Integrating sciences to sustain urban ecosystem services

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Integrating sciences to sustain urban ecosystem services

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Abstract

Effective water management within urban settings requires robust multidisciplinary understanding and an appreciation of the value added to urban spaces by providing multifunctional green-blue spaces. Multifunctional landscapes where ecosystem service provisions are 'designed-in' can help 'transition' cities to more sustainable environments which are more resilient to changing future conditions. With benefits ranging from the supply of water, habitat and energy to pollutant removal, amenity and opportunities for recreation, urban water bodies can provide a focal point for reconnecting humans and nature in otherwise densely built-up areas. Managing water within urban spaces is an essential infrastructure requirement but has historically been undertaken in isolation from other urban functions and spatial requirements. Increasingly, because of the limits of space and need to respond to new drivers (e.g. mitigation of diffuse pollution), more sustainable approaches to urban water management are being applied which can have multiple functions and benefits. This paper presents a review of ecosystem services associated with water, particularly those in urban environments, and uses the emerging language of ecosystem services to provide a framework for discussion. The range of supporting, provisioning, regulating and cultural ecosystem services associated with differing types of urban water bodies are identified. A matrix is then used to evaluate the results of a series of social, ecological and physical science studies co-located on a single stretch of a restored urban river. Findings identify the benefits of, but also barriers to, the implementation of a transdisciplinary research approach. For many, transdisciplinary research still appears to be on the edge of scientific respectability. In order to approach this challenge, it is imperative that we bring together discipline specific expertise to address fundamental and applied problems in a holistic way. The ecosystem services approach offers an exciting mechanism to support researchers in tackling research questions that require thinking beyond traditional scientific boundaries. The opportunity to fully exploit this approach to collaborative working should not be lost.

Keywords

Millennium Ecosystem Assessment, multifunctional landscapes, urban ecosystem services, water

I Introduction

With the theme of World Water Day 2011 being urban water management and the development of the Intergovernmental Panel on Biodiversity and Ecosystem Services, now is a timely opportunity to review the role of water in urban areas using the emerging language of ecosystem services. Urban areas are of increasing importance as a human habitat. Of the 6.91 billion people on earth, 3.49 billion (or 50%) are reported to live in urban areas, with the urban population predicted

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to increase by a further 2.8 billion by 2050 (UN, 2009). Urban population growth is predicted to be greatest in 'developing' counties, exceeding urban growth in 'developed' countries by a factor of almost five (UN Habitat, 2008). Of this rapidly growing urban population, approximately 33% are reported to live in slum areas. It is within this context that the Brundtland (1987) definition of sustainable development (meet the needs of the present without compromising the ability of future generations to meet their own needs) has never seemed more urgent or challenging.

Publication of the Millennium Ecosystem Assessment (MA) has led to increasing international awareness of the importance of the services, goods and benefits gained from the environment that benefit humans, and the need to recognize and value these goods and services within policy development and implementation (MA, 2005). This led directly to the concept of ecosystem services, an emerging transdisciplinary approach providing a framework through which the benefits accrued from ecosystem services can be interrogated from multiple perspectives in an approach consistent with systems thinking. While the drive to develop and implement a more integrated approach is at the forefront of urban water management research (e.g. Makropoulos et al., 2008) and legislation (e.g. EU Water Framework Directive (WFD), 2000), this approach still effectively 'segregates' water management from other components of urban landscape. In contrast, the ecosystem service approach facilitates the integration of information from both physical and social sciences on a diversity of aspects that contribute to human health and well-being. However, rather than an alternative management strategy, an ecosystem services approach can be seen as an integrating mechanism to inform policy-making and delivery from a more holistic perspective.

As a contribution to the debate on urban water management, this paper considers the multiple roles of water components in urban areas in terms of the supporting, provisioning, regulating and cultural ecosystem services (the key types of ecosystem services identified in the MA) it can deliver at a local scale. This analysis leads to the development of an urban water ecosystem services matrix which is used to support an evaluation of the findings of a series of social, environmental and physical science studies implemented within a single case-study location. The paper concludes with a consideration of the barriers to and opportunities for facilitating transdisciplinary research as a fundamental approach to underpin the development of the robust database required to ensure 'today's solution' is not 'tomorrow's problem'.

