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Urban Green Infrastructure and Ecosystem Services

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Inside:

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POSTbriefs are responsive policy briefings from the Parliamentary Office of Science and Technology based on mini literature reviews and peer review.

Background

Human health and subjective wellbeing (emotional states and life satisfaction) can be considered the overarching outcome of optimal ecosystem service provision.[1] Ecosystem services are the benefits provided to humans by natural systems that range from food and water to recreation and climate regulation. Those elements of the natural environment that provide benefits to humans are referred to as 'natural capital'. The UK Natural Capital Committee have defined natural capital as 'elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans' (POSTnote 542).

In urban areas, the elements of the natural environment providing ecosystem services are referred to as 'green infrastructure'. Urban green infrastructure is not just open spaces such as parks, playing fields, cemeteries, allotments, and private gardens, but also green roofs and walls, street trees and sustainable urban drainage systems (SUDs), as well as ponds, rivers and canals. The EU green infrastructure strategy defines it as: 'a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas'. However, existing urban green infrastructure in the UK has not been strategically planned to deliver ecosystem services.

Strategic improvement of urban green infrastructure has been proposed as a cost effective public health measure.[2] There is a body of research on the benefits of exposure to vegetation and other aspects of natural habitats for human health,[3] an overview of which is provided by POSTnote 538 Green Space and Health. The specific elements of the natural environment that provide benefits are uncertain and almost all the evidence is correlative,[4] but some recent studies have suggested that the frequency of exposure to natural settings and the extent of vegetation cover may be important.[5] There is also evidence that green infrastructure can provide other ecosystem services in urban areas (POSTnote 448), demand for some of which may increase with

1 Sandifer, P and Sutton-Grier, A, 2014, Connecting stressors, ocean ecosystem services, and human health, Nat.Resour.Forum 38,157-167.
2 van den Bosch, M, and Nieuwenhuijsen, M, 2017, No time to lose - Green the cities now, Environ Int., 99:343-350.
3 ten Brink, P, *et al*, , 2016, The Health and Social Benefits of Nature and
Biodiversity Protection. A report for the European Commission (ENV.B.3/ETU/2014/0039), Institute for
European Environmental Policy, London/Brussels
4 Shanahan, D, 2015, Toward Improved Public Health Outcomes From Urban Nature, American Journal of Public Health, 105 (3): 470-477
5 Cox, D, *et al*, 2017, Doses of Nearby Nature Simultaneously Assoicated with Multiple Health Benefits, Int. J. Environ. Res. Public health, 14 (2), 172
Cox, D, *et al*, 2017, Doses of Neighbourhood Nature: The Benefits for Mental Health of Living with Nature, Biosciences, 67 (2): 147-155

climate change.[6,7] This brief provides an overview of the ecosystem service contributions of urban green infrastructure and the challenges for improving the provision of these services.

The Urban Environment

In the 21st Century, the majority of the human species will live in urban areas. In 2014, Defra estimated 45 million people in England lived in urban areas, 83% of the population.[8] The UN have estimated 60% of people globally are expected to be living in towns and cities by 2030, up from 54.5% in 2016. It projects that 662 cities will have at least 1 million residents by 2030, up from 512 cities in 2016, and the global rural population will continue to decline.[9] Urban population growth will increase demand for public services, housing and other infrastructure, placing more pressure on urban environments. Urban areas in the UK will also be affected by a range of other changes, including: a trend towards an older human population; increased energy and resource efficiency requirements; integration of 'smart' technologies and materials into urban infrastructure; and, shifts in societal values.[10] Different forms of urban development and management are likely to arise in response to these drivers, which may provide opportunities to enhance the provision of ecosystem services in urban areas. For example, systematic reviews have suggested provision of green space is important for promoting physical activity in older people and cross-sectional surveys have linked older people's life satisfaction to the quality of open spaces (POSTnote 539).

What Constitutes an Urban Area?

Three factors are commonly used as policy criteria for defining what is urban – total human population size, human population density and impervious surface area or built structures – although there is no agreed definition of an urban area.[11] Urban areas delineated on the basis of illumination at night, censuses, administrative boundaries and other supplementary data were estimated to constitute 3,500,000 km^2, around 3% of the global land surface, in 2010.[12,13] A meta-analysis of 180 studies using satellite imagery to identify urban areas

6 Raymond, C, *et al*, 2017, An impact evaluation framework to support planning and evaluation of nature-based solutions projects. Report prepared by the EKILIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas. CEH, UK.

7 EC, 2015, Towards an EU research and innovation policy agenda for nature-based solutions & re-naturing cities, Final report of the Horizon 2020 expert group on 'Nature-based solutions and re-naturing cities'

8 Defra, Official Statistics, Rural population 2014/15

9 Population Division of the Department of Economic and Social Affairs of the United Nations

10 WSP | Parsons Brinckerhoff, 2015, The UK in 2030: Key trends for the built environment

11 Seto, K, *et al*, 2011, A Meta-Analysis of Global Urban Land Expansion. PLoS ONE 6(8):): e23777

12 CIESIN, 2010, Center for International Earth Science Information Network (CIESIN), Columbia University, Gridded Population of the World (GPW), version 3 and Global Rural-Urban Mapping Project (GRUMP)

13 Liu, Z *et al*, 2014, How much of the world's land has been urbanized, really? A hierarchical framework for avoiding confusion, Landscape Ecol, 29:763–771

from built structures, showed these areas increased by 58,000 km^2 from 1970 to 2000 and estimated a further increase of 1,527,000 km^2 by 2030.[11] While these areas are dominated by the built environment and human activities, they also often encompass a variety of natural and semi-natural habitats and species. The 2011 UK National Ecosystem Assessment (NEA) estimated more than 6.8% of the UK's land area could be classified as 'urban': more than 10% of England; 1.9% of Scotland; 3.6% of Northern Ireland; and, 4.1% of Wales. The NEA classification of urban areas includes rural development, roads, railways, waste and derelict ground (including vegetated wasteland), gardens and urban trees.[14]

Urban areas are the focus of human activities and resource use, with some estimates suggesting they account for 75% of global resource consumption.[15] The resource flows in and out of urban areas, 'urban metabolism',[16] affects the provision of ecosystem services at global scale.[17] For example, the urban demand for ecosystem services, such as food provision, can only be fulfilled at a geographic scale beyond those of city boundaries.[18] However, the focus of this briefing is provision of ecosystem services from green infrastructure in and around urban areas. Urban green infrastructure mainly consists of open spaces or semi-natural areas partially or completely covered by vegetation.[19] They often constitute a significant portion of the urban area; for instance, natural/semi-natural green space with a conservation designation takes up 11% of urban land in England.[20] Given their proximity to human activity and occupancy, services supported by these areas can have disproportionate benefits.[21] For example, the economic value of the recreational benefit of woodlands near urban areas is higher than woodland in remote areas.[22]

Environmental Effects of Urbanisation

Urbanisation is the process by which a rural ecosystem, such as semi-natural grassland, becomes an urban one, and has been identified as a cause of loss, degradation and fragmentation of habitats.[23] It creates both challenges

