Science for Environment Policy

DG Environment News Alert Service

IN-DEPTH REPORT

The Multifunctionality of Green Infrastructure

March 2012

EUROPEAN COMMISSION

environment

Contents

Figures

Tables

Executive Summary

Green Infrastructure (GI) stands to improve quality of life in many ways, through its environmental, social and economic credentials, based on the multifunctional use of natural capital. Potentially a very valuable policy tool, GI's multifunctionality could contribute to the achievement of a number of policy aims and fulfil the needs of a variety of stakeholder groups.

GI can be created in many places, covering natural and semi-natural areas in urban, rural and marine areas, as well as man-made elements, such as green roofs and ecoducts over motorways, and restored lands, such as wetlands and mangroves. One of its major attractions is its ability to perform multiple functions on the same piece of land and/or water. While biodiversity remains at the core of GI, it is much more than a biodiversity conservation instrument.

This report describes the different functions that GI seeks to execute and explores the scientific evidence behind its ability to perform these functions, using case studies where available. The functions are described in terms of four broad roles that GI performs:

- Protecting ecosystems state and biodiversity
- Improving ecosystem functioning and promoting ecosystem services
- Promoting societal wellbeing and health
- Supporting the development of a green economy, and sustainable land and water management

The roles of GI are highly interdependent, for example, societal wellbeing in coastal and river areas depends on flood retention by wetlands or natural drainage systems, which in turn depend directly on the provision of ecosystem services, such as soil and water regulation. These, in turn, are highly reliant on biodiversity to uphold the health of the ecosystems to provide ecosystem services.

Evaluating the many aspects and functions of GI is a complex process. Although some elements with clear functions and objectives can be easy to measure, such as the ability of green roofs to reduce stormwater runoff, it can be challenging to identify one overall measurement encompassing all the different GI objectives. As such, the evaluation of GI may require a combination of qualitative or descriptive assessments with quantitative measures, using input from both ecological and social sciences. For example, quantitative measures of changes in ecosystem services could be combined with descriptive measures of existing political infrastructure to support policy measures and stakeholder participation.

Indeed, stakeholder participation will be crucial to the success of GI and, as a tool that spans several scientific and political disciplines, GI policy will require creative methods to inform its planning, implementation and evaluation. Although this may present a challenge, it should not hamper the adoption of GI policy tools and its use on the ground, but stimulate progress in developing assessment tools and adaptive evaluation methods to measure the impacts of GI.

Introduction

Green Infrastructure (GI) is the network of natural and semi-natural areas, features and green spaces in rural and urban, terrestrial, freshwater, coastal and marine areas (Naumann *et al.,* 2011a). It is a broad concept, and includes natural features, such as parks, forest reserves, hedgerows, restored and intact wetlands and marine areas, as well as man-made features, such as ecoducts and cycle paths. The aims of GI are to promote ecosystem health and resilience, contribute to biodiversity conservation and enhance ecosystem services (Naumann *et al.,* 2011a). Ecosystem services are services provided by nature, such as water regulation, that benefit the environment and humans.

The EU Working Group on GI strategy has proposed that GI also promotes integrated spatial planning by identifying multi-functional zones and incorporating habitat restoration measures into land-use plans and policies (GI Working Group Task 1 Recommendations, 2011). Ultimately, GI can benefit human populations and contribute to a more sustainable economy based on healthy ecosystems delivering multiple benefits and functions.

One of the key attractions of GI is its multifunctionality, i.e. its ability to perform several functions and provide several benefits on the same spatial area. These functions can be environmental, such as conserving biodiversity or adapting to climate change, social, such as providing water drainage or green space, and economic, such as supplying jobs and raising property prices.

A good example of this multifunctionality is provided by the urban GI of a green roof, which reduces storm water runoff and the pollutant load of the water, while also decreasing the urban heat effect, improving the insulation of the building and providing habitat for a variety of species.

It is the multifunctionality of GI that sets it apart from the majority of its 'grey' counterparts, which tend to be designed to perform one function, such as transport or drainage without contributing to the broader environmental, social and economic context (Naumann *et al.,* 2011a). As such, GI has the potential to offer win-win, or 'no regrets' solutions by tackling several problems and unlocking the greatest number of benefits, within a financially viable framework. GI can therefore be a highly valuable policy tool to promote sustainable development and smart growth by meeting multiple objectives and addressing various demands and pressures (EEA, 2011a).

Policy is already acknowledging GI and a communication will be adopted by the EC this year. GI has been linked to numerous initiatives, particularly in terms of the environment and climate change, such as Target 2 of the EU Biodiversity Strategy (Naumann *et al.,* 2011a), as well as EU policies on adaptation to climate change (COM 147, 2009), cohesion (COM 17,2011) and energy efficiency (COM109, 2011).

With its multifunctionality, GI involves several policy areas, which means it is potentially of interest to a variety of stakeholders, such as private businesses, planning authorities, conservationists, the public and a range of policymakers with responsibilities ranging from the local to the European (Naumann *et al.,* 2011a; Naumann *et al.,* 2011b). To ensure GI does fulfil its many functions, the relevant stakeholders need to be involved in its planning, implementation and evaluation.

Good research and monitoring of GI can contribute to the communication of its potential and its successful implementation. Communities can be unaware of the benefits provided by GI or believe it is more expensive or difficult to implement than grey infrastructure (Foster *et al.,* 2010). With several stakeholders involved, a conflict of interests is possible, which again highlights the need for consultation and participation to integrate different values attributed to GI.

Although GI has been studied since the 1970s in countries including Germany under the guise of 'landscape planning', it is still a relatively new EU policy instrument, which means there is not a large amount of specific research around its multifunctionality when applied to the EU.

In their research framework for urban green spaces, James *et al.* (2009) have outlined questions they believe should be answered for GI to progress effectively. In particular, they recommend more research on the global competitive gains from GI at an economic, environmental and social level, and on how multidisciplinary considerations can be integrated into methods for quantifying and valuing GI.

There is a body of research on ecosystem assessment and, more recently, on the trade-offs between ecosystem services, which could be applied spatially to the GI concept, for example, in gathering indicators and methods to determine the contribution of different land uses to the promotion of GI.

Owing to its multifunctionality, there is no single science or discipline responsible for GI (Benedict & McMahon, 2002). The nearest integrative scientific discipline accountable for its evolution is 'landscape planning' (see above). GI relies on the theories and practices of numerous scientific and land planning professions, such as conservation biology, landscape ecology, urban and regional planning, geographic analysis, information systems and economists.

Since GI has roots in several disciplines, its evaluation will need to reflect this. Research into GI also needs to adjust to different spatial scales as its application can range from individual buildings to neighbourhoods and cities to entire regions (Naumann *et al.,* 2011a).

The Multifunctionality of Green Infrastructure

This report focuses on the scientific research surrounding the multifunctionality of GI. By its very nature, multifunctionality is difficult to assess and its different functions tend to require different forms of measures and indicators. For example, evaluation of effects on biodiversity is often conducted in a different way to evaluation of GI's ability to prevent flooding or improvement in health of the surrounding community. Yet all these functions are likely to be inter-dependent and it is challenging to find a measure to capture this and integrate them into one measurement of performance.

Placing a monetary value on the functions performed by GI is one method of deriving a comprehensive assessment of its contribution through several functions. For example, estimates can be made of the money saved from implementing GI that protects against flooding, or the monetary value of carbon sequestered by GI, or the financial contribution GI makes to the local economy through increased recreation and tourism.

Monetary valuations are also easy to communicate to stakeholders and the public and can feed directly into policy decisions (Vandermeulen *et al.,* 2011). However, there are still several values provided by ecosystems upon which it is difficult to place a financial figure, particularly the more cultural and aesthetic values.

Nevertheless, work on the economic evaluation of ecosystem services, such as the EEA experimental framework for ecosystem capital accounting in Europe (2011b), is highly informative in this area but for any form of evaluation to be effective, monetary or otherwise, the objectives of GI need to be clear so these can be used as a starting point. The EU GI Working Group provides expert input and collects stakeholders' views on GI and the policy options. It has compiled some general objectives of an EU GI strategy which are outlined in Box 1 and could be used as guidelines for setting objectives of individual projects.

This report considers the different types of function that GI seeks to execute and the evidence behind its ability to perform these functions. Firstly, it explores some general issues surrounding the evaluation of GI in terms of defining GI features or elements, identifying comparable costs and benefits, and issues surrounding indicators and multi-level evaluation. Following this general section the report is divided into sections on four 'types' of GI function or 'roles':

- Protecting ecosystems state and biodiversity
- Improving ecosystem functioning and promoting ecosystem services
- Promoting societal wellbeing and health
- Supporting the development of a green economy and sustainable land and water management

The third role of 'promoting societal wellbeing and health' is a form of ecosystem service since it is a beneficial outcome to humans that results from the healthy functioning of ecosystems. As such, it could be included in the section covering GI's role of promoting ecosystem services, but with the increasing importance of this role, it is described here in a separate section.

This report identifies some of the GI features that carry out these roles and their costs and benefits, exemplified by case studies. It also identifies any indicators that could be used to monitor the performance of these roles and highlight areas where indicators need to be developed. It should be remembered that the four types of role are not independent but are highly contingent on each other. For example, GI's role in protecting biodiversity is highly dependent on its role in promoting ecosystem services and vice versa.

In reality, the performance of GI's roles cannot be separated but for the purposes of communicating them clearly in this report, they are considered one-by-one. With the interactions between the types of function, the linear format of this report provides challenges in representing the connections and inter-dependence of multifunctionality. However, links are made wherever appropriate and integrated in a final section.

Box 1: Objectives of EU GI Strategy in Working Group on a GI strategy for EU Task 1

- To enhance, conserve and restore biodiversity by *inter alia* increasing spatial and functional connectivity between natural and semi-natural areas and improving landscape permeability and mitigating fragmentation.
- To maintain, strengthen, and, where adequate, to restore the good functioning of ecosystems in order to ensure the delivery of multiple ecosystem and cultural services.
- To acknowledge the economic value of ecosystem services and to increase the value itself, by strengthening their functionality.
- To enhance the societal and cultural link with nature and biodiversity, to acknowledge and increase the economic value of ecosystem services and to create incentives for local stakeholders and communities to deliver them.
- To minimise urban sprawl and its negative effects on biodiversity, ecosystem services and human living conditions.
- To mitigate and adapt to climate change, to increase resilience and reduce the vulnerability to natural disaster risks – floods, water scarcity and droughts, coastal erosion, forest fires, mudslides and avalanches – as well as urban heat islands.
- To make best use of the limited land resources in Europe.
- To contribute to a healthy living, better places to live, provisioning open spaces and recreation opportunities, increasing urban-rural connections, contributing to sustainable transport systems and strengthening the sense of community.

1 General Issues Surrounding Scientific Research of GI

1.1 GI features and/or elements

There are a wide variety of GI features, ranging from conservation areas, to urban trees to fish ladders that connect habitats. GI can also include areas that have been restored to their original or near-to-original state and elements of grey infrastructure, such as bridges to allow wildlife to cross roads.

The features or elements are not always simple to define and descriptions of GI can change depending on the stakeholder (Horwood, 2011). One feature can be a combination of several elements, for example, ecological networks consist of core conservation areas, ecological corridors and buffer zones but these can also be features in their own right. In addition there are some features/elements that lend themselves better to scientific monitoring and evaluation, for example, green roofs which have easily measurable goals, such as the reduction of water runoff and clear indicators. Features, such as these tend to attract more research. The different GI features often perform several functions and as such they are relevant to more than one of the four roles considered in this report.

1.2 Costs and benefits of GI

GI's complexity makes it is difficult to reach a full quantification and valuation of GI initiatives. However, the background paper for the GI Expert Workshop (Ecologic, 2011) has identified the generic types of costs and benefits associated with GI projects and which have been used in subsequent analyses (Naumann *et al.,* 2011a & b; Mazza *et al.*, 2011).

1.2.1 Costs of GI projects:

Costs vary considerably between projects and, in their review of 90 GI projects, Naumann *et al.* (2011a) found individual budgets ranged between €0.5 to €5 million. Five very large projects had budgets over €25 million. Costs can be placed into one of two categories:

- **Financial costs** are spent on the resources deployed in creating, managing and developing GI, such as labour costs, materials, energy etc. They typically include one-off costs, such as research surveys and mapping for development of GI plans, costs of land purchase, compensation to create, restore and enhance GI. There are also recurrent costs in maintaining GI and ongoing monitoring, evaluation and communication activities. One-off costs tend to be the largest proportion of overall costs, but the recurrent costs of maintenance are often not fully recorded by projects as they can be mainstreamed into other programmes, such as agri-environment schemes and general planning budgets.
- **Opportunity costs** are the economic opportunities foregone as a result of GI. These may include foregone development, restrictions on resource use, and loss of socio-economic opportunities (e.g. use of land for regeneration or community uses). These costs are usually poorly understood and likely to be greater for projects in areas where there are high rates of development or for projects restoring semi-natural habitats on productive agricultural land.

One important consideration to note is that GI is often at its most practically and financially effective if it is dovetailed into other planning or architectural projects. For example, if a drainage system is being overhauled, sustainable drainage features, such as bio swales and permeable pavements could be installed simultaneously. Similarly, if a new transport infrastructure is being introduced, this is the opportune time to introduce ecoducts or bridges to help the mobility of wildlife. However, this can make it difficult to trace the specific costs of installing GI, as they can be confounded by costs for other infrastructure (Naumann *et al.*, 2011a).

The estimation of unit costs can be a useful way to communicate and compare costs of GI projects, usually in terms of money per unit area of land. However, Naumann *et al.*, (2011a) suggest missing data can make this problematic. Unit costs can also be done for other units, for example, the unit cost per green bridge in the Alpine Carpathian Corridor project (see Box 3, page 8) was estimated to be €4 million per green bridge.

1.2.2 Benefits of GI

On the whole, evidence of the benefits of GI is less quantifiable and more variable than costs (Naumann *et al.*, 2011a). Benefits are largely expressed in qualitative terms, such as habitat protection or recreational opportunities (Naumann *et al.*, 2011b). If they are quantified it is often in terms of the amount of GI projects or area of GI land that is created or maintained. The background paper for the GI Expert Workshop (Ecologic, 2011) identified some general indicators of benefits:

- Changes in the provision of GI - the extent and quality of habitats, corridors, ecosystems, green spaces and features
- Changes in the provision of ecosystem services e.g. volume of carbon stored, level of reduction of flood risk, reduction in soil erosion
- Changes in the socio-economic value of provided ecosystem services e.g. value of carbon storage, value of reductions in property damage
- The economic and social impacts of GI projects, i.e. their impacts on employment, GDP and local communities

In their study of 127 GI projects Naumann *et al*. (2011a) found that benefits were described qualitatively in 77 projects while 31 lacked information about benefits and only 19 (15% of projects) provided any quantitative evidence of benefits. Benefits to ecosystem services (ESSs) were identified in 57% of projects and wildlife benefits, such as habitat enhancement and species conservation, were identified in 53% of projects. 51% of projects had identified socio-economic benefits, whilst 55% of projects had multiple benefits in terms of economic, social and environmental.

A step forward in the quantification of GI benefits has been in the economic evaluation of ESSs. As one of the roles of GI is to promote ESSs and protect ecosystem functioning (see section 3), a monetary measurement of the value of ESSs could contribute to the evaluation of this GI role. The TEEB (The Economics of Ecosystems and Biodiversity) reports have initiated a better understanding of the economic value of ESSs and the tools that take account of this value.

1.3 Evaluation and indicators

McDonald et al. (2005) proposed guidelines or checklists of best practices for developing and evaluating GI plans. They highlight the multifunctionality of GI, stressing that what defines GI is its inclusion of goals for protecting ecological functions alongside goals for providing benefits to humans, in terms of land use, such as agriculture, forestry and green urban space. This raises an interesting discussion about whether to prioritise certain goals and functions of GI.

Milder (2007) distinguishes between conservation-with-development approaches and development-with-conservation approaches, where the latter are generally led by developers and prioritise the goal of land development, whilst the former tend to be led by conservation organisations and prioritise the reduction of development impact on conservation.

The secondary functions of GI have been termed co-benefits, for example, urban forests provide the co-benefits of carbon sinks and purifying drinking water alongside climate mitigation functions, such as storm-water and air pollution management (Foster *et al.*, 2011).

Wright (2011) argues that an environmental focus of GI is fundamental to secure its objectives, which suggests that monitoring should prioritise environmental aims. The EU GI Working Group recommends that if GI is designed for purposes other than biodiversity conservation it should never entail negative trade-offs. As such, biodiversity should be the 'judge' playing a key role in navigating between bad, good and better choices. The Working Group suggests that monitoring of an EU GI strategy would need multiple layers and links over sectors, although targets would be sectoral. It suggests that data and methodology sources could be gained from existing initiatives, such as marine mapping and Corine Land Cover applications.

