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The interrelationship of green infrastructure and natural capital

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ABSTRACT

The terms green infrastructure and natural capital are interrelated. Natural capital as a concept is focused upon environmental assets which can provide ecosystem services, either directly or indirectly to humans; the concepts of natural capital and ecosystem services emphasize the benefits humans obtain from the natural environment. Green infrastructure is a concept with a wide range of definitions. The term is sometimes applied to networks of green open spaces found in or around urban areas. In other contexts green infrastructure can describe alternative engineering approaches for storm water management, with co-benefits of temperature control, air quality management, wildlife habitats and/or recreation and amenity space. No environments are completely free of human influence and therefore no environments are entirely natural. Rather, there is a spectrum of degrees of 'naturalness' ranging from environments with minimal human influence through to built environments. A trio of case studies presented herein illustrates how green infrastructure projects are a practical application of the natural capital concept in that they seek to preserve and enhance natural capital via a management approach which emphasizes the importance of environmental systems and networks for the direct provision of ecosystem services to human populations. Natural capital forms critical components of all green infrastructure projects.

1. Introduction

Capital is a stock which possesses the capacity to give rise to a flow of goods and services. Classical economics identify land, labour and human-made capital as the different types of capital stocks (Smith, 2008). In the modern context, Ekins et al. (2003) describe four kinds of capital: (i) *manufactured capital,* made up of material goods such as machines or infrastructure which contribute to production processes, (ii) *human capital,* made up of individuals and their capacity to work, iii) *social and organisational capital* consisting of networks which allow the mobilisation of inputs from individuals, and (iv) *ecological capital,* also called *natural capital*, which provides resources for production, absorbs wastes, provides the underlying conditions which allow production to proceed and contributes more broadly to human welfare. Natural capital roughly corresponds with the classical economics factor of production of land (Costanza and Daly, 1992) and is the focus of this article. Crossman and Bryan (2009) link natural capital with ecosystem services, defining it as "the stock from which ecosystem goods and services are provided". Earlier, Hinterberger et al. (1997) suggest that nature can be seen as capital and the services provided by nature as income. Thus, natural capital is related to but different to ecosystems services, which can be defined as "the aspects of ecosystems utilized (actively or passively) to produce human well-being" (Fisher et al., 2009).

The concept of natural capital has grown in prominence in recent years, with bodies such as the UK's Natural Capital Committee and the Natural Capital Initiative being established in the UK, and internationally, bodies such as the Natural Capital Coalition, and the World Forum on Natural Capital, together with hundreds of journal articles published which discuss natural capital. Along with the concept of natural capital, the term 'green infrastructure' has also gained prominence, and as with natural capital, a variety of definitions of this term are used. For example, Naumann et al. (2011, p1) describe green infrastructure as "the network of natural and semi-natural areas, features

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and green spaces in rural and urban, and terrestrial, freshwater, coastal and marine areas, which together enhance ecosystem health and resilience, contribute to biodiversity conservation and benefit human populations through the maintenance and enhancement of ecosystem services".

The aim of this article is to evaluate the concepts of natural capital and green infrastructure to assess the extent to which they interrelate. As argued by Ekins et al. (2003), "[n]atural capital is a metaphor to indicate the importance of elements of nature….. to human society", with critical natural capital that which sustains key environmental functions and which cannot be substituted by manufactured capital for sustaining these functions. Green infrastructure similarly is a metaphor indicating the importance of key components of the environment (Abhijith et al., 2017) and also directly emphasizes the critical services provided by these components due to its analogy with constructed infrastructure that is vital to urban living (Thomas and Littlewood, 2010; Tiwary and Kumar, 2014). Following a review of the natural capital and green infrastructure concepts, this article analyses how the concepts of green infrastructure and natural capital overlap and the implications of considering these two terms together. Three green infrastructure case studies are then analysed from a natural capital perspective to inform a discussion of the usefulness of these concepts and their interrelationship.

2. The concept of natural capital

Rather than try to define natural capital in precise terms, some researchers provide examples of what they mean by the term. Thus, Schumacher (1973, p5) in one of the earliest direct uses of the term 'natural capital' gives as an example fossil fuels while noting in relation to human-made capital that "[f]ar larger is the capital provided by nature and not by man". Cleveland (1994) gives examples such as stands of timber, the operation of the hydrologic cycle, fossil fuels and mineral deposits. The World Bank (2011) gives the examples of agricultural land, protected areas, forests, minerals, and energy, while Brand (2009) gives the examples of ecosystems, air and water. Berkes and Folke (1994) give examples of oil and minerals, fish, wood and drinking water, along with environmental services such as the maintenance of the atmosphere and the operation of the hydrological cycle. However, such environmental services are arguably the product of natural capital rather than natural capital itself, suggesting that the concept of natural capital is closely tied up with that of ecosystem services. Human wellbeing is derived from the ecosystem services stemming from the interaction of natural capital with other forms of capital.