14 Davies, L, *et al*, 2011, Chapter 10: Urban. In: The UK National Ecosystem Assessment Technical Report. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge.
15 UNEP, 2014, Climate Finance for Cities and Buildings – A Handbook for Local Government. UNEP Division of Technology, Industry and Economics (DTIE), Paris.
16 Clift, R, *et al*, 2015, Urban metabolism: a review in the UK context, Review for the Government Office for Science Foresight Future of Cities project
17 Ravetz, J, 2015, The future of the urban environment and ecosystem services in the UK, Review for the Government Office for Science Foresight Future of Cities project
18 Gómez-Baggethun, E, and Barton, D, 2013, Classifying and valuing ecosystem services for urban planning, Ecological Economics 86:235-245
19 European Commission, 2016 Mapping and Assessment of Ecosystems and their Services, Urban ecosystem, 4th Report, Technical Report 102.
20 GLUD (Generalised Land Use Database). Physical Environments, Generalised Land Use Database Statistics for England
21 Grafius, D, *et al*, 2016, The impact of land use/land cover scale on modelling urban ecosystem services, Landscape Ecology, 31: 1509-1522
Grimm, N, *et al*, 2008, Global change and the ecology of cities, Science 319: 756-760
22 Natural Capital Committee, 2015, The State of Natural Capital: Protecting and Improving Natural Capital for Prosperity and Wellbeing, 3rd Report
23 McKinney, M, 2008, Effects of urbanization on species richness: a review of plants and animals
Urban Ecosyst., 11: 161–176

and opportunities for biodiversity, the variety of living things. For example, the nature of urban areas can create opportunities for colonisation by non-native species which, in turn, may become invasive and affect native species; this is reflected in the high levels of non-native plant species in towns and cities (POSTnote 439). However, urban areas also provide habitats and food sources for predators such as foxes, rats and bats, with relationships emerging between humans and urban wildlife.[24] How such changes in local biodiversity affect ecosystem service provision is not yet fully understood (Box 1).[25,26]

Human activities in urban areas can have direct effects on ecosystem service benefits, such as air quality.[27] For example, the UK is in breach of nitrogen dioxide (NO_2) limits in 38 out of its 43 areas including in London, Leeds and Birmingham, which are projected to exceed EU air quality thresholds up to or beyond 2030.[28] The dominant source of air pollutants in UK urban environments is now emissions from vehicles (POSTnote 458). As well as affecting human health,[29] excess nitrogen deposition from air to the soil reduces the number and diversity of plant species.[30] Soils in urban areas can also be subject to high levels of pollution because of previous human activities.[31] Former factories, mines, steelworks, refineries and landfills have left a legacy of contamination by chemicals, heavy metals, tar, gases, asbestos and radioactive substances in the soils of many UK urban areas. The Environmental Audit Committee have highlighted that untreated contamination may have a negative effect on public health.[32] It noted that research studies have found a statistically significant relationships between soil metal content and respiratory

24 Adams, C, and Lindsey, K, 2011, Anthropogenic Ecosystems: the influence of people on urban wildlife populations. In: Niemelä, J., Breuste, J.H., Guntenspergen, G., McIntyre N.E, Elmqvist, T., and James, P. (eds) Urban Ecology: Patterns, Processes, and Applications. Oxford, Oxford University Press

25 Harrison, P, *et al*, 2014, Linkages between biodiversity attributes and ecosystem services: a systematic review, Ecosystem Services 9: 191-203

Tomimatsus, H, *et al*, 2013, Sustaining ecosystem functions in a changing world: a call for an integrated approach, Journal of Applied Ecology 50(5): 1124-1130

26 Newbold, T, *et al*, 2015, Global effects of land use on local terrestrial biodiversity, Nature, 520, 45-50

27 Von Dohren, P, and Hasse, D, 2015, Ecosystem disservices research: a review of the state of the art with a focus on cities, Ecol Ind 52: 490-497

Kronenberg, J, 2015, Why not to green a city? Institutional barriers to preserving urban ecosystem services, Ecosystem Services, 12: 218-227 ?

28 House of Commons Environment, Food and Rural Affairs Committee, Air quality, Fourth Report of Session 2015–16, HC479

House of Commons, Environmental Audit Committee, Action on Air Quality, Sixth Report of Session 2014-15, HC212

29 WHO Regional Office for Europe, 2016, Urban Green Spaces and Heath

30 Power, S, *et al*, 2011, Effects of vehicle exhaust emissions on urban wild plant species, Environmental Pollution, 159: 1984-1990

31 Elmqvist, T, *et al*, 2015, Benefits of restoring ecosystem services in urban areas, Current Opinion in Environmental Sustainability 14:101-108

32 House of Commons Environmental Audit Committee, Soil Health, First Report of Session 2016–17, HC 180

illnesses in Glasgow,[33] and between self-reported poor health and the proportion of local authority ward area comprising brownfield sites.[34]

As noted above, a predominant characteristic of urban areas is the extent of impervious surfaces. Degraded, sealed soils beneath impervious surfaces, urban buildings and infrastructure will not provide a range of ecosystem service benefits provided by unsealed and intact soils, such as pollutant attenuation and surface water flow attenuation. Urban landscapes comprising 50-90% impervious surfaces can result in 40-83% of incoming rainfall becoming surface water runoff.[35] In the UK, the piped drainage systems built before 1940 to remove surface water usually combine urban runoff in the same pipe as raw sewage. During heavy rainfall, excess combined sewage bypasses treatment works, discharging directly into watercourses through overflow pipes. Newer systems direct urban runoff and sewage through separate pipes, but surface water, containing urban pollutants, still tends to discharge directly into watercourses without treatment.

In 2007, the Royal Commission on Environmental Pollution 26th report on the Urban Environment set out the evidence for how urbanisation can affect human wellbeing. It made recommendations to Government on the need for a coherent policy framework that recognised the complexity of urban areas and their contribution to meeting environmental targets and improving the health and wellbeing. This included planning policy and guidance that described the range of functions and benefits associated with the natural environment of urban areas and promoted the use of green infrastructure. However, although strategic improvements in urban green infrastructure can mitigate some of the adverse environmental effects of urbanisation, they will be insufficient without other policies to reduce negative effects of urbanisation. For instance, urban air pollution is most effectively addressed by reducing traffic rather than increasing levels of vegetation to trap air pollutants (see below).

33 Morrison, S, *et al*, 2014 An initial assessment of spatial relationships between respiratory cases, soil metal content, air quality and deprivation indicators in Glasgow, Scotland, UK: relevance to the environmental justice agenda, Environ Geochem & Health, 36(2): 319–332

34 Bambra, C, *et al*, 2014, Healthy Land? An examination of the area-level association between brownfield land and morbidity and mortality in England, Environment and Planning A, 46:433-454

35 Pataki, D, *et al*, 2011, Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions and misconceptions, Front. Ecol. Environ, 9:27-36

Box 1. Maintenance of Ecological Processes and Biodiversity

The integrity of ecological systems is assessed by measures of the ability of an ecosystem to support and maintain the ecological processes related to energy flow, mineral cycling and water cycling.[36] This includes the structures in ecosystems, such as physical habitats, the array of species which depend on them and the interactions between the species, habitats and processes (structure, composition and function).[37,38] For example, soil is composed of living organisms, minerals, organic matter, air and water. A single gram of soil may contain millions of individual cells and thousands of species of bacteria. Soil organisms build and maintain soil structure and influence its chemical properties by weathering bedrock, aggregating mineral and organic constituents and developing the resulting porous structure of soil, which provides a range of habitats. This structure in turn affects the movement of water and gases and the transfer of nutrients and energy. Soil communities are highly diverse and vary greatly depending on factors such as air, temperature, acidity, moisture, nutrient content and organic matter.[39]

When an ecosystem has integrity, it should be withstand and recover from most disturbances that occur naturally, such as droughts, or from human disruption.[36] However, assessing the integrity of an ecosystem requires understanding of what attributes of an ecosystem are most crucial to maintaining it.[37] For example, the connections between biodiversity and the functioning of ecosystems have only been studied in small scale experiments. New approaches will be needed to understand the consequences of large scale changes in biodiversity over longer time scales.[40] In the case of soils, it is known that soil organisms maintain ecological processes, such as carbon storage, nutrient cycling and plant species diversity, as well as soil fertility, but extent of their role in ecosystem functions and services are not yet fully understood. Species richness (the number of species represented in an area) is known to be important for ecosystem functioning.[41] For example, reductions in soil biodiversity reduce nitrogen cycling in leaf litter,[42] affecting ecosystem service benefits, such as timber production. Highly urbanised ecosystems usually have reduced species richness, but more moderate levels of urbanisation, such as suburban areas, may increase species richness for some groups of species, such as plants and birds.[47,14] Ecological studies have also suggested that levels of 'functional diversity', the diversity of organisms' characteristics or traits linked to their roles in ecosystems, like being a pollinator, is critical to maintaining ecosystem functioning.[43,44] An assessment of 4,424 species that contribute to some ecosystem functioning in Great Britain showed declines over forty years.[45]

36 Parrish, J, *et al*, 2003, Are we conserving what we say we are? Measuring ecological integrity within protected areas, BioScience, 53: 851 - 860

37 Wurtzebach, Z, and Schultz, C, 2016, Measuring Ecological Integrity: History, Practical Applications, and Research Opportunities, BioScience, 66 (6): 446-457

38 Mace, G, *et al*, 2011, Conceptual Framework and Methodology, In: The UK National Ecosystem Assessment Technical Report, UK National Ecosystem Assessment, UNEP-WCMC, Cambridge.