Most available monitoring tools are at the landscape level. Tools at the urban level are mostly limited to Urban Atlas datasets, which are pan-European comparable land use and land cover data for large urban zones with more than 100,000 inhabitants. Some of these databases have already been used in the mapping and implementation of GI.

In order to evaluate effectively, there is a need to be clear and genuine about project goals, which requires the creation of definitions, guidelines and standards, as well as reliable statistics on conservation development. In 2007, the Streamlining European Biodiversity Indicators (SEBI) initiative summarised the properties of efficient indicators of ecosystem resilience. Amongst them are relevance to policy, a well-founded methodology, acceptance by stakeholders, an appropriate spatial coverage and the ability to detect temporal trends. The SEBI initiative (2010) identified several indicators with specific relevance to GI, such as the 'fragmentation of natural and semi-natural areas', the 'fragmentation of river systems', 'ecosystem coverage' and 'nationally designated protected areas'. With so many aspects of GI to be evaluated, it may be that a combination of several indicators will be the best way to represent overall performance. Furthermore, indicators will vary according to their purpose, for example, one type of indicator may be needed for communicating the benefits of GI, whilst others are better at monitoring and capturing the different functions.

1.4 Multi-level evaluation

Owing to the different elements involved in GI, McDonald *et al.* (2005) highlight the importance of basing GI design on both science and stakeholder feedback. Similarly, Hostetler *et al.* (2011) propose a systems approach to GI, which involves the views of built environment professionals and residents.

Angelstam *et al.* (2003) recommend that both natural and social sciences are involved in conservation planning and policy implementation, for example, assessing not only the qualities of the habitat and species, but also the qualities of the conservation institutions and management. This is encompassed by the concept of ecological solidarity (Thompson *et al.*, 2011), which consists of two main elements, in terms of the dynamics of ecological processes and biodiversity, and the social recognition that humans are part of ecosystem functions.

This proposal of evaluation at both a natural and social scale is further supported by research conducted by Mabelis & Maksymiuk (2009) who demonstrate the importance of public participation in the success of green urban policy in their comparative analysis between the Hague and Warsaw. This is investigated in more detail in Section 3.

2.0 The Role of GI for Protecting Ecosystem State and Biodiversity

Urbanisation, industrialisation, unsustainable agriculture and the continued expansion of grey infrastructure are increasingly eroding our natural fabric and natural capital. Over the years landscapes have become more and more fragmented and polluted which in turn has disrupted the state of ecosystems and the patterns and level of biodiversity (Mazza *et al.*, 2011).

When landscape is fragmented it leaves smaller patches of intact natural habitat and creates a greater proportion of 'edge' habitat between differing land cover types (Weber, 2007). Although some generalist species that can live in a range of habitats may benefit from this fragmentation, the majority are negatively affected, particularly large animals with large home ranges e.g. carnivores and ecological specialists (Weber, 2007).

Impacts vary among habitats and species and should be considered on a case-by-case basis, but to give some idea of the impact Lucius *et al.* (2011) suggest that negative effects generally start to appear when about 70% of the original habitat has been lost. Such impacts can include changes in species, composition of different species, community structure, population dynamics, behaviour, breeding success, individual fitness and a range of ecological and ecosystem processes (see Section 3). These changes can have a range of negative or sometimes positive impacts, and to ensure all the possible impacts are considered within GI initiatives, there should be consultation with relevant experts and stakeholders from the beginning.

One of the ways to remedy these changes caused by fragmentation, or to provide a means for ecosystems to adapt is to create conservation areas, such as the Natura 2000 network on an EU scale. In the past these have tended to focus on protecting species or habitats, but it is becoming increasingly recognised that there is a need to acknowledge nature as a system rather than individual parts (see Box 2). This means shifting conservation to the ecosystem level, rather than the level of species or habitat (Vimal *et al.*, 2011).

The Convention on Biological Diversity has adopted the ecosystem approach where it defines an ecosystem as 'a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit'. The ecosystem approach aims to integrate the management of land, water and living resources in a way that promotes conservation and sustainable use.

It applies scientific methodologies to encompass the essential processes, functions and interactions among organisms and their environment. It also recognises that humans, with their cultural diversity, are an integral component of ecosystem and gain benefits from ecosystems in the form of ecosystem services (ESSs).

Box 2: Science behind conservation at the ecosystem level

The shift to conservation at the ecosystem level is based on the large body of evidence that demonstrates habitat fragmentation is a threat to the survival of species (Boitani *et al.*, 2007). Theoretically, it has its roots in island biogeography theory, which, although developed from work done on islands (MacArthur & Wilson, 1967), considers an island to be any area of suitable habitat that is surrounded by unsuitable habitat, for example, lakes surrounded by dry land or fragmented forests. Island biogeography theory states that the number of species found on an 'island' depends on immigration, exmigration and extinction, where the two former processes depend on connectivity between different 'islands'.

Further theoretical support comes from metapopulation theory (Hanski, 1999), which suggests that no single population can guarantee long-term survival of a given species, but the combined effect of many connected populations could. As such, the long-term survival of populations depends on the cohesion of habitat networks as it determines whether or not local extinction and recolonisation rates are in equilibrium (Opdam *et al.*, 2005). In turn, this maintains the structures, material and energy flows of ecosystems which can provide different ecosystem services (see Section 3).

It is now argued that a strict distinction between biodiversity and ESSs is not helpful, especially in the implementation of GI, since it can lead to management decisions that provide specific sectoral ESSs, such as renewable energy, intensified forestry and agriculture, rather than applying an integrated 'ecosystem approach'. The role of promoting ESSs is discussed in more depth (see Section 3) but, as mentioned, GI does not perform this role separately to its role of protecting biodiversity or its role of promoting health or a sustainable economy. All roles are highly interactive.

At the heart of the ecosystem concept of conservation are the connections and interactions between species, habitats and resources. Ecosystems are not static but open, dynamic and discontinuous systems and their interactions and connections evolve in space and through time (Fisher *et al.*, 2009). Maintaining and enhancing connectivity is one way to help offset the losses caused by fragmentation and a number of 'connective' sub-functions can be identified that contribute to the role of GI in protecting biodiversity and ecosystem state, for example, increasing connectivity between natural areas, improving the ability of organisms to move through a landscape ('landscape permeability') and mitigating further fragmentation.

Ideally, research into fragmentation and ecosystem degradation and how GI addresses this should occur at regional and landscape levels (Hoctor *et al.*, 2007). It is difficult to conduct scientific research at this scale but attempts have been made, for example, at the Savannah River Ecology Laboratory in South Carolina, which is an 803 km^2 research park. Experiments here at the landscape scale strongly support the role of corridors in maintaining biodiversity and facilitating functional ecological processes (Mabry & Barrett, 2002; Dunning *et al.,* 1995). LIFE Nature and, to a certain extent, LIFE Environment, have already made a significant contribution to protecting Europe's biodiversity thought investments in GI, mainly on a local or regional level. Further work is now needed to assess the substantial knowledge acquired through LIFE-funded projects.

2.1 GI features that contribute to the role of protecting ecosystem state and biodiversity

- **Nature-rich areas,** which function as core and hubs for GI. These areas are often protected, such as Natura 2000 sites, as well as other wildlife areas and nature reserves, for example, Marine Protected Areas and Special Protected Areas.
- Wildlife and natural areas, which could be wilderness areas or managed areas; some of them would need to be still protected, maintained, enhanced or restored.
- Areas of high value for biodiversity and ecosystem health outside protected areas, such as floodplain areas, wetlands, coastal marshlands, extensive grasslands and forests.
- Ecological corridors or strips of vegetation used by wildlife to allow movement between two areas. In general, there are three types of corridor:
    1. Linear corridors are long strips of vegetation, such as hedgerows, strips of forest, and the vegetation growing on banks of rivers and streams.
    2. Stepping stone corridors are a series of small, non-connected habitats.
    3. Landscape corridors of diverse, uninterrupted landscape elements (e.g. riparian zones).
- Greenways and greenbelts, where greenways are corridors of undeveloped land and greenbelts are belts of parks or rural land that are surrounding or within a town or city.
- Ecoducts or green bridges are structures that connect two areas of nature and allow wildlife to travel across significant barriers, such as roads and railway.
- Fish ladders, fishways or fish passes are a series of pools at the side of a stream, enabling freshwater organisms to swim upstream, around a dam or other obstruction.
- Ecological stepping-stones are a series of usually small, unconnected habitats that allow animals to move from one to another.
- Ecological buffer areas are zones that surround areas of ecological value to minimise the impacts of an adjacent land use.
- Restoration of landscape and ecosystems. This can be 'passive' where the damaging activity ceases or 'active', which involves targeted actions, such as planting vegetation on brownfield land. Examples of habitats that are often restored are bogs and fens, grasslands, rivers and wetlands, woodlands
- Urban elements, such as parks, gardens, churchyards, sports pitches, allotments, urban ponds and canals, green roofs and green walls.
- Agricultural land that is managed sustainably with regard to the protection of biodiversity and ecosystems.

As discussed in the introduction, GI features do not always fall into distinct categories during practical implementation. For example, Natura 2000 sites are core areas but, with the increasing emphasis on ecosystem protection, they tend to also include elements of ecological corridors and buffer zones. Similarly the above features often perform functions that are described in the other sections of this report, particularly the protection of ecosystem functioning and promotion of ecosystem services (see Section 3).

2.2 Benefits and costs of GI providing the role of protecting ecosystem state and biodiversity

This section will review the research on costs and benefits of three major forms of GI that have been implemented in Europe and across the world that contribute to the role of protecting biodiversity and ecosystem state. These are ecological corridors, ecological networks and restoration.

2.2.1 Ecological corridors

During recent decades more data have become available on corridors and how they address the problem of fragmentation (Bennett & Mulongoy, 2006; Damschen *et al.*, 2006; Dixon *et al.*, 2006). Gilbert-Norton *et al.,* (2009) conducted a meta-analytic review of the effectiveness of ecological corridors and concluded that, over the previous ten years, there had been a growing body of well-designed experiments to assess the efficacy of corridors. This has been done on a case-by-case, and often species-by-species, basis and generally in terms of their main function, which is to increase the movement of plants and animals between habitat fragments. Measures were both direct (proportion of individuals that moved, movement rate of individuals and number of seeds moved) and indirect (species abundance and richness). They analysed 78 experiments from 35 studies conducted between 1988 and 2008 and found that the amount of movement between habitat patches was approximately 50% greater if corridors were in place compared to patches that were not connected by corridors.

The beneficial impact of corridors varies from species to species, for example, a literature survey conducted by Alterra in the Netherlands found that from 18 species of butterflies, mammals and amphibians, nine are strongly dependent on corridors whilst nine are only dependent to some extent or not at all (Vos, *et al.*, 2005).

The effectiveness of corridors also varies with size and other characteristics. A study of riparian forest corridors (those adjacent to rivers or water) in the Brazilian Amazon (Lees & Peres, 2008) has suggested that riparian strips should be more than 400 metres wide (200m on either side of the stream) and should border streams that are more than 10 metres wide for the corridor to be successful in improving bird and mammal species richness.

Some have criticised ecological corridors for their lack of definition in that they can vary in size and goals. However, on the basis of an in-depth analysis of ecological corridors in the Netherlands, Van der Windt & Swart (2008) suggest that the vagueness of ecological corridors provides them with a valuable flexibility i.e. because an ecological corridor does not prescribe a certain size or function it can be used by many people and for different landscapes and species. They describe it as a boundary object which is 'strong enough to bind and flexible enough to leave room for different operating forms and interpretations'. This flexibility is also valuable in mitigation for climate change, as its impacts are constantly changing. In particular, 'stepping stone habitats' can improve landscape permeability and protect biodiversity.

Models have indicated that climate change will cause species in Europe to move north and west in order to find appropriate climatic conditions for their survival or to keep track of their 'climate space' (Davies *et al.*, 2006). Stepping stones provided by GI could assist this movement. Even species that do not travel far will need to move to a new habitat with a more suitable microclimate.

There has been some criticism about the lack of hard proof of the functionality of ecological corridors in protecting biodiversity and ecosystem state (Pearce, 2011), but there are an increasing number of studies evaluating the effectiveness of corridors using more representative measures. For example, Vergnes *et al.* (2011) demonstrated a positive impact of green corridors on arthropods in urban landscapes, in terms of individual species richness and abundance, but also in terms of taxonomic and functional composition, where the former is the number and arrangement of distinct species and the latter represents the functions provided by the landscape to the species, such as improving opportunities for dispersal and supplying appropriate habitat.

Van der Windt & Swart (2008) point out that the success of ecological corridors may not always be explained by scientific soundness alone, but also by their social robustness, in terms of support from multiple stakeholders, which leads to more effective decision-making and implementation. In addition these stakeholders bring knowledge and experience to GI initiatives which may often be based on scientific information and research. The terms 'regulatory science', 'postnormal science' or 'contextualised science' have been used to describe this form of criteria or judgement that represents support and acceptance from stakeholders (Van der Windt & Swart, 2008).

In their review, Gilbert-Norton *et al.* (2009) observe that natural corridors (those existing in the landscape prior to the study) showed more wildlife movement than manipulated corridors, which had been created. This suggests that it is better to protect natural landscape features that function as corridors, rather than create new corridors. This is supported by Karieva *et al.* (2007), who suggested that the complexity and multifunctional components of undisturbed landscapes are difficult to replicate using constructed nature and ecosystems.

The study by Gilbert-Norton *et al.,* (2009) also highlights that the studies it reviewed did not examine the long-term/ultimate goals of corridors, which is to maintain and restore population viability of isolated populations or species diversity. To investigate whether corridors actually reduce population extinction would require more long-term and complex research, which is often expensive. More cost-effective evaluations tend to stay close to the objectives and proposed deliverables of the project (see Box 3) and for these to be informative there must be clear objectives from the start (Mazza *et al.*, 2011). Pearce (2012) proposes that there is a need to establish research that investigates more directly the achievement of goals in terms of restoring and maintaining species diversity and encouraging gene flow between populations, but it can be difficult to specify and measure objectives in this area.

2.2.2. Ecological Networks

Ecological networks consist of core areas (or hubs), corridors and buffer zones, where the corridors create a connection between core areas. Over the years ecological networks (ENs) have gained significant interest from conservationists and policymakers. Opdam *et al.* (2006) propose that simple core areas or nature reserves face problems as they are fixed in space and time but ENs allow development and adaption through the connections between the areas. They propose that ENs can combine biodiversity conservation and sustainable landscape development as well as facilitating stakeholder decision-making.

In their review of ENs, Boitani *et al.* (2007) suggest that, in their simplistic form, this form of GI is limited for biodiversity conservation, mainly because ENs are species specific i.e.

Box 3: Case study of GI protecting biodiversity and ecosystem state - Restoring the Alpine-Carpathian Corridor

Both the Alps and the Carpathian mountain ranges are important habitats as is the connection between the two. However, the traditional migration route of the Alpine Carpathian Corridor is blocked by traffic routes and intensive land use.

A partnership between Austrian and Slovakian organisations aims to construct and preserve a green corridor of about 120 km long between the Alps and Carpathians. This three-year cross border and cross-sectorial project started in 2009 under the European Territorial Cooperation Objective of the European Regional Development Fund (ERDF). It has the following functions:

- To safeguard ecological connectivity between the Alps and Carpathians
- To enable migration of wildlife and exchanges between populations
- To mitigate the fragmentation effects of motorways by building green bridges over highways
- To reconnect existing stepping stones to produce nesting and feeding places
- To produce sustainable development in the region that benefits man and wildlife by the integration of ecological networks into spatial planning.

Table 1: Estimated costs of project (Naumann *et al.*, 2011a)

One off costs	Planning. Surveys, preparatory studies	€1,015,000
	Communication and consultation	€440,460
	Project management and administration	€205,000
	Spatial planning	€67,500
	Land management and restoration works	€130,850
	Creation of connectivity features	€3,000,000
	Total	**€4,858,810**
Recurrent costs	Project management and administration	€80,000
	Research and Monitoring	€20,000
	Total	**€100,000**
OVERALL TOTAL COSTS		**€4,958,810**

As there were no significant additional changes in land use or restrictions on development there were no opportunity costs.

Evaluation and monitoring activities

The work packages defined in the project have been used as a basis for evaluating the project's provision of the proposed deliverables and whether it is on track with the time schedule. As such this will mainly assess the (cost) efficiency and implementation of the project, rather than direct biodiversity and ecosystem benefits.

they can only improve the mobility of one or a few species and the information needed for their implementation is only available for a handful of species. However, this criticism is not specific to ENs since it is inherently complex to quantify ecological connectivity for more than one species, owing to the natural differences in their movement patterns (Vimal *et al.*, 2011).