The UK's Natural Capital Committee (2017b, p1) defines natural capital as "the elements of the natural environment which provide valuable goods and services to people, such as clean air, clean water, food and recreation". Along similar lines, the Natural Capital Coalition (2016) defines natural capital as the stock of natural resources (renewable and non-renewable) that yield a flow of benefits to people. Costanza and Daly (1992, p38) also define natural capital as a natural stock "that yields a flow of valuable goods and services into the future". Costanza and Daly go on to distinguish between renewable and non-renewable natural capital. Whereas renewable natural capital is active and self-maintained via solar energy, non-renewable natural capital is passive, generally yielding no services until it is extracted. Examples of renewable natural capital include forest ecosystems yielding a flow of services, such as recreational space and erosion control, but can also be harvested to yield goods, such as wood. Non-renewable natural capital includes fossil fuels and minerals (Costanza and Daly, 1992). Most definitions of natural capital perhaps unsurprisingly emphasize "natural" as the defining element; Daly (1994) argues that unlike other forms of capital, natural capital cannot be produced by humans. Segura and Boyce (1994) suggest that designation of natural resources as "natural capital" has occurred because the availability of natural resources can no longer be taken for granted, with their depletion needing to be treated as a cost.

2.1. Valuing of natural capital

Since one of the key reasons for the development of the concept of natural capital is to highlight its importance to human societies, monetary valuations can be used to reveal its value relative to other forms of capital. However, the real value of natural capital is reflected to only a limited extent by market prices and so non-market valuation techniques are frequently used (Farley, 2008). As the UK's Natural Capital Committee (2017a) argues, decisions about natural capital investment may not provide the best outcome for society if they are based upon market prices alone.

The use of non-market valuation techniques, however, raises the question of whether a single metric can adequately capture the multiple attributes of natural capital (Farley, 2008). As Chiesura and de Groot (2003) argue, while economists use monetary units for valuing natural capital, natural scientists quantify natural capital using physical units. However, using physical units to quantify natural capital presents challenges when trying to determine whether natural capital stocks are increasing or decreasing as it is problematic to sum up very different physical components, while monetary units provide a common metric to quantify stocks (Hinterberger et al., 1997).

Despite the methodological challenges of using physical units for valuing natural capital, for some forms of natural capital, such as endangered species, estimating value in monetary terms can be seen as unacceptable (Farley, 2008). Even putting aside principled objections, there are serious methodological concerns with non-market valuations based upon methods such as stated preferences and revealed preferences. Not only can these seriously underestimate values, their application involves normative assumptions about who should participate in decision making (Farley, 2008).

Previous studies note that monetary valuations of natural capital can face the problem that sharp reductions in capital can be outweighed by higher prices (Hinterberger et al., 1997). Arrow et al. (2012) propose the use of shadow pricing for valuing capital gains in non-renewable natural capital. Farley (2008) however, argues that for natural capital which is approaching the threshold of criticality, monetary valuations may be inappropriate as capital stocks can change faster than the valuation and decision making processes proceed. Despite the methodological challenges, natural capital valuations have been included in comprehensive wealth accounting studies developed by the World Bank and other institutions (UNU-IHDP and UNEP, 2012; World Bank, 2011).

2.2. Natural capital and the natural-manufactured spectrum

While natural capital can be defined as the stock from which ecosystem goods and services are provided, natural capital is not necessarily "natural" in the sense of being free of human influence. In relation to soil natural capital stocks, for example, Dominati et al. (2010) distinguish between inherent soil properties (such as slope, depth and clay type), and manageable soil properties–characteristics which respond to active management (such as contents of nutrients and organic matter and macro-porosity). While inherent soil characteristics cannot easily be altered, farmers and other land managers can optimise manageable soil properties to maximise particular ecosystem service outputs such as human food provision. Likewise, Robinson et al. (2013) argue that virtually all ecosystems are shaped in some way by humans, while some are even created by humans, and so identifying truly natural capital is difficult. Crossman and Bryan (2009) also note that overexploited agricultural land requires management or land-use change in order to restore its depleted natural capital stock, observing that some natural capital can be the result of determined human effort. Similarly, Segura and Boyce (1994, p480) and Hinterberger et al. (1997, p4) suggest that humans can "invest in natural capital" through measures such as planting trees or restoring wetlands. This suggests a symbiotic relationship whereby natural capital (and the ecosystems sustained) may exist as a result of deliberate and continuing the human effort, with humans then depending upon that natural capital for their survival. Irrigated farm land is an example of this symbiosis. Such an ecosystem sustains the human communities which maintain its water system and fertility through careful stewardship.