39 Heinrich Böll Foundation, Berlin, Germany, and the Institute for Advanced Sustainability Studies, The Soil Atlas 2015

40 Brose, U, and Hillebrand, H, 2016, Biodiversity and ecosystem functioning in dynamic landscapes, Philos Trans R Soc Lond B Biol Sci., 371(1694): 20150267

41 Hooper, D, *et al*, 2012, A global synthesis reveals biodiversity loss as a major driver of ecosystem change, Nature, 486, 105–108

42 Bardgett, R and van der Putten, W, 2014, Below ground biodiversity and ecosystem functioning, Nature, 515 (7528), 505-511

43 Mace, G, *et al*, 2014, Approaches to defining a planetary boundary for biodiversity, Global Environmental Change, 28:289-297

44 Tilman, D, *et al*, 2014, Biodiversity and ecosystem functioning, Annual Review of Ecology, Evolution, and Systematics, 45, 471–493

45 Oliver, T *et al*, 2015, Declining resilience of ecosystem functions under biodiversity loss, Nature Communications 6:10122

Urban Natural Capital

The value of green infrastructure is enhanced through appropriate management of its natural capital. Monetary and nonmonetary valuation methods of natural capital can be applied to urban green infrastructure (POSTnote 542). For example, Birmingham City Council and its partners have devised a Natural Capital Planning Tool (NCPT). This has calculated the value of green infrastructure as £400m of benefit to the local government over a 25-year timeframe.[46] The Natural Capital Committee's 4th Report to the Government's Economic Affairs Committee highlighted the importance of the Government's natural capital pioneer projects for establishing templates for best practice, which include an urban pioneer project in Greater Manchester.[47] It also recommended that local authorities and major infrastructure providers should ensure that natural capital is protected and improved.[48] The National Infrastructure Commission have subsequently highlighted the need to consider natural capital in the planning of future infrastructure.[49] The Natural Capital Initiative is helping the construction industry to develop natural capital tools, such as approaches to ensuring green infrastructure delivers a range of ecosystem services.[50]

The Department for Business, Energy and Industrial Strategy (BEIS) have funded an Ordinance Survey open data initiative to map green spaces throughout Great Britain.[51] The urban green space data from this project, along with property information, is being used by ONS and Defra to value natural capital in urban environments within the UK. It will identify the variety of different greenspaces and provide information on their extent, function and accessibility, and the provision of ecosystem services.[52]

Key Services for Urban Ecosystems

The Millennium Ecosystem Assessment (MA) split ecosystem services into four main categories (POSTnote 377): supporting services (such as nutrient cycling), regulating services (such as pollination), provisioning services (such as food) and cultural services (such as recreation).[53] The European Environment Agency's Common International Classification of Ecosystem Services (CICES) developed for natural capital accounting (POSTnote 542) splits ecosystem services into just regulating, provisioning and cultural services.[54] The supporting services are treated as an integral part of the functioning of ecosystems (Box 1). Types of habitats differ in the contribution they make to the provision of different ecosystem services. For instance, forests play a key role in carbon storage and sequestration. Urban ecosystems are distinct in terms of the high coverage of

46 Hölzinger, O, 2013, Tool Guidance: Natural Capital City Tool (NCCT) for Birmingham, version 5
47 Urban Pioneer Greater Manchester Scope
48 Natural Capital Committee, 2017, Improving Natural Capital: An assessment of Progress
49 National Infrastructure Commission, 2017, The impact of the environment and climate change on future infrastructure supply and demand
50 Natural Capital in the Construction Industry
51 Ordnance Survey releases open dataset and free map of Britain's Greenspaces
52 OS MasterMap Greenspace Layer
53 Millennium Ecosystem Assessment
54 European Environment Agency, CICES

impermeable surfaces, the density of the human population and the levels of air and noise pollution. Most studies of urban ecosystems have concentrated on the subset services that contribute to mitigating the effects of urban ecosystems on human wellbeing.[55] For example, the Mapping and Assessment of Ecosystems and their Services (MAES) project identified sixteen main urban ecosystem services (Table 1) based on the CICES classification and the UK NEA nine based on MA classification (Table 2).

However, which ecosystem services are most relevant in a given city will depend on its environmental, social and economic characteristics. Findings from the Urban Biodiversity and Ecosystem Services research project across seven cities in Europe and the US suggest that cultural services, such as recreation, education and cultural heritage, are some of the most valued in urban areas.[56] Communities are more likely to support management measures if they enhance cultural services,[57] but they can be difficult to quantify and place monetary values on.[58] This raises challenges for their inclusion in urban planning and for decision-making where trade-offs have to be made between levels of provision of different ecosystem services.[59] Examples of services considered important for human wellbeing in urban areas include:

- **Urban temperature regulation**: Urban areas often experience elevated ambient temperatures compared with the surrounding countryside. This is because cities and towns have extensive heat absorbing surfaces, such as concrete and tarmac, concentrated heat production and impeded air flow.[60] For example, the centre of London is on average 5°C warmer than surrounding rural areas,[61] which can increase the risks of heat stroke and exhaustion during heatwaves. Green infrastructure can lower air temperatures through the evaporation of water from vegetation, shading and modifying wind flow.[62,63] However, the configuration, size and type of green infrastructure determines the extent of cooling effects beyond the immediate area.[61] For instance, the combined green spaces of

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55 Derkzen, M, *et al*, 2015, Quantifying urban ecosystem services based on high-resolution data of urban green space: an assessment for Rotterdam, the Netherlands, J Appl Ecol, 52(4), pp.1020-1032

Gómez-Baggethun, E, and Barton, D, 2013, Classifying and valuing ecosystem services for urban planning, Ecological Economics 86:235-245

56 Kremer, P, *et al*, 2016, Key insights for the future of urban ecosystem services research, Ecology and Society, 21 (2): 29

57 Andersson, E, *et al*, 2015, Cultural ecosystem services as a gateway for improving urban sustainability, Ecosystem Services 12: 165-168

58 Gómez-Baggethun, E, and Barton, D, 2013, Classifying and valuing ecosystem services for urban planning, Ecological Economics 86:235-245

59 Langemeyer, J, *et al*, 2016, Bridging the gap between ecosystem service assessments and land-use planning through Multi-Criteria Decision Analysis (MCDA), Environmental Science and Policy: 62:45-56

60 Arnfield, A. J., 2003, Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island, International Journal of Climatology, 23, 1-26

61 University College London. LUCID Project

62 Pataki, D, *et al*, 2011, Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions and misconceptions, Front. Ecol. Environ, 9:27-36

Gill, s, *et al*, 2007, Adapting our cities for climate change: the role of green infrastructure, Built Environ, 33: 115-133

63 Gunwardena, K, et al, 2017, Utilising green and bluespace to mitigate urban heat island intensity. Science of the Total Environment, 584-585: 1040-1055