Boitani *et al's* review is somewhat dated and there has since been growing evidence that ENs can provide a range of biodiversity and ecosystem benefits, often through the use of modelling. For example, in the Izmir province in Turkey Hepcan *et al.* (2009) indicated there would be positive impacts on the habitat and numbers of four important species through the introduction of an EN, whilst in the Barcelona Metropolitan Area, Pino *et al.* (2012) indicated that an EN would contribute towards mitigating future connectivity loss.

The Pan European Ecological Network (PEEN) has been developed to help achieve the effective implementation of the Convention of Biological Diversity at a European level. There are three subprojects: Central and Eastern Europe, completed in 2002; South-eastern Europe, completed in 2006; and Western Europe, also completed in 2006. In their review of the PEEN Jongman *et al.,* (2011) suggest there is a need to quantify the economic benefits of ecological networks and make them explicit through interdisciplinary research and integrated long-term research on the social, economic and ecological mechanisms that maintain biodiversity and its ecological services. They highlight the variation in habitat data across Europe and suggest one of the biggest challenges faced by the PEEN is to develop a common approach among over 100 European-wide agencies that are responsible for biodiversity conservation. This again highlights the need for thorough stakeholder consultation to support successful GI initiatives.

Boitani *et al.,* (2007) suggest the difficulty in evaluating ENs could be due to problems encountered when attempting to prove that an EN as a whole (the synthesis of core areas, corridors and buffer areas) has an effect on some biodiversity value such as species richness in the presence of many confounding variables. The issues around evaluating a synthesis of features with confounding variables will always be encountered by a concept, such as GI. However, it also this complexity that potentially makes it so valuable as a biodiversity conservation tool as it addresses the interactive quality of ecosystems.

Vimal *et al.* (2011) suggest that the complexity of ENs and their links means there will be an inevitable amount of uncertainty but this should not prevent the implementation of ENs as part of GI. Van der Windt & Swart (2008) suggest that in the face of uncertainty and lack of a hard evidence-base, the quality of decision-making can be improved by the participation of the stakeholders.

Boitani *et al.* (2007) make a valid point that the evaluation of ENs can be difficult if there are no explicit quantitative objectives against which to test them and this must be considered when designing GI. The IEEP and Alterra report on the reflection of land use needs into EU policy (2010) highlights the importance of developing and agreeing clear objectives for ENs and then gathering evidence that these objectives have been reached. This would be supported by a shifting emphasis in the EN concept from a simple combination of features (core areas, corridors and buffer areas) to a multi-objective tool, which puts function at the core of its definition.

Boitani *et al.,* (2007) suggest this could be done in terms of ecological functions, such as nutrient cycling and soil development (see Section 3). Vimal *et al.* (2011) also suggest that the critical ecological functions of ENs should be identified, which could then be used as a means for evaluation. The EEA report on GI and territorial cohesion (2011a) points out that GI can be explored in two ways which can be applied to ENs: either structurally, in terms of different land cover types or with a more functional approach that seeks to identify areas and networks, in terms of the functions they provide. The difference between structural and functional connectivity will be discussed in more detail in Section 2.3 on indicators and methodology.

2.2.3. Restoration

Many projects have set out to recover ecosystems that have been degraded, damaged or destroyed, typically as a result of human activities. Rey-Benayas *et al.'s* (2009) meta-analysis of 89 scientific assessments of the outcomes of restoration actions reviewed their impact on biodiversity and ecosystem services. Actions included cessation of damaging activity, planting of trees and grasses, reintroduction of wildlife and soil adjustments. The studies reported impacts on three types of ecosystem service as defined by the Millennium Ecosystem Assessment: supporting services, such as nutrient cycling; provisioning services, such as timber and food crops; and regulating services, such as water and air purification (see Section 3).

The fourth type of service defined by the Millenium Ecosystem Assessment - cultural services - was not reported in any of the studies reviewed. The studies measured biodiversity with indicators, such as species abundance, species richness, growth, or biomass of organisms present.

The review showed that for the 89 studies considered, the measures of biodiversity and provision of ecosystem services were higher in restored systems than in systems that had been degraded. It also demonstrated a correlation between the measures of biodiversity and the provision of ecosystem services in the studies. This provides support for the interdependence of biodiversity and ecosystem services, where biodiversity plays a central role in ecosystem functioning and therefore service provision (Fisher *et al.,* 2009) and ESSs contribute to the maintenance of biodiversity.

Rey-Benayas *et al.'s* review (2009) reveals that restored systems have better biodiversity and are better at providing ecosystem services than degraded systems. However, this is not the case when compared to intact reference ecosystems. This indicates that restoration can never fully bring an area back to its original state, which would imply the need for a form of prioritisation scheme in the implementation of GI where preservation initiatives are considered to be more important than reparation initiatives.

However, there may be cases when restoration is required before other GI measures can be introduced to effectively improve connectivity. More research is needed on when and where restoration will be a more effective GI tool compared to natural regeneration or re-establishment of certain ecosystem types.

2.2.4. Possible costs

As with any new initiative there will be economic costs, mainly for purchasing, designing, constructing, restoring, maintaining and protecting connectivity features (see Section 1.2 for typology of costs). Naumann *et al.* (2011a) have reviewed the costs of numerous GI projects and the overall costs of The Alpine-Carpathian Corridor project is cited in Box 3. They also estimated the unit costs for 13 EU-funded restoration projects through finances spent.

The costs ranged from €250 per hectare of blanket bog restored for a peat lands restoration project in Scotland, to €321,343 per hectare of park restored in Glasgow. In general, they found that costs were less for larger scale projects compared to those targeting small areas of land. Those targeted on specific species conservation, e.g. sites restored for butterflies, also tended to have higher costs, as did those that involved labour intensive restoration work, such as tree and scrub removal. Restoration of urban parks and green spaces also tend to have very high costs, especially if it involves work on buildings and gardens.

There may also be some inevitable trade-offs regarding various options in terms of spatial locations, land use and land management policies and various economic alternatives for protecting the land.

There have been some concerns raised about possible costs to the environment although there is little evidence to support the existence of these and they remain hypothetical. One concern is that increasing connectivity might facilitate the invasion of unwanted or alien species.

In their study on plants, Damschen *et al.* (2006) found that habitat patches connected by corridors did not promote exotic species. However, this is only one study and the possibility should perhaps be considered on a case-by-case basis. Nevertheless alien species tend to invade areas that have been disturbed or where ecosystem health is low. Since the objective of GI is to restore and sustain ecosystem health, it should theoretically discourage invasive species as long as it remains true to its objectives.

Another concern that has been raised by some is that increased immigration caused by improved connectivity could also facilitate the spread of infectious diseases and cause 'out-breeding suppression' where crosses between the offspring of different populations of the same species have lower fitness than offspring of crosses between wildlife from the same population (van der Windt & Swart, 2008; Mazza *et al.,* 2011). There is as yet no evidence of this occurring but future monitoring should perhaps consider the possibility in its design.

Recent research by Frankham *et al.* (2011) has indicated that out-breeding suppression is more likely in crosses between two populations when the populations have fixed chromosomal differences, have exchanged no genes in the last 500 years, or inhabit different environments. They therefore suggest that any concerns about out-breeding suppression in recently fragmented populations are probably excessive.

2.3 Indicators and monitoring methodology

Although various measures have been developed to study the role of GI in protecting biodiversity and ecosystem health, there appears to be a lack of evaluation over relevant time and spatial scales. For example, although there is research into the use of ecoducts and fish passes by wildlife, there is very little research to actually compare species dispersal before and after their construction and no long-term research on their effectiveness.

The definition and measurement of connectivity has been controversial because it can be at the patch scale or the landscape scale, and can be defined either structurally or functionally (Minor & Urban, 2007; Vimal *et al.,* 2011). Structural connectivity is a property of the landscape features and their spatial arrangement, whereas functional connectivity refers to the behaviour of species and ecological processes across the landscape.

Structural connectedness is the easiest to measure, but it is only the physical background for the real function of connectivity, which is to facilitate the movement of organisms. Both can be used to evaluate the effectiveness of GI, but functional connectivity has a more direct relationship to its ultimate goals and aims. However, there is a difficulty with functional connectivity as it is species, population and context specific, which means it cannot give an overall view of connectedness for the ecosystem. This is not such a problem if GI features have been applied specifically to facilitate movement of one species, such as the red deer in central Europe (Bruinderink *et al.,* 2003).

However, even if GI aims to improve connectivity for selected species, there are still unresolved issues in evaluations and design, such as the use of gross averages over large areas when there could be large differences between areas. Assessments can consider focal or indicator species that can be said to represent the ecosystem. For example, in their study of the potential benefits of an EN in the Izmir Provence in Turkey, Hepcan *et al.* (2009) focussed on four species: *Hyaena hyaena, Lynx lynx, Caracal caracal* and *Felis chaus*. However, this practice has been debated (Boitani *et al.,* 2007), as it must rely on several assumptions about the co-occurrence of species and the ability of individual species to be 'surrogates' for the health of the ecosystem.

Ervin *et al.* (2010) suggest that effective indicators should be relevant, easily understandable, easily communicated, easily measurable, reliable and widely applicable. They also highlight that one of the most important reasons for monitoring is adaptive management of an area, which means the inclusion of thresholds, for example, degree of fragmentation, loss of habitat, and decrease in biodiversity.

These thresholds would be measured by appropriate indicators, such as fragmentation/connectivity indicators (see below), and species richness (see Box 4). When the thresholds are reached they would trigger management and policy intervention.

The 'fragmentation of natural and semi-natural areas' is one of the EU Streamlining European 2010 Biodiversity Indicators (SEBI – 2010), as is 'fragmentation of river systems'.

Box 4: Indicators from the Report on Implementation and Efficiency of GI (Mazza *et al.,* 2011), and Guide to Integrating Protected Areas into Wider Landscapes (Ervin *et al.,* 2010)

These reports have identified a number of possible indicators of ecosystem resilience, biodiversity and connectivity, which could potentially assess GI's performance of this role. Examples are listed below:

Species related

- Species richness, i.e. the number or different species in a given area
- Occurrence or turnover of rare species
- Presence or turnover of keystone or focal species (which tend to be the most sensitive species)
- Species movement across new connectivity features

Habitat related

- The actual amount of protected or restored area of land or water
- Physical attributes of area e.g. hydrology, soil condition, nutrient status
- Functional habitat area, i.e. habitat patch size and/or functional connectivity as assessed through various habitat fragmentation or connectivity indicators that aim to capture the status and trends in a quantifiable form (see below).

Other

- Indices related to deviation from the undisturbed or natural situation, such as the Natural Capital index (ten Brink & Tekelenburg, 2002), which assesses the difference between natural conditions and the actual situation in terms of species composition and abundance.
- The delivery of ecosystem services that are a priority for the area under consideration, such as carbon storage and water purification (see Section 3)

It is calculated from the Corine Land Cover (CLC) database (CooRdinate Information on the Environment – Corine) and provides information on the trends in 1990-2000-2006 of the fragmentation pattern of natural and semi natural areas at the pan-European level (Estreguil and Caudullo, 2011a; EFDAC pattern map viewer, 2011). Each hectare of natural/semi-natural lands is assigned a fragmentation pattern depending on its landscape mosaic context, i.e. how it is intermingled with other natural, agricultural and artificial lands. The indicator also provides the trends of the average patch size of 'unfragmented' natural/semi-natural lands and fragmentation patterns can be mapped.

Some possible methods of measuring functional connectivity are:

- **Network (graph-based) indicators** represent the landscape as a set of nodes (usually habitat patches or other spatial units of interest) and the links/edges or connections between the nodes represent the ability of an organism to move between nodes. It is species specific and well suited to selecting areas for habitat reserves and conservation areas (Minor & Urban, 2007).
- **Equivalent Connected Area (ECA)** is defined as the size of a single patch that would provide the same probability of connectivity as the actual habitat pattern in the landscape (Saura *et al.,* 2011). It was used to report trends in functional connectivity in European forests from 1990-2000-2006 using Corine land cover data and the high resolution JRC forest type map of 2006 in the FOREST EUROPE report 2011 (Estreguil and Caudullo, 2011b; EFDAC pattern map viewer, 2011).

  The index is calculated at the landscape scale for forest species that can, on average, disperse about 1km. Saura *et al.,* (2011) conclude that ECA is useful in communicating to policy makers and society. Again it is species specific so it may be necessary to identify 'flagship species' that are sensitive to changes in habitat. Saura *et al.,* (2011) suggest that reptiles, amphibians, small rodents, passerine birds and plants with wind-dispersed seeds (Sutherland *et al.,* 2000; Tackenberg *et al.,* 2003; Smith & Green, 2005; Vittoz & Engler, *2007*) would be most affected by changes in forest connectivity.
- **Effective mesh size expresses** the probability that any two points chosen randomly in a region are connected, i.e. they are not separated by barriers, such as transport routes or built-up areas or natural features. The more barriers fragmenting the landscape, the lower the probability that two points are connected, and the lower the effective mesh size (*meff*) which is measured in km^2. Jaeger *et al.* (2008) applied it to Switzerland to assess fragmentation and sustainable development and concluded that it was a successful, flexible and easily interpretable indicator. More recently Jaeger *et al.* (2011) used effective mesh size to analyse landscape fragmentation in Europe and recommended its use in planning of transport infrastructure.

The above measures of connectivity are often used for the spatial planning of conservation initiatives, including GI. Recently a new framework with accompanying GIS software called *Zonation* has been developed to support decisions in conservation planning (Finnish Centre of Excellence in Metapopulation Biology, 2011).

Zonation identifies areas that are important for retaining habitat quality and connectivity for multiple species, habitats or ecosystems with the long-term aim of improving species survival. It produces a hierarchical prioritisation of the landscape based on features that describe species, connectivity, land use needs, landscape condition etc. which can then be mapped geographically so stakeholders can see the most important areas for conservation. Such a tool could inform the planning and possibly the monitoring of GI.

3.0 The Role of GI for Improving Ecosystem Functioning and Promoting Ecosystem Services (ESSs)

Ecosystems are important as nature's building blocks and to provide habitats for species and, when functioning adequately, they provide a number of essential services that benefit humans. The connections and interactions between organisms and the physical environment produce many ecosystem processes, such as decomposition or production of plant matter, which then enable the ecosystem to perform a multitude of functions, such as nutrient cycling and soil development.

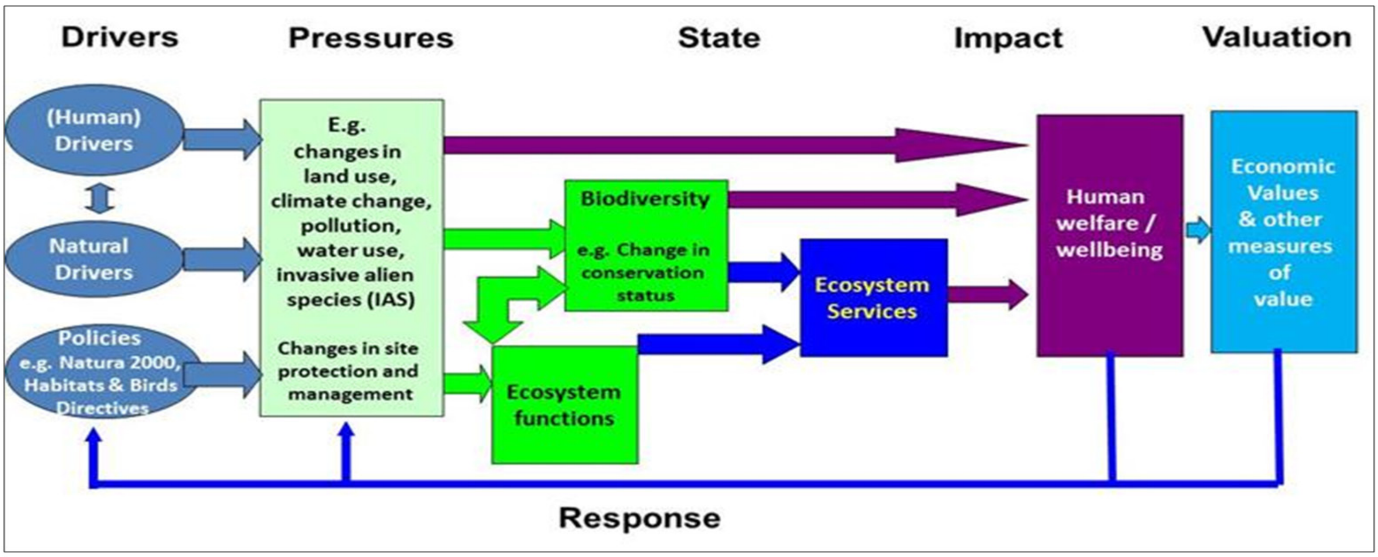
Ecosystem services (ESSs) are the beneficial outcomes to humans or the natural environment that result from ecosystem functions (see Fig. 1). In order for an ecosystem to provide services to humans there needs to be some interaction with, or at least some appreciation by, humans. They represent ecological processes and resources expressed in terms of goods and services they provide (Chapman, 2012). Thus, processes of ecosystems are value-neutral, while their services have value to society. Figure 1 outlines the relationships between ecosystem functions, biodiversity and ecosystems for the case of the Natura 2000 network within a Drivers Pressures States Impacts framework to illustrate the influences and interactions.