Given the varying nature of human influence on natural capital, De Groot et al. (2003) and Daly (1994) propose that there is an additional type of capital, namely cultivated capital, which refers to semi-natural systems with varying degrees of human influence. The term cultivated capital, however, does not adequately capture the nature of a restored habitat, such as forest, that may have been directly planted by humans but no longer be under direct human management. It is thus neither cultivated nor natural.

Katz (1997) argues that, strictly speaking, there is nothing truly natural on earth since the whole planet has been influenced by pollution, technology or other human interferences. Recent work of Waters et al. (2016, p137) indicates humans have had such a pervasive impact on the earth that it justifies the use of a new geological time unit, the "Anthropocene", which they suggest began in the mid-twentieth century. Since the start of the Anthropocene, humans have driven global-scale alterations of the geochemical composition of sediments, atmospheric compositions of gases such as carbon-dioxide and methane, average global temperatures, sea levels, and extinction rates (Waters et al., 2016). However, pervasive human impacts on the environment go back much further. Evidence suggests that early humans contributed to the loss of megafauna via hunting but pronounced climate change also played a key role (Barnosky et al., 2004), with there being considerable debate about the relative importance of these two factors. Significant human impact on biodiversity and other forms of natural capital has clearly been extensive for thousands of years even if the degree of impact has grown exponentially in recent decades.

Recognising that natural capital can be managed, degraded, replaced and sometimes restored, with all environments having some degree of human influence, suggests that there are varying degrees of naturalness rather than absolutes. On this basis, the IUCN et al. (1991) outline a spectrum of ecosystems which captures the varying degrees of human influence. The spectrum ranges from natural systems through to built systems. They define natural systems as ecosystems where since the industrial revolution human influence has been no greater than that of other species and where humans have not affected the structure of the ecosystem; the impact of climate change is excluded since it affects all ecosystems and would thus eliminate any ecosystem on the planet from being natural (IUCN et al., 1991). Modified systems are ecosystems where humans have more impact than any other species but where the structural components are not cultivated; examples include naturally regenerating range lands and naturally regenerating forest. Cultivated systems are ecosystems where humans cultivate most structural components, such as in farmland, while built systems are ecosystems dominated by human made structures, such as buildings, mines or dams (IUCN et al., 1991). In addition, degraded systems are ecosystems whose diversity, productivity and habitability have been significantly reduced, with modified systems, cultivated systems, and built systems all potentially able to be described as degraded systems and considered unsustainable (IUCN et al., 1991).

The existence of a spectrum of capital types, ranging from natural capital through to manufactured capital–depending upon the extent of human influence–in no way undermines the value of natural capital any more than it undermines the value of manufactured capital. Maintenance of a range of the different forms of capital along this spectrum is critical to human survival due to their interaction and interdependencies. Forest ecosystems, for example, contribute to the productivity of adjacent farmlands and provide critical ecosystem services for urban environments such as freshwater supply.

3. The concept of green infrastructure

As noted in the introduction, green infrastructure can be defined as the network of natural and semi-natural spaces in urban and rural areas which provide ecosystem services (Naumann et al., 2011). Although the concept of green space dominates most definitions of green infrastructure, many definitions of green infrastructure emphasize that the term refers to more than just a collection of open spaces, placing emphasis on the fact that green infrastructure refers to planned networks of spaces (Environment Agency et al., 2013; West of England Green Infrastructure Group, 2011). Thus, the UK Environment Agency et al. (2013, p12) define green infrastructure as "the living network of green spaces, water and other environmental features in both towns and the countryside". The European Commission (2013a, 2013b) also stresses the interconnection between green spaces in its definition of green infrastructure, noting that green infrastructure is a strategically planned network of natural and semi-natural spaces which provides benefits to people via multiple ecosystem services. Informal green space is not the same thing as interconnected green space networks which can be considered to be infrastructure (Ashley et al., 2011). Thus, not all green (or blue space–human-made or natural areas of water) is necessarily green infrastructure whether or not it is located in an urban or rural environment–a space must be part of a planned network to be green infrastructure.

