasingly popular, whether through representation on a not-for-profit company board with other stakeholders, including the local authority, or through committed sums or financial contributions to public space services. This can help to resolve some of the issues related to funding highlighted by the Board members, associated with financial and economic issues. The challenges and barriers to adaptation via urban greening identified in this research are likely to be transferrable to collaborative approaches to urban centres more generally, such as towns centre management and business improvement district schemes, in the UK and elsewhere.

In summary, the Oxford Road Corridor case study emphasises the value of collaborative approaches to adaptation of cities. Whilst this section focused on a small area in Manchester city centre, the next section explores the collaborative approaches to adaptation at wider spatial scales.

5. Building adaptive capacity through inter-organisational cooperation on climate change adaptation

5.1. Introduction

Planning for climate change can be assisted by building a robust evidence base on hazards and vulnerabilities in cities (see Sections 2 and 3) to inform targeted planning responses to reduce associated risks. However, as the conceptual framework that lies behind this article indicates, we need more than evidence to increase adaptive capacity and reduce extreme weather and climate change risks in cities (Mehrotra et al., 2009). The previous sections also highlighted interdependencies between natural, social and technological systems in cities, and the need for cross-sectoral and scalar adaptation responses. A key dimension of adaptive capacity to respond to the changing climate can be found in the existence of multi-level governance frameworks in which information and resources are shared across scales; since cooperation is crucial to strategically identifying risks and adaptation priorities at an appropriate spatial scale (Bulkeley, 2010; Kern & Bulkeley, 2009). In spatial planning, this can be characterised as a networked form of multi-level governance that involves partners beyond formal political institutions (Rydin, 2010). In this section, we do not interrogate adaptation governance frameworks per se but instead focus on the extent to which cooperation and collaboration are taking place from the UK scale down to actors working in Greater Manchester.

There are a number of reasons why analysing the networks in a specific conurbation is fruitful. Firstly, the introduction to this article notes that spatial planning is a good tool for strategically coordinating and implementing climate change adaptation policy (see also Blanco & Alberti, 2009a, 2009b). Here, spatial planning's collaborative aspect comes to the fore. On a small scale this is demonstrated by the analysis of the Oxford Road Corridor case study in Section 4. In this respect, individuals or groups exist in relational webs in which they are shaped by context; however, they can also actively effect change particularly where there is mutual dependence on certain resources such as land or water (Rydin, 2010). Collaborative planning can build inclusiveness into policy approaches through shared agenda setting and learning opportunities (Healey, 2006) as well as helping to manage complex ecosystems (Bodin & Crona, 2009; Brummel et al., 2012). Facilitating open dialogue between diverse stakeholders, particularly where the future is uncertain, can engender trust through the creation of shared meanings that can act as a basis for change (Booher & Innes, 2002; Healey, 2006; Rydin, 2010). Webs of interaction are held together by particular brokers in a network where open lines of communication become important (Vogel, Moser, Kasperson, & Dabelko, 2007). Similarly, for Booher and Innes (2002, p. 229), networks survive if the information flow is transparent enough to ensure that all stakeholders can utilise it in order to bring about innovation and sustain changes in policy and action.

Secondly, previous case study research on how cities respond to climate change adaptation have drawn attention to the critical role of networks and partnerships in accounting for local level action on climate change adaptation in a variety of urban regions (Bulkeley et al., 2009; CAP, 2007; Tanner et al., 2009; Wilson, 2006). Not only do they work across sectors, they are, particularly in Europe, enmeshed in vertical linkages across scales. Some cities participate extensively in transnational networks, such as Local Governments for Sustainability (ICLEI), through which they can draw support and share best practice (Carter, 2011; Kern & Bulkeley, 2009). Networks can also have a sectoral focus on infrastructure, water or energy. Research indicates that the existence of social networks at various scales, both formally and informally, can be an indicator of adaptive capacity (Ingold, Balsiger, & Hirschi, 2010; Pelling & High, 2005; Tompkins & Adger, 2003) and, hence, a city's readiness to respond to challenges and exploit opportunities linked to the changing climate.

Thirdly, adaptation strategies at the national level have increasingly become established in Europe to provide the supporting framework for advancing adaptation at local levels (Biesbroek et al., 2010; Corfee Morlot et al., 2009; Greiving & Fleischhauer, 2012; Swart et al., 2009). Obligations to use assessment instruments and to include adaptation goals in sectoral and spatial planning laws are powerful, yet flexible, means of integrating adaptation policies into local and regional practice (Swart et al., 2009). For example, the UK's Climate Change Act (2008) compelled all companies and organisations that fulfil essential public functions to undertake and report on the extent to which they have identified and planned for future climate change risks. National governments can also empower local authorities to take action by providing funding, removing institutional barriers and supporting inter-municipal collaboration (Corfee Morlot et al., 2009; Swart et al., 2009). However, a review of national adaptation strategies across the EU judges that insufficient attention is paid to the extent to which there is communication across sectors and scales fostered by these national strategies (Greiving & Fleischhauer, 2012).

Lastly, the regional or metropolitan scale is often identified as a conduit to linking national and local level adaptation, particularly when it is related to spatial planning (Blanco & Alberti, 2009a, 2009b). There is evidence that social networks that raise adaptive capacity are emerging in European countries at a sub-national level (Juhola & Westerhoff, 2011). In a review of regional adaptation strategies in Europe, Ribeiro et al. (2009) conclude that more attention needs to be afforded to implementing rather than formulating, adaptation strategies. However, the long-time horizons associated with such action will, undoubtedly, face changing electoral cycles that may impede their implementation. Difficult economic times hinder these activities with organisations often competing over scarce resources. Consequently, sharing information and working in partnership can be resource-effective. A UK example offers an extreme, but instructive, case in this regard since during the course of the EcoCities research that underpins this article, a change in government resulted in the removal of a formal regional tier for spatial planning.

5.2. *Identifying the networks*

As a research method, social network analyses (SNA) are increasingly used in the planning literature and are regarded as a particularly adept at visualising and mapping relational networks (Dempwolf & Lyles, 2012). By looking at information exchange and direct collaboration, SNA provides: "a useful tool for visualising, analyzing, understanding, and remembering complex networks of actors..." (Dempwolf & Lyles, 2012, p. 2).

It is used here to analyse which public, private and third sector organisations in Greater Manchester, and beyond the conurbation boundaries, are currently involved in adaptation and the extent to which they collaborate or communicate with one another. Answering such questions can help to understand the policy choices and actions that Greater Manchester can take in the future. An added question that emerged during the EcoCities research programme was the extent to which significant administrative and economic changes at national and regional tiers of spatial planning, as ushered in following a UK General Election in 2010, have on the durability and quality of these networks.

Organisations with a stake in climate change adaptation in Greater Manchester were identified based on a stakeholder mapping exercise (Carter, 2009). Additional non-governmental organisations, private sector companies and research institutions interested in environmental issues were taken into consideration. A questionnaire was sent to 93 organisations between October 2010 and October 2011 (see Kazmierczak, 2012a, 2012b). The questionnaire included a list of each organisation according to type and spatial level of operation (Table 7). Respondents were asked to identify the organisations that their body had communicated or collaborated with in relation to climate change adaptation in the last 3 years. Communication was defined as exchanging information and collaboration meant that the organisations have worked together (Corteville & Sun, 2009). An assumption was made that those who collaborated with each other also exchanged information.

The questionnaire survey achieved a 62% response rate. This was considered sufficient to draw conclusions about the flow of information because only the non-directional relationships between organisations were investigated. Gaps in the data could be filled by symmetrical responses. Also, the paucity of information from non-respondents was addressed by a qualitative analysis of publicly available meeting minutes, reports and consultation exercises. The survey also helped to

Table 7
Stakeholders in climate change adaptation in Greater Manchester considered in the study.

1 Stakeholder type	2 Spatial scale				
	National	North West of England	Greater Manchester	Local	Total (no. responses)
Public sector/NDPB	18	14	12	11	55 (33)
Third sector	3	4	4	3	14 (10)
Research	7	0	0	0	7 (5)
Private	11	4	1	1	17 (9)
Total (no. responses)	39 (21)	22 (14)	17 (10)	15 (12)	93 (57)

identify the partnerships active in the north-west of England, which may play a crucial role in adaptation to climate change through the adaptive capacity that they provide.