II Urban water drivers

Water is present in urban areas in a variety of natural (e.g. rivers, wetlands and groundwater), artificial (e.g. canals and sustainable drainage systems) and 'hybrid' (e.g. restored rivers) forms which exist on a range of spatial and temporal scales. While urban watercourses account for a small proportion of the total length of rivers, they are of disproportionate importance due to their high public profile (RCEP, 2007) and the high degree of both direct (e.g. culverting) and indirect (e.g. erosion-driven channel enlargement) morphological change (Chin, 2006; Mooney et al., 2009). For example, of the 2362 water bodies (areas of water which have similar levels of modification and surrounding land use) identified across Scotland, 258 water bodies run to some extent through urban areas (Bromley, personal communication, 2010). Of these 258 water bodies, only 50 water bodies (equating to 2% of the total number) are completely contained within urban areas.

Recent years have seen a trend toward protection and improvement of the urban water environment. This arises from a need in many countries to conserve and reuse water (e.g. Water Sensitive Urban Design (WSUD) in Australia and Low Impact Development (LID) in the USA). Both WSUD and LID advocate the need to incorporate all aspects of water into urban development and planning from the earliest stages. This is to maximize the opportunities for context-sensitive water-cycle management (Lloyd et al., 2002), effectively encouraging the continuation of natural water processes within an urban environment. In addition, urban river restoration projects have arisen from a desire to improve the urban environment and better manage urban open spaces in response to water quality (e.g. EU WFD, 2000) water quantity (e.g. EU Floods Directive, 2007), conservation (e.g. UN Convention on Biodiversity, 1992) and quality-of-life agendas (e.g. Defra, 2007). There are many large- and small-scale examples of river restoration globally (e.g. Bernhardt et al., 2005, for synthesis of projects in the USA). Parallel efforts are occurring in terms of promoting the use of surface water and stormwater management through the promotion of stormwater best management practices (BMPs) in many countries (also known as sustainable urban drainage systems (SUDS)). Stormwater BMPs are a wide range of constructed systems from wetlands and ponds to infiltration trenches and swales which mimic natural hydrological processes including infiltration, detention, groundwater recharge and evapotranspiration (Villarreal et al., 2004; Yang and Li, 2010).

Many of these approaches to urban water management are driven by practical requirements to, for example, reuse water, 'slow the flow' generated by rainfall in impermeable urban environments and mitigate flooding/inundation from small-scale storm events. Further drivers include the need to reduce the pressure on existing sewer infrastructure and wastewater treatment plants in terms of both capacity and treatment efficiency as well as the need to control urban diffuse pollution as part of the approach to achieving ambitious EU WFD objectives. All of the approaches presented above represent more sustainable ways to manage urban water resources but also provide an opportunity to support and enhance ecosystem service provision in urban settings.

III Ecosystem services

The MA divides the services provided by the environment which benefit people into four categories, acknowledging that these categories can and do overlap extensively (MA, 2005). The application of the four categories (supporting, provisioning, regulating and cultural) to the services, goods and benefits associated with urban water bodies are discussed in the following sections.

1 Supporting services

The MA (2005) describes supporting services as the processes which are essential for the production of all provisioning, regulating and cultural services. Supporting services differ from the other types of services in that their impacts on humans are indirect and/or occur over very long periods of time. Examples include primary production, oxygen production, soil formation, water cycling and habitat provision (MA, 2005; Table 1). Primary production is at the base of all food chains. While the process of urbanization is reported to reduce regional net primary productivity (Deyong et al., 2009; Milesi et al., 2003), the photosynthetic activities of aquatic and terrestrial vegetation sustained by urban water bodies contribute to the mitigation of the net loss of primary productivity. However, the extent to which the primary productivity of water bodies achieves this has yet to be quantified on a city scale. Similarly, terrestrial and aquatic vegetation contributes to oxygen levels within the atmosphere and water bodies (Nakova et al., 2009) but data on the magnitude of this impact specifically in relation to urban water bodies could not be sourced. Lakes, streams and rivers may all play a key role in the formation and retention of alluvial soils and sediments, with, for example, soil accretion rates of 1 cm year^{-1} reported for coastal marshes (Nyman

Table 1. Examples of ecosystem services associated with urban water components together with ecosystem goods, benefits and possible units of measure