Other definitions of green infrastructure emphasize ecological functions rather than the provision of green space. Tzoulas et al. (2007, p3) describe green infrastructure as "all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas". Under this definition, a habitat which is ecologically important but not a green space might be considered to be a piece of green infrastructure. Also arguing that not all green infrastructure is green space, Mell (2013) contends that the term green infrastructure is applied both to visually green spaces, as perceived by the public, as well as infrastructure which fulfills sustainability functions. Thus, a cycle route which promotes personal mobility and healthy living, although being a civil engineering project, might be considered to be green infrastructure under this more expansive understanding of the term. Similarly, previous pavement which balances the hydrologic cycle (e.g., Wardynski et al., 2012) or the use of vegetation for storm water management and other water management solutions might also be described as a form of green infrastructure.

Given this multiplicity of definitions, Horwood (2011) argues that the meaning of green infrastructure is not fixed or established but is adaptable to the context in which it is being applied. Similarly, Wright (2011) argues that there are diverse and varied interpretations of the concept of green infrastructure which depend upon the context in which the term is applied, and indeed that ambiguity is unavoidable since the pursuit of a precise meaning of the term is not possible and would not be productive. Theoretical definitions of the term are more environmental in focus, while policy related definitions are more socioeconomic in focus (Wright, 2011). In line with this, Mell (2013) suggests that the ambiguity surrounding the concept of green infrastructure means that its application is not constrained and this ambiguity facilitates best practice delivery.

3.1. Types of green infrastructure

Green infrastructure can include various natural and semi-natural green spaces, including parks and gardens, amenity green space, allotments and city farms, cemeteries and churchyards, green corridors such as rivers or railway embankments, conservation and nature reserves, and archaeological sites (Town and Country Planning Association, 2012). Beyond these various forms of open space, green infrastructure can also refer to formally engineered systems, also commonly described as sustainable drainage solutions (SuDS) rather than green infrastructure in the UK (Department for Environment Food and Rural Affairs, 2011), Water Sensitive Urban Design in Australia, and Low Impact Development in the USA (Fletcher et al., 2015). These include green and blue roofs, swales, infiltration and filter drains and strips, wetlands and ponds, bio-retention areas and rain gardens, detention and infiltration basins, and permeable surfaces located in urban or rural areas (Ashley et al., 2011; Foster et al., 2011).

3.2. Aims, objectives and drivers of green infrastructure development

There are numerous drivers of green infrastructure development: policies and strategies, spatial planning requirements, local and regional needs, and private and social actors (Naumann et al., 2011). Rather than having the environment pose limits on development, green infrastructure is presented as a way of allowing economic growth while satisfying environmental needs (Horwood, 2011).

A wide range of objectives have been put forward for green infrastructure. These include improving human health and wellbeing (Dunn, 2010; Kambites and Owen, 2006; McDonald et al., 2005; Naumann et al., 2011; Young, 2011), improving urban aesthetics (Dunn, 2010; Young, 2011), biodiversity conservation (European Commission, 2013b; Kambites and Owen, 2006; McDonald et al., 2005; Naumann et al., 2011), water management (Dunn, 2010; European Commission, 2013b; Kambites and Owen, 2006; Naumann et al., 2011; Young, 2011), sustainable land management (McDonald et al., 2005; Naumann et al., 2011), climate change mitigation and adaption (Moore and Hunt, 2013; Naumann et al., 2011; Young, 2011), job creation (Dunn, 2010), and urban regeneration (Dunn, 2010; Kambites and Owen, 2006; Wright, 2011).

While desired objectives vary from one green infrastructure system to another, in general, green infrastructure is seen more as a tool for increasing biodiversity in urban areas in the UK and Europe, whereas in the US green infrastructure is linked to low impact development and surface water management (Ashley et al., 2011; Mell, 2013). The stated aims of green infrastructure systems in the provision of green space, nature conservation, and environmental regulating services (Mell, 2008; Naumann et al., 2011) overlap considerably with aims relating to the conservation of natural capital.

3.3. Benefits of green infrastructure

The broad range of objectives associated with green infrastructure development suggests these systems may provide a diverse range of benefits. Foster et al. (2011) note that although many green infrastructure projects are implemented with a single goal in mind, most projects provide multiple benefits. Many of the benefits identified for green infrastructure are also benefits identified for natural capital although benefits accruing directly to humans are identified more frequently in the context of green infrastructure. Cited benefits of green infrastructure to humans include reduced air pollution in urban areas (Al-Dabbous and Kumar, 2014; Dunn, 2010; Gallagher et al., 2015), reduced urban heat island effects (Dunn, 2010; Forest Research, 2010), and improved health and mental well-being (Kambites and Owen, 2006). Benefits to ecosystems include the provision of habitat areas and green corridors for wildlife (Kambites and Owen, 2006), increased permeability of urban areas for ecosystems (Forest Research, 2010), more resilient ecosystems and greater biodiversity (West of England Green Infrastructure Group, 2011), reduced runoff and flooding (Forest Research, 2010), and increased pest control (European Commission, 2013a). Indirect benefits of enhanced green space include higher property values, reduced crime and the promotion of a greater sense of community as people are drawn out of their houses to make greater use of outdoor space (Dunn, 2010).