Richmond Park and Wimbledon have a notable cooling effect on London's atmospheric heat island, whereas the linear Lee Valley Park does not.[61,64]

- **Provision of community food**: The amount of food UK urban areas can produce is limited; for example, London urban farming produced 21 metric tonnes (MT) of food in 2013,[65] compared to 12,101,000 MT of wheat across the UK in total.[66] However, community food production, such as allotments, can be multifunctional, providing well-established social and health-related benefits.[67] There are around 20,000 ha of allotments in England.[68] Those involved in gardening have increased levels of exercise and tend to eat more vegetables (POSTnote 499).[69]
- **Improving air quality**: vegetation can reduce air pollution directly by trapping and removing fine particulate matter and indirectly by reducing air temperatures. However, the effects of the various vegetation types deployed in different built environments has yet to be fully evaluated and quantified. For example, green roofs and walls may improve air quality, but only a small number studies have been undertaken. Vegetation and trees in open areas can reduce exposure to pollution,[70,71] but beneficial effects depends on multiple factors, such as the weather, wind flow conditions, the pollution concentration, and the type, location and quality of vegetation.[72,73] For example, if the configuration of street trees along busy roads is not adequately planned, they may trap and contain air pollution leading to a deterioration in air quality compared to roads without trees, as highlighted in recent guidance from National Institute for Health and Care Excellence (Nice).[74] By contrast, 1.5 to 2.5 m hedges planted along such roads can improve air quality.[71,75]
- **Reducing surface water flooding**: Reduced infiltration in areas with high levels of impermeable surfaces leads to rapid surface flows into pipes, culverts and channelised urban waterways, increasing peak flood

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64 ARUP, 2014, Reducing Urban Heat Risk: A Study on Urban Heat Risk Mapping and Visualisation.
65 Sustain, 2014. Reaping rewards: can communities grow a million meals for London?
66 Defra, 2013. Farming Statistics – 2013 wheat and barley production, UK
67 Soga, M. *et al*, 2017, Health Benefits of Urban Allotment Gardening: Improved Physical and Psychological Wellbeing and Social Integration. Int. J. Environ. Res. Public Health, 14, 71; doi:10.3390
68 Campbell, M. and Campbell, I. (2009) A survey of allotment waiting lists in England. National Society of Allotment and Leisure Gardeners (NSALG).
69 Pearson, J, *et al*, 2010, Sustainable urban agriculture: stocktake and opportunities, International Journal of Agricultural Sustainability, 8(1-2):7-19
70 Escobedo, F, *et al*, 2011, Urban forests and pollution mitigation: analysing ecosystem services and disservices, Environ Pollution, 2011, 159: 2078-2087
71 Irga, P, *et al*, 2015, Does urban forestry have a quantitative effect on ambient air quality in an urban environment? Atmos. Environ. 120, 173-181
72 Vos, P, *et al*, 2013, Improving local air quality in cities: to tree or not to tree? Environmental Pollution 2013, 183: 113-122
Setälä, H, *et al*, 2013, Does urban vegetation mitigate air pollution in northern conditions? Environ Pollut, 183: 104-112
73 Abhijith, K, *et al*, 2017, Air pollution Abatement Performances of Green Infrastructure in Open Road and Built-up Street Canyon Environments – A Review. Atmospheric Environment
74 NICE guideline Draft for consultation, 2016, Air pollution: outdoor air quality and health
75 Gromke, C, *et al*, 2016, Influence of roadside hedgerows on air quality in urban street canyons, Atmos. Environ., 139:75-86

flows.[76] OFWAT has highlighted that accommodating the increasing volume of surface water flows expected with climate change in piped drainage systems would be prohibitively expensive.[77] Green infrastructure, such as parks, reduces urban runoff by enabling rainfall to soak into the underlying soil. Sustainable drainage systems (SuDS) provide natural drainage processes through a network of predominantly above-ground surface water management features, such as swales (POSTnote 529). They channel, slow and store surface water and control the rate it enters sewers and watercourses. SuDS have similar costs to conventional drainage systems and can provide a range of additional benefits, such as improving biodiversity, amenity, and air quality, as well as reducing the warming effect of densely packed buildings in urban areas.[78] In addition to SuDS, restoration of urban watercourses, their associated riparian vegetation and connections to floodplains, can be used to convey or store urban run-off while encouraging water infiltration and improving water quality.[74]

- **Reducing pollution of urban watercourses**: Diffuse pollution of urban waterways arise from numerous small pollution sources that are conveyed into watercourses via surface water run-off from paved surfaces. Water contaminated with urban pollutants requires additional treatment before it is fit for human consumption, as well as reducing the recreational and cultural amenity of watercourses (POSTnote 529). One of the additional benefits of SuDS are the removal of urban pollutants before it enters watercourses. They can also reduce the amount of surface water entering combined sewage systems and likelihood of subsequent discharges of untreated sewage into watercourses during heavy rainfall events.
- **Noise Reduction:** Transport, construction and other activities make noise a major problem in towns and cities, affecting health through physiological and psychological effects. WHO have estimated the range of disease burden in Europe from noise at 1.0 – 1.6 million Disability Adjusted Life Years (a measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or early death).[79] Studies have suggested that vegetation can attenuate noise by absorption, dispersal and destructive interference of sound waves, and soils can indirectly reduce noise through their absorptive capacity.[80] The effectiveness of vegetation in reducing noise depends on: how close it is to a noise source (the closer it is, the more noise it mutes), the noise frequency and the type of vegetation. Other factors that can mediate its effectiveness are sound duration, climate (temperature, humidity, wind direction, wind speed) and soil type.[81] However, some studies suggest people overrate the ability of

76 Dadson, J, *et al*, 2017, A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK, Proc. R. Soc. A, 473:20160706

77 Ofwat, 2008, Preparing for the future – Ofwat's climate change policy statement

78 CIRIA, 2015, The SuDS Manual

79 WHO Regional Office for Europe, 2011, Burden of disease from environmental noise. Quantification of healthy life years lost in Europe. .

80 Van Renterghem, T, *et al*, 2012, Road traffic noise shielding by vegetation belts of limited depth, Journal of Sound and Vibration, 331, 2404–2425

81 Derkzen, M, *et al*, 2015, Quantifying urban ecosystem services based on high-resolution data of urban green space: an assessment for Rotterdam, the Netherlands, J Appl Ecol, 52(4), pp.1020-1032

vegetation to attenuate noise, suggesting there is also a psychological effect.[82]

- **Carbon Storage:** Although the contribution to overall carbon storage will be limited compared to more extensive habitat types, urban ecosystems are potential carbon reservoirs.[83] Almost all above-ground carbon storage is in tree biomass, with only a small amount stored in shrubs and herbaceous borders. For example, a study has estimated that trees account for 97% of total carbon stored in biomass in Leicester.[81] The management of trees, mown lawns and flower beds found in many urban ecosystems may also result in more GHGs being emitted than carbon stored.[79] Soil carbon content is usually defined by the amount of organic matter contained within it. Soil microbes can make carbon and nitrogen available to plants, immobilise carbon and nitrogen in soil, and also decompose organic material to CO_2 (POSTnotes 486 and 502). The amount of carbon stored in urban green space top soils can be significant, particularly in domestic gardens.[84] However, the ability of urban soil to store carbon is reduced when it is degraded or disturbed, as will be the other beneficial processes it provides, such as water filtration. The mosaic of land uses in urban areas leads to diverse patchwork of soil types, a substantial part of which are sealed under impervious surfaces.[85] A study in Leicester, looking at soils across the city, including under sealed surfaces, found that he amount of organic carbon stored (20.2 kg OC m^{-2}) was substantially higher than in rural arable soils (14.3 kg OC m^{-2}). Based on the estimates of carbon storage in soil and above ground biomass for Leicester, the study estimated that 17.6 kg m^{-2} of carbon is stored across the entire typical UK urban area.[86]
- **Environmental Settings and Biodiversity:** The UK NEA highlighted the conceptual difficulties in defining cultural ecosystem services (non-material benefits). It suggests 'environmental settings' (Table 2) as the relevant ecosystem service; places where humans interact with each other and with nature to give rise to cultural goods and benefits, such as recreation. Individuals will experience multiple cultural goods and benefits from environmental settings, but as these settings range from land and seascapes to urban parks and gardens, they will support different aggregations of goods and benefits.[87] The different characteristics of environmental settings that constitute cultural services may also be affected by the absence or presence of species.[88] Human interactions with animals

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82 Yang, F, *et al*, 2011, An assessment of psychological noise reduction by landscape plants, International Journal of Environmental Research & Public Health, 8, 1032-48.