Categories of ecosystem services	Types of ecosystem services	Ecosystem goods and benefits	Example units of measurement
Supporting services	Primary production	The goods and benefits of sustaining services are their role in facilitating other services to take place	$g\ C\ m^{-2}$
	Production of oxygen		$g\ O_2 \cdot m^{-2}$
	Soil formation		$cm\ year^{-1}$
	Water cycling		% permeability
	Provisioning of habitat		hectares
Provisioning services	Food	Meat and vegetables	tonnes/hectare
	Water	Potable and non-potable water	litres/hectare
	Renewable energy	Hydropower	mega watts
	Genetic resources	Pollutant degrading species	cfu/ml
Regulating services	Climate regulation	Reduced urban temperatures	°C
	Water regulation	Reduced runoff volume/velocity	m^3; ms^{-1}
	Erosion control	Stabilization of sediments	g/m^2
	Water purification	Removal of pollutants	mg/L
Cultural services	Spiritual value	Mental well-being	Numbers of users (reduced demand on mental health services)
	Educational value	Increased environmental awareness	Kg (reduced littering of water bodies)
	Aesthetics	Increased house prices	% (increase in house price)
	Recreation	Physical well-being	% (reduced levels of mortality)

et al., 1990) and 1.0 to 7.6 mm yr^{-1} for floodplains affected by periodic floods (Saint-Laurent et al., 2008). The impact of urban areas on riverbank sediments in terms of increased metal concentrations has been reported (de Miguel et al., 2005) with Scharenbroch et al. (2005) suggesting that urban soils can be physically, chemically and biologically distinguished from other soil types.

Surface and ground water bodies play a key role in water cycling, and hence the renewable provision of freshwater (Postel and Carpenter, 1997), as receivers of rainfall through both direct (deposition) and indirect (runoff) routes. Surface water bodies may recharge groundwater (and vice versa), returning water to the atmosphere directly (evaporation) and indirectly (evapotranspiration), with the relative importance of these mechanisms varying greatly in relation to factors such as climate and level of vegetative cover (Krüger and Pearlmutter, 2008). Urban development is associated with an increase in ground impermeability due to the development of roads, pavements and buildings, etc, and a consequent reduction in vegetative cover. This has profound effects on the functioning of the water cycle, reducing the recharge of groundwater and other surface water bodies with potential impacts on both water supply and soil stability (e.g. rapid subsidence of areas of Mexico city due to over abstraction of groundwater; Osmanoğlu et al., 2011). Further impacts include reduction of evapotranspiration processes and increased volumes of runoff (Madlener and Sunak, 2011; Shi et al., 2007). In relation to the provision of habitat, urban water components such as garden ponds and stormwater BMPs can make a crucial contribution, with both the water body and its associated vegetation providing habitat for a range of flora and fauna (Davies et al., 2004; Kazemi et al., 2009) including pollinators (a further supporting service). As well as direct habitat provision, the strategic location of urban water components can also facilitate habitat provision contributing to landscape connectivity objectives (Le Viol et al., 2009).

2 Provisioning services

Provisioning services relate to the production of products from ecosystems, including water, food, fuel and genetic resources (MA, 2005; Table 1). As a function of their impermeable nature, urban areas are excellent at generating water through their detention of rainfall, enabling large volumes to be generated quickly (Carter and Jackson, 2007; Semadeni-Davies et al., 2008). Rainfall (or stormwater) runoff is typically viewed as wastewater and its management a major challenge; rain can fall in the wrong place at the wrong time in relation to meeting domestic, irrigation and industrial water needs. Stormwater runoff mobilizes pollutants deposited on surfaces from a range of sources (e.g., traffic, atmospheric deposition, wear and tear of road materials) (Eriksson et al., 2007; Karlsson et al., 2010). Further sources of stormwater pollution include ‘misconnections’ (where foul sewage is wrongly plumbed into surface water sewers) with the discharge of combined sewer overflows (CSOs) into receiving water bodies causing further degradation of urban water quality. While the challenges of using stormwater as a contribution to meeting local water needs abound, current and projected water demands are of such a scale (1.2 billion people currently lack access to clean drinking water with up to two-thirds of the world’s population predicted to be affected by water scarcity by 2100; Rijsberman, 2006) that the generation of stormwater by cities is now beginning to be seen as a valuable resource (Berndtsson, 2010). Innovative thinking is required to enable such a paradigm shift to be realized. However, the proximity of water supply and demand in urban areas should be embraced and opportunities for its sustainable exploitation sought. Urban water bodies do already contribute to the provision of water within urban environments (e.g. 80% of the drinking water in London (UK) comes from its rivers (Mayor of London, undated). However, the use of stormwater to fulfil a suite of functions from groundwater recharge to irrigation and water supply is an underutilized resource.