4. Green infrastructure and natural capital

The concepts of green infrastructure and natural capital are thus clearly interrelated. Whereas natural capital emphasizes the benefits humans obtain from the natural environment, green infrastructure emphasizes the benefits humans receive from incorporating elements of the natural environment and environmental processes within human-dominated landscapes. However, as noted previously, humans interact with, enhance and degrade natural capital, with many forms of natural capital, such as soils and forests, being extensive managed by humans in some contexts.

The case studies below examine the natural capital components of three green infrastructure projects, examining the extent to which these projects sustain or enhance the natural capital of their local environments. These case studies were chosen to provide examples of green infrastructure projects which span the natural or modified capital spectrum of the IUCN et al., 1991.

4.1. Case study 1: landscape scale restoration at Nutfield Marshes, Surrey, UK

The Nutfield Marshes Project, near Redhill in southern England, is an example of green infrastructure created on a former mining site that demonstrates how the exploitation of a non-renewable natural capital asset can subsequently lead to the development of other natural capital assets such as biodiversity. The scars of mineral extraction are a major feature of the project area's landscape in four out of the five sites which comprise the Nutfield Marsh network. The project has successfully linked The Moors and Spynes Mere, two 'core' conservation sites supporting a rich variety of wildlife, thereby creating a continuous, functioning wildlife corridor 3km in length.

The Moors site is an eight-hectare wetland nature reserve which attracts a variety of aquatic invertebrates and amphibians. Public access routes provide the public with an opportunity to easily observe wildlife while the reserve's retention and slowed release of floodwater provides flood alleviation downstream in the town of Redhill. Spynes Mere is a former sandpit at the eastern end of the Nutfield Marsh wildlife corridor which has been restored to wetland wildlife habitat by the owners, Sibelco UK and managed as a nature reserve since 2003 by Surrey Wildlife Trust. Although the site remains in use for draining Sibelco UK's aggregate workings to the east, it provides sanctuary for large numbers of wintering wildfowl, including Tufted duck, Gadwall and Pochard. Grassland communities, hedgerows and bare ground further enrich the site.

Connecting The Moors and Spynes Mere are three other sites which provide a range of restored habitats (Surrey Wildlife Trust, 2014). Mercers Country Park is another former sandpit which was restored in the 1970s for commercial leisure use which now comprises mainly water sports and angling. Holmethorpe Lagoons consists of two lagoons developed by a housing developer, with one lagoon open and easily accessible to local residents for passive recreation while the other has been buffered by strategically planted reeds and other vegetation in order to encourage wildlife via the creation of a more naturalistic environment. Mercers West is a third Sibelco UK-owned former sandpit in the project area is also recently restored as a nature reserve.

The Nutfield Marshes project illustrates well how green infrastructure can form significant natural capital which provides a rich array of ecosystem services to its local community (Surrey Nature Partnership, 2015; Surrey Wildlife Trust et al., 2017). These include aesthetic and recreational cultural services, water purification and flood alleviation regulating services, and soil formation and nutrient cycling supporting services. As a planned network of wetlands and green spaces created deliberately from landscapes degraded by the extraction of non-renewable natural capital, it is an example of green infrastructure which does not fit neatly on the natural or modified capital spectrum of the IUCN et al. (1991). While parts of the network are largely self-sustaining natural systems where human impact is minimised and wildlife flourishes, other parts are very obviously modified systems managed for direct human benefit while still providing