The questionnaire data was then analysed as a social network; a method that carries its own terminology. Organisations are regarded as 'nodes' and the communication or collaborative relationships between them are represented as 'ties'. The 'density' of the network reflects the percentage of all possible ties that are actually present; the more dense the network, the greater the percentage of potential ties that are actually realised. 'Degree centrality' is the number of ties that every node has. In this instance, it refers to the number of organisations which each stakeholder exchanged information or collaborated with. 'Betweenness centrality' refers to the position of a node in a network. Nodes with higher values of betweenness are connected to other important organisations or nodes that might otherwise act discretely. They play a 'broker' role in the network; this is a powerful role, but can be a point of failure if removed as it breaks the connection between otherwise separate groups of nodes.

Two analyses were carried out. Firstly, for the set of organisations identified as adaptation stakeholders before October 2010 (Fig. 19). The second analysis became important following the changes to the UK spatial planning system introduced in Section 1 (Fig. 20). It was carried out on the organisations unaffected by the abolition of the regional tier of planning or the review of non-departmental public bodies (NDPB) by October 2011. The visualisations of the networks were conducted using UCINET Social Network Analysis Software Version 6 (Borgatti et al., 2002) and NetDraw Network Visualisation (Borgatti, 2002).

To supplement the quantitative character of the social network analysis, and to learn more about the nature of ties and the impact of policy change on them, a series of semi-structured interviews were carried out. The interviews involved representatives of organisations at different UK spatial levels with a stake in climate change adaptation in the Greater Manchester conurbation. These organisations included local authorities, the AGMA commissions, the Environment Agency, third sector organisations and research institutions. Below, the results from SNA are combined with the interviews.

5.3. Co-operation across scales on climate change adaptation

Communication and collaboration between different spatial levels and types of stakeholders was thought to be crucial to successful adaptation by our interviewees, who all emphasised that the interlocking scales of adaptation are best addressed through multi-level governance structures with each level having different responsibilities and powers. Flooding was identified as the archetypal climate-related problem in this respect, and can only be adequately addressed through collaboration at different spatial scales. Flood risk cuts across boundaries and any measures implemented in one jurisdiction may simply push the risk downstream. Recognising this, the UK's Flood and Water Management Act (2010) encourages collaboration amongst local authorities. As noted by one interviewee: *We should be focussing our efforts not specifically to help one specific location but to make sure that it's joined up to strategically address risks across the region.*

Moreover, interviewees noted that no one spatial level can be responsible for implementing all adaptation responses. For example, in terms of flooding, regulations affecting the insurance industry were thought to be more appropriately set at the national level, whilst issues relating to maintaining transport networks are a task for regional stakeholders. Notionally, the interviewees considered working in partnership as something beneficial; however this raises questions over the extent to which this is realised in practice.

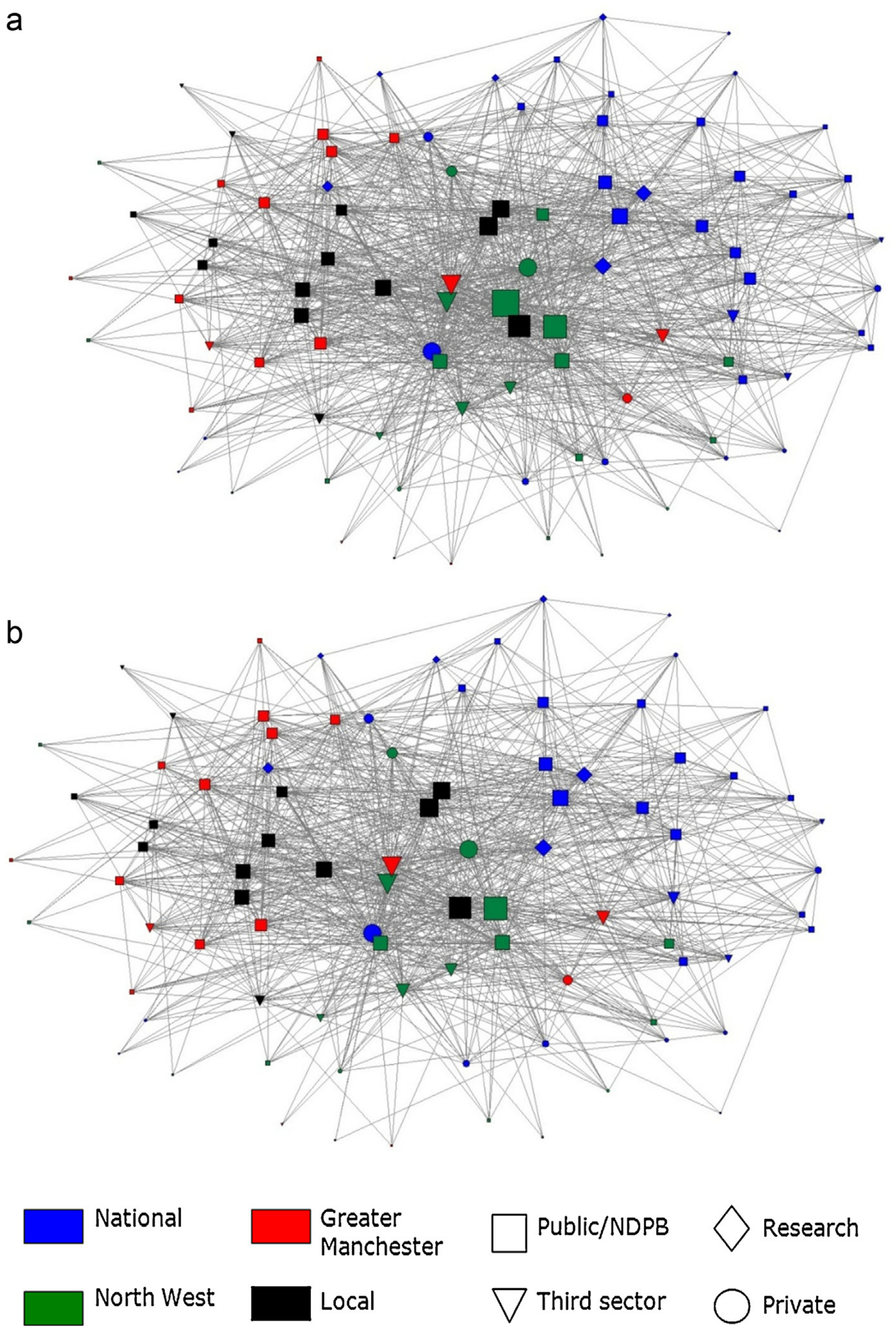

Fig. 19. Social network in communication: (a) October 2010; (b) October 2011. The size of the node represents the degree centrality (the number of ties to other nodes).

The overall density of the communication and collaboration ties in the entire network was not particularly high; respectively one-third and one-fifth of the possible ties were realised. The density of the network was deeper on communication than it was on actual collaboration on climate change adaptation activities. These findings could lead to an initial assumption that there is insufficient communication and collaboration on climate change adaptation issues among the organisations engaged in this research. However, the list of stakeholders included organisations with wide ranging interests and, therefore, the