While urban water bodies can and do provide a range of foods, elevated pollutant levels have also been reported in foods originating from urban water bodies (e.g. a ban on commercial fishing in Sydney harbour following the detection of elevated levels of dioxins in fish and crustaceans (Rudge et al., 2008)). Within an EU context, the ongoing implementation of the EU WFD (2000) is anticipated to mitigate (or at least halt) degradation of urban water-body quality. However, the impact of sediment on surface water quality should not be overlooked, particularly in an urban water context. Sediments can act as both pollutant source and sink, with the point discharge of storm flows into urban watercourses resuspending previously settled sediments and associated pollutants with deleterious impacts on overlying water quality (Cho et al., 2010; Crabill et al., 1999; Scholes et al., 2008).

Water has been used to generate power throughout the last two millennia. On a global basis, hydropower accounts for 19% of electricity production, with the largest producers of hydroelectricity including China, Canada and Brazil (USGS, 2010). Large hydroelectric plants are typically constructed outwith urban areas due to the need for dam and reservoir construction. However, as the most usable land (in terms of elevation, water supply and access) have already be used, the rate of dam construction has fallen over the last 30 years with the USGS (2010) predicting that the future for hydroelectricity will be associated with the construction of small-scale community hydroelectric plants. The development of smaller hydroelectric systems which can be 'run of the river' installations (i.e. not requiring the construction of dams) facilitates their use within urban areas. A review of the use of the small hydropower sector within EU Member States by Punys and Pelikan (2007) identified 17,200 plants in operation. While the location of these plants is not clear, the use of small-scale hydropower systems in urban areas is being examined in several cities: for example, the use of micro-hydroelectric power plants in Portland (USA) (DJC, 2010) and the use of a mini-hydropower plant in Grenoble (France) (SESAC, undated).

Further provisioning services include the supply of genetic information used in animal and plant breeding, biochemicals (used for pharmaceuticals) and ornamental resources (e.g. flowers and shells) (Decaëns et al., 2006; MA, 2005; Wang et al., 2010). As noted earlier, urban water bodies are typically in receipt of diffuse pollution from a range of sources. While this may at first appear to exclude the generation of services such as the supply of genetic information, the presence of species able to tolerate and/or degrade elevated pollutant levels offers interesting opportunities in relation to, for example, the field of microbial bioremediation (Galvao et al., 2005). The potential for plants, bacteria and fungi which can degrade or immobilize organic and inorganic pollutants has received considerable attention (Bender and Phillips, 2004; Desai et al., 2010), with drivers such as the EU Environmental Quality Standards Directive (2008) providing a strong driver for the development of cost-effective technologies to mitigate identified and emerging priority substances.

3 Regulating services

Regulating services relate to the goods and benefits generated through the regulation of ecosystem functions including processes such as climate regulation, water regulation, water purification, erosion control and pollination (de Groot et al., 2010; MA, 2005; Table 1). Urban water bodies contribute to the delivery of many of these ecosystem services. However, while there is an established evidence base on, for example, the role of stormwater BMPs in the regulation and purification of water (e.g. DayWater BMP Catalogue, 2005), the interpretation of this evidence in terms of ecosystem services is only beginning to emerge. While their performance is reported to vary in relation to a range of factors including system type, influent loading and catchment characteristics, the water quantity and quality role of a range of stormwater BMPs is well documented to reduce surface water volumes, velocities and pollutant loadings (Hatt et al., 2006; Jefferies et al., 1999; Merete Muthanna et al., 2007). Less well understood is the potential for stormwater BMPs to provide a range of further regulating services, such as mitigation of the urban heat island, carbon sequestration, noise regulation and pollination. While different types of stormwater BMPs are appropriate in different situations, each can offer 'added value' in terms of ecosystem service provision.

While many urban watercourses were channelized to promote the transport of flood waters away from built-up areas, restoring urban rivers is now recognized as offering a cost-effective approach to flood management through enhancing local flood attenuation, watercourse flood storage capacity and reduced downstream flooding (EA, 2002). The breaking-down of concrete river channels also reopens the potential for further processes such as groundwater recharge to take place and provides habitat for the movement and migration of plant, animal and insect species (Wilby and Perry, 2006) both as a potential adaptation to climate change and as contributions to biodiversity and conservation objectives. Urban rehabilitation projects have been identified to provide opportunities to access nature (Landrigan et al., 2004) and the provision of mental and physical health benefits typically associated with urban green space (see section III(4) below). While these benefits have not yet necessarily been discussed in terms of ecosystem services, it is the provision of such services and goods that are identified as drivers behind the increase in the number of river restoration programmes initiated in recent years (Skinner and Bruce-Burgess, 2005).