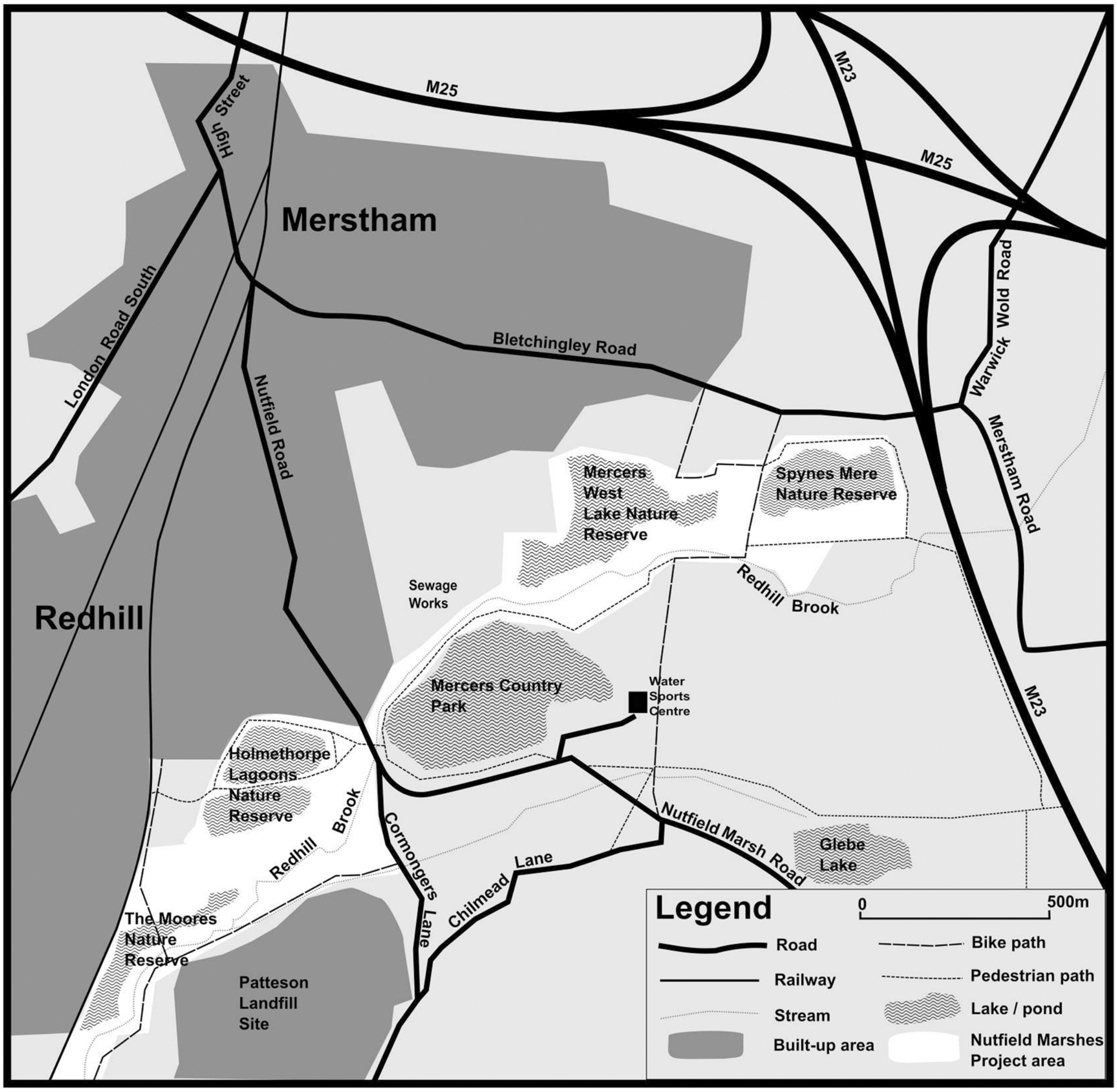

Fig. 1. The Nutfield Marshes case study area, located in Surrey, UK, adjacent to the town of Redhill and the M25 London ring road.

important habitat and a corridor for wildlife. See Fig. 1 for a map showing the case study area.

4.2. Case study 2: Constructed Stormwater Wetland (CSW) in Raleigh, North Carolina, USA

Constructed stormwater wetlands are perhaps the most ecologically-based practices used in green infrastructure. Many are constructed to serve the principal purposes of storm water detention, nutrient abatement and as educational/passive recreational natural areas in otherwise urban environments. In North Carolina, constructed stormwater wetlands have been implemented extensively since 1999 when the state passed very stringent rules regarding nitrogen discharge from new developments (State of North Carolina, 1999). At the time, CSWs were credited with the highest nitrogen removal of all stormwater practices.

Originally built in 2002 to comply with local site development stormwater requirements, this constructed wetland treats runoff from a large school rooftop and associated parking lots. This engineered 0.2-ha system consists of a winding open-water channel, shallow marsh areas dominated by bulrush (*Schoenoplectus* sp.) and pickerel weed (*Pontedaria cordata*) and a large deep water pool near the outlet. The system was first studied to quantify reductions in stormwater pollutant loads delivered to downstream ecosystems–the intended objective of this CSW. The system was found to reduce mass pollutant loads of total phosphorus, total nitrogen, and sediment by 59%, 47%, and 72%, respectively (Line et al., 2008).