83 Davies, Z, *et al*, 2011, Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale, J Appl Ecol, 48, pp. 1125–1134

84 Cameron, R. *et al*, 2012, The Domestic Garden – Its Contribution to Urban Green Infrastructure, Urban Forestry and Urban Greening, 11 (2): 129-137

85 Gaston, K *et al*, 2010, Urban environments and ecosystem functions, In: Urban Ecology, Ed. Gaston, K (Ecological Reviews), Cambridge University Press

86 Edmondson, J, *et al*, 2012, Organic carbon hidden in urban ecosystems, Scientific Reports 2, Article number: 963

87 Church, A, *et al*, 2011, Chapter 16: Cultural Services, In: The UK National Ecosystem Assessment Technical Report, UK National Ecosystem Assessment, UNEP-WCMC, Cambridge

88 Hinchliffe, S, *et al*, 2005, Urban Wild Things: a cosmopolitical experiment, Society & Space, 23, 643–658

and plants could generate cultural goods if people value environmental settings where certain types of wild animals or plants are present,[85] but the majority of the limited available evidence are largely observational studies.[89] For example, a perennial meadow experiment at ten urban green-spaces in southern England (five experimental sites and five control sites) assessed green-space visitor responses to the creation of biodiverse urban meadows. While responses varied between visitor types, on average people preferred naturalistic vegetation and all of the meadow treatments where preferred to the standard amenity mown grass. Meadows that contained more plant species had the highest preference scores. They were seen as less pleasing in winter, but visitors were willing to tolerate this when provided with information on their additional benefits, such as increased levels of plant and insect biodiversity.[90] However, other studies that have used objective metrics of biodiversity, such species richness (Box 1), are inconclusive and suggest a complex relationship between biodiversity and self-reported wellbeing (the 'people-biodiversity paradox').[91,87,92] Some studies suggest that abilities to perceive levels of diversity is often poor,[87,93,94,90] and that interactions are influenced by people's perceptions of biodiversity rather than actual levels present. Given the complex social and ecological factors that may influence the outcome of interactions,[95,96,90] carefully designed interdisciplinary studies would be needed to understand the relationships between urban biodiversity and cultural ecosystem services.[90]

- **Pollination:** Domestic and community gardens, as well as vegetation occurring in other types of urban green infrastructure, benefit from pollinators. Urban ecosystems can support high levels of diversity for some groups of pollinators, such as bumblebees, but this requires a network of good quality habitats for pollinators (such as flowering meadows) in close proximity to areas benefitting from pollination.[97] For example, bee abundance on green roofs and in managed green spaces in Switzerland was positively correlated with connectivity to surrounding habitat.[98] Increasing floral resources in urban green spaces, such as gardens, can increase pollinator abundance and diversity.[99] However, systematic studies

89 Shwartz, A, *et al*, 2014, Enhancing urban biodiversity and its influence on city-dwellers: An experiment. Biological Conservation, 171: 82-90
90 Southon, G, *et al*, 2017, Biodiverse perennial meadows have aesthic value and increase resident's perceptions of site quality in urban green-space, Landscape and Urban Planning: 158: 105-118
91 Fuller, R, and Irvine, K, 2010, Interactions between people and nature in urban environments, Pages 137-171 in Gaston, K.J., ed. Urban Ecology. Cambridge University Press.
92 Pett, T, *et al*, 2016, Unpacking the People-Biodiversity Paradox: A Conceptual Framework, BioScience 66 (7): 576-583
93 Dallimer, M, *et al*, 2012, Biodiversity and the feelgood factor: Understanding associations between self-reported human wellbeing and species richness. BioScience 62:47-55
94 Fuller, R, *et al*, 2007, Psychological benefits of greenspace increase with biodiversity. Biol Lett, 3: 390-394
95 Hartig, T, *et al*, 2014, Nature and Health, Annual Review of Public Health, 35: 207-28
96 Lovell, R, *et al*, 2014, A systematic review of the health and wellbeing benefits of biodiverse environments. Journal of Toxicology and Environmental Health B 17:1-20
97 IPBES,2016, Assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production.
98 Braaker, S, *et al*, 2014, Habitat connectivity shapes urban arthropod communities: the key role of green roofs, Ecology 95: 1010-1021.
99 Dicks, L, *et al*, 2010, Bee conservation: evidence for the effects of interventions.

that compare the value of different urban habitats for pollinators in multiple cities are lacking.[100] Studies have shown that urban areas are able to successfully support pollinator conservation measures,[101] such as reseeding road verges and altering mowing regimes to provide resources for pollinators.[95] For example, under England's National Pollinator Strategy the Highways Agency are committed to creating area of species rich grasslands on estimated at 3,500 ha of road verges by 2021. However, commentators suggest more studies are need to understand which measures would most effectively support pollinators in urban areas;[98] for instance, the benefits of managing road verges for pollinators could be offset by mortalities from vehicle strike.[102]

Assessing Levels of Service Provision

The MA defined ecosystem condition as the capacity to provide ecosystem services. However, ecosystem services can be dependent on processes that act and interact at different scales. Some services may be directly supplied to the immediate urban areas, such as pollination, but others like carbon storage may contribute less directly, working instead at a regional/national/international scale over longer time periods. Greater understanding of how biodiversity generates ecosystem services benefits in different urban habitats and at different scales may be required to be able to effectively assess ecosystem condition.[103,104]

Although current methods and data for testing relationships between biodiversity and service delivery remain imprecise and uncertain,[105,106] the total extent and spatial configuration of green infrastructure is known to be critical for the capacity to provide some ecosystem services.[53] Urban green infrastructure consists of a fragmented mosaic of diverse smaller patches of vegetation with different uses within which larger areas such as parks are set. This mosaic will include remnants of original vegetation, brownfield land, established new vegetation, areas of bare ground and areas being colonised by plants.[107,108] Mapping where, when and what services are provided by

100 Senapathi, D, *et al*, 2016, Landscape impacts on pollinator communities in temperate systems: evidence and knowledge gaps, Functional Ecology, 31:26-37
101 Baldock, D, *et al*, 2015, Where is the UK's pollinator biodiversity? The importance of urban areas for flower visiting insects, Proceedings of the Royal Society of London B: Biological Sciences 282 (1803)
Hicks, D, *et al*, 2016, 'Food for Pollinators: Quantifying the Nectar and Pollen Resources of Urban Flower Meadows'. PLoS ONE, vol 11
102 Baxter-Gilbert, J, *et al*, 2015, Road mortality potentially responsible for billions of pollinating insect deaths annually, Journal of Insect Conservation, 19 (5): 1029-1035
103 McPhearson, T, *et al*, 2016, Advancing urban ecology towards a science of cities, BioScience 66 (3): 198-212
104 Kremer, P, *et al*, 2016, Key insights for the future of urban ecosystem services research, Ecology and Society, 21 (2): 29
105 Grafius, D, *et al*, 2016, The impact of land use/land cover scale on modelling urban ecosystem services, Landscape Ecology, 31: 1509-1522
106 Baro, F, *et al*, 2015, Mismatches between ecosystem services supply and demand in urban areas: a quantitative assessment in five European cities. Ecol. Indic. 55, 146-158
107 Gaston, K, *et al*, 2013, Managing urban ecosystems for goods and services, Journal of Applied Ecology, Volume 50 (4): 830–840
108 Su, S, *et al*, 2012, Characterising landscape pattern and ecosystem service value changes for urbanisation impacts at an eco-regional scale, Applied Geography, 34: 295-305

this combination of physical, ecological and social features in an urban area could inform planning, and there is an increasing number of studies on urban ES mapping approaches.[109] For example, the ONS Data Science Campus in collaboration with ONS's Natural Capital Accounting have been investigating the potential for a nation-wide dataset describing publicly accessible trees surrounding the urban road network, using street-level imagery and satellite data.[110]