Together with urban watercourses, urban lakes and ponds can act as heat sinks contributing to mitigation of the urban heat island effect (Defra, 2010), with the use of wet pavements also reported to reduce day and night-time temperatures in urban areas (Yamagata et al., 2008). The vegetation associated with urban water features can also contribute to insulation (e.g. green roofs) and cooling (Castleton et al., 2010), linking into the concepts of green infrastructure, urban greening and low-impact development (Montalto et al., 2007), as well as providing habitat for pollinators.

4 Cultural services

Cultural services refer to the non-material benefits humans gain from ecosystem services such as spiritual, aesthetic and educational values, and opportunities for recreational activities (MA, 2005; Table 1). That natural environments supply more than the necessities of food and water, but additionally provide restorative and preventative health benefits, has been reported for centuries (see review by Ward Thompson, 2010). In the context of increasing obesity and mental illness reported in many countries (Minet Kinge and Morris, 2010; NHS, 2010; Pieniak et al., 2009), the role of green spaces in urban areas in providing a relatively low-cost contribution to improving and maintaining physical and mental health has become a focus of attention for both researchers and policy-makers (Maas et al., 2006; van den Berg et al., 2010).

Recent research by White et al. (2010) reported that natural and built environments containing water are associated with higher preferences than either environment without water. Of particular note is their finding that built environments containing water were as preferred as purely green space, suggesting that the presence of water confers some level of intrinsic value irrespective of location. Restoring urban rivers is seen as an opportunity to connect urban communities with nature and improve well-being through the provision of safe and attractive places for exercise, tranquillity and opportunities for education (EA, 2006). However, concerns over potential human health risks related to recreational users coming into contact with urban river sediment have also been raised (Scholes et al., 2008). Larger urban water bodies can provide opportunities for recreational activities such as boating, canoeing and fishing, with water bodies of all sizes providing attractive locations for more reflective and passive activities. Stormwater BMPs, for example, can (depending on the type of system) contribute to the provision of cultural services within both these active and passive categories. The role of BMPs in mitigating water quality and quantity is noted in the section on regulating services, with their potential to provide amenity, recreational and educational benefits providing the third corner of SUDS (BMP) triangle (a theoretical concept facilitating the selection of SUDS in relation to achieving combined water quantity, quality and amenity objectives (D'Arcy and Frost, 2001)). Research on the social impact of BMPs found that residents living close to mature BMPs ponds valued the systems in terms not only of flood management but also their role in attracting wildlife and improving the landscape, with residents suggesting that homes located close to well-designed, managed, established BMPs would achieve a 10% premium (Apostolaki, undated).

IV Ability of selected urban water components to contribute to the delivery of identified ecosystem services

The list of urban water components identified in Table 2 is not intended to be exhaustive but instead to be indicative of the main generic types and scales of water features found in urbanized areas. Channelized watercourses refer to open concrete channels from drainage channels up to river-scale systems, with natural/restored watercourses referring to similar types and scales of watercourses in which banks are not reinforced with concrete or the concrete casing has been broken down. Lakes and ponds refer to natural quiescent water bodies, with reservoirs and settlement ponds their artificial counterparts. Vegetated filters include systems such as small-scale constructed wetlands, swales and green roofs. The ability of each identified urban water component to contribute to a range of the ecosystem services generated is identified, where a tick indicates the water component is considered to routinely contribute to the delivery of the identified service and a cross indicates the urban water component is not considered to routinely contribute to its delivery.

From Table 2 it can be seen that all urban water types identified are considered to have the potential to contribute to the delivery of a range of ecosystem services. However, as data on the contribution of various water component types to deliver specific types of ecosystem services is scarce (and urban water-specific data scarcer still), it is not possible to add any quantification to the value assessments benchmarked below. The presence of vegetation in the natural and restored rivers, lakes and ponds, and vegetated filters categories is considered to contribute to primary production and oxygen production, and likewise the absence of vegetation within groundwater is responsible for its non-contribution to these services. While reservoirs and settlement tanks may be host to vegetation, these typically more managed systems are considered to make a less important contribution together with channelized watercourses where flow velocities are not conducive to the establishment of permanent vegetation. Urban water components that are free to 'spill over' onto established floodplains (e.g. restored rivers) are considered to have the potential to contribute to soil formation. When considered in terms of supporting macroflora and macrofauna, all identified urban water components (with the exception of groundwater) are considered to have the ability to provide habitat, with all types of urban water components contributing to the functioning of the water cycle.With the exception of