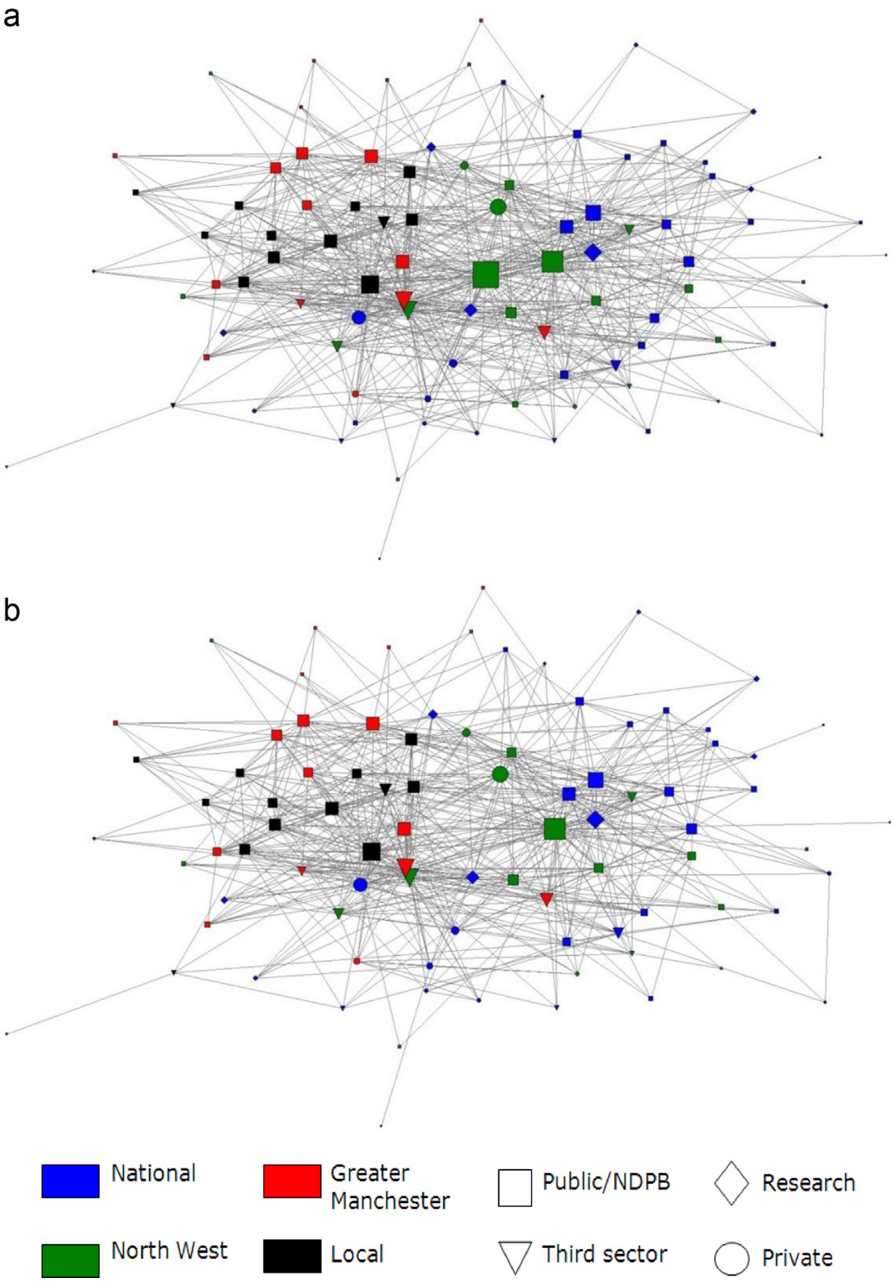

Fig. 20. Social network in collaboration: (a) October 2010; (b) October 2011. The size of the node represents the degree centrality.

collaboration and communication networks on climate change adaptation cannot be expected to achieve 100% density.

Table 8 shows that in 2010 the North West Development Agency (NWDA) had the highest degree centrality (number of connections), betweenness (strategic position in the network), closeness (proximity to other organisations) and centrality (both in the case of communication and collaboration). The Environment Agency's north-west regional office followed. Both organisations were the most active in terms of being involved in, controlling and monitoring the networks of communication and collaboration on climate change adaptation. This is due to their role in spatial planning in the region: the NWDA was one of nine Regional Development Agencies in England with a key role in working in partnership, primarily with business, in land use development and regeneration. Similarly, the

Table 8
Five highest ranked organisations in terms of degree, betweenness and closeness scores (all organisations, October 2010).

Rank	Communication			Collaboration		
	Degree (no.)	Betweenness	Closeness	Degree (no.)	Betweenness	Closeness
1	NWDA (85)	NWDA	NWDA	NWDA (64)	NWDA	NWDA
2	EA NW (73)	EA NW	EA NW	EA NW (52)	EA NW	EA NW
3	Stockport MBC (69)	Stockport MBC	Stockport MBC	Manchester CC (43)	Manchester CC	Manchester CC
4	Red Rose Forest (59)	Arup, Manchester	Community Forests NW	Red Rose Forest (43)	United Utilities	Red Rose Forest
5	Community Forests NW(59)	United Utilities	Red Rose Forest	Community Forests NW (41)	UKCIP	Community Forests NW

Environment Agency has oversight on rivers, flooding and pollution.

The network was characterised by an uneven distribution of the number of ties between different organisations (Figs. 19 and 20), with a small number of actors holding a high proportion of the connections. These are represented by the large nodes in Figs. 19 and 20 (the size of the node is proportional to the number of its connections with other nodes). They act as hubs of activity (communication or collaboration, respectively) and provide ties between other nodes in the network, thus improving the flow of information and resources. When these key actors are removed, the density and connectivity of the entire network is weakened. This is demonstrated by the lower concentrations of lines in Figs. 19b and 20b. The figures demonstrate that, as a result of the abolition of the regional tier of planning in October 2010 and the changes to the UK planning system in 2011, the overall density of the resultant network in 2011 marginally dropped; by 1% in the case of communication and by 0.7% in terms of collaboration. While the overall differences may seem small, Table 9 shows that when the spatial levels are compared it is at the regional level where the density of the communication and collaboration networks were the most affected by the removal of organisations working at that scale including the NWDA, the Government Office Northwest and the Northwest Regional Assembly (compare the presence of green squares, representing public sector regional bodies, between Fig. 19a and b for communication; and Fig. 20a and b for collaboration). National level collaboration increased and local and sub-regional collaborative ties showing negligible change. Interviews with key stakeholders shed further light on the actual effect of these changes on spatial planning and climate change adaptation activities.

5.4. Taking the region out of Greater Manchester's network

When asked about the significance of losing the regional level of planning, particularly the NWDA and the Government Office for the North West, our interviewees thought that it negatively affected the links between the national level and the local authorities. Firstly, from a national point of view, collaborating with nine regions was perceived by one interviewee to be logistically easier than dealing with four hundred local authorities. This potentially may impact on the cascade of information on adaptation down to the local level. Secondly, the regional level was thought to be the most appropriate scale where local knowledge could be combined with the depth of expertise on adaptation issues. One interviewee reflected that: "*at regional level you had a good balance between the ability to specialise, ability to innovate and still having a good local knowledge of how to apply that to a local area, nationally again you'll have huge specialisms but you won't know how to apply that to a local area, so that's the gap.*"

The NWDA was considered to be a major policy driver through its championing of the adaptation agenda (see Section 4 regarding green infrastructure solutions), and by acting as a nexus for different organisations from across the region working on adaptation. With its loss, the potential for Greater Manchester to collaborate with other counties in the region, or neighbouring authorities outside of the region, may be lower. This could also inhibit shared learning between cities and city-regions as they progress adaptation policies. One interviewee, active at the sub-regional level, noted that through the NWDA, Greater Manchester had: '*...easier links into Merseyside and the rest of the region*'. The NWDA's removal was deemed painful for the third sector due to

Table 9
Density (%) of communication and collaboration between stakeholders at different spatial levels and change between 2010 and 2011.

Stakeholder level	Date of analysis	National		North West of England		Greater Manchester		Local	
		Communication	Collaboration	Communication	Collaboration	Communication	Collaboration	Communication	Collaboration
National	2010	36.7	20.6	30.4	18.6	20.3	9.3	23.4	10.7
	2011	36.0	21.5	29.4	17.0	20.3	9.3	23.9	10.8
NW	2010			52.8	33.0	33.5	23.0	40.5	17.1
	2011			46.7	28.5	30.5	21.0	37.5	14.7
GM	Both[a]					32.6	25.2	52.1	37.2
Local	Both[a]							64.2	37.3

[a] No change, as the numbers of stakeholder organisations at these levels did not change between 2010 and 2011.

reduced funding opportunities for adaptation activities; although other interviewees speculated that national and local fiscal retrenchment would nevertheless have impacted on the NWDA's ability to fund third sector adaptation programmes even if it continued to exist.

Magnifying the importance of the NWDA, however, could imply a simplistic assumption that flows of information and resources work down through the spatial scales. Through the interviews, it became apparent that, due to its economic significance in the region and its well-established and highly collaborative governance framework, Greater Manchester was seen as the driver, rather than the recipient, of many regional policies. An interviewee from the Environment Agency observed that: ''*my experience of how Manchester city region operated in terms of the Regional Spatial Strategy was that it had a very clear identity and, and it actually drove a lot of the regional policy.*'' In the case of adaptation, Greater Manchester was seen to be well-positioned, particularly through its power to deal with flooding because the natural watershed maps closely onto the political and administrative boundaries denoted by its ten local authorities. Progress has been made through the Strategic Flood Risk Assessment (Scott Wilson, 2008), which provides an example of a collaborative cross-district approach that may be extended beyond local authorities to include stakeholders such as national agencies and service providers.