Action 5 of the EU Biodiversity Strategy to 2020 requires member states to map and assess ecosystems, and the European Commission has provided guidance for mapping and assessing urban ecosystems (MAES).[19] Mapping of urban green infrastructure can be based on a structural classification of the elements of green infrastructure, such as land cover types or vegetation characteristics (such as tree height),[111] on a functional classification of the uses of green infrastructure, such as land use type or purpose (e.g. allotments),[112] or a mixture of both.[113] However, although models have been developed that allow the evaluation of multiple services,[114] such as InVEST and ARIES,[115] without use of high resolution data the complexities of urban landscapes will not be represented.[116] Commentators have also suggested better understanding of complexity of the interactions that give rise to ecosystem services are needed if mapping approaches are to be effective predictors of provision.[102,101]

Ecosystem Disservices

Urban ecosystems can also give rise to ecosystem disservices. These are interactions with biodiversity and ecosystems that give rise to actual or perceived negative effects on human health, such as pests and diseases,[117] or reduce levels of an ecosystem service benefit.[118,119] They can arise from both from relatively undisturbed ecosystems or human activities that alter

109 Pulighe, G, *et al*, 2016. Insights and opportunities from mapping ecosystem services of urban green spaces and potentials in planning, Ecosystem Services 22 (Part A):1–10
110 Data Science Campus, Mapping the urban forest
111 Grafius, D, *et al*, 2016, The impact of land use/land cover scale on modelling urban ecosystem services, Landscape Ecology, 31: 1509-1522
112 Green Surge FP7 Research Project
113 European Urban Atlas
114 Crossman, N, *et al*, 2013, A blueprint for mapping and modelling ecosystem services, Ecosystem. Serv., 4: 4-14.
115 InVEST and ARIES
116 Grafius, D, *et al*, 2016, The impact of land use/land cover scale on modelling urban ecosystem services, Landscape Ecology, 31: 1509-1522
Derkzen, M, *et al*, 2015, Quantifying urban ecosystem services based on high-resolution data of urban green space: an assessment for Rotterdam, the Netherlands. J Appl Ecol, 52(4), pp.1020-1032
117 Oosterbroek, B, *et al*, 2016, Assessing ecosystem impacts on health: A tool review, Ecosystem Services, 17: 237-254
118 Shackleton, C, *et al*, 2016, Unpacking Pandora's Box: Understanding and Categorising Ecosystem Disservices for Environmental Management and Human Wellbeing, Ecosystems, 19: 587-600
119 Lyytimäki, J, and Sipilä, M, 2009, Hopping on one leg: The challenge of ecosystem disservices for urban green management, Urban Forestry and Urban Greening 8: 309-315

ecosystems.[120] For example, the natural diversity of organisms in soil may include disease-causing organisms that directly affect human health, such as parasitic worms (helminths).[121] However, the loss of soil diversity may also affect human health, as interactions between soil bacteria and the bacteria found on skin and in the gut may have a beneficial influence on the human immune system.[122] The gut microbiota of inhabitants of urban areas in developed countries is greatly reduced in comparison to hunter gathers and rural farmers in developing countries.[123] Gut microbiota of limited diversity is characteristic of human inflammation-associated conditions, such as obesity (POSTnote 495) and inflammatory bowel disease.[124] Reduced skin microbiota diversity is also characteristic of some skin disorders, such as eczema and psoriasis.[125]

The concept of disservices is intended to establish a comprehensive overview of the net effects for environmental planning than solely concentrating benefits.[117] Some disservices can be prevented or controlled, such as stopping an invasive non-native plant species from becoming established in an urban area that will have adverse effects on human wellbeing (POSTnote 439). Other negative effects on human wellbeing may arise from cultural perceptions, such as the fear of overgrown green spaces (POSTnote 538). Such perceptions may vary between individuals depending on factors such as age, gender and socioeconomic status.[126,127] Discussions between urban residents that enjoy benefits from green infrastructure and those that incur disservices may be necessary to inform polices and ensure levels of any disservices are tolerable. For example, a masterplan was developed in consultation with the local community to regenerate Burgess

120 Lyytimäki, J, 2015, Ecosystem disservices: Embrace the catchword. Ecosystem Services, 12: 136

121 Baveye, P, *et al*, 2016, Soil "Ecosystem" Services and Natural Capital: Critical Appraisal of Research on Uncertain Ground, Frontiers in Environmental Science, 4 (41)

122 Wall, D, *et al*, 2015, Soil Biodiversity and Human Health, Nature, 528: 69-75

123 World Health Organization and Secretariat of the Convention on Biological Diversity, 2015, Connecting Global Priorities: Biodiversity and Human Health, A State of Knowledge Review

Rook, G, 2013, Regulation of the immune system by biodiversity from the natural environment: An ecosystem service essential to health, Proc Natl Acad Sci USA 110 (46): 18360–18367

De Filippo, C, *et al*, 2010, Impact of diet in shaping gut microbiota revealed by a comparative study in children from Europe and rural Africa, Proc Natl Acad Sci USA 107(33):14691–14696.

124 Rook, G,2010, 99th Dahlem conference on infection, inflammation and chronic inflammatory disorders: darwinian medicine and the 'hygiene' or 'old friends' hypothesis, Clinical and Experimental Immunology, 160 (1), 70-79

Garn, H, *et al*, 2016, Current concepts in chronic inflammatory diseases: Interactions between microbes, cellular metabolism, and inflammation, Journal of Allergy and Clinical Immunology, 138 (1), 47-56

125 World Health Organization and Secretariat of the Convention on Biological Diversity, 2015, Connecting Global Priorities: Biodiversity and Human Health, A State of Knowledge Review

Hanski I, *et al*, 2012, Environmental biodiversity, human microbiota, and allergy are interrelated, Proc Natl Acad Sci USA 109(21):8334–8339.

126 Maruthaveeran, S, and van den Bosch, C, 2014, A socio-ecological exploration of fear of crime in urban green spaces: A systematic review, Urban Forestry and Urban Greening 13: 1-18

127 Von Dohren, P, and Haase, D, 2015, Ecosystem disservices research: A review of the state of the art with a focus on cities, Ecological Indicators

Park in Southwark that met the needs of the community while enhancing levels of biodiversity.[128] However, studies on ecosystem disservices remain limited compared to ecosystem services.[125]

Planning Green Infrastructure

If strategically designed and planned, green infrastructure can deliver multiple benefits for human wellbeing. UK cities, such as Birmingham, Manchester and London, are producing green infrastructure plans to address this.[129,130,131] Paragraph 99 of the England's National Planning Policy Framework (NPPF) requires that Local Plans should take account of climate change over the longer term, including factors such as flood risk, coastal change, water supply and changes to biodiversity and landscape. Green infrastructure should be planned as climate adaptation measures to manage these risks. However, realising benefits from green infrastructure also requires the right built infrastructure in the right place. At one end of the possible development spectrum are extensive low density urban areas where built land and green spaces, such as large suburban gardens, are interspersed.[132] Suburban gardens are a significant component of the UK's urban green infrastructure, an estimated 13% of urban land, although it is decreasing because of increasing conversion to impermeable surfaces and infill development (gardens being sold for development).[133,134]