Additional ecosystem services were assessed in this and 19 other CSWs in North Carolina by Moore and Hunt (2012). Representing one of the older systems analysed, mean sediment carbon density in this CSW (2100 $g\,C\,m^{-2}$) was greater than the average of 19 other wetlands surveyed as part of this study, suggesting that constructed wetlands sequester carbon over time. The 20 constructed wetlands overall showed a carbon accumulation rate of 84 $g\,C\,m^{-2}\,yr^{-1}$, comparable to the soils of grasslands and re-established forests (Riedell et al., 2010). The presence of vegetation in these systems was hypothesized to be a key driver of carbon sequestration benefits. This CSW also contributed to local biodiversity, supporting over 15 aquatic macroinvertebrate families. Dragonfly larvae and other predatory species comprised the majority of this biodiversity, suggesting this and other CSWs may also play a role in regulating pest (e.g. mosquito) populations.

Finally, Moore and Hunt (2012) quantified the ability of this and 19 other constructed stormwater wetlands and 20 constructed stormwater ponds to provide recreation and education cultural services. Scores of 0 (poor service provision) to 4 (high service provision) were assigned qualitatively. This wetland scored well for recreation (3 of 4) and education (4 of 4) due to its location near a middle school and golf course. The larger sampled data suggested that wetlands offer greater recreational services because they were more frequently located on open public access land than ponds, which were often located in the back lots of private developments. Fifty-five percent of the wetlands had walking trails, boardwalks, and wildlife viewing areas compared to just 25% for ponds.

Along the spectrum of natural capital (IUCN et al., 1991), the authors consider this CSW (and others like it) to be a modified system. While humans have provided the base infrastructure (including excavation of physical space, construction of drainage systems, and the initial planting of vegetation), once established, this green infrastructure ecosystem has evolved without further direct human intervention. Since 2002, plant species have self-organised within the CSW, new species have colonized, and a diversity of fauna has established (Moore and Hunt, 2012). The CSW is clearly an environmental asset providing important ecosystem services.

4.3. Case study 3: Street Edge Alternative (SEA) Street, Seattle, Washington, USA

In more heavily built-up urban areas, where larger footprint practices are not economically feasible due to high land costs and/or insufficient space, green infrastructure is often located in the street scape. Much of a municipality's managed space lies in the street scape, which makes stormwater retrofitting more likely to occur there. A term for placing green infrastructure in the street scape is 'green streets' (Page et al., 2015).

In 2001, the city of Seattle, Washington State, installed one of the USA's first green streets by renovating a three-block residential local access road with bioswales and right-of-way vegetation while reducing the amount of pavement by 11%, all to more closely mimic the stormwater volumes and rates of a pre-development condition (Ward et al., 2008). The street's previously linear road geometry was changed to a winding pattern. One hundred new evergreen trees and 1000 new shrubs were planted in bioswales—linear planted sections of road edges that convey storm water away from the driving lane. The curb and gutter system was removed, allowing stormwater runoff to sheet flow into these bioswales and infiltrate into the native soil rather than discharging to the piped sewer system.

Horner et al. (2002) quantified the benefit of the SEA Street to stormwater runoff reduction. They concluded that the project has prevented the discharge of all dry season flow and 98 percent of the wet season runoff, fully capturing rainfall events of up to 19 mm. Compared to a conventional street, the SEA Street reduces run off volume to the local creek in wet months by a factor of 4.7. This reduction in stormwater runoff–flood regulation–is one of the ecosystem services provided by the natural capital components of this green infrastructure development to its local neighbourhood. Other ecosystem services provided include water purification regulating services and aesthetic cultural services, with these aesthetic cultural services having direct financial value. Ward et al. (2008) applied a hedonic pricing analysis to evaluate the effect of this green infrastructure development on property values. They found that houses in parcels receiving SEA Street treatments in Seattle sold for approximately 5.5% more than similar houses in the same neighbourhood.

Construction costs of the 2nd Avenue SEA Street were compared to conventional street retrofits, the latter being the replacement of the street, sidewalk paving, and traditional pipe installation, both of which include planning, design, and close-out phases (Conservation Research Institute, 2005). The capital cost of the system was estimated at $850,000 ($650,000 in 2001 dollars), 25% less than a conventional street would have cost on overall construction costs (Conservation Research Institute, 2005; Seattle Public Utilities, 2016). While the landscaping and site preparation line items were more expensive for SEA Street implementation by $34,300 and $23,100, respectively, stormwater management, site paving, and sidewalks were cheaper with the low impact SEA street implementation. Overall, an estimated cost savings of $217,000 was calculated (Conservation Research Institute, 2005)

This installation of green infrastructure clearly has more direct ongoing human intervention. For example, permeable pavement parking spaces on this street need to be street cleaned. The bioretention cells are inspected regularly so that clogging does not occur and will occasionally be pruned. Despite some human intervention, this green street does have colonizing species of vegetation and has returned this landscape to a more natural hydrology. Based upon these factors, the authors describe this system as cultivated natural capital (IUCN et al., 1991).