The concept of ESSs and ecosystem functioning is useful for considering GI benefits as it provides a relatively constant language and form of measurement for policymakers and other stakeholders (EEA, 2011a). According to the Millennium Ecosystem Assessment (MA, 2005), ESSs fall into four categories: provisioning services, such as food and water; regulating services, such as flood and disease control; cultural services, such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth.

Climate change can exacerbate fragmentation, degrading the very ecosystems that can serve to mitigate its impacts through the services they provide. This vicious circle makes the promotion of ESSs and protection of ecosystem functions through GI even more important. Examples of services specifically associated with adaptation to and mitigation for climate change are the management of storm-water runoff, water capture and conservation, flood prevention, storm-surge protection, defence against sea-level rise, accommodation of natural hazards, carbon storage and reduced ambient temperatures and urban heat island effects (Foster *et al.,* 2011).

The value of ESSs has become increasingly recognised on the policy agenda and it has been reported that human use of most ESSs is increasing (Carpenter *et al.,* 2009). However, there is also evidence that the condition of most services has decreased in last 50 years (Carpenter *et al.*, 2009). By strengthening and maintaining the good functioning of

Figure 1: Benefits of Natura 2000 (from ten Brink *et al.,* 2011)



Source: Adapted from Braat and ten Brink et al. *(2008)*

ecosystems, GI can promote the multiple delivery of ESSs. This can be either by existing ecosystems, such as wetlands or floodplains or new ecosystems, such as through green roofs and vertical farms, especially on landscapes that have been intensively degraded, as with urban areas. The provision of services through the presence of ecosystems on agricultural land is also very valuable. On the basis of previous research Tzoulas *et al.* (2007) have created a framework that links GI, ecosystem functions and services and ecosystem health (see Fig. 2) where an ecosystem can be considered healthy if it is free from, or resilient to, stress and degradation, and maintains its organisation, productivity and autonomy over time. The letters in the top three boxes represent the GI features, ecosystem functions and services, and level of ecosystem health respectively. The framework also connects these concepts to socio-economic, community, physical and psychological health (see Sections 4 and 5). Tzoulas *et al.* (2007) propose that this framework brings together ecological and social systems in a 'conceptual meeting point' for different disciplines involved in GI.

Pataki *et al.* (2011) suggest that improvements in the quantification of ESSs, could be made by linking them more concretely to measurable ecosystem processes, for example, the removal of nitrates from storm water by urban plants and vegetation is a desired ecosystem service but understanding the process of urban aquatic nitrogen cycling (e.g. sources, sinks, fluxes) is necessary to quantify the removal of nitrates by GI. They suggest a greater integration of biogeochemical science into the design and evaluation of GI, bringing together precise scientific knowledge with knowledge about planning and social needs.

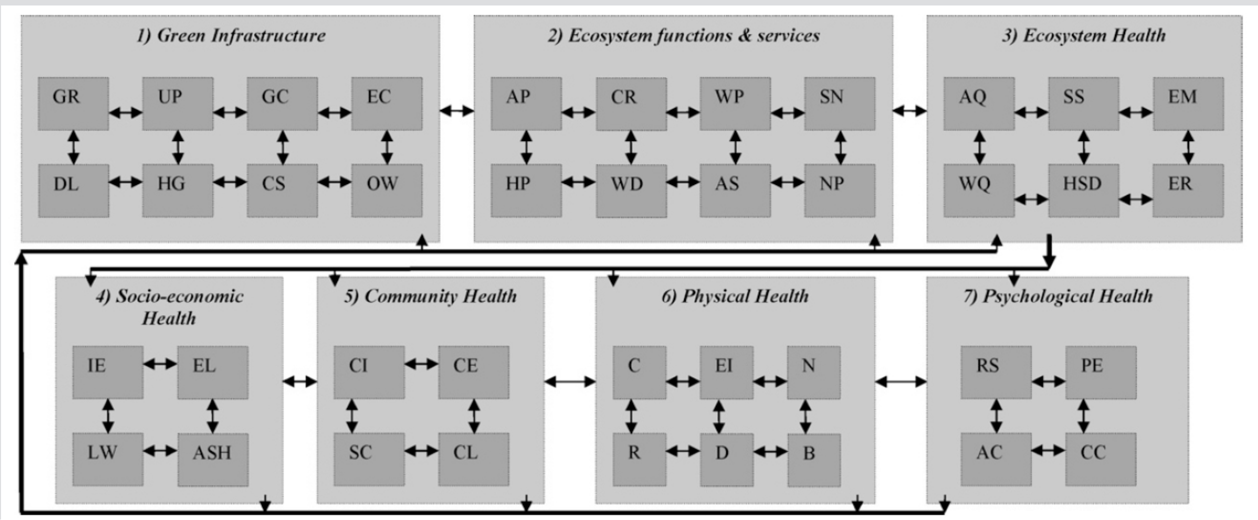
In a similar vein, Grimm *et al.* (2000) suggest that an integration of ecologists and social scientists could provide a more realistic understanding of the natural world that could contribute to the planning and evaluation of GI. This would combine information on climate, species pools, and nutrient cycling with associated human activity variables, such as land-use change, resource consumption and waste production. They believe that humans should be incorporated into ecosystems rather than considered simply as benefactors. This is supported by Thompson *et al.'s* (2011) concept of ecological solidarity that places GI, such as protected lands, within a greater social context and territorial area and calls for integrated management in which human activities are an integral component.

Lyytimäki *et al.* (2008) also suggest there is a need to bridge the gap between a social science approach (focusing on lifestyle) and a natural science approach (focusing on biodiversity). They stress the large regional and even temporal variation in what is considered to be ESSs and possible disservices where disservices are negative or

Figure 2: Conceptual framework linking Green Infrastructure, Ecosystem and Human Health (Tzoulas *et al.*, 2007)

The framework has two main parts separated by two-way arrows. The top half (ecosystem) has three interrelated boxes and the bottom half (human health) has four interrelated boxes. Two-way arrows indicate two-way interactions.

Key: GR: green roofs; UP: urban parks; GC: green corridors; EC: encapsulated countryside; DL: derelict land; HG: housing green space and domestic gardens; CS: churchyards, cemeteries and school grounds; OW: open standing and running water; AP: air purification; CR: climate and radiation regulation; WP: water purification; SN: soil and nutrient cycling; HP: habitat provision; WD: waste decomposition; AS: aesthetic and spiritual; NP: noise pollution control; AQ: air quality; SS: soil structure; EM: energy and material cycling; WQ: water quality; HSD: habitat and species diversity; ER: ecosystem resilience; IE: income and employment; EL: education and lifestyle; LW: living and working conditions; ASH: access to services and housing; CI: sense of community identity; CE: community empowerment; SC: social capital; CL: culture; C: cardiovascular; EI: endocrine functions and immunity; N: nervous system; R: respiratory; D: digestive; B: bone tissue; RS: relaxation from stress; PE: positive emotions; AC: attention capacity; CC: cognitive capacity.



unintended consequences. For example, planting urban trees may increase allergic responses to pollen in some residents (see section 3.2). They recommend a participatory approach to understand what kind of ecosystem functions are experienced as services and possible disservices.

Similarly, Felson & Pickett (2005) review the concept of 'designed experiments', which balance ecological goals with important design factors, such as public amenities and safety, using the overlap of ecologists and urban designers to test the ecological effects of different landscaping strategies. This generates opportunities for research whilst creating amenities and enhancing urban space and can feed into adaptive monitoring and evaluation of ESS promotion which informs the GI project as it progresses (Chapman, 2012). An example is the Landschaftpark in Germany where scientists and designers experiment with techniques, such as phytoremediation and phytoextraction on brownfield sites so remediating the land to parkland whilst exploring the science of cleaning contaminated soils (Felson & Pickett, 2005).

In terms of evaluating GI's role in protecting ecosystem functions and promoting ESSs, it is important to remember that functions and services vary according to area and population and time. Harrison *et al.* (2010) identified temporal trends in the use of the main ESSs and their status in Europe. This indicated that there have been increases in demand for ESSs, such as timber from forests, water flow regulation from rivers and wetlands and recreation and ecotourism. All of these can be promoted by various forms of GI, for example, the planting of new forests can provide timber and a location for ecotourism, whilst the restoration of wetlands will promote water flow regulation. There have been decreases in the demand of other ESSs, such as livestock production, freshwater capture fisheries and wildfoods. Harrison *et al.* (2010) acknowledge that there will be national and regional differences in the importance of ESSs.

3.1 GI features that perform the role of improving ecosystem functioning and promoting ecosystem services

The features mentioned in Section 2 are instrumental in performing this role due to its interdependence with the role of protected biodiversity and ecosystem state. The following GI features are also important in the role of protecting ecosystem functioning and promoting ecosystem services:

- Areas of high nature value outside protected areas, such as floodplain areas, riparian zones, wetlands, coastal marshlands, natural forests and semi-natural grasslands and sustainably managed agricultural lands. These can promote ESSs, such as water regulation, carbon storage and coastal protection.
- Restored habitats that have specific functions and/or species in mind, for example, to increase foraging areas, breeding or nesting for these species or to enhance the carbon and water cycles of those areas.
- Ponds and wetlands, including integrated constructed wetlands for water filtration.
- Urban trees, vegetation and soils which can remove CO_2 from the air and also sequester carbon.
- Vegetated landscapes to absorb and harvest water and convey it either to a storage facility for reuse or discharge it into downstream drainage systems. These include:
    1. green vegetated roofs or ecoroofs
    2. rain/infiltration gardens and trenches
    3. bio- or grass swales (bio swales) which generally consist of a drainage course with gently sloped sides and filled with vegetation or compost
- Pervious or permeable pavements made from porous materials, such as asphalt or recycled glass or with a layer of soil underneath (sub-soiling).

Sustainable Urban Drainage Systems (SUDS), also known as Low Impact Development in the US and Water Sensitive Urban Design (WSUD) in Australia, integrate storm water management into the design of urban landscapes. These tend to use a combination of some of the GI features mentioned above, such as green roofs, pervious pavements, bio swales and the preservation of natural lands.

3.2 Benefits and costs of performing the role of improving ecosystem functioning and promoting ecosystem services

3.2.1. Ecosystem services and disservices

In order to consider GI's ability to perform roles of protecting ecosystem functions and promoting ESSs, some researchers have used the concepts of ecosystem services and disservices, where the latter are negative or unintended consequences for humans or the environment.

Pataki *et al.* (2011) reviewed the influence of planned urban green space on three major ESSs and the presence of possible accompanying disservices. The services are climate regulation, the regulation of urban water run-off and pollution and regulation of air quality. Examples of possible disservices are increasing allergens, promoting invasive plants, hosting pathogens or pests, inhibiting human mobility and safety or increasing water and fertiliser use for management of urban trees and plants. As touched upon in Section 2.2, there is no evidence of the unwanted side effects of GI which are labelled ecosystem disservices but nevertheless the possibility that they might occur should be kept in mind when evaluating the performance of GI.

Pataki *et al.* (2011) identify that certain services and disservices are relatively easy to quantify, such as the deposition and uptake of the pollutants ozone, CO_2 and particulates. For example, the pollutant uptake by urban trees has been modelled to have a monetary value of $383 per 100 trees, whilst in Chicago, Nowak (1994) estimated that trees were estimated to remove 6190 tonnes of air pollution per year, which equates to an average improvement of air quality of approximately 0.3%.

Pataki *et al.* (2011) suggest that the quantification of biogeochemical processes in urban green infrastructure could improve our understanding of urban ecosystem services and disservices resulting from designed urban green spaces. They stress that there are also influences on human health through cultural and psychological effects but highlight the lack of knowledge about the specific relation of these services to ecological or biogeochemical processes. To address this, they recommend greater collaboration between ecologists, social scientists and epidemiologists to explore the interactions and provide more quantifiable benefits and costs.

Lyytimäki *et al.* (2008) also use the concept of ecosystem disservices. They include safety issues in dark parks, pollen causing health problems, decreased visibility for drivers and invasive species. They raise the point that the distinction between an ecosystem service and disservice can be dependant on context and actors involved. For example, being able to walk down a tree-lined street can increase quality of life for pedestrians, but tall and leafy trees can cause annoyance to drivers or residents of nearby houses. This dependency on context needs to be considered during evaluation, as well as the inclusion of a range of stakeholders who might be affected by the implementation of GI. Again this can make the evaluation and monitoring of GI a complex process but one that, with the application of creative and innovative approaches, can meld natural and social sciences (Chapman, 2012; Grimm *et al.,* 2000; Felson & Pickett, 2005).

3.2.2. Green roofs and Sustainable Urban Drainage Systems (SUDS)

Relative to other features there is a large amount of research into the effectiveness of green roofs. These promote several ESSs and are a good example of multifunctionality. Their priority is storm water management through the interception, evaporation, absorption and transpiration of precipitation. This reduces the amount of water that reaches combined sewer overflows during large rainfall events and lessens the untreated sewage that is discharged into local streams and rivers. It also reduces flooding, streambed and bank erosion.

Green roofs can also promote the thermal performance of roof membranes so that, during the summer, shading and evaporative cooling lessens the heat exchange into the building (Wong *et al.,* 2003), whilst in winter the roof acts as insulation (Liu & Baskaran, 2003). They also reduce urban heat island effects, which are caused by the absorption of direct solar radiation by buildings and the lack of vegetation in urban areas (Heidt & Neif, 2008) and contribute towards the maintenance of good air quality by taking up NOx and CO_2 from the atmosphere (Clark, 2005). Finally green roofs can provide habitat provision for insects and birds (Coffman & Davis, 2005; Baumann, 2006), rare plants and lichens (Brenneisen, 2006) and collebolans, which are an important group of invertebrates for soil carbon cycling so providing another ESS (Schrader & Bonning, 2006).

The relatively large amount of research into green roofs could be because they have easily quantifiable aims, such as reducing storm water runoff and pollutant loading. Oberndorfer *et al.* (2007) reviewed the evidence that green roofs provide the ESSs listed above. This suggested that green roofs retain a varying amount of rainfall of up to 100% depending on the depth of substrate covering the roof, the slope of the roof and the type of vegetation. Bass *et al.* (2003) modelled that 50% of green cover would reduce temperatures by as much as 2°C in some places in Toronto, and Gill *et al.* (2007) suggested that increasing the current area of GI in Greater Manchester by 10% could result in a cooling of up to 2.5°C. In their review of policy to establish green roof infrastructure, Carter & Fowler (2008) highlight the importance of spatial analysis to maximise green roof benefits and suggest that the green roofing of commercial areas and industrial sites provides the most benefit.

Due to this variation in the efficacy of green roofs there will be an increasing need for standards and guidelines to ensure they are designed correctly to provide the ESSs for which they are intended (Dvorak & Volder, 2011). An example is the green roof guidelines produced by the German Landscape Research, Development and Construction Society (FLL) that are used for the design, specification, maintenance and testing of green roof sites. They contain recommendations for the optimal depths of substrate and for different plant categories, based on empirical findings from green roof research. They also have recommendations for materials, particle size, pH and permeability of substrate.

Research has also been conducted on other forms of Sustainable Urban Drainage Systems (SUDS). For example, Kazemi *et al.* (2011) studied the impact of bio swales in Australia and showed they had greater species richness and biodiversity compared to gardenbed and lawn-type green spaces. This suggests that, similar to green roofs, bio swales are not only effective in promoting the ESSs of storm water retention, but also instrumental in conserving the diversity of invertebrates.

More generally, Funk *et al*. (2009) showed that the use of GI for sustainable urban drainage systems improved water quality and the diversity of species, such as dragonflies and molluscs downstream of the water quality enhancement site. Further benefits from SUDs are a reduction in the need for salt application in streets and reduced road noise (Foster *et al.*, 2011; Van Renterghem &, Botteldooren, 2009). With predicted increases in soil sealing (IEEP, 2010) and therefore decreases in soil water storage capacity (about 0.8% in the EU from 2000 to 2030) the need for SUDS is likely to be greater in the future.

3.2.3. GI for adaption to and mitigation for climate change

Some research investigates the role of GI in the mitigation of climate change by modelling future effects. For example, Pyke *et al.* (2011) used a simple storm water model to assess the effects of low impact development (LID) in Boston. LID is the American equivalent of Sustainable Urban Drainage Systems (SUDS) in Europe. This research focussed on the method of decreasing impervious or impermeable cover, under future precipitation scenarios. Their results suggest that even a modest reduction in impervious cover (from 25 to 16%) would have the potential to significantly reduce increases in storm water runoffs that are associated with increases in future precipitation.