At the other end of the spectrum are compact urban areas alongside separate, large, contiguous green space, such as a greenbelt (see HoCL Briefing SN00934).[130] The 2017 white paper, 'Fixing our broken housing market' (SN03741), highlighted the Government's intention to conserve greenbelts and to amend England's National Planning Policy Framework to encourage building on previously used sites, brownfield land. In 2010, there was around 1.6 million ha of greenbelt, equating to 13% of England's land area,[135] and 68,910 ha of brownfield land, 0.5% of England's land area.[136] Studies have suggested that that compact urban forms are needed for maintaining the majority of ecosystem services and biodiversity, but that some interspersion of green and built infrastructure may also be necessary to ensure that people benefit from

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128 LDA Design, Burgess Park
Shepherd P, 2017, Designing biodiversity into multi-use urban park and green infrastructure, BSG Ecology, Presentation at CIEEM Spring Conference 2017, Mainstreaming Biodiversity into Future Cities
129 Birmingham City Council, Green Living Spaces Plan
130 Manchester City Council, 'Green and Blue Infrastructure' consultation
131 Green Infrastructure Task Force Report, 2015, Natural Capital: Investing in a Green Infrastructure for a Future London
132 Lin, B, and Fuller, R, 2013, Sharing or sparing? How should we grow the world's cities? Journal of Applied Ecology 2013, 50, 1161–1168
133 GLUD (Generalised Land Use Database), 2005, Physical Environments, Generalised Land Use Database Statistics for England 2005
134 Dallimer, M, *et al*, 2011, Temporal changes in greenspace in a highly urbanised region, Biol Lett, 7: 763–766
135 CPRE and Natural England, 2010, Green Belts: a greener future
136 National Land Use Database of Previously Developed Land 2010 (NLUD-PDL)

urban green space.[137,138] It has been suggested that compact cities featuring large parks or nature reserves located in the optimal place yield the most benefits,[139] but even limited open green space in in dense urban areas can provide benefits to large numbers of beneficiaries.[140] London, one of the most densely populated UK cities, is still classified as green or blue over 47% of its area.[129]

Despite recent projects to develop new 'garden' cities and towns (see HoCL Briefing SN06867), such as Ebbsfleet, and proposals for legislation for New Towns Development Corporations in the white paper to support these,[141] there are no planning rules on urban forms based on the available evidence for ecosystem service provision. One widely cited example of good practice in the UK is that of the new community of Cambourne in Cambridgeshire.[142] It comprises three linked villages – Upper Cambourne, Greater Cambourne and Lower Cambourne – built on 400 ha of former arable farmland. The master plan for the development protected the remaining areas of semi-natural habitat and linked them together with a variety of new green infrastructure, such as woodland planting, meadows, lakes, amenity grassland, playing fields, allotments, and formal play areas. It also includes 12 miles of new footpaths, cycleways and bridleways and 10 miles of new hedgerows.[143] Green infrastructure accounts for 240 ha of the developed area and is jointly managed by the parish council and the local wildlife trust. The wildlife trust has suggested levels of biodiversity on the site are now higher than when it was arable farmland.[144]

Urban Green Space Strategies

The House of Commons Communities and Local Government Select Committee has recommended that local authorities should work collaboratively with Health and Wellbeing Boards, and other relevant bodies where appropriate, to prepare and publish joint park and green space strategies. The 2011 NEA also suggested the ecosystem service benefits that could be further derived from urban areas are potentially substantial. Only 48% of local authorities have current green space strategies - down from 76% in 2014 - and even less have green infrastructure strategies for the creation of new sites, such as Birmingham.[127] In 2011, the NGO Greenspace Scotland mapped information on the location, extent and type of green space across all of Scotland's

137 Iain Stott, *et al*, 2015, Land sparing is crucial for urban ecosystem services, Frontiers in Ecology and the Environment, 2015, 13 (7): 387–393
138 Soga, M, *et al*, 2014, Land sharing vs. land sparing: does the compact city reconcile urban development and biodiversity conservation? Journal of Applied Ecology, 51: 1378-1386
139 Stott, I, *et al*, 2015, Land sparing is crucial for urban ecosystem services, Frontiers in Ecology and the Environment, 13 (7): 387–393
140 Elmqvist, T, *et al*, 2015, Benefits of restoring ecosystem services in urban areas, Current Opinion in Environmental Sustainability, 14:101-108
141 Department for Communities and Local Government, 2017, Fixing our broken housing market
142 Landscape Institute, Cambourne
143 Town & Country Planning Association and The Wildlife Trusts, 2012, planning for a healthy environment – good practice guidance for green infrastructure and biodiversity
144 The Wildlife Trusts, Cambourne, an exciting exemplar of development which is good for wildlife

urban settlements based on data provided by all 32 Scottish Councils.[145] In collaboration with Ordinance Survey, the Scottish Government released an updated open access version of the urban green space map in 2017, defining sites using the typology set out in the Scottish Government Planning Advice Note 65.[146,147]

The UK is also a signatory to the UN Sustainable Development Goals (SDGs). These include SDG 11.7, which requires universal access to safe, inclusive and accessible, public green space is provided, particularly for women, children, older persons and persons with disabilities, by 2030. Estimates of the amount of green space in urban areas in England vary, but Natural England's Accessible Natural Green space Standard (ANGSt) projected that only half of the urban population live within 300 metres of green space.[148] It has also been calculated that the most affluent 20% of local authority wards in England have five times the amount of green space as the most deprived 10%.[149] A recent study of a UK urban population found 75% of interactions with nature in a natural setting were experienced by just 32% of the population.[150] Paragraph 73 of the NPPF requires planning to be based on robust and up-to-date assessments of the needs for open space, sports and recreation facilities and opportunities for new provision. The assessments should identify specific needs and deficits or surpluses of open space, sports and recreational facilities in the local area.

By comparison, a range of other approaches for ensuring the provision of green infrastructure have been established in other countries. One well known example is the 'Biotope Area Factor' used in Berlin, which requires a given proportion of a site to be left covered in vegetation, but the types of green space are weighted differently according to the benefits they provide. This was introduced in the 1980s to compensate for deficits in open space provision and aims to retain high densities of development while improving green infrastructure.[151,152] Other examples include the Urban Green Space Conservation Act in Japan, which enables local government to designate private or public land as a 'Green space conservation area'. Once a land is designated, it must be conserved as a green area and private owners benefit from tax deduction or subsidy provision.[153] The Singapore Index on Cities' Biodiversity is a tool designed to allow cities to monitor and evaluate their progress and performance related to conserving and enhancing biodiversity and ecosystem services, and was endorsed by the Convention on Biological Diversity in 2009.[154]

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145 Greenspace Scotland
146 A new digital map of greenspace in Scotland will be released in Spring 2017
147 OS MasterMap Greenspace Layer
148 Natural England, 2011, Green space access, green space use, physical activity and overweight
149 Written evidence submitted by Department for Communities and Local Government to the Communities and Local Government Select Committee
150 Cox D, *et al*, 2017, The rarity of direct experiences of nature in an urban population, Landscape and Urban Planning, 160: 79-84
151 Sieber, J, and Pons, M, 2015, Assessment of Urban Ecosystem Services using Ecosystem Services Reviews and GIS-based Tools, Procedia Engineering 115: 53 – 60
152 European Climate Adaptation Platform
153 2004 Landscape Act, Japan
154 User's manual on the Singapore index on cities' biodiversity