5. Discussion

Green infrastructure is a concept with a wide range of definitions. The term can be applied to almost any green open space found in urban areas or in the vicinity of urban areas (and is sometime also applied in rural areas), giving weight to the importance of such spaces by highlighting their functional value as critical infrastructure. A stricter application of the term highlights that green infrastructure refers to planned networks of green areas, not just any green open space, with the infrastructural aspect coming from the synergistic effects of a network of spaces and their planned interconnections. These are the common understandings of the concept of green infrastructure as it is frequently applied in the UK and elsewhere in Europe. In other contexts, and particularly in the USA, green infrastructure is also commonly used to describe alternative engineering approaches for storm water management, temperature control or air quality management which depend upon the use of vegetation, infiltration and evapotranspiration. Such low impact development approaches can be more cost effective, have lower energy and material requirements than alternative grey infrastructure engineering systems and produce additional benefits such as providing wildlife habitats or amenity space. Such benefits are not typically provided by conventional engineered infrastructure.

While natural capital as a concept is focused upon environmental assets which provide ecosystem services, either directly or indirectly, to humans, given the use of the word "natural" the emphasis is on assets which exist in the absence of substantial human input. This could be understood as fundamentally different and indeed incompatible with the concept of green infrastructure but given the pervasive impact of humans on the planet, there are no environments which are completely free of human influence and therefore no environments which are entirely natural and indeed, some natural capital researchers acknowledge that humans can play a direct role in the creation of natural capital.

There is a spectrum of degrees of naturalness as outlined by the IUCN et al. (1991) that ranges from environments with minimal human influence through to human built environments. On this spectrum, the US understanding of green infrastructure is perhaps further towards the "built" end of this spectrum while the European understanding is somewhat closer to the "natural" end of the spectrum.

Natural capital as a concept is different in focus to that of green infrastructure but it is not incompatible. As the case studies above illustrate, each could be described from a natural capital or green infrastructure perspective depending upon the context and language used. Green infrastructure projects are a practical application of the natural capital concept in that they seek to preserve and enhance natural capital via a management approach which emphasizes the importance of environmental systems and networks for the direct provision of ecosystem services to human populations. Natural capital forms critical components of all green infrastructure projects.

Adapting the ecosystem service cascade model proposed by Haines-Young and Potschin (2010), green infrastructure projects plan and develop landscape structures, supporting or creating an ecosystem or series of ecosystems, which provide services, such as pollutant filtration, leading to benefits to humans. Green infrastructure projects thus form the context and means in which natural capital may be protected, restored or created by humans, with the resulting ecosystem providing direct (and indirect) benefits to humans.

Both concepts of natural capital and green infrastructure focus upon environmental assets, the ecosystems these environmental assets support and the ecosystem services they provide. The concepts of natural capital and green infrastructure highlight the value of environmental assets to human societies and the importance of preserving and enhancing these assets to maximise the services they provide. Environmental assets, whether largely natural in origin or resulting from human intervention, underpin the ecosystem services upon which human societies depend. Green infrastructure projects are a means of creating or enhancing such assets to maximise the specific ecosystem services which they provide. Further research is needed on how green infrastructure in its different forms can be extended and made more pervasive across urban areas for the benefit of humans and the ecosystems upon which we are dependent.

6. Conclusions

The spectrum of the naturalness of environments (ranging from environments with minimal human influence through to human built environments) in relation to the concepts of natural capital and green infrastructure emphasizes the important role of human societies in the maintenance of environmental assets and the ecosystem services they provide. Whereas the concept of natural capital highlights human dependence on the natural environment, it doesn't adequately draw attention to the role humans can play in maintaining and enhancing their local environments and the ecosystem services they provide–potentially, a symbiotic relationship. The concept of green infrastructure emphasizes this but fails to encompass the broader concepts reflected in the term natural capital. The two terms interrelate in that natural capital forms key components of green infrastructure, with the development of green infrastructure being one conceptual means to create or sustain natural capital. Natural capital as a metaphor is an attempt to better incorporate the natural environment into economic decision making while green infrastructure is a metaphor which attempts to better incorporate the natural environment into urban planning and civil engineering.

The spectrum of naturalness of environments in relation to natural capital suggests the need for a broader conception which overtly recognises the symbiotic relationship between humans and the environments they depend upon and manage (to varying extents). The conception of a natural capital–built capital spectrum would better emphasize the stewardship role which humans must play with their environment rather than just being the recipient of ecosystem services.

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