Therefore, the loss of key actors at the regional level planning will not necessarily lower the adaptive capacity of the conurbation. The Environment Agency's role has strengthened and it is now the key deliverer of national government adaptation policy. With a focus on key sectors for spatial planning including health, water and transport, the Environment Agency's existing structure and networks and could increase the reach of adaptation advice across the country (Personal Communication, October 2012). Similarly, one interviewee drew attention to the continuing incentives for partnership through the European Regional Development Fund (ERDF), which continues to be delivered through the spatial unit of the region. Even so, one lesson to be learned from the removal of the NWDA is that where power is invested heavily in one network broker, there should be moves towards a more even distribution of power through in order to safeguard against sudden changes.

To a certain extent, this can be seen in the network where representatives of Greater Manchester's local authorities and third sector organisations had extensive contacts (high scores of degree centrality) in 2010 (Table 8). Looking across the different spatial levels, the

Table 10
Density (%) of communication and collaboration between different types of stakeholders after October 2010.

Stakeholder type	Public sector/NDPB		Third sector		Research		Private	
	Communication	Collaboration	Communication	Collaboration	Communication	Collaboration	Communication	Collaboration
Public sector/ NDPB	39.7	23.0	33.8	19.8	27.6	15.6	24.1	12.6
Third sector			50.0	31.1	25.8	18.0	31.7	17.1
Research					50.0	25.0	29.1	19.4
Private							25.9	13.0

highest density of communication and collaboration ties was present between organisations at the local level (Table 9). This was followed by the density of ties between Greater Manchester and local levels. These high levels of interactions are explained by the long-established presence of the Association of Greater Manchester Authorities (AGMA) (see the Introduction). These organisations are not directly affected by changes to the regional tier of government and, despite cuts in central government funding, they remain crucial actors. Their role in planning for climate change adaptation becomes elevated because of regional restructuring. Our interviewees emphasised that the high level of collaboration stems from voluntary agreements between the districts and AGMA. This bodes well for integrated spatial planning across the conurbation; one interviewee reiterated that: "*The key thing is that the ten authorities are working together and when AGMA sets out a strategy, everybody goes along with it*".

As noted above, collaboration on adaptation issues has been largely driven by the joint approach to flood risk assessment, which in Greater Manchester is firmly based in the spatial planning agenda. Equally, there are green infrastructure strategies as well as cross-authority networks on planning and housing development. Although the loss of the NWDA could be significant in respect of progressing adaptation in Greater Manchester, it is encouraging that there are strong ties within the city-region between organisations with a role to play in planning for climate change. This study demonstrates that for secure networks to endure over time, they must display vertical connections that link organisations across different spatial scales. The experience of Greater Manchester, and its long history of collaboration between local authorities through AGMA, demonstrates that when a significant governance change does occur (in this case the removal of the regional tier) that established connections across scales can help to make planning for climate change a more effective process. Indeed, without governance frameworks that extend above the local municipal level, adaptation will be a challenging prospect.

5.5. Local-level communication and collaboration

Spatial planning integrates across sectors; hence its perceived usefulness to climate change adaptation. In the absence of strong regional spatial planning, private and third sector organisations may have the capacity to fill a gap. Communication and collaboration ties between the public sector/NDPB organisations and third sector organisations are fairly well developed in Greater Manchester (Table 10). The links between the public sector and research institutions and business were less well developed. The disappearance of the regional tier of governance could represent an opportunity for other actors to strengthen their presence; an interviewee commented that: "*there's a big threat there but equally there's an opportunity in between that for other organisations to come in, public and private sector, to come in and... provide solutions to the local.*"

The UK's Localism Act (2011) has elevated the importance of neighbourhood-scale planning. The National Planning Policy Framework (CLG, 2012) potentially gives communities power to specify policies and land use designations for their local area as long as the resulting neighbourhood plans align with the official local development plan (subject to compliance with its overall vision). Local communities may have significant weight over approving planning applications (ASC, 2011). There are concerns about the consistency of such 'bottom-up' planning arrangements between locations due to competing priorities. This, combined with the absence of direction from higher tiers, may jeopardise strategic objectives and large-scale solutions (Ellis, 2011, 2012). Moreover, climate change adaptation planning requires considerable expertise, which may not exist within the local communities (The Green Alliance, 2011).

Local communities and neighbourhoods were not investigated in this research; but the literature is beginning to identify climate change experiments in cities that occur without reference to municipal or formal authorities and, similarly, we concur that these more informal arrangements should be explored in subsequent research (Castán Broto & Bulkeley, 2013). This has implications for future research and practice on climate change adaptation. Indeed, when asked about the extent to which there needed to be strong multi-level links guiding adaptation initiatives; our interviewees stressed the need to empower communities, for example, their access to financial resources. A prominent local politician phrased it thus: '*it's not about a strong central – regional – local, but local – regional – central in that case, that empowering very local communities to be able to draw in resources from a wider spatial scale*'.

The higher densities of connections between stakeholders operating at the local and conurbation scale levels could be considered positive since the location-specific character of climate change impacts means that the local level is seen as an optimal scale to formulate and deliver adaptation strategies (Alber & Kern, 2008). On the other hand, the lower density of communication and collaboration between local and national level stakeholders may mean that local authorities do not have an appropriate channel for guidance and support from central government on the implementation of relevant national climate change adaptation policies (Bulkeley et al., 2009). Further, if the cooperation between the national and the local level is a two-way process, the scarcity of ties means that there is little opportunity for central government to learn from the experiences of the local authorities engaged in implementing climate change adaptation policies (Corfee Morlot et al., 2009). In the Greater Manchester network, national-level organisations tended to work together at the national level, cooperating less regionally, and even less with local and conurbation levels. This is similar to research undertaken in Switzerland, where national level actors were considered to be less integrated into the network (Ingold et al., 2010). One interviewee observed that the localism agenda is likely to further decrease connections between national and Greater Manchester actors: "*There were undoubtedly people (...) in Defra who were very committed to adaptation and very interested in GM [Greater Manchester] as a place to do business but now we don't work in that way because of localism, devolution and I don't think there is that attraction with Defra officials around looking at GM.*"

The social network analysis looked at organisations involved in climate change adaptation in Manchester. Yet, interviewees pointed to the role of specific individuals who can act as climate change champions or leaders. Such persons were identified by our interviewees as willing to take the adaptation agenda forward and utilise their position within certain organisations as a platform to achieving this: "*I think it can come down to a sort of almost leadership within those authorities.*" However, if adaptation is led by individual champions, then cooperation that is driven forward only on this model could be at risk when individuals are removed, for example, from reduced financial resources, retirement, or redundancy, and are not replaced by a similar individual. A representative of the Environment Agency was able to observe that in Greater Manchester: "*spatial planning's being very hard hit [...] and they've lost a lot of expertise*." Certainly, in terms of flood risk management, local authorities are hampered by a lack of technical experience needed through insufficient resources to recruit and retain experienced flood risk managers (National Audit Office, 2011, p. 9). The question, which this research was unable to address, is how knowledge can be retained in networks even when individual expertise is lost.

5.6. New partnerships

A significant proportion of the communication and collaboration in the North West and in Greater Manchester has been facilitated by partnerships, or voluntarily existing groups, operating in the region (Table 11). The bodies involved in these partnerships were mainly North West in scope and public or third sector in character.

Table 11
Partnerships facilitating communication and collaboration in the region (as of October 2010).

Partnership	Organisations in communication	Organisations collaborating
NW Climate Change Adaptation Group	23	14
NW Climate Change Partnership	19	12
NW Climate Change Unit	13	9
NW Green Infrastructure Think Tank	15	9
NW Green Infrastructure Unit	15	9

As noted above, the loss of the NWDA as an adaptation champion may hold opportunities for forging new partnerships. The Environment Agency, currently one of the leading actors on climate change adaptation, now supports Climate UK. This is a not-for-profit Community of Interest Company working with regional Climate Change Partnerships across the UK to promote collaborative action on climate change. The role of research institutions was also thought to be crucial. Universities were regarded as sources of evidence on climate change impacts, vulnerabilities and possible responses, including the economic benefits of adaptation. Such evidence can help third sector organisations to carry out work for the local authorities. Also, the private sector can positively support local authorities in building their adaptive capacity and developing adaptation strategies and plans, and this is taking place in Greater Manchester.