In the UK, local authorities directly manage only a small proportion of the green space in urban areas, creating challenges for strategic management of urban green space,[105] as well as for setting appropriate targets for improving its condition.[19] For example, in Leicester, green space covers 56% of the urban area (73km^2), 80% of which is privately managed. Of this, 40% is associated with households and the rest is privately managed non-domestically.[105] How gardens are managed by households will have a significant effect on the overall benefits provided by green space. For instance, the increase in paving over front gardens for parking has increased surface water flows and pressure on urban drainage systems.[155] By contrast, in Milton Keynes, a self-financing independent charity, the Parks Trust, was set up to manage 2,023 ha of green infrastructure, including around 80 miles of landscaped areas alongside the grid roads. This constitutes about 25% of the city's area, and the trust is working with developers, Milton Keynes Development Partnership, and Milton Keynes Council to bring more green space into its stewardship.[156]

Optimising Urban Green Infrastructure

At present, the integration of ecological knowledge into green infrastructure design is minimal,[157] and green space is usually managed for amenity outcomes, rather than other ecosystem service benefits. Less 35% of all English local planning authorities have access to an in-house ecologist for advice, and most planners have no relevant expertise or training.[158] The London Assembly Housing Committee has also recently highlighted how lack of ecological expertise could hamper consideration of biodiversity in the planning process.[159] A greater understanding of how and when a greater diversity of plant species in green infrastructure would provide additional benefits is an emerging area of study.[160] For example, the type and number of plant species may be important for the benefits green infrastructure provides. However, at present plant species known to be able to withstand particularly stresses tend to be used for specific types of green infrastructure, such as *Sedum* species for green roofs. *Sedum* species only require shallow growing media, little nutrient input and little or no irrigation. However, using deeper growing media to support different plant species could provide other benefits, such as enhanced visual aesthetics, pollinator resources or retention of surface water.

The type of management required to sustain ecosystem services is likely to vary with the size and nature of green space and the ecosystem service benefits being delivered.[105] For example, sustaining pollinator services requires provision

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155 Cameron, R, *et al*, 2012, The Domestic Garden – Its Contribution to Urban Green Infrastructure, Urban Forestry and Urban Greening, 11 (2): 129-137
156 The Parks Trust, Milton Keynes
157 Adler, F, and Tanner, C, 2013, Urban Ecosystems: Ecological Principles for the Built Environment, Cambridge University Press, Cambridge.
158 Oxford, M. 2013, Ecological Capacity and Competence in Local Planning Authorities: What is needed to deliver statutory obligations for biodiversity? Report published by the Association of Local Government Ecologists.
159 London Assembly Housing Committee, 2017, At Home with Nature: Encouraging biodiversity in new housing developments
160 MacIvor, J, *et al*, 2016, Phylogenetic ecology and the greening of cities, Journal of Applied Ecology`, 53, 1470–1476

of resources for pollinators throughout the flowering season. Restoring services can also involve significant expenditure, such as the decontamination and remediation of polluted, compacted and sealed urban soils. However, valuation of the benefits arising from restoration projects suggest such approaches can be cost-effective, although there may be a lag of decade or more before benefits are realised.[161]

A recent survey of practioners, including local authorities, has suggested that the lack of evidence stating the economic benefits is the most significant gap in the case for investing in green infrastructure.[162] However, substantial sums are already spent annually in urban areas on managing green spaces without any understanding of the outcomes for ecosystem service provision and human wellbeing. This includes both expenditure by local authorities on parks and amenity areas, as well as private land owners on the matrix of smaller green spaces, such as gardens. The activities affecting service provision range from landscaping, managing vegetation, through to measures such as mowing and tree surgery, to installing green roofs and walls. The complexity of the make-up of green space, the number of land managers involved and their conflicting management objectives will create challenges for any policy framework created.

However, urban areas are also likely to change significantly in the next 5 to 10 years creating opportunities. For example, technology is changing the nature of retailing in urban areas with implications for how urban space is used and self-driving autonomous vehicles may require less road space. The emerging field of research on urban ecosystems can offer new insights into addressing the trade-offs and interdependencies that arise, including opportunities for enhancing human wellbeing.[163] The Convention on Biological Diversity's City Biodiversity Outlook report highlighted that maintaining urban ecosystem services can significantly improve human wellbeing,[164] and other commentators have argued that international conservation instruments, such as CBD and Ramsar Convention, should include urban areas within their scope.[165]

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161 Elmquist, T, *et al*, 2015, Benefits of restoring ecosystem services in urban areas, Current Opinion in Environmental Sustainability 14:101-108

Pataki, D, *et al,* 2011, Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions and misconceptions. Front. Ecol. Environ, 9:27-36

162 Schüder, I, 2017, Translating Green Infrastructure research into decision making and practice, CEH

163 Haase, D *et al*, 2014, Ecosystem Services in Urban Landscapes: Practical Applications and Governance Implications, AMBIO, 43:407-412.

164 Secretariat of the Convention on Biological Diversity, 2012, Cities and Biodiversity Outlook

165 Sirakaya, A, *et al*, 2017, Ecosystem services in cities: Towards the international legal protection of ecosystem services in urban environments, Ecosystem Services, In Press

CICES Section	CICES Class	Class type (urban ecosystem services)	Service providing unit (SPU)	Demand
Provisioning	Cultivated crops	Vegetables produced by urban allotments and in and the commuting zone	Crop fields, fruit trees, private and public gardens	Consumption
	Surface water for drinking		Watershed	
	Ground water for drinking			
	Surface water for non-drinking purposes			
	Ground water for non-drinking purposes			
Regulating	Filtration/sequestration/storage/accumulation by ecosystems	Regulation of air quality by urban trees and forests	Forest, trees, shrubs	Risk of exposure to pollutant concentration beyond thresholds
	Global climate regulation by reduction of greenhouse gas concentration	Climate regulation by reduction of CO_2	Vegetation, soil	
	Micro and regional climate regulation	Urban temperature regulation	Forest, trees, shrub, herbs, lawns, wetlands, water bodies	Risk of exposure to high temperatures
	Mediation of smell/noise/visual impacts	Noise mitigated by urban vegetation	Forest, trees, shrubs, vegetated surfaces	Risk of exposure to noise
	Hydrological cycle and water flow maintenance	Water flow regulation and run off mitigation	Trees, shrubs, vegetated and permeable surfaces	Risk for flood sensitive areas or land use
	Flood control		Wetlands	Exposure to flooding
	Pollination and seed dispersal	Insect pollination	Crop fields, fruit trees, private and public gardens	Dependency on insect pollination
Cultural	Physical use of land-/seascapes in different environmental settings	Nature based recreation	Parks, gardens, forest, trees, agricultural areas in the commuting zone, wetlands, water bodies, waterways, Natura 2000 sites	Preferences; Potential and direct use
	Scientific	Nature based education		
	Educational			
	Heritage, cultural			

Table 1: Key urban ecosystem services organised by CICES section, class and class type, and by type of service provision unit and expression of demand for the MAES study.

Ecosystem service	Final ecosystem service	Description of the main goods and benefits from the Urban environment
Provisioning	Crops, plants, livestock, fish,	Food: e.g. vegetables, fruit, meat, milk, honey
		Fibre: e.g. compost
		Ornamental: e.g. flowers
		Genetic resources
	Trees, standing vegetation & peat	Trees: e.g. timber, wood chippings
		Fuel
	Water supply	Drinking water
		Industrial use of water
		Energy
Provisioning/ Cultural	Wild species	Wild food: e.g. berries
		Recreation and tourism
Cultural	Environmental settings	Physical and mental health
		Spiritual and religious
		Heritage: includes cultural heritage, aesthetic and inspirational, security and freedom, neighbourhood development, social and environmental citizenship
		Recreation and tourism
		Education
Regulating	Climate	Avoidance of climate stress
		Carbon sequestration
	Hazard	Erosion protection
		Flood protection
		Avoidance of climate stress
	Purification	Clean air
		Clean water
		Clean soil
	Noise	Noise reduction

Table 2: The NEA summary of the main goods and benefits derived from final ecosystem services provided by the urban environment using the MA Classification.