As well as increases in precipitation another concerning impact of climate change is the increase in temperature and heat waves, particularly as these are linked to health problems, including heat exhaustion and heat stroke, especially among more vulnerable groups, such as children and the elderly (see Section 4). As with precipitation, these effects are often worse in urban areas. The so-called 'urban heat island effect' is caused by changes in the absorption and reflection of solar radiation due to the thermal conductivity and specific heat capacities of materials used in urban areas.

Bowler *et al.* (2010) reviewed evidence of the cooling effect of urban greening and indicated that on average a park was 0.94°C cooler in the day and that larger parks and those with trees tended to be the coolest. However, the evidence for the cooling effect is mostly based on studies that compare existing variation in greenness rather than a more scientific manipulation of the level. Research on how exactly GI improves temperature would help inform and improve GI design, for example, whether evapotranspiration by shorter vegetation or shading by trees is more important in the cooling effect and how this specifically affects health.

Nevertheless, the lack of knowledge on these specific processes need not hinder the implementation of GI but instead highlights the need for research to be conducted

Box 5: Retro-fit of SUDS in Augustenborg, Malmo, Sweden

Augustenborg was the target of this project after having experienced socio-economic decline and floods from overflowing drainage. The key aim of the initiative was to create a more sustainable neighbourhood by focusing on combating flooding, waste management and enhancing biodiversity. A system was created to collect rainwater from rooftops and other impervious surfaces and channel it through canals, ditches, ponds and wetlands before finally draining into a traditional closed sub-surface storm water system or SUDS. Biodiversity was addressed through the creation of new wetland habitats.

Table 2: Estimated Costs from 1998 (Naumann *et al.*, 2011b)

One off costs	Project planning	€666,000
	Investment in infrastructure (pumping station and stormwater pipes)	€1,900,000
Recurrent costs	Maintenance	€17,000 per year for 14 years: €238,000
OVERALL TOTAL COSTS		**€2,804,000**

No opportunity costs related to foregone land use were reported but there may have been foregone recreational uses in terms of large open fields used for sports that were to be used for retention ponds.

Identified benefits (Naumann *et al.*, 2011b)

- Improved water regulation and surface runoff and protection from flooding
- Improved water quality
- Reduced carbon emissions
- Reduced pluvial and sewer risk
- Aquifer recharge (relieving stress in water scarce areas)
- Enhancement of urban spaces
- Increased biodiversity
- Increased aesthetic and amenity values of landscape and increased eco-tourism

alongside GI implementation as suggested by Felson & Pickett (2005) in their concept of 'designed experiments' and Chapman (2012) in the concept of adaptive monitoring based on ESSs.

3.2.4. Possible costs and financial value of ESSs

Over the years, researchers have developed numerous methods to place a financial value on ESSs as a means to communicate their importance and encourage their protection. Some have criticised attempts to give monetary value to ESSs whilst others believe it could provide an easy-to-communicate method to evaluate this GI role, especially when making comparisons to grey counterparts as part of the decision making process.

There are several techniques for putting a price on ESSs, for example, using figures from the EU Emissions Trading Scheme or the social value of carbon for evaluating carbon sequestration by forests and wetlands (see case study – Box 6), using figures on healthcare costs of lessening asthma and other respiratory diseases by improving air quality by forests, and using prices for topsoil for valuing the provision of soil and peat from forests and forested wetlands (Weber, 2007). Weber (2007) applied this latter technique to Cecil County in the US, and estimated that forests and wetlands provide $2.1 billion in ESSs each year, which is two thirds of the county's economic output ($3.3 billion in 2006). A total of 80% of this ecosystem value was within the GI of Cecil County, which represents just over one third of the total land. Financial valuation has the advantage of providing a common currency, which can be used to tally up the benefits of different functions supplied by GI and estimate a total cost-benefit analysis (see Box 6).

3.3 Indicators and monitoring methodology

The previous section has identified several indicators with which to measure the efficacy of specific GI features, usually in terms of the functions they aim to serve. For example, the effectiveness of green roofs is primarily measured in terms of storm water runoff and pollutant load but also in terms of other benefits, such as supported biodiversity and heat control. Other green water retention features, such as bio swales, restored wetlands, riparian zones and riparian forests (those that are adjacent to water bodies, e.g. Clerici *et al.*, 2011) are again measured by the functions they set out to perform, primarily water retention but also of other functions, such as the provision of habitat and stepping stones for certain species.

Other examples of direct indicators for regulating ESSs include pollutant levels for air quality, amount of carbon stored for carbon sequestration, nitrate concentration for water quality, soil organic carbon for soil quality. In other instances, proxy measures are used, for example, the rooting depth of plants can be used as a proxy for erosion control (Layke, 2009). Cultural ESSs can often be measured using property values (see Section 5) or by the number of visitors to a site (see Box 6 for UK National Forest project).

When GI performs, protects or improves several ESSs, it is difficult to produce an overall picture of its effectiveness and there may be a need for prioritisation of ESSs for a clearer sense of overall value. There has been a growing trend towards placing a financial value on ESSs and this can provide a means to evaluate the benefits provided by GI, in terms of promoting ESSs and protecting ecosystem functioning. Some examples of placing a financial value on ESSs as a means to gauge the benefits of GI are shown in Box 6 on the UK National Forest project. Valuations like these have been informed by the Economics of Ecosystem Services and Biodiversity (TEEB), which was developed from the Millennium Ecosystem Assessment and aims to promote better understanding of the true economic value of ESSs. This has provided extensive knowledge that has contributed greatly to the valuation of ESSs and therefore potentially to assessing the value of GI when it performs the role of promoting ESSs.

3.3.1 Direct use values

The TEEB synthesis report (2010) identified that direct use values or those gained from provisioning services, such as crops and livestock, fish and water are the easiest and most likely to be priced, simply because they are often traded on markets and therefore have some form of price already. Values can also be derived for the ecosystem products or services that contribute to the production of commercially marketed goods. For example, water quality affects the productivity of irrigated agricultural crops, or the costs of purifying municipal drinking water. Thus, the economic benefits of improved water quality can be measured by the increased revenues from greater agricultural productivity, or the decreased costs of providing clean drinking water. This highlights the valuable role GI can play on agricultural lands and is considered in more depth in Section 5.

A good example cited in the TEEB report is bee keeping which overall generates US$213 million annually in Switzerland. A single bee colony ensured a yearly agricultural production worth of US$1,050 in pollinated fruits and berries in the year 2002, compared to just US$215 for direct products from beekeeping, e.g. honey, beeswax, pollen (Fluri & Fricke 2005).

Therefore, through the promotion of provisioning services, GI has the potential to contribute to several values. However, in examples like this it must be remembered that increased, and therefore more intensive agriculture, due to better irrigation or pollination may jeopardise other ESSs, such as maintenance of soil quality. This means there may be a trade-off between the ESS benefits and the knock-on effects on intensive agriculture, which should be considered in the monitoring and evaluation of GI. To use the terminology of Pataki *et al.* (2010) and Lyytimäki *et al.* (2008) by promoting one ESS, an ecosystem disservice could be promoted at the same time.

3.3.2. Non-use values

In comparison, non-use values are not associated with actual use but stem from people's knowledge that nature exists ('existence value') or because they wish it to exist for future generations ('bequest value') or for others in present generations ('altruist value'). In the main, these are values of spiritual or cultural importance and are rarely valued in monetary terms.

One method that attempts to tap into values is 'willingness to pay' where individuals are asked to estimate the maximum amount they would be willing to pay in order to receive a certain ESS or to avoid something undesired, such as pollution, which would be mitigated by GI. The contingent valuation method (CVM) involves directly asking people how much they would be willing to pay for specific environmental services or the amount of compensation they would be willing to accept to give up specific environmental services.

An example of this is the estimation of the benefits of Sites of Specific Scientific Interest in the UK where researchers estimated that the public is willing to pay £827 million for benefits provided by SSSIs in England (GHK *et al.,* 2011). Another option is to use preferences or the contingent choice

Box 6: Case study of GI protecting ecosystem functions and promoting ESSs.

UK National Forest project

The National Forest project was conceived in 1987 to create a large, new forest for the nation in lowland Britain that would demonstrate multi-purpose forestry and improve an area damaged by past mineral workings. Its aims were economic regeneration from the restoration of mining sites and the support of future agriculture through rural diversification. Commercial forestry was blended with additional benefits including economic regeneration, landscape and ecological enhancement, rural diversification and community engagement, and creation of a new recreational and tourism resource. The Forest area spans 518 km^2, representing an increase from 6% to nearly 19% since 1990 with 19,000 hectares of new and existing woodlands, hedgerows, meadows, heathlands and wetlands. The project targeted nine priority species: otters, bats, adder, bluebell, black poplar, rudder darter dragonfly, water vole, redstart and barn owl. Several ESSs are promoted, such as carbon sequestration, recreational services and timber and forestry products.

Table 3: Estimated Costs of Project (Naumann *et al.*, 2011a)

One off costs	Project management and administration	€11,357,206
	Land management and restoration works	€18,907,908
	Other/unspecified	€4,220,828
	Total	**€34,485,943**
Recurrent costs	Land Management, buildings and maintenance	€2,669,136
	Other Equipment	€39,400
	Project Management and administration	€1,491,418
	Research and Monitoring	€47,378
	Total	**€4,247,332**
OVERALL TOTAL COSTS		**€38,733,275**

Much of land converted to woodland had been former mining areas with few development opportunities so by regenerating the area the project has brought significant opportunities for economic development rather than lost them. A report by eftec (Dickie & Thomson, 2010) suggested that opportunity costs are likely to be negative.

Benefits of Project (Naumann *et al.,* 2011a)

The project created 6,229 hectares of new woodland, planted 7,800,000 trees and increased woodland cover by 207%. The value of timber production from 1991-2100 is estimated to be €11 million. In addition it created or returned to management 1,750 hectares of other habitats. The benefits due to biodiversity improvement in terms of habitats created is estimated at €56 million (based on habitats of high biodiversity value being worth £300 per hectare and habitats of low biodiversity value being worth £30 per hectare). The benefits due to landscape enhancement were estimated at €57 million, whilst benefits gained from regeneration of the land is estimated at €57 million. The total carbon sequestered to date is estimated to be 66,000 tonnes which it is estimated to be worth €209 million (based on the value of £50 per tonne of CO_2). The project created 86 km of new cycle ways as well as 45 new sports and recreation facilities and 20 new tourism attractions. It has 8,686,500 visitors a day and 84% of the local population are satisfied by landscape improvements. The value of recreational use is estimated at €628 million which includes the tourism value of €321 million. The project created or safeguarded 333 forest-related jobs, created five forest-related business activities. In total the benefits were estimated at €1,005 million (£909 million).

Evaluation and Monitoring

Eftec (Dickie & Thomson, 2010) was commissioned to assess the costs and benefits of the UK National Forest project over the period 1990 to 2100. The total benefits came to €1,005 million whilst costs, including the grants, came to €210 million (£188 million). This means the benefits exceeded the costs by €795 million (£721 million) with a cost ratio of 4.8 to 1. The benefits were also found to exceed costs by a factor of 2.6 to 1 over the 1990 to 2010 time period.

Figures in sterling are from the original eftec report. Figures in euros are from Naumann et al. *(2011a)* method, which infers values from the hypothetical choices or tradeoffs that people make between one set of ESSs at a given price and another group of ESSs at a different price. As it focuses on tradeoffs among scenarios it is suited to policy decisions where a set of possible actions might result in different impacts on natural resources or environmental services.

3.3.3. Indirect use values

Indirect use values often come from regulating services, such as water purification, climate regulation and pollination. They have only recently been assigned figures but there is increasing research in this area and the TEEB report (2010) provides cases of valuating different services provided by ecosystems or ecosystem elements. For example, the planting of 400,000 urban trees in Canberra, Australia aims to regulate microclimate, reduce pollution and thereby improve urban air quality, as well as reducing energy costs for air conditioning and sequestering carbon.

These benefits are expected to amount to US$20-67 million over the period 2008-2012, in terms of the value generated or savings realised for the city (Brack, 2002). An example of a tool used to value ESSs provided by sustainable storm management is the Green Value Calculator developed in Chicago (see Box 7).

3.3.4. Value from mitigating or avoiding damaging events

Often valuation can be established in terms of 'money saved' from avoiding damage or replacement. For example, the De Doorbaak project in the Netherlands created a 13km-long stream to reconnect the Regge River to its catchment area to prevent flooding. It was estimated that this saved up to €30 million by preventing flooding and, when combined with other benefits, such as biodiversity protection and the provision of recreational values this outweighed the €40.8 million costs of the project, especially over time (Naumann *et al.*, 2011b). In the US, it has been estimated that overall wetlands provide $23.2 billion in storm protection services (Cotanza, 2008).

The calculation of value is based on the assumption that, if people incur costs to avoid damages caused by lost ESSs or to replace the ESSs, then those services must be worth at least the costs that people paid to replace them. As such, the methods are most appropriately applied in cases where damage avoidance or replacement expenditures have actually been, or will actually, be made. Some other examples of cases where these methods might be applied include:

- Valuing improved water quality by measuring the cost of controlling effluent emissions.
- Valuing storm protection services of coastal wetlands by measuring the cost of building retaining walls.
- Valuing fish habitat and nursery services by measuring the cost of fish breeding and stocking programs.

3.3.5. Making the link between GI and ESSs

Placing economic value on the ESSs that GI aims to promote is clearly a way in which some of the functions provided by GI can be assessed and potentially compared to other policy options. However, in order to make this valuation accurate, greater knowledge is needed about how exactly GI contributes to promoting these ESSs and protecting the ecosystem functions that feed into these services. It is important to be clear about the functions that GI is setting out to deliver (Pataki *et al.*, 2011) in order to evaluate its efficacy and it is important to understand possible interactional and additional effects to assess multifunctionality. TEEB (2010) cites that ESS provision is often dependent on critical thresholds so that an ecosystem's capacity to provide services can change drastically and in a non-linear way.

For example, some thresholds have already been passed in certain coastal areas where 'dead zones' now exist, for a range of coral reefs and lakes that are no longer able to sustain aquatic species, and for some dryland areas that have been effectively transformed into deserts (TEEB, 2010).

The distance to an ecological threshold could affect the value of the ESS and ideally ESS indicators should allow us to anticipate the proximity to such tipping points. However, there is some question as to whether a specific threshold for a whole ecosystem can really exist due to the complexity and dynamic quality of ecosystems. Species populations can fall below their Minimum Viable levels, which can cause their extinction at a certain area and period of time but it is difficult to place a threshold on the different ecosystem services and interactions in nature and landscapes. Further advances in scientific knowledge to anticipate how the provision of ecosystem services changes over time and space would help in the valuation of ESSs and thus feed into monitoring how well GI protects ecosystem functioning and promotes ESSs.

Box 7: Chicago centre for Neighbourhood Technology (CNT) Green Value Calculator

The CNT in Chicago has developed several storm-water management tools and alongside this a calculator to help users compare costs, benefits and performance of GI. Various GI features can be entered into the tool, such as green roofs, tree cover and drainage swales alongside relevant parameters, such as roof size, number of trees, area of permeable pavement, average slope and soil type etc. The tool then calculates volumes for site improvements for storm-water detention, annual discharge, reductions in peak flow and ground-water recharge when compared to no improvements.

Green Values Stormwater Toolbox, see: www.greenvalues.cnt.org

4.0 The Role of GI in Promoting Societal Health and Wellbeing

In addition to the aesthetic value of living near parks, gardens, fields, rivers or wetlands, there is a growing body of evidence that contact with the natural environment can contribute significantly to human health and wellbeing. This is because natural ecosystems provide a variety of services some of which promote basic human survival, for example, by limiting the spread of disease or reducing air pollution.