Interviewees thought that working in partnership with the private sector, and other actors including research institutions, should help to progress adaptation planning locally. One interviewee stated that: "*Greater Manchester could create a central centre of excellence which allows the ten authorities and their partners and the private sector partners to work as one in a more meaningful way.*" Local Enterprise Partnerships (LEPS) were identified as a possible mechanism for encouraging cooperation between stakeholders on adaptation within and beyond Greater Manchester. However, their non-statutory status and narrow economic remit were thought to be barriers. In terms of delivering adaptation responses, LEPS could be hampered by resources with one interviewee noting: "*The problem with the LEPs at the moment is that they don't necessarily have the capacity and the resources to be able to respond.*"

Local Nature Partnerships (LNP) have also been established to raise awareness of the services and benefits of a healthy natural environment and contribute to the green economy. One exists for Greater Manchester and it may provide a vehicle to address adaptation issues. Although their power to deliver adaptation action on the ground was questioned by some interviewees, it was clear that in order for it to operate, the LNP had to cooperate and make proposals in collaboration with the economic development agenda. It was noted that the Greater Manchester LNP proposal was linked to the LEP; thus, the economic and environmental agendas are being brought together. One LNP representative said that:

> *A draft constitution [. . .] said that there would be cross representation between the LNP and LEP in some way [. . .] again how that'll work in practice I'm not quite sure [but] there's been a decent history of engagement between the Environment Commission and the LEP and it may be that actually that's how it pans out.*

There is also evidence that a history of working in partnership at regional level continues in new guises. Three LEPs at the regional scale – Cheshire and Warrington, Liverpool, and Manchester – are collaborating on an inward investment project that will improve connectivity across through 'the Atlantic Gateway'. An 'Adapting the Landscape' programme of work has been agreed as part of this and builds upon earlier projects started before changes to spatial planning occurred (North West Regional Development Agency, 2009). Via this programme, business organisations, research institutions, community groups and local authorities have come together to encourage climate change adaptation and sustainability to be embedded in economic plans, along with infrastructure, as an investment priority (Atlantic Gateway, 2012). This emerging evidence demonstrates that collaborative approaches are becoming firmly established as a way to progress the adaptation agenda and, further, that strong links forged before significant changes to spatial planning policy continue to endure despite the loss of regional bodies.

5.7. Complex multi-scalar adaptation networks

The social network analysis revealed a complicated conurbation and municipal-level picture in the collaborative exercise of planning for climate change adaptation. This seems to be an advantage: the complexity and longevity of the network bode well for its capacity to withstand significant shocks to the system. The removal of the formal regional tier of planning reconfigured the network. However, while change may delay progress on adaptation until the reconfiguration is complete, it does not suggest that it completely stalls. Moreover, while the region may have disappeared from the view of the UK's national government, it nevertheless remains a unit for analysis through the organisation of semi-public bodies, such as utilities companies and the Environment Agency, and, formally, as an important spatial unit at the European scale.

In terms of cooperation at local authority level, the outlook from Greater Manchester's point of view is favourable. Although institutional histories are particular, the voluntary cooperation across local authority boundaries means that the case is instructive for other urban regions. It demonstrates that for larger-than-local policy initiatives, such as climate change adaptation, collaboration can and does result in workable spatial strategies. Greater Manchester now has a climate change strategy, works collaboratively on flood risk, and, as the Atlantic Gateway project shows, the private sector takes on board the climate change adaptation imperative. However, given the ebb and flow of policy and resources, there is a need to ensure that the work and knowledge that has gone on to result in specific strategies should be future-proofed in order to safeguard against organisational change. This means paying attention to communication and collaboration over time as well as across spatial scales. One example here would be to ensure that 'institutional memory' (Pollitt, 2000) is preserved and knowledge passed on when individuals retire or when there is significant organisational restructuring.

Climate change adaptation will not occur simply through the command of spatial planning strategies. In the end, climate impacts and solutions will be locally specific. Therefore, more collaborative forms of community-based planning could build on the pre-existing links to encourage and sustain neighbourhood-based initiatives (Castán Broto & Bulkeley, 2013). There is a need to focus on building the resources for communities to work within the frameworks set at higher scales in order to build upon existing adaptive capacity. However, this needs to pay due attention to research showing that stakeholder networks should not be accepted uncritically: not all networks and the people that participate in them are equal in status (Baker et al., 2010; Sherlock et al., 2004).

Through the emerging Greater Manchester spatial strategy, and its allied climate change strategy, a common language has developed across sectors and has been consolidated by a research base, in spite of the whims of electoral cycles and administrative change (see MacKillop, 2011). The experience of Greater Manchester is positive. The cross-sectoral communication and collaboration described above, and the level of adaptive capacity that it implies, should offer important lessons for other European cities who equally aspire to responding to the adaptation imperative.

6. Adapting cities to the changing climate: progressing the planning response

6.1. Introduction

Due to factors including their expanding populations, urban landscapes and growing economic prominence, cities face a particularly strong adaptation imperative. The adaptation agenda asks new questions of city leaders, planners, businesses and communities. Current weather extremes and the threat of further rapid climate change should force sustained contemplation of what this means for planning cities today and for the future. The EcoCities project, on which this article is based, recognised this challenge and focused on the Greater Manchester city-region as a research laboratory and on issues related to building capacity to adapt. Greater Manchester is not an isolated case, and can offer adaptation insights to other cities and urban areas.

Within this article, we have looked at these broad themes with particular reference to spatial planning, which has a key role to play in progressing adaptation responses. Theoretically, planners are well positioned to support urban adaptation, and recent action in related areas including managing flood risk demonstrates that this can be realised in practice (White & Alarcon, 2009; Wilson, 2006). The core characteristics and underlying functions of planning as a discipline, including its futures perspective, cross-sectoral approach and participatory ethos, connect strongly to the adaptation agenda. Blanco and Alberti (2009a, 2009b) indicate that the planning profession can play a vital role in every aspect of adaptation to climate change impacts.

Local authorities, whilst being key to the delivery of place-specific adaptation measures, are constrained in performing this role by a range of factors. These include the clearly demarcated boundaries that exist between sectors that have their own internal working processes and timescales, and limited expertise, particularly with interpreting climatic data (Rydin, 2010). Institutional processes, cultural norms and regulation, where these exists (Adger et al., 2005; Bulkeley, 2010), and variable access to financial, technical and human resources (Carter & Sherriff, 2011) are also factors limiting spatial planning's adaptation contribution.

Buildings and infrastructure constructed today need to be adapted to future climates, as should the urban landscapes that they are situated within. The current generation have an urban inheritance that, in some respects, is sub-optimal in the face of the changing climate; drainage systems are sometimes overwhelmed by extreme rainfall and buildings are located in floodplains. Given our awareness and knowledge of climate change, it is now inappropriate to pass on buildings, infrastructure and landscapes that are poorly adapted, and planning has a key role to play in guarding against this. It is important, therefore, to remain focused on building the capacity of the planning profession to support their role in delivering positive urban adaptation outcomes. Indeed, where features including legislation, guidance and relevant data are available to support the role of the planning system in responding to weather and climate extremes, the adaptive capacity of cities and urban areas increases.

Drawing on insights that emerged from the preceding sections of this article, the EcoCities project more broadly and the substantial body of academic literature on climate change impacts and adaptation in Greater Manchester, we aim to identify and explore issues that can support capacity building and advance adaptation planning. This scope of themes covered in this section is by no means exhaustive. We acknowledge that there are many other relevant agendas that deserve fuller treatment, for example linking to the involvement of communities in adaptation, the behavioural dimension of adaptation, the links between climate change adaptation and mitigation and exploring the financial costs and benefits of adaptation responses. However, we believe that there are several emerging issues arising from the research in Greater Manchester that offer transferable lessons to other cities and urban areas engaged in or planning to embark on an adaptation programme. Broadly, we limit these observations to themes that exhibit links to our core guiding agendas of spatial planning and building urban adaptive capacity, and in doing so we hope to inform the rapidly emerging international adaptation agenda.