Table 2. Overview of selected urban water-body components and their potential to contribute to the delivery of identified ecosystem services within an urban environment

		Type of urban water component					
Category of ecosystem service	Type of ecosystem service	Channelized watercourse	Natural and restored watercourse	Lakes and ponds	Reservoirs and settlement ponds	Vegetated filters	Groundwater
Supporting	Primary production	X	✓	✓	X	✓	X
	Oxygen production	X	✓	✓	X	✓	X
	Soil formation	X	✓	✓	X	X	X
	Water cycle	✓	✓	✓	✓	✓	✓
	Habitat	✓	✓	✓	✓	✓	X
Provisioning	Food	✓	✓	✓	✓	X	X
	Water	✓	✓	✓	✓	X	✓
	Renewable energy	✓	✓	X	✓[a]	X	X
	Genetic resource	✓	✓	✓	✓	✓	✓
Regulating	Climate regulation	✓	✓	✓	✓	✓	X
	Water regulation	✓	✓	✓	✓	✓	✓
	Erosion control	✓	X	✓	✓	✓	✓
	Water purification	X	X	✓	✓	✓	✓
Cultural	Spiritual value	X	✓	✓	✓[a]	X	X
	Educational value	X	✓	✓	✓	✓	X
	Aesthetics	X	✓	✓	✓[a]	✓	X
	Recreation	X	✓	✓	✓[a]	X	X

[a]associated with reservoirs only

vegetated filters and groundwater, all other urban water components may contribute to the provision of food (e.g. fish and prawns), with only vegetated filters considered not to routinely contribute to the direct supply of water. However, it should be noted that the quality of water (and through association sediment and biota) in a channelized urban watercourse is of potential concern in relation to human consumption (see section III(2) above). The use of urban water components to generate renewable energy in the form of hydropower requires there to be a vertical fall of water, for example, when a river runs down a hillside, over a waterfall, man-made weir or discharges from a reservoir, with the latter two scenarios potentially being the most relevant within an urban environment. All water components identified may be host to micro-organisms and hence provide a potential reserve for genetic resources. In terms of regulating services, open-vegetated and unvegetated water components can act as heat sinks contributing to the mitigation of the urban heat island effect, with the former category also contributing to cooling through evapotranspiration. All urban water systems are considered to contribute to the regulation of water through a range of processes including infiltration, detention and subsequent reduced velocity discharge. Erosion control is provided by the reinforced banks of channelized watercourses and settlement tanks, the larger storage volumes associated with lakes, reservoirs and groundwater and the buffering capacity of vegetation within vegetated filters. Mitigation of water quality is associated with natural and artificial quiescent water bodies (promoting sedimentation of particulate matter and associated pollutants), vegetated filters (processes including adsorption, settlement in association with flow reduction and microbial degradation) and groundwater (adsorption and microbial degradation). The flashy nature of artificial urban watercourses is not conducive to such pollutant removal processes and, while restored rivers are generally considered to mitigate water quality, there is little quantitative data available to support this hypothesis.

Groundwater and channelized urban watercourses are not considered to offer great potential for the delivery of cultural services, being underground and artificial, typically linear features, respectively. Natural and restored water features such as rivers, lakes and ponds and larger quiescent water bodies such as reservoirs are typically viewed as aesthetically pleasing features, offering opportunities for reflection and contemplation (spiritual values) and recreation (e.g. boating and fishing). Together with vegetated filters, these urban water components can be host to a diversity of plant and animal life presenting a focal point for school- and community-focused activities such as pond dips, nature walks and conservation actions. As typically smaller-scale systems, vegetated filters in general are considered to offer limited opportunities for either spiritual enrichment or recreational activities but may present opportunities for small-scale nature studies.

V Application of an ecosystem services approach to a restored urban river

In order to illustrate the utility of an ecosystem service approach to urban water environments, an evaluation of the ecosystem services, goods and benefits delivered by a restored section of the River Brent (Tokyngton Park, North London, UK) has been undertaken. The River Brent is a heavily urbanized river in receipt of both stormwater runoff and combined sewer overflows. In 1947, the meandering section of the River Brent which ran through Tokyngton Park was replaced with a U-shaped concrete channel as a flood-management measure (Environment Agency for England and Wales, undated a). Discussions between the Environment Agency for England and Wales (EA), the London Borough of Brent and the London Waterways Partnership led to the identification of the Tokyngton Park

Table 3. Overview of River Brent case study and potential to contribute to the delivery of identified ecosystem services within an urban environment