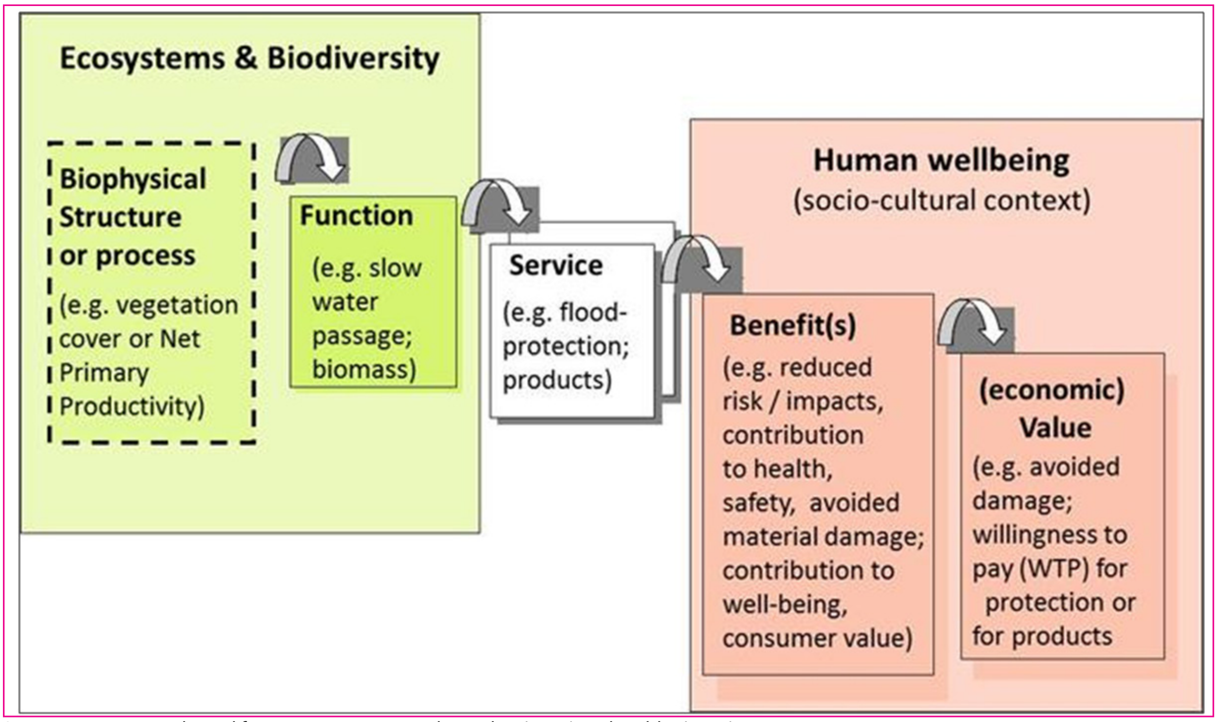
However, The World Health Organization defines human health not simply in terms of lack of illness or disease, but as a 'a state of complete physical, mental and social wellbeing' (WHO, 1948), which recognises that a wide variety of factors contribute to overall good health. This contribution of GI to human health is a form of ESSs since it is a beneficial outcome to humans that results from the healthy functioning of ecosystems. It could therefore be included in the previous section that covers GI's role of promoting ecosystem services but, with the increasing recognition of this role, it is described here in a separate section.

GI can make health-related ESSs, such as air and water quality management (see Section 3 and Fig. 3) available to inhabitants. Promoting GI is particularly important in urban environments since more than 50% of the world's population live in cities (United Nations, 2001) and it is estimated that most do not have easy access to green spaces (Hladnik & Pirnat, 2011).In addition, many other health benefits can be derived from the existence of GI features. These benefits encompass physical, psychological/emotional and socio-economic benefits and can be identified at both the individual and community level.

Several factors related to public health are closely associated with maintaining biodiversity within natural habitats, which is one of the roles provided by GI (see Section 2). For example, species biodiversity offers protection against the spread of certain diseases (Zaghi *et al.*, 2010).

Biodiversity is also a resource for chemical compounds for use in medicine and a number of synthetically-produced drugs are designed to mimic chemicals found in nature (Ganesan, 2008; Kingston, 2011). As a means of protecting and promoting biodiversity and ESSs (see Sections 2 and 3), GI can therefore contribute to these critical aspects of public health.

In addition, many other health benefits can be derived from the existence of GI features. These benefits encompass physical, psychological/emotional and socio-economic benefits and can be identified at both the individual and community level.



Source: TEEB 2011, adapted from Haines-Young and Potschin (2009) and Maltby (2009)

4.1 GI features that perform the role of promoting societal health and wellbeing

By protecting biodiversity and ecosystem state and by promoting ESSs, the GI features mentioned in previous sections (2 and 3) contribute to the promotion of health and wellbeing. Below are some additional features, many of which overlap with those previously mentioned:

- Public parks, pathways, playing fields, cycle paths and jogging tracks that encourage outdoor activity and promote good physical health.
- Urban vegetation, i.e. allotments, trees, green roofs and private gardens that regulate air quality and reduce the 'urban heat island' effect.
- Wetlands, grassed areas and urban forests that reduce the risk of flooding, sewage overflow and clean water contamination.
- Communal parks, village greens and town squares that enhance community attachment, social cohesion and a sense of environmental responsibility.
- Green spaces in a residential community that attract tourism and investment and improve employment and income potential.

4.2. Benefits and costs of GI performing the role of promoting societal health and wellbeing

4.2.1. Physical health

A growing number of epidemiological studies indicate that the presence of GI features increases time spent outdoors (independent of age, sex, marital and socio-economic status) (Booth *et al.*, 2000; Humpel *et al.*, 2002; Humpel *et al.*, 2004; Pikora *et al.*, 2003). This, in turn affects physical health. For example, several studies report a link between the abundance of green space and the self-perceived health of a representative cross-section of inhabitants of a given area (de Vriers *et al.*, 2003; Payne *et al.*, 1998). Access to walkable green streets and spaces has also been associated with objective measures of health, such as increased longevity of senior citizens in China (Takano *et al.*, 2002; Tanaka *et al.*, 1996) and reduced blood pressure and body mass index (Orsega-Smith *et al.*, 2004).

Avoiding a sedentary lifestyle has a variety of health benefits, both preventative and restorative. For example, increased physical activity associated with access to green spaces is associated with a reduced risk of a stroke (Wannamethee & Shaper, 1999), cardiovascular disease (Lee *et al.*, 2001; Sesso *et al.*, 1999; Wei *et al.*, 1999) and obesity (Nielsen & Hansen, 1007). Availability of nearby GI therefore not only encourages people to take more physical exercise, but also to travel more sustainably by either foot or bicycle through green spaces which has an additional benefit in reducing CO_2 emissions produced by other transport (Moffat *et al.*, 2010).

These epidemiological studies are complemented by a number of controlled experiments, which identify the direct physiological effects of specific human/ecosystem interactions. For example, active contact with nature, i.e. recreational walking in a natural setting, as opposed to an urban environment, has been found to significantly reduce blood pressure (Hartig *et al.*, 2003). Participating in activities in green settings reportedly improves the functioning of 7-12 year old children with attention deficit disorder (Faber-Taylor *et al.*, 2001). One suggested mechanism for such associations is that emotional changes triggered by nature can induce or mediate physiological changes (Tzoulas *et al.*, 2007). This assertion is, in turn, based on the hypothesis that humans have an innate instinct to connect with nature, a theory known as biophilia (Kellert & Wilson, 1993), driven by an evolutionary history of dependence on natural ecosystems for survival. In addition to observations about the positive impact of increased contact with nature, the relationship has also been studied in reverse. For example, environmental stress caused by the removal or deterioration of natural habitat has been linked to chronic anxiety, chronic stress and high blood pressure (Henwood, 2002) and the perception of ill-health of inhabitants of Karachi, Pakistan (Qureshi *et al.*, 2010).

Health benefits of GI exist not just at the individual level, but also at the community, city and even regional levels. Natural GI features, such as mangroves, wetlands and forests, protect coastal populations from the damaging effects of storms and sea surges, (Danielsen *et al.*, 2005; Primavera, 2005). The maintenance and promotion of such features can protect an area from the damaging effects of natural disasters, decreasing injuries and deaths. For example, mangroves can provide a buffer for the destructive effects of tsunami (Dahdouh-Guebas *et al.*, 2005).

GI can contribute significantly to improving air quality and water quality. In summer, absorption of heat by dark surfaces in urban areas, such as concrete rooftops and roads, contribute to the 'urban heat island' effect (see Section 3), which can significantly increase the temperature of urban areas compared to surrounding areas. Excessive heat presents a range of health risks, from fairly benign swelling to potentially fatal heat stroke (Frumkin, 2002). Increasing vegetation cover within urban areas, for example, with green roofs and facades (see Box 8), can increase shading and the natural capacity of plants to cool the air by several degrees through evapotranspiration (Pérez *et al.*, 2011; Susca *et al.*, 2011; Whitford *et al.*, 2001).

The replacement of natural green spaces with concrete and impermeable pavements in urban areas reduces the effectiveness with which rainfall, snow melt and storm water are absorbed and returned to groundwater aquifers (see Section 3). This results in elevated levels of surface water run-off, which increases the likelihood of local flooding and sewers reaching overcapacity. A further sanitation risk is that as excess run-off flows over the urban ground it can accumulate contaminants, such as oil, grease, toxins and pathogens, and deposit them in surface waterways (rivers, lakes and wetlands) and groundwater (Frumkin, 2002).

4.2.2. Psychological/emotional health

It is thought that regularly visiting a favourite place of natural beauty can be a source of emotional release, enabling people to relax and clear their mind of troubles (Korpela & Hartig, 1996; Korpela *et al.,* 2001). Other studies have found that green spaces visible from apartment blocks reduces residents' mental fatigue (Kuo, 2001; Kuo & Sullivan, 2001). Natural features and open spaces also play an important role in social cohesion at the community level. For example, by encouraging pedestrianism, GI has been found to increase the likelihood of informal interactions and help promote a sense of community spirit (Kim & Kaplan, 2004). Places of natural beauty can also have cultural and aesthetic value which, in turn, can improve a sense of wellbeing and health.

4.2.3. Socio-economic health

GI improves the aesthetic look of an area, which in turn effects property prices and attracts tourism and investment to the area, with positive consequences for many socio-economic aspects of a neighbourhood or city, such as employment, income, living and working conditions, access to public services and good-quality housing (Tzoulas *et al.,* 2007, see section 5). This makes a strong case for the contribution of GI to any new development and for the regeneration of urban areas. It has also been acknowledged that a healthy and well-functioning community is likely to continue to enhance ecosystem services to capitalise on the resources available to them, therefore initiating a positive feedback loop reinforcing the benefits of GI (Butler & Oluoch-Kosura, 2006).

4.2.4. Possible Costs

Despite growing evidence of the link between GI and public health and wellbeing, the benefits of GI must be weighed up against the social and economic costs, including 'lost opportunity' costs of protecting valuable habitat against land development. Additionally, empirical scientific evidence must be considered in spatial planning decisions to avoid unintended consequences of modifying natural habitat. For example, it has been suggested that non-native vegetation and the introduction of invasive species may lead to new pollen allergies emerging in the population (Cariňanos & Casares-Porcel, 2011), which could counteract the functions that GI aims to provide. However, so far it would seem that weighing such negative consequences or ecosystem disservices up against the reported positive effects indicates that GI brings multiple benefits at comparatively little cost. However, improved scientific understanding of unintended consequences on human health will be necessary to minimise future risks associated with GI implementation.

4.3 Indicators and monitoring methodology

While epidemiological and experimental studies can contribute significantly to a better understanding of environmental determinants of health and wellbeing, most rely on self-reported assessments of health from participants. Such outcomes are subjective rather than objective. It is difficult with subjective analyses to separate the direct effects of GI from indirect consequences of GI that may also influence health, such as reduced traffic noise and improved air quality and, as such, they are unable to determine cause-and–effect relationships, only associations. The evidence available is strong enough to draw conclusions

Box 8: Case studies of GI promoting societal health and well-being

Green facades and the urban heat Island effect in Catalonia, Spain (Pérez *et al.*, 2011)

Llieda in Catalonia, Spain, experiences extreme climatic conditions, with low rainfall and very hot summers. Scientists monitored the behaviour of a green facade for a full year (Sep 2008 – Aug 2009) to test its ability to mitigate the "urban heat island" effect through shading and evapotranspiration. Results revealed that the level of light between the green façade and the wall was far lower than in the open air, indicating a significant shading effect, which peaked in July and August as the leaves reached maximum size. The surface temperature of the wall in an area that was unshaded by vegetation was on average 5.5ºC higher than in partially covered areas. The difference was higher in August and September, reaching a maximum of 15.2ºC.

Can GI reduce healthcare expenditure?

A study in the UK by Bird (2004) estimated that if 20% of the population who live within 2km of a green space used it for 30 minutes of physical activity per day on five days per week, the saving to the National Health Service could be over £1.8 million (€2.7 million) per year (Bird, 2004). An improved understanding of the empirical links between GI and health will lead to increasingly detailed and accurate estimates of the economic implications of GI.

about the potential health benefits of GI. However, many more empirical studies using objective measures of health, such as longevity, blood pressure and BMI (Orsega-Smith *et al.,* 2004) are needed to strengthen the scientific basis behind reported associations and to resolve methodological limitations of epidemiological research (Tzoulas *et al.,* 2007).

As the scientific basis is developed further, complex multi-level epidemiological studies that combine a wide variety of social, cultural, economic and psychological influences can begin to quantify the importance of interlinking factors. Various frameworks for this have been developed, such as that proposed by Tzoulas *et al.,* (2007, see Fig 2). Based on a large, analytical literature review, their conceptual model links GI features with the ecosystem services they provide and the various aspects of public health that they influence, at the individual and community level (see Sections 3 and 5). Some of the proposed health indicators are death rates, incidence of cardiovascular and respiratory disease, depression and psychological illnesses (Tzoulas *et al.,* 2007). By linking health measures to GI and ESSs it attempts to quantify cause-and-effect mechanisms, which will help, strengthen the integration of GI into urban and spatial planning and to evaluate the cost efficiency of its implementation.

5.0 The Role of GI in Supporting the Development of a Green Economy and Sustainable Land and Water Management

The popularity of GI is highly dependent on its multi-functionality and its ability to offer sustainable and effective solutions to several problems. Although economic value has been discussed in previous sections, especially in terms of monetarising ESSs, GI can have a more direct financial contribution by developing and supporting a green economy. At the heart of a green economy are sustainable development and a valuation of natural capital and ecological services. More and more, industry and the business sector are interacting with the funding of GI. This is not just to restore ecosystems degraded by their activities, but also to conserve nature to provide services at rates more economical than grey measures, such as water purification, and to invest in potential business opportunities, such as biomimicry.

GI can also contribute economically through the provision of sustainable land and water management. Examples are agri-environmental schemes and sustainable forestry management whose implementation can consist of practices, such as the banning of chemical products, low intensity use of fertilisers, diversified crop rotations and improvement of the ecological state of hedgerows or grasslands to maintain biodiversity and ecosystem connectivity, whilst ensuring a sustainable supply of crops, timber and other forestry products.

Examples of sustainable techniques for water management are the setting up of Marine Protected Areas (MPAs) and maintaining riparian areas and wetlands. A good example of the economic contribution of GI is High Nature Value (HNV) farming which, in most cases, is a low-input farming system, often comprising of semi-natural vegetation, such as hedgerows, grasslands and scrubs (i.e. dehesas and montados are typical examples of extensive, productive and sustainable lands with a high biodiversity). HNV maintains threatened species and habitats but also contributes to soil carbon storage and the protection of water resources, as well as sustaining an active rural population in fragile areas.

All these benefits are dependent on each other in that profitable and sustainable agriculture depends on the maintenance of ESSs and biodiversity and vice versa. Some claim that GI features on farmland, forestry and water reduce the productivity and efficiency of land compared to intensive agriculture and fishing, but what is important is their contribution to a long-term sustainable supply of food and timber from the diversified portfolio of products. By providing these features, GI can contribute towards protecting biodiversity, promoting ESSs and maintaining sustainable and productive agricultural lands.

5.1 GI features that perform the role of supporting the development of a green economy and sustainable land and water management

The features mentioned in previous sections (2, 3 and 4) contribute to this role by protecting biodiversity, promoting ESSs and promoting societal health and well-being. The features can also directly contribute to the development of a green economy for example, through creating a need for the manufacture of certain forms of infrastructure, such as ecoducts, and through the provision of jobs for the creation and maintenance of GI features.

5.2 Costs and benefits of GI performing the role of supporting the development of a green economy and sustainable land and water management

5.2.1 Less grey infrastructure – more funding

The strategic placement of GI reduces the need for grey infrastructure and the community's susceptibility to floods, fires, and other natural disasters. As cited in Section 3.2, prime examples are green roofs, which not only reduce the need for expensive water treatment facilities but also improve energy efficiency. By saving on the installation of grey infrastructure there is a freeing up of funds for other community needs, which in turn helps to improve its economic state. As Benedict & McMahon (2002) point out, this can create a healthy cycle in that initially we need to actively promote GI systems to free up funding, but this can then be used to build further GI which in turn releases further funding. As such the funding cycle should hopefully sustain itself. GI can also contribute to the economy through mitigating impacts of flooding and other natural disasters. For example, Morris & Camino (2010) estimate that the value of an additional hectare of wetland in the UK, due to flood protection properties, is £407 per hectare per year for inland wetland and £2,498 per hectare per year for coastal wetland.

5.2.2. More green jobs and more productive workforce

GI can yield safe and reliable jobs. Planning GI requires skilled individuals, such as architects, designers and engineers but its implementation also requires 'green collar' jobs in construction, maintenance and installation (Dunn, 2010). For GI features that require a form of new infrastructure, such as bridges or green roofs, this will require investment which in turn will generate income for those working in the sectors and possibly improve the economy where these manufacturers and businesses are based. For features, such as conservation areas and urban parks, these will require maintenance and monitoring and, in some cases, re-landscaping.