6.2. Repositioning adaptation within urban planning

Adaptation sits as one of multiple agendas competing for the attention of urban planners and decision makers and the resources they have at their disposal. At present, climate change adaptation appears to be a peripheral agenda, making it susceptible to budget cuts and curtailing of related activity. Bulkeley (2010) observes that climate change policy is often marginalised and therefore placed in competition with other economic, social and political processes for scarce resources. In the climate change sphere, relative to adaptation, much existing climate change policy and research effort is targeted at climate change mitigation (ASC, 2010; RCEP, 2010; Whitehead, 2013). Næss (2010) describes this as mitigation tunnel vision. This is also the case in Greater Manchester, where the low carbon agenda has secured a firmer purchase within city-region scale governance structures than adaptation.

To increase its scope and reach, attention could usefully be paid to strategies for repositioning adaptation as a core element of progressive visions of urban futures. Crucially, political support for adaptation needs to grow, increasing the likelihood that resources and capacity will be mobilised. Foregrounding the multiple benefits that adaptation brings offers the potential to increase traction around the agenda, particularly through demonstrating links to other spatial planning concerns including economic competitiveness, public health and social inequality. Repositioning adaptation in this way could in itself strengthen the status of planning profession.

Five themes emerged from EcoCities that could support a move in this direction. These are localising adaptation; safeguarding future prosperity; protecting the most vulnerable in society; building the resilience of critical infrastructure; and adapting across the science-policy interface. Progressing these themes is achievable within the current context of urban planning and development. They do not require a radical departure from existing structures and mechanisms. Further, they are not limited, geographically, to the Greater Manchester case study city-region and are of relevance to conurbations and urban areas more generally. Further research in these areas would be beneficial to support associated policy and practice. We now explore each of the five themes in turn.

6.2.1. Localising adaptation

Unlike the mitigation agenda, which is focused on reducing emissions to the atmospheric commons to lessen the future magnitude of climate change impacts globally, the locus of control and benefits associated with adaptation resides more locally. The UK's Adaptation Sub Committee observes that: "Adaptation will more often than not be a local activity in response to locally specific climate risks and opportunities" (ASC, 2010, p. 54). The European Environment Agency (EEA, 2012) adds that adaptation decisions are often context-specific; that is they depend on local circumstances. Communicated effectively, this notion can provide a powerful incentive for local action. Given that spatial planning helps to shape cities and urban areas, at conurbation, neighbourhood and building scales, it has an important role to play in materialising proactive adaptation responses locally. However, in certain circumstances, for example along Manchester's Oxford Road Corridor where much of the land is in private ownership and is already developed (Section 4), planning may have less scope to stimulate adaptation benefits. It is here that public realm work takes on a greater significance, for example through urban greening along transport routes. Further, Section 2 emphasises that if the consequences of changes in weather and climate are communicated to end users, this can enhance the impact and utility of the data for groups including planners. At present, local scale data of this type is generally rare. There is a need to generate data and insights on the local nature of adaptation to increase its relevance for decision makers operating at the urban scale decision makers.

Legislative approaches and conceptual models developed at supranational and national scales, which are aimed at supporting urban adaptation planning, must recognise the diversity of local adaptation. Cities and urban areas are not homogeneous in respect of their climate challenges and adaptation opportunities, and should not be treated as such. Where legislation and regulations are created to foster adaptation, it would be useful to consider encouraging and supporting local climate change assessments. Conceptual models targeted at strengthening understanding of adaptation approaches should regard the local nature of adaptation as a foundational principle. This could be progressed by developing adaptation typologies. Different cities not only face varying climate hazards, but also display different levels of vulnerability and capacity to adapt to them. Understanding similarities between cities in respect of issues such as current and projected climate hazards and overarching socio-economic characteristics can support the development of broad city types in these respects (Carter et al., 2012). Such an approach would encourage more effective adaptation planning and policy making. In addition, adaptation policy responses and resources can be more effectively allocated to address risks to certain groups of cities where the need is high. In addition to helping to localise adaptation, a typology-based approach also sets out a framework for selecting candidate cities for comparative and collaborative work on the development of adaptation strategies and responses.

6.2.2. *Safeguarding future prosperity*

Building resilience to the changing climate in Greater Manchester can help to safeguard future prosperity, and may support growth and employment. There are significant direct costs associated with weather and climate events (ASC, 2010; EEA, 2010; Stern, 2007), which can also have more insidious financial implications. For example, heat hits workers productivity (McCartney & Humphreys, 2002; Niemelä et al., 2002). At a time where much policy locally, nationally and internationally is focused on boosting economic growth, this is a message that could chime strongly with decision makers. Consequence-based insights demonstrating that adapting a conurbation such as Greater Manchester to the changing climate can bring benefits locally, such as enhancing economic competitiveness as identified by the Oxford Road Corridor Board (Section 4), are valuable in this respect.

In the short to medium term, decisions are likely to remain economically focused. Reducing the exposure of critical infrastructure to climate change hazards (Section 3) is a good example of the contribution that adaptation can make in this respect. In addition, developing and implementing adaptation solutions can stimulate job creation locally, for example linked to retrofitting buildings and urban landscapes to lessen risks. Governing for and implementing adaptation response can reduce perceived risks linked to living and investing in a city, potentially offering a competitive advantage over other locations in respect of issues including property insurance premiums. Early movers, such as Chicago, have already launched 'green deal' jobs programmes around adaptation, and have instituted innovative approaches to incentivise developers to adopt adaptation measures (Kazmierczak & Carter, 2010).

In some cases, urban adaptation responses can make the area more attractive to residents and visitors, for example via urban greening (McEvoy et al., 2008; Wilson et al., 2008). Other adaptation responses can deliver financial benefits in the context of climate change mitigation and energy savings (Hacker et al., 2005; Hacker & Holmes, 2007); a naturally ventilated office building will need less energy for cooling making it more cost effective to run. In order to progress the economic dimension of adaptation, it is crucial that weather and climate impacts and the value of associated adaptation responses are more thoroughly costed. This would support the identification of no-regret or low-regret adaptation options that can yield immediate economic and environmental benefits exceeding initial cost, which can be very low compared to potential benefits delivered under the changing climate (Willows & Connell, 2003).

6.2.3. *Protecting the most vulnerable in society*

Given their high population densities, adaptation strategies in urban areas should pay close attention to reducing the vulnerability of people and communities. Section 2 emphasises that this is especially valuable where climate change impacts already affect cities and urban areas, and that a vulnerability based approach has merits due to the inherent uncertainties associated with future climate change projections. Wider research has shown that some groups are more vulnerable to climate change hazards than others. For example the elderly are at far greater risk of ill health or death due to increased levels of heat (Semenza et al., 1996; Smoyer, 1998). Vulnerability lends itself well to spatial analysis (for example see Lindley et al., 2011). This broadly encompasses identifying areas where exposed locations (e.g. flood zones, heat stress 'hot spots') and sensitive receptors (e.g. elderly people, critical infrastructure) intersect. In Greater Manchester, this approach established that groups that are sensitive to climate hazards are disproportionately exposed to these events (Section 3).

Taking a wider perspective on vulnerability to climate change, it is clear that it connects to issues of social justice and inequality (Adger et al., 2006; Lindley et al., 2011). As poorer and disadvantaged members of society often excessively shoulder the impacts of climate change, reducing this potential threat can help to advance social goals through recognising and acting upon apparent inequalities. This brings a significant political dimension to the adaptation agenda. Progress could be achieved via spatially targeted adaptation action, underpinned by adaptation policies and regulations, to support improvements in the physical environment (resilient and adapted housing, greener urban neighbourhoods), enhance appropriate provision of emergency services and address the underlying causes of vulnerability (such as poor health and material deprivation). Localised patterns of vulnerability of communities and demographic groups highlight the need to channel adaptation responses through the spatial planning system. It is also vital that communities are made aware of these issues and engaged at the point of developing community based bottom-up adaptation response. Decision makers must be aware that adaptation responses can, themselves, have implications for social justice and in cultural contexts, for example linked to the loss of valued assets (Adger et al., 2009).