Category of ecosystem service	Type of ecosystem service	Types of urban water component in Tokyngton Park: Channelized watercourse – Potential	Channelized watercourse – Actual	Vegetated filters – Potential	Vegetated filters – Actual	Natural and restored watercourse – Potential	Natural and restored watercourse – Actual
Supporting	Primary production	X	X	✓	✓	✓	✓
	Oxygen production	X	X	✓	✓	✓	✓
	Soil formation	X	X	X	X	✓	✓
	Water cycle	✓	✓	✓	✓	✓	✓
	Habitat	✓	✓	✓	✓	✓	✓
Provisioning	Food	✓	X	X	X	✓	X
	Water	✓	X	X	X	✓	X
	Renewable energy	✓	X	X	X	✓	X
	Genetic resource	✓	X	✓	X	✓	X
Regulating	Climate regulation.	✓	✓	✓	✓	✓	✓
	Water regulation	✓	✓	✓	✓	✓	✓
	Erosion control	✓	✓	✓	✓	X	X
	Water purification	X	X	✓	✓	X	X
Cultural	Spiritual value	X	X	X	X	✓	✓
	Educational value	X	X	✓	X	✓	X
	Aesthetics	X	X	✓	✓	✓	✓
	Recreation	X	X	X	X	✓	✓

site as appropriate for a river restoration programme. Following its completion in 2003, the urban water components present in Tokyngton Park include a section of channelized watercourse (retained from the original channel), a restored river and a small wetland (vegetated filter).

Both prior to and following restoration, this section of the Brent has been the focus of a range of independently implemented projects including evaluations of its ecology (England, 2004; McMullen, 2007), geomorphology (EA, undated b; McMullen, 2007), social impact (Ahmed, 2007), public perception (Apostolaki, 2007) and sediment dynamics and sediment quality (Adeyemi et al., 2009). Together with observations made on site by the authors during several sampling trips over the time period 2005–2010, data generated through these studies form the basis for the assessment presented in Table 3 (cells shaded grey). Where data was not available, data sourced from the literature has been used to inform an estimate of whether identified service is delivered (unshaded cells in Table 3).

The ecosystem services potentially delivered by each urban water component are identified in columns 3, 5 and 7 of Table 3 (taken from Table 2), with columns 4, 6 and 8 presenting an assessment of whether services identified are generated in practice. In relation to supporting services, each urban water component is considered to contribute to the provision of habitat, although site-specific ecology data was only available for the restored river and channelized components (England, 2004; McMullen, 2007). From Table 3 we can see that supporting services are better provided by the more naturally functioning 'restored' features at the site. For example, the restored river contributes to all of the supporting services listed in Table 3. McMullan (2007) found biological water quality (based on macro-invertebrate counts) within the restored habitat was better than in the adjacent channelized section, indicating that river restoration does lead to an improved habitat. These results support the findings of research by England completed before and after the river restoration programme which also reported an improvement in habitat (England, 2004). However, later work by McMullen (2007) reported macro-invertebrate scores in 2007 which were similar to those taken in 2004, indicating that there had been no further improvement in habitat quality. A continued input of surface runoff from the surrounding urban environment and input from CSOs were identified as contributing factors. All three urban water components were observed to receive rainfall and runoff indicating that all components contribute to the functioning of the urban water cycle. While the channelized section is not anticipated to contribute to primary production, oxygen production or soil formation, the identified studies did not include measurements of these parameters and therefore these assumptions cannot be verified. The presence of vegetation in the restored river section and wetland area supports the assumption that these components will contribute to the delivery of primary production and oxygen production. Evidence from overbank flows in the restored river section (in the form of river debris and trash collected in trees at overbank height) indicates that the river does flow over the floodplain offering the potential for a contribution to the service of soil formation.

With respect to provisioning services, the channelized section and restored river components are identified to have the potential to generate food, water, renewable energy and genetic resources. Ahmed (2007) undertook a qualitative survey of the restored river section which included the identification of recreational activities undertaken by park users, and their perceptions of the social and visual values of the restoration work on the river. Of the respondents surveyed, none identified any of the listed activities suggesting that the restored river does not currently deliver these provisioning goods and benefits. While the use of the channelized section and wetland were not included within the scope of the questionnaire, it is suggested that these sections do not deliver provisioning services. Further evidence in relation to the delivery of renewable energy in the form of hydropower is generated from the fact that no installations of the type required to generate hydropower were observed on site. All three water components were anticipated to contribute to climate regulation through processes such as evaporative cooling and evapotranspiration (restored river and wetland only) although none of the studies specifically monitored these aspects. All three components are considered to contribute to water regulation through processes such as retention of elevated flows reducing surface flooding (observed in both the restored and channelized section during wet weather events). While the channelized section and wetland components are considered to contribute to erosion control, the restored rivers' 'naturalized' riverbanks were highly eroded, supporting the assumption that the restored river section was not resilient to elevated flows. While water quality was not determined, the initial results of a sediment sampling campaign indicate that the concentrations of a range of heavy metals in sediment do not vary considerably between the channelized and restored sections. The wetland component was not monitored; however, there is an extensive literature base on the pollutant removal performance of wetland systems and on this basis the wetland is predicted to deliver water-quality benefits.