Mills *et al.* (2010) found that the Environmental Stewardship schemes in England provided employment for many local businesses, such as those involved in stone-walling and hedge restoration and some farm advisors. The creation of the National Forest in the UK increased the number of local jobs by 4.1% and local regeneration using GI attracted £96 million of investment (CESR, 2004). The recent study on the economic value of the benefits provided by tourism and recreation and employment supported by the Natura 2000 (Bio intelligence service, 2011) suggests the network (which contributes to a European Green Infrastructure) directly supports approximately 8 million full time jobs and indirectly an additional 4 million.

With increasing demand for environmental knowledge and skills there will be an increasing demand for training and education in environmental and sustainability studies. These will consist of purely environmental courses, and environmental elements will need to be incorporated into disciplines, such as engineering and economics. This can contribute to the economy in regions with academic institutions that teach green skills and knowledge. It has been suggested that GI has real potential for informing people about climate change (Moffat *et al.*, 2010) and that it can be used in school education to inform young people about the environment. GI's role in protecting and maintaining ESSs can also increase employment, especially in the case of provisioning services, such as timber and fisheries, but also by supplying tourism and recreation, which will bring money into the area, both through visitors to green space, forests etc. and through hospitality required for visitors.

The role of GI in promoting societal health and wellbeing (see Section 4) is also influential to the economic role of GI since a healthier workforce will be more productive and lose less work days from ill health. For example, Rujgrok *et al.* (2006) have calculated the value of deciduous forests in regulating air quality to be €9,800 to €61,400 per hectare through costs saved from reduced risk of diseases caused by air pollutants. Further benefits to the economy can be from increases in physical activity, which reduce economic losses due to illness, disabilities and premature death as well as improving labour productivity. In addition it has been estimated that improved health among the population due to physical activity in a green space will save on costs in health services (Bird, 2004, see Box 8).

5.2.3. Agriculture

Another economic function performed by GI is its contribution to sustainable farming. For example, HNV farmland often contains many GI features and can be important in the long-term sustainable supply of food and timber. The Gallecs Project in Spain (Naumann *et al.*, 2011a) aimed to create a buffer zone between the urban fringe and the countryside through the restoration of natural habitats and sustainable agricultural and forest management. By protecting 7.5 million m^2 of land from urbanisation, significant levels of development have been foregone but economic activity has been enhanced through the promotion of sustainable farming with organic products producing high profit margins. This demonstrates the value of maintaining or implementing GI on agricultural lands and how, with a long-term vision, it can support productive agriculture and maintain biodiversity and ecosystem health.

Dunn (2010) has argued that by creating space to grow produce in urban areas, GI can lower food costs for those living in cities, particularly those in poverty, by diminishing transport costs. Urban agriculture not only provides drainage and storm water management services but can also enhance food security and promote local economic development. Residents can have greater economic opportunities both as producers and consumers of affordable, healthy produce (Dunn, 2010). GI can also help regenerate land that has been contaminated from its former uses so it is once again productive. For example, trees have the potential to remove and immobilise contaminants through the processes of phytoremediation and phtyostabilisation, and these are relatively inexpensive (Hutchings, 2002).

5.2.4. Property values

GI can contribute to the economy by improving property values. This is due to aesthetic reasons but also, in terms of green roofs and other natural water management systems that improve the energy and water-use efficiency of housing and safeguard it against storm and flood damage. Also influential to this is the impact of green space on revitalising degraded neighbourhoods and increasing a sense of community (see Section 4). In fact, Dunn (2010) suggests that GI should be targeted to areas of urban poverty as this is where it would provide the greatest benefit since this group often live in areas that suffer the most from air pollution, poor water quality, bad health, safety issues, low and high unemployment. This is supported by the findings of the UK Sustainable Development Commission (SDC) (2010) who reported that poorer social groups have lower access to green spaces.

Since green space has a positive effect on health conditions, such as obesity, mental health, circulatory disease and asthma (see Section 4) and these are significant factors in health inequalities, the SDC suggests that, if planned correctly, green space could reduce inequalities between socio-economic groups. Although Dunn (2010) argues that areas of urban poverty have the greatest need for GI, she does not address the possibility that, once GI features have been implemented in an area, its value and property prices could increase, which could mean that only the affluent could afford to live there and benefit from the GI whilst the poor would no longer be the benefactors. This possible side effect should be kept in mind when designing GI that aims to alleviate urban poverty.

5.2.5. Possible Costs

Dunn (2007) makes the point that GI does come at some cost and that if it does not return on these investments, then it is clearly not contributing economically. This has been covered in previous sections in terms of opportunity costs and financial costs for the provision and maintenance of GI. However, one of the difficulties of evaluating GI is that its return is not consistent over time. For example, trees with mature canopies can absorb the first half-inch of rainfall but trees take decades to create a mature canopy, whereas grey infrastructure can provide the same function almost instantaneously. This means that GI could be mistakenly evaluated negatively because it takes time to develop and mature before it can conduct its function optimally and reap economic benefits (Dunn, 2010; Dunn, 2007).

5.3 Indicators and methodology

Theoretically, the economic impact of GI can be measured in terms of its influence on GDP at the national level or some other economic performance indicator at the regional, local or European level. For example, the implementation of Natura 2000 network in Spain, which comprises various GI features, such as core areas, buffer zones and ecological corridors was estimated to increase the GDP by between 0.1 and 0.26% at a national level (Fernandez *et al.,* 2008).

In some cases, such as the manufacture of a new technology or the introduction of a new green recreation area, the economic impact may be easy to assess, whilst in others it may be difficult to unpick the specific impact of GI from other possible impacts. This could be especially true if GI is introduced as part of a larger planning project or grafted onto existing GI.

Other indicators of GI's ability to perform the role of supporting a green economy could be the number of green jobs created or increases in wages. For example, Mills *et al.* (2010) investigated the employment impacts of the Environmental Stewardship schemes in England and found that it supported one full-time job in the local economy for every €1 million spent initially on agri-environmental schemes. On a larger scale it has been estimated that a fully funded Natura 2000 network could support 207,000 jobs across the EU, mostly in rural areas (Rayment *et al.*, 2009).

Performance of this role can also be assessed in terms of money saved from replacing grey infrastructure counterparts or from flood damage avoidance, energy efficiency improvements and water savings (see Section 3). Money made from agricultural produce, timber and fisheries that rely on GI can be valued using market prices.

Property or land prices have been mentioned as a measurement of the provision of cultural and social ESSs (see Section 3) and can also reflect economic impact. This can be done using the 'hedonic pricing method'. For example, using data on the variation of house prices with proximity to green space, an estimate can be made as to the value of the green space, or at least the impact on house prices. This is illustrated in a recent study in the UK (cited in Bateman *et al.,* 2010) that indicated a 1% increase of green areas within a local area (1 km around the house) increased house prices from 0.06 to 0.4%, depending on the type of green area. A study by CABE (2004) reported that in the Netherlands a view of a park raised the house prices by 8%, and having a park nearby raised house prices by 6%.

The economic benefits associated with increased tourism and recreation provided by GI can also be represented by the number of visits to an area and some studies have placed an average value per visit, for example, Zandersen *et al.* (2009) valued a visit to forest in Europe at an average of €4.52 per visit. However, this can vary widely from between €0.6 per visit and €112 per visit, depending on the area.

6.0 Assessing Multifunctionality

From discussions in previous sections of this report, it can be seen that GI has the potential to perform many functions, spanning different environmental, social and economic areas. However, the evaluation and monitoring of these functions is complex, not only because it involves different types of measures to assess different functions, but also possible interactions between these functions and their impacts. This section will consider some examples of research that has investigated the interactions of different functions and explore research needs for the future.

6.1. The relationship between the roles and scales of GI

Biodiversity and ESSs are closely related, for example, Maestre *et al.* (2012) demonstrated that species richness was positively and significantly related to the ability of dryland ecosystems to maintain functions, such as carbon storage, productivity and the build-up of nutrient pools. However, Harrison *et al.* (2010) has highlighted that ESS and biodiversity priorities do not always overlap and we cannot assume that improving one through GI automatically improves the other. A typical example of this is the conflict that can occur between protection of biodiversity and the provision of ESSs, such as food supply from agricultural areas or carbon storage in plantations.

Cardinale *et al.* (2011) investigated the role of diversity in ecosystems in detail by reviewing two decades of experiments. They conclude that biodiversity does regulate several ecosystem processes, such as productivity, decomposition and nutrient cycling that are important both for the functioning of ecosystems themselves and for humanity. This is supported by research by Diaz *et al.* (2005) that suggests the support of ESSs, such as primary production and nutrient cycling, will depend on the maintenance of biodiversity.

Cardinale *et al.* (2011) suggest that in the future we may be able to offer concrete predictions about the number of species needed to sustain certain ecological processes. This will require greater knowledge of how diversity relates to ecological processes over time and at the scale of whole ecosystems.

Some (e.g. Loreau *et al.,* 2001) have suggested that it is functional diversity rather than species diversity per se that enhances ESSs i.e. it is more important that the species within the ecosystem perform a range of functions. Greater knowledge on the relationship between biodiversity and ESSs will inform the planning of GI and the evaluation of its efficacy.

GI works at a broad ecosystem scale, but to make its evaluation understandable and relevant, approaches are needed that combine the rigour of small-scale studies with the breadth of broad-scale assessments. Nelson *et al.* (2009) used a spatially explicit modelling tool called Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) to analyse the impact of three different land use scenarios in a river basin in Oregano in the US on a range of ESSs, biodiversity conservation and commodity production. It is not so much the results of this study that are of interest, since they are specific to the Oregano river basin, but the synergies or trade-offs identified between the different outputs. It found little evidence of a trade-off between ESSs and biodiversity conservation, but did find a negative correlation between commodity production and both ESSs and biodiversity conservation, indicating that land use decisions based only on commodity production could be to the detriment of ESSs and biodiversity. The study makes the point that before policies are introduced that pay for ESSs, the links between biophysical provision and ultimate use by people need to be explored where possible.

6.2. A conceptual framework for mapping the functions of GI

Tzoulas et al. (2007) have proposed a theoretical framework that could potentially be used to map the different roles and functions of GI and the interactions between them. It consists of seven interrelated boxes, three that are related to ecosystems and four related to human health (see Fig. 2 in Section 3). Mathematical modelling can be done within and between each of the boxes using multivariate analysis of indicators, such as habitat size and connectivity, habitat heterogeneity, amount of pollutants, income, employment, proximity to services and incidence rates for depression, cardiovascular and respiratory disease.

6.3. Overall economic valuation of GI using Total Economic Value approach

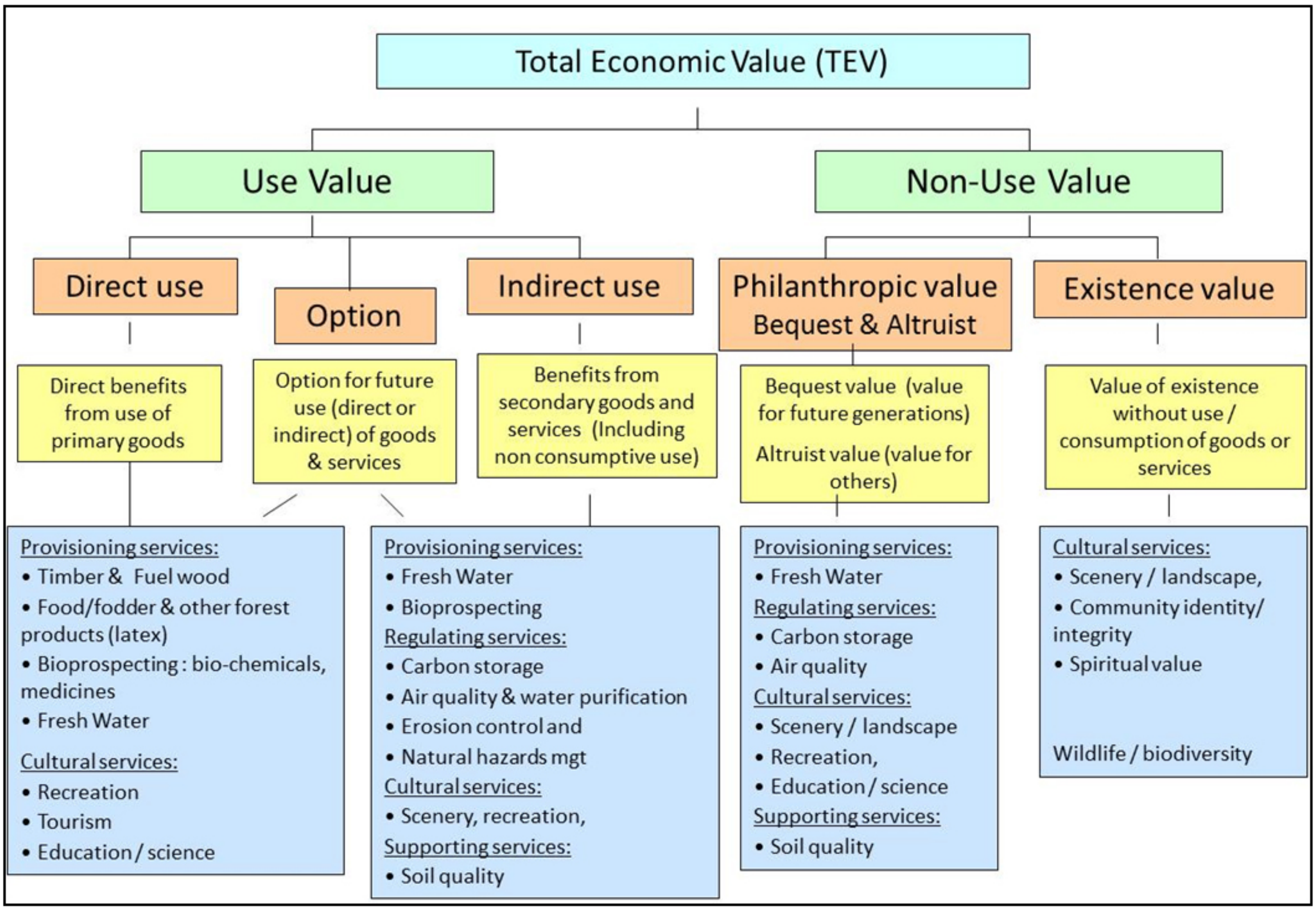
To come to an overall conclusion on the effectiveness of a GI project it is helpful to put the costs and benefits of its different functions into a common measure. The most recognised method to do this is economic valuation. The concept of Total Economic Value (TEV) aims to capture the full value of different components of natural resources. It recognises a range of values, including direct use values, such as provision of food and water, indirect use values, such as air and climate regulation, and non-use values, such as protection for future generations (ten Brink *et al.,* 2011).

Vandermeulen *et al.* (2011) propose a TEV model to evaluate GI investments. They applied it to a case study of a green cycle belt in Bruges in combination with a multiplier analysis to evaluate the impact on the regional economy, from factors including increased wages and more jobs. Using a time horizon of 20 years, they estimated it had an economic value of €5,592,892. They highlight that this figure is dependant on assumptions and also that the objectives of the evaluation will limit or define the choice of benefits and costs and this affects the results. They suggest that by starting the choice of costs and benefits from the objectives of the evaluation and the project (in this case the goal of increasing biking in a green environment) then a correct choice of costs and benefits can be guaranteed.

A total economic value approach was also used to estimate the economic value of the overall benefits of the Natura 2000 network (ten Brink *et al.*, 2011, see Fig 4). Their first estimate used valuation results from a relatively small number of site-based studies and scaled them up to provide an estimate of the whole Natura 2000 network. This produced an estimate of €200-300 billion per year at present.

They also calculate an estimate based on ESS analysis using data from TEEB and the Millennium Ecosystem Assessment to estimate value of services provided by Natura 2000, such as carbon storage, reduction of damage from weather events, tourism, water purification, pollination and food provision. The estimate seemed to broadly match that of estimate which used the site-based studies, at about €200-300 billion per year.

Figure 4: The Total Economic Value (TEV) framework in the context of Natura 2000 (ten Brink *et al.,* 2011)



Source: White et al*, 2011, adapted from Kettunen* et al *(2009), adapted from Pearce & Moran 1994*

7.0 Summary and Conclusions

The scope and span of GI means it has the potential to be a highly effective policy tool since it can perform several functions at several scales, whilst taking into account the multiple connections and interactions which are so essential in nature. It has been suggested that a comprehensive accounting of its multiple benefits can help to realise the full net-benefits of GI (Foster *et al.,* 2011) but this is complex to investigate empirically.