6.2.4. Building the resilience of critical infrastructure

Infrastructure instillations and networks, linked to sectors including energy, transport, water supply and waste water treatment, are of paramount socio-economic importance for cities and urban areas. Indeed, integrated infrastructure networks have been central to urban growth allowing cities to expand and support increasing populations. They are also highly complex. Urban systems and critical infrastructures are tightly linked making them interoperable, meaning that a change in one system may affect the functioning of another (RAE, 2011; Schauser et al., 2010; URS Corporation Limited, 2009; Wilbanks et al., 2007). The UK's National Infrastructure Plan now identifies climate change as one of five long term challenges (Her Majesty Treasury and Infrastructure, 2010), and the UK Climate Change Risk Assessment highlights the interdependencies between different types of infrastructure as a particular risk (Defra, 2012).

The problem is that many key urban infrastructures are fixed assets with long life spans, yet were not designed to be resilient to the pressures that the changing climate is projected to impose on them. Indeed, much infrastructure was designed to standards that assume the climate remains constant, and would be difficult and expensive to upgrade or replace (Ecologic Institute, AEA, ICLEI, & REC, 2011; Kamal-Chaoui & Robert, 2009). In addition to the changing climate, growing populations and associated demands for infrastructure focus attention on how cities can foster growth and development whilst also responding to climate change. Transitioning to climate resilient infrastructure is a major challenge facing urban areas generally, and it is one that planners and policy makers must address. Taking the specific issue of flooding of transport infrastructure, which emerged as a key risk in Greater Manchester (see Section 3), there is a broad suite of possible adaptation options available crossing grey, green and softer social responses (Highways Agency, 2011; Shaw et al., 2007). Certain infrastructure can also support the achievement of adaptation goals. For example, green spaces can help to cool the city and social infrastructure, such as schools, can act as shelters in the event of flooding. Again, spatial planning has a key role to play capturing these benefits in locations where need is identified as being greatest.

6.2.5. Adapting across the science-policy interface

Even if adaptation can be repositioned and linked to core local authority priorities, such as economic growth and social welfare, moving from problem recognition based on assimilating available data on climate hazards and vulnerabilities to the design and delivery of adaptation responses via spatially and sectorally diverse stakeholder networks remains a challenging task. Here, the manner in which research is designed and presented can support positive action that crosses the science-policy interface. Section 2 established that if weather and climate change data produced by researchers was more 'user friendly' and easy to interpret, this would enhance the confidence of people to apply it in practice. This principle is also likely to hold for data produced on other dimensions of adaptation, including vulnerability. Lemos et al. (2012) emphasise the usability gap in the context of climate science outputs, noting that data can be regarded as usable (rather than useful) when it is actually deployed by decision makers in practice. They argue that enhancing the usability of data is dependent on three interlinked factors; "...user perceptions of information fit; how new knowledge interplays with other kinds of knowledge that are currently used by users; and the level and quality of interaction between producers and users" Lemos et al. (2012, p. 789).

In the context of adaptation planning, cooperation between local government, academia, business, the third sector and communities brings additional expertise, resources and connections that can act to build adaptive capacity. Joint working of this type is taking place in Greater Manchester, yet is not firmly embedded and is challenged by deregulatory processes at the national level (discussed in Section 5). A key area of opportunity to break dominant silo-based approach to policy making and planning lies in developing collaborative partnerships between multiple stakeholder groups to co-evolve themes and projects (Ostrom, 1996). Options include developing 'living laboratories', which offer a new governance approach for progressing urban sustainability (Evans & Andrew Karvonen, 2011). This model moves universities beyond the preparation of capacity enhancing research outputs into the process of supporting the development of strategies and actions in practice.

Collaborative approaches focused on co-producing knowledge can bring additional benefits to researchers (Bovaird, 2007; Collins & Evans, 2002; Heron & Reason, 2001). These are applicable to building adaptive capacity to respond to the changing climate and include strengthening the relevance of research questions, refining the nature of research outcomes produced to support their uptake in practice, providing a forum to discuss the uses and limitations of research outputs and creating platforms for future engagement. A collaborative approach lessens problems linked to traditional research enquiries, which include the division between researchers' thinking and the concerns of research end users, where the dominance of the researchers' theoretical perspective which can inhibit practical action (Heron & Reason, 2001). Connecting research to policy and practice resonates at the highest levels. The EU's new programme for research and innovation, Horizon 2020, recognises the need for research that aligns closely with policy development, stimulates innovation and improves economic competitiveness (European Commission, 2011).

6.3. *Urban adaptation and the resilient city*

The preceding discussion on repositioning adaptation within urban planning and decision making is set largely within the context of existing governance structures and dominant development models. Although this means that the previous themes have the potential to be more readily absorbed into current structures and processes, there is a corresponding need to be more prospective and to look beyond current systems and established approaches towards a broader vision of adapting cities to the changing climate. There are fundamental questions to be addressed, and related research to be progressed, on how cities can transition into a future where the consequences of climate change pervade all aspects of their functioning. Without such enquiry, as noted by Pelling (2011, p. 3), there is a danger that the focus of adaptation will remain limited to "...the preservation of an economic core..." Similarly, Whitehead (2013) suggests that today's urban adaptation policies connect to a lineage of neoliberal urban environmentalism tracing back to the 1970s. Indeed, several of the arguments on repositioning adaptation posed above, regarding issues including safeguarding future prosperity and protecting critical infrastructure, in essence link environmental protection to supporting economic growth, upholding market-based assumptions and securing competitive advantage. We conclude this article by broadening the adaptation debate beyond these themes. Taking a more holistic perspective of cities leads us to explore the role of adaptation as a constituent element of understanding and governing a resilient 21st century city, encompassing agendas including dynamism and complexity.

6.3.1. *Building climate resilience into cities*

Broadly, climate change impacts arise in cities where climate variables (such as extremes of temperature and precipitation) interact with and impact on features of urban systems (including people, the built environment and infrastructure). The resulting consequences may be physical (e.g. damage to infrastructure and natural habitats) and/or socio-economic (e.g. loss of revenue, threats to health and wellbeing). Given the complexity of urban systems and the interrelationships between their constituent elements, it is difficult to isolate the impacts of climate change to specific sectors and themes. Indeed, the impacts and consequences of extreme weather and climate change hazards connect across sectors, spatial scales, and time horizons. For example, although the direct physical impacts of a flood can appear spatially obvious and can often be remedied in the short to medium term, such as damage to the built environment, indirect socio-economic impacts such as psychological harm to flood victims are more diffuse, intangible and long lasting.

Given the scope and complexity of extreme weather and climate change impacts, decisions over the design and implementation of adaptation responses have much broader implications for cities than may be immediately apparent. Adaptation responses should ideally be seen as equally multi-faceted and synergistic as cities themselves, which highlights the value of perceiving adaptation as part of the core fabric of how cities are planned and managed. Adaptation responses connect to a wide spectrum of issues from generating food security and improving health and wellbeing, in addition to responding to the immediate causes and impacts of climate change itself. Adger et al. (2005, p. 78) note that it is; "...difficult to separate climate change adaptation decisions or actions from actions triggered by other social or economic events." It is natural to question, therefore, whether adaptation could be more effectively organised as part of a holistic integrated vision of a resilient and dynamic 21st century city. Following on from While et al.'s (2004, p. 551) notion of an 'urban sustainability fix', an 'urban adaptation fix' must look further than a linear and thematically selective interpretation of how cities and urban areas strategise and plan adaptation responses.

To progress urban adaptation, it appears that taking a holistic systems perspective is a valuable tactic. This is emerging in certain related disciplines, for example flood risk management (Zevenbergen et al., 2008), and in the context of city planning more broadly (Ravetz, 2000a, 2000b). To advance a systems approach to urban adaptation, it will be necessary to identify connections between different elements of cities – their transport networks, energy systems and governance frameworks – and to perceive where and how extreme weather and climate hazards could threaten their effective operation. Spatially targeted and thematically integrated adaptation responses can then be developed, ideally in a collaborative forum. A systems perspective also requires seeing cities as inextricably linked, spatially, to their rural hinterlands and beyond into global networks of people, goods and services. It is increasingly recognised that the international implications of climate change on local sectors and services are an important consideration (Defra, 2013; Foresight International Dimensions of Climate Change, 2011), and these issues should be factored into adaptation planning and policy making. Additional research will be needed into these hinterland and international connections, their consequences locally, and possible adaptation implications and responses.