In relation to the delivery of cultural services, as aims of the river restoration programme include encouraging recreation, improving visual amenity value, engaging the community in nature conservation and reducing crime (EA, undated a, it is indicated that the channelized section (either pre- or post-completion of the downstream restoration programme) does not deliver any clear cultural goods or benefits. The EA's report indicates that the restored river section has achieved several of its objectives including engaging the local community with nature and improved visual amenity value. The results of a park user survey (Ahmed, 2007) support these findings, also indicating that the restored river section provided a better opportunity for play, and was perceived by the respondents to be safer, more attractive and better for wildlife. While the wetland area was not included in the park user survey, the vegetation is well established suggesting that it has aesthetic value. However, as the neighbouring restored river section was not identified as a site for educational activities, it is considered that these goods are not currently exploited within a wetland context.

While the individual studies are each of research and practical value, when collated and compared they provide a more holistic analysis of the impact of the river restoration programme, adding value and insight to the multiple benefits arising from a local park enhancement scheme. This integration of findings from a range of social, ecological and physical science studies within a single framework is considered to be of value to policy-makers and practitioners through facilitating understanding of the wide-ranging benefits of environmental protection. Results may also be used to inform the development of land-management plans with a view to enabling the delivery of further ecosystem services (e.g. potential for the weir located in the channelized section to generate hydropower) and support researchers in the development of transdisciplinary research approaches through an enhanced awareness of the multifunctional aspects of, for example, urban rivers.

VI Conclusions

As an approach to informing the conservation of ecosystems, the MA (and its framework to support the evaluation and integration of services, goods and benefits generated by ecosystems) continues to have considerable impact on a national and international scale. This paper uses the emerging language of ecosystem services to consider the role of urban water components to contribute to the delivery of a range of ecosystem services, goods and benefits. Quantitative and/or qualitative data on the contribution of water components located in urban areas to the delivery of ecosystem services is scarce. However, knowledge derived from papers published in a range of disciplinary fields strongly indicates that urban water components contribute to the delivery of ecosystem services in all of the MA categories, supporting the view that urban water bodies should be seen as multifunctional components of urban space.

A key aspect of this conclusion is the diversity of scientific, policy and practitioner disciplines from which information has been drawn, including social science, psychology, geomorphology, hydrology, environmental science, ecology, government departments and environmental regulators. Also of note is the finding that despite the completion of several single-discipline studies on the same case-study site it was only possible to qualitatively comment on the provision of ecosystem services in a few cases. While acknowledged to be a single case-study site, these findings complement each other, providing support for the implementation of a transdisciplinary research approach. However, transdisciplinary research has yet to emerge as a fully respectable research approach within many academic communities. Many funding bodies do now support knowledge transfer activities and are taking part in initiatives which promote co-funded research across the disciplines, but the continued emphasis of funding along single discipline lines means that for many transdisciplinary research still appears to be on the edge of mainstream scientific agendas. In order to approach this challenge and position transdisciplinary research in the centre of scientific advancement rather than on the periphery, it is imperative that we bring together discipline-specific expertise to address fundamental and applied problems in a holistic way. One approach to addressing this would be the development of a Transdisciplinary Research Institute or Society, akin to the Royal Society of Chemistry or Institute of Physics, with its own peer-review journal. The development of a high-profile body which could represent and promote research and researchers keen to cross traditional single-discipline divides would raise awareness and the prestige of transdisciplinary working. In providing an internationally recognized framework which facilitates transdisciplinary research, the ecosystem services approach offers an exciting mechanism to support researchers in tackling research questions that require thinking outwith traditional scientific boundaries. Ensuring quality-of-life for future generations facing an uncertain future is a challenge unlikely to be fully addressed by one discipline alone. The opportunity to fully exploit this approach to collaborative working should not be lost.

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