It appears, as the US National Research Council (2009) suggests, that new ways of thinking and learning are needed to function effectively in a context influenced by climate change. The theme of resilience (introduced in Section 1) links to this holistic cross-cutting perspective of cities and the position of adaptation within urban agendas. Despite the existence of a substantial body of literature on the subject, Davoudi (2012, p. 299) suggests that it is not clear exactly what resilience means; "...beyond the simple assumption that it is good to be resilient." In the context of extreme weather and climate change in cities, a dynamic interpretation of resilience seems to be appropriate. Tompkins and Adger (2003, p. 3) emphasise that; "Adaptation is not about returning to some prior state, since all social and natural systems evolve, and in some senses co-evolve with each other over time". Resilience, from the perspective of adaptation, is not about maintaining the status quo. It should reflect the capacity for evolution in themes including people's behaviour, the form of urban landscapes and modes of food production and sourcing in response to the changing climate. There is a need to avoid 'lock-in' of particular infrastructures and behaviours that are not suited to the evolving climate future that the science suggests cities face in the 21st century.

A dynamic interpretation of resilience also reflects the continual processes of change that drive cities. Climate change is one of numerous exogenous and endogenous drivers of change impacting on the growth and development of cities in the 21st century (Foresight Land Use Futures Project, 2010; Smil, 2008). Cities are in a constant state of evolution, with demand for and supply of services that they provide and the resources that they draw on modifying as time passes. The EcoCities project identified ten drivers of change with significant potential to influence Greater Manchester over the coming decades, one of which is climate change (Carter, 2011a). Fig. 21 separates these drivers into external forces impacting on the city and those that express themselves within the conurbation. Many of the drivers are generic in nature, particularly those that operate at a global scale. They are not static and do not operate in isolation; they are interconnected and constantly evolving. Indeed, they will all have some bearing on each other such is the nature of complex interconnected urban systems (Batty, 2007; Meadows, 2009; Ravetz, 2000a, 2000b; Ruth & Coelho, 2007). Scenario development methods can be usefully applied to the task of exploring how conurbations may evolve,

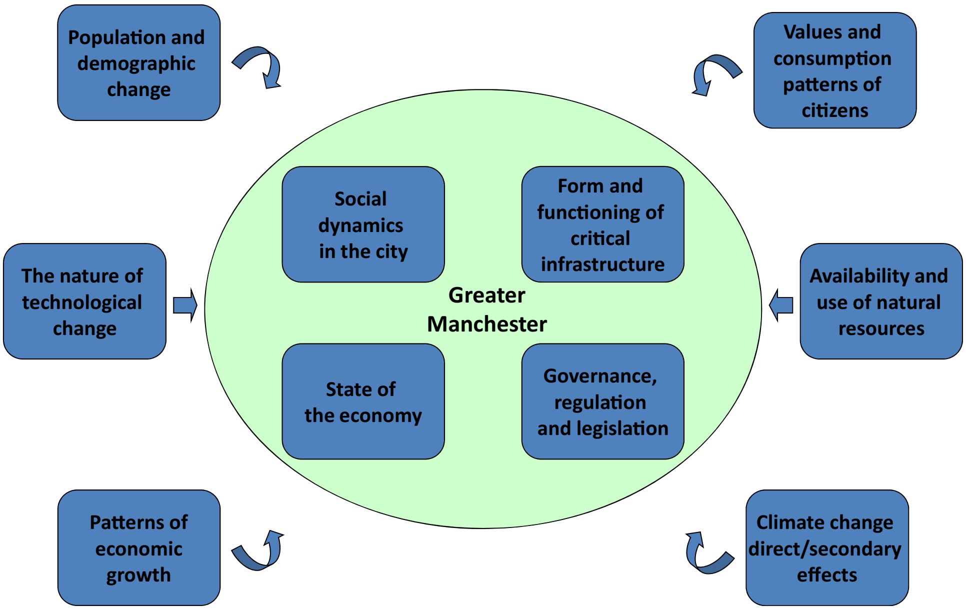

Fig. 21. Drivers of change influencing the growth and development of Greater Manchester.

influenced by such driving forces. A land use modelling exercise, informed by a scenario set developed within the EcoCities project (Carter, 2011b), mapped contrasting land use patterns for Greater Manchester to 2050 (Carter, 2012). These provided a framework for visualising and interrogating the possible implications of future land use change for the adaptation agenda, and clarified that different land use futures will lead to different adaptation futures.

In the context of urban planning, de Roo (2010, p. 9) argues that dynamism and instability is both the normal state of affairs and potentially valuable; "Situations that are "out of equilibrium" are likely to be far more common than stable situations and are a necessity for development and progress." This perspective approaches Pelling's (2011) vision of adaptation as a progressive and transformational process, and Shaw and Theobald's notion of resilience to climate change as involving "bouncing forwards" as opposed to "bouncing back" (Shaw & Theobald, 2011).

Wilkinson et al. (2010, p. 38) found that although resilience thinking has yet to widely filter into planning practice, from the experience of the planning practitioners that they studied, resilience can be usefully be applied "as a metaphor for change." Here, resilience presents an opportunity to act as a bridging concept between the natural and social sciences, and to embrace themes including dynamism and transformation (Davoudi, 2012). These themes fits well with the role of spatial planning as a central pillar in designing and creating more climate resilient cities. Planning's future perspective, cross-sectoral collaborative approach and influence across multiple spatial scales all lend well to supporting the progressive adaptation of cities and urban areas. Wilkinson et al. (2010) argue that 'resilience thinking' is relevant to planning theory and practice for reasons including the opportunity it presents to better understand the impacts of urbanisation on ecosystems, the distance it places between planning and linear thinking, the interdisciplinary approach that it encourages. Further, patterns of resilience are spatially diverse and uneven (Pike et al., 2010), implying that planning can play a role in shaping places to enhance resilience to climate change where this is needed the most.

Resilience thinking can encourage a different approach to planning and designing urban areas for future climates. Through incorporating climate change adaptation within the remit of the planning system, encompassing themes linked to urban resilience, this can stimulate changes within the system itself. As noted by Davoudi et al. (2010, p. 14):

> ...recognition of the complexity, uncertainty and irreversibility demonstrated by climate science is changing the nature and framing of spatial planning, with an increasing expectation for it to play a part in mitigation and adaptation efforts.

However, given the potential value of adopting progressive and dynamic notions of cities, and the importance of developing resilience to extreme weather and climate change, it is worrying that Jabareen (2013, p. 221) notes scholarship on the subject "...typically overlooks the multidisciplinary and complex nature of urban resilience." It appears that further research and awareness raising is needed to embed a more holistic view of cities and their relationship to the weather and climate that they experience.

Just as climate change looks set to reshape the form and function of cities and urban areas, it is appropriate that spatial planning, and our understanding of urban systems that underpins the profession, also transforms with the spaces it is designed to manage. Resilience thinking challenges traditional approaches to environmental and spatial planning, and to the role of researchers in this process, raising questions over whether appropriate urban visions and governance structures are in place to develop effective adaptation responses. The cross-cutting nature of the adaptation agenda exposes the silo based approaches that drive many organisations. In order to deliver on goals focused on resilience and adaptation, "intelligent institutional leadership" is required to identify, prepare for and respond to rapid change (Pike et al., 2010, p. 68), such as that linked to the changing climate. Here, building adaptive capacity within cities enables them to become better prepared for and able to respond to shocks and systemic changes driven by extreme weather and climate change. In effect, building adaptive capacity makes cities more resilient to climate change.

Cities and urban areas have made progress over recent years, and adaptation strategies and action plans steadily emerging, supported by research outputs and guidance on the topic. Nevertheless, adaptation has yet to become a prominent agenda amongst city governors and planners and new approaches are needed to understand and react effectively to urban adaptation challenges and opportunities. It is also clear that the development of a collaborative, sociotechnical agenda is vital. Associated research into different modes of collaboration and the utility of the outcomes they produce would be valuable, as would further enquiry on approaches to reposition and mainstream adaptation into urban development. With a view to encouraging transferable learning, comparative work on these themes engaging different cities would be constructive. There is a need to move beyond sustainable urban visions towards the grounded creation of new interdisciplinary networks, adaptive capacities and collaborative practices, assembled to respond to the adaptation imperative at the urban scale.

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