GI is set in a scientific framework and firmly based on knowledge about the impacts of fragmentation, land use change, and pollution, but currently it has little hard quantitative evaluation and monitoring (Naumann *et al.*, 2011(a & b); Ervin *et al.*, 2010; van der Windt & Swart, 2008). This is partly because GI is a relatively new concept and, as yet, no rigorous evaluations have been undertaken with baseline measures and continuing measurements of agreed indicators over time. Information on the outcomes of GI is available, but it tends to be on a specific feature or part of GI and specific to the context in which the GI is taking place, making it hard to apply it to other situations. Examples of where there has been more comprehensive monitoring are the Natura 2000 sites, where the Total Economic Value of the network's benefits has recently been estimated (ten Brink *et al.,* 2011).

Evaluation and monitoring of GI need to use the appropriate level of scientific rigour. Although we should strive to evaluate using quantitative scientific procedures, it may be appropriate to also draw on post-normal or contextualised science. Post-normal science evaluates the social robustness of the project in terms of its ability to appeal to stakeholders and span different policy and geographical areas. This does not require strict quantitative evidence, but aims to provide as much scientific knowledge as possible alongside offering transparency and communication advantages when informing the implementation of GI (van der Windt & Swart, 2008; Vimal *et al.,* 2011). It could involve intermediate research institutes positioned in the network of stakeholder groups and advisory committees with experts from relevant scientific institutions and stakeholders (van der Windt & Swart, 2008). This would not replace rigorous scientific assessment of GI but go alongside it, to complement the findings and also to contribute to the design of future evaluations of GI initiatives by providing important stakeholder knowledge on GI and its assessment.

7.1. Quantitative evidence and monitoring

The lack of quantitative analysis is also partly the result of the nature and complexity of many GI initiatives. GI appropriately occurs at an ecosystem level, but this makes it challenging to monitor its impacts at this scale and identify indicators to reflect the complex interactions between the functions that GI sets out to perform. In terms of existing research, studies tend to use more specific indicators for monitoring at the level of species, habitat and biogeochemical cycles.

Some GI features lend themselves better to evaluation, measurement and identification of costs and benefits. For example, ecoducts and natural water management systems, such as green roofs, tend to have clear functions and measures exist to assess the performance of these functions. However, even in the case of ecoducts, where they have been found to promote greater movement of animals, there is still little evidence that they are having the ultimate desired effect on species composition and population distribution.

It has been highlighted that ecosystems should not be seen as stable entities but as continuously developing dynamic systems that provide services depending on the level of their ecosystem health (Fisher *et al.,* 2009). GI and the evaluation of GI must take this into account, which can prove challenging because there is not necessarily a stable state that needs to be achieved, but more a reduction in vulnerability or a level of ability to re-establish. However, many researchers are striving to define resilience and vulnerability so it can be applied to evaluations and frame the development of indicators. (Mazza *et al.,* 2011; Naumann *et al.,* 2011a & b).

These challenges should not be a barrier to implementing GI initiatives. It is possible to start implementation before assessments are completed and then revise and improve, amending objectives and actions as time goes on and more assessments are completed (Ervin *et al.*, 2010). This is known as adaptive monitoring (Chapman, 2012) and to contribute optimally it is useful is to consider monitoring from early on i.e. during the planning of GI. In this manner it can be integrated as fully as possible into the project, a process that is promoted by the concept of 'designed experiments' (Felson & Pickett, 2005).

For ecosystem-based approaches, Naumann *et al.* (2011b) have suggested that there is a need for detailed assessments at a local scale. In particular, the monetary assessment of benefits is a useful means of communicating the advantages of GI to a range of stakeholders, but caution needs to be taken with the assumptions needed to convert natural benefits into financial currency and also because monetary assessments could be considered to compound the materialistic values of society rather than directly address the need for a deeper social shift in valuing environment and sustainability.

In order to ensure constancy of assessments, Naumann *et al.* (2011b) also recommend the development of shared protocols and guidelines so that results can be scaled-up or combined.

7.2. Difficulty in defining GI and its functions

There is a tendency by some members of the scientific community to suggest that research into GI will be hindered by its broad definition (van der Windt, 2008). This is both in terms of what comprises GI and also what functions it seeks to perform. Many countries may have had a form of GI in place for many years, but do not label it 'GI' or see the need to evaluate it as such. For example, in their report on the design, implementation and cost elements of GI, Naumann *et al.* (2011a) found that out of the 127 GI initiatives that they assessed only 20% explicitly identified themselves as GI. The projects they studied were very diverse and Naumann *et al.* (2011a) point out that interpretations of GI vary in their emphasis of components and features as well as the functions and services provided and they propose a definition that considers all of these (see Box 10).

The EEA report on territorial cohesion and GI (2011a) suggests that when a broader definition of GI is applied, that includes both green spaces and the fact that they are interlinked, this will assume the provision of all types of GI functions. In comparison, a narrow definition that only refers to the linkages and interconnectivity will assume only those functions that refer to species migration, resilience to climate change and higher recreational value. Van de Wendt *et al.* (2008) suggest that it is the vagueness of definition of ecological corridors that allows them to be flexible and therefore makes them attractive to several different groups of stakeholders.

As well as GI itself, the functions that it performs also need definition. A feasible evaluation of GI requires the identification of its functions or even sub-functions and objectives so that the GI can be assessed in its performance of these. However, if functions become too specific this may lose the sense of GI as a holistic concept. A balance needs to be struck between sufficiently specifying functions and objectives, to allow effective monitoring without losing the holistic impacts that are so essential to GI's multifunctionality. When a GI initiative is performing several functions, there could be more prioritisation so that the more important functions are given sufficient weighting in the evaluation. This could be achieved through stakeholder participation which is discussed in more detail below.

7.3. Spatial and temporal scales of GI

GI is a spatial concept and it should be evaluated as such. Moffat *et al.* (2010) recommended that benefits will be achieved if GI is integrated with more traditional land development and built infrastructure planning. For meaningful evaluation there needs to be a definition of spatial borders but again it must be a balance between specification and acknowledging the importance of links and interactions that do not recognise spatial borders. More recently there have been estimations of costs and benefits per hectare of land (Naumann *et al.*, 2011 a & b; ten Brink *et al.,* 2011) and this would seem a positive way to communicate and amalgamate costs and benefits.

GI takes time to reach its ultimate objectives – in the realm of 20 years – and, as the recognition of it as a concept is relatively new, there are unlikely to be any thorough long-term evaluations as yet. In addition, it is often the case that GI projects can incur large one-off costs initially but deliver a flow of benefits in the long-term and this must be considered when setting up evaluations (Naumann *et al.,* 2011a). For example, benefits derived from sequestration of CO_2 and the prevention of natural disasters is likely to outweigh any financial and opportunity costs in the long run and will make GI projects potentially more cost effective than traditional grey infrastructure (Doswald & Osti, 2011).

The long-term impact of GI causes another issue in that ecosystems are very flexible and changeable (Chapman, 2012) and perhaps the objectives set out at the beginning of the project may no longer be appropriate 20 years later, especially in the face of climate change and other trends. Indeed the need to find measures and methodologies that are sensitive to these natural changes in ecosystems is a challenge in itself.

7.4. Stakeholder Participation

It must also be remembered that the lack of evaluative evidence is often the result of a lack of resources as evaluation or monitoring at this scale would require substantial political and financial support. It is often a case of prioritising implementation of GI over monitoring and doing the best that is possible within the resource limitations. In their in-depth study of six case studies Naumann *et al.* (2011a) found that, on average, only 2% of project costs went towards research and monitoring. Because GI is multifunctional, it spans across many policy sectors and these sectors may have different priorities, which will affect how they evaluate GI. For example, although GI may make environmental sense, it could seem to contradict objectives of agricultural policy or spatial planning. Many have stressed the importance of

Box 9: Definition of 'Green Infrastructure' (Naumann *et al.*, 2011a)

Green Infrastructure is the network of natural and semi-natural areas, features 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. Green Infrastructure can be strengthened through strategic and co-ordinated initiatives that focus on maintaining, restoring, improving and connecting existing areas and features, as well as creating new areas and features.

participation and involvement of stakeholders in successful planning and implementation of GI (Moffat *et al.,* 2010; Grimm *et al.,* 2000; Vimal *et al.,* 2011).

Vimal *et al.* (2011) suggest the spatial representations of GI should aim to allow stakeholders to visually understand the biodiversity, ecosystem and human pressure elements involved and how to prioritise actions. They recommend involving stakeholder consultation. Monitoring and evaluation can be instrumental in participatory approaches by collecting the views of those involved and constantly feeding them into the development of GI. On the other hand evaluation can also include some measure of participation to monitor whether GI is performing this function, i.e. community cohesion and social inclusion (see Sections 4 and 5 and Moffat *et al.,* 2010).

There are several knowledge gaps surrounding GI (see Box 10). This raises the issue of uncertainty and how much can be tolerated before research is no longer considered useful. For example, if using a general value for an ESS from previous research and mapping it onto a specific GI feature in a specific context, a large number of assumptions and uncertainties have to be made since the provision of ESSs differ according to context and area. Ideally an analysis of the impacts of GI would allow determining, for example, the impact of increasing forest area on carbon stores and water quality or what an increase in wetland area would be on flood protection i.e. mapping the spatial quality of GI to the function or functions that it performs. This requires greater knowledge of the functional relationship between ecosystem properties, such as area, and ecosystem functions and services.

However, caution must be taken that GI initiatives are not hindered by concerns over uncertainty, as this is something inherent in such a complex concept (Vimal *et al.,* 2011; van der Windt & Swart, 2008). Scientific research should strive to reduce uncertainty by investigating the knowledge gaps mentioned in Box 10 but this should not prevent GI initiatives from going ahead. Instead it should encourage research to be integrated into GI projects so the results can feed into them as they progress in the form of adaptive monitoring (Ervin *et al.,* 2010).

Research also needs to explore further the possible interactions, conflicts and trade-offs between different functions (Horwood, 2011). Moffat *et al.* (2010) highlight that, when appropriately planned, the benefits of GI could become additive and even synergistic, meaning it could outreach the sum of the individual benefits. However, currently there appears to be an assumption that GI will enable multi-functionality without the need to make choices and, as such, it has the potential to 'provide it all' This may be the case in most instances, but there must be room in evaluations and monitoring to consider trade-offs between functions and possible side effects (Pataki *et al.,* 2011).

As research continues to develop, we will gain more insight into the links and connections that are so inherent to the concept of GI and, with this, be able to develop meaningful ways to evaluate this complex but highly valuable policy initiative. With the necessity for stakeholder consultation, future research could involve a strong element of citizen science, which would serve the dual goals of stakeholder participation whilst conducting localised research cost-effectively (Mabelis & Maksymiuk, 2009).

Much of the attraction of GI lies in its multifunctionality, interdependency and, to a certain extent, flexibility of definition. Although we must strive to inform and monitor GI with the best possible scientific methodology it must not stifle GI with an absolute need for hard scientific figures. Quantitative research and high levels of certainty are desirable, but not always possible with a concept, such as GI. As such its implementation should encourage new and innovative ways to comprehensively evaluate this exciting policy initiative, which can also amalgamate the views of multiple stakeholders.

Box 10: Knowledge gaps to be addressed in GI

- Information gaps and challenges linked to the measurement of ESS provision, e.g. links between biodiversity, ESS and benefits.
- Information gaps and challenges linked to valuation, e.g. limited amount of valuation studies at regional or national level and across a range of services.
- Lack of knowledge about the processes that map GI onto the functions it sets out to perform. There is plenty of research on the value of ESSs and on measuring biodiversity with species richness, for example, but there is little firm knowledge on the chain of processes that GI takes to have its impacts on biodiversity, ESSs and socio-economic variables.
- Lack of knowledge about how different functions interact and if there are any trade-offs or additionality effects when GI performs several functions.
- Lack of knowledge about thresholds in terms of biodiversity and ESSs, i.e. the presence of tipping points when biodiversity starts to increase/decrease or when ecosystems start to provide services.
- Lack of knowledge of benefits provided by GI in terms of permeability and how easily species can move through habitat. Patterns of benefit of increased habitat permeability cannot be extrapolated to predict species' behavioural responses (Moffat *et al.,* 2010).
- Similarly general patterns of response to climate change cannot be extrapolated between species. This is made even more problematic by the uncertainty that remains in climate models' predictions. (Moffat *et al.,* 2010).
- Knowledge gaps with regard to possible opportunity costs and quantifiable ecological and socio-economic benefits (Naumann *et al.,* 2011b).

References

Angelstam, P., Mikusinski, G., Rönnbäck, B-I. *et al.* (2003) Two-dimensional Gap Analysis: A tool for efficient conservation planning and biodiversity policy implementation. *Ambio* 32(8):527-534.

Bass, B. Krayenhoff, E.S., Martilli, A. *et al.* (2003) The impact of green roofs on Toronto's urban heat island. *Proceedings of the First North American Green Roof Conference: Greening Rooftops for Sustainable Communities; 20–30 May, Chicago. Toronto (Canada), Cardinal Group.* Pages 292-304

Bateman, I.J., Mace, G.M., Fezzi, C. *et al.* (2010) Economic Analysis for Ecosystem Service Assessments. *Environment Resource Economics*. 48(2):177-218.

Baumann, N. (2006) Ground-nesting birds on green roofs in Switzerland: Preliminary observations. *Urban Habitats* 4:37-50

Brenneisen, S. (2006) Space for urban wildlife: Designing green roofs as habitats in Switzerland. *Urban Habitats* 4:27-36

Benedict, M.A. & McMahon, E.T. (2002) Green Infrastructure: Smart Conservation for the 21st Century. *Renewable Resources Journal*. 20(3) : 12-17.

Bennett, G. and K.J. Mulongoy (2006) *Review of experience with ecological networks, corridors and buffer zones. Technical Series no. 23.* Montreal: Secretariat of the CBD (SCBD).

Bio intelligence service (2011) *Estimating the economic value of the benefits provided by tourism/recreation and employment supported by Natura 2000*, Final Report. Brussels: DG Environment, European Commission.

Bird, W., (2004) *Natural fit. Can green space and biodiversity increase levels of physical activity?* Sandy: Royal Society for the Protection of Birds.

Boitani, L., Falcucci, A., Maiorano, L. & Rondinini, C. (2007) Ecological Networks as Conceptual Frameworks or Operational Tools in Conservation. *Conservation Biology.* 21(6) 1414-1422.

Booth, M.L., Owen, N., Bauman, A.E., Clavisi, O., Leslie, E., 2000. Social-cognitive and perceived environment influences associated with physical activity in older Australians. *Preventative Medicine.* 3: 15-22.

Bowler, D.E., Buyung-Ali, L., Knight, T.M. & Pullin, A.S. (2010) Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning.* 97:147-155.

Braat and ten Brink (eds) (2008) *The Cost of Policy Inaction - The case of not meeting the 2010 biodiversity target*. Brussels: European Commission.

Brack, C.L. (2002) Pollution mitigation and carbon sequestration by an urban forest. *Environmental Pollution*, 116:195-200.

Bruinderink, G.G., van der Sluis, T., Lammerstsma, D., Opdam, P. & Pouwels, R. (2003) Designing a coherent ecological network for large mammals in northwestern Europe. *Conservation Biology* 17:549-557.

Butler, C.D. & Oluoch-Kosura, W., 2006. Linking future ecosystem services and future human well-being. *Ecology and Society.* 11(1):30.

CABE (2004) *The value of public space.* London: Commission for Architecture and the Built Environment.

Cardinale, B.J., Matulick, K.L., Hooper, D.U. et al. (2011) The Functional Role of Producer Diversity In Ecosystems. *American Journal of Botany* 98(3): 572-592.

Cariňanos, P. & Casares-Porcel, M., (2011). Urban green zones and related pollen allergy: A review. Some guidelines for designing urban spaces with low allergy impact. *Landscape and Urban Planning.*101(3): 205-214.

Carpenter, S.R., Mooney, H.A., Capistrano, A.J. et al. (2009) Science for managing ecosystem services: beyond the Millenium Ecosystem Assessment. *Proceedings of national Academy of Science USA* 106:1305-1312.

Carter, T. & Fowler, L. (2008) Establishing Green Roof Infrastructure Through Environmental Policy Instruments. *Environmental Management* 42:151-164.

Carter, T. & Jackson, C.R. (2007) Vegetated roofs for stormwater management at multiple spatial scales. *Landscape and Urban Planning* 80:84-94.

CESR (2004) *Much more than trees 2: measuring the social and economic impact of The National Forest.* Stafford: Staffordshire University Centre for Economic and Social Regeneration (CESR).

Chapman, P.M. (2012) Adaptive monitoring based on ecosystem services. *Science of the Total Environment* 415:56-60.

Chan, K.M.A., Shaw, M.R., Cameron, D.R. et al. (2006) Conservation planning for ecosystem services. *PLoS Biology* 4(11): e379.

Clark, C. (2005) Optimization of Green Roofs for Air Pollution Mitigation *Proceedings of 1st North American Green Roof Conference: Greening Rooftops for Sustainable Communities.* Washington DC May 4-6 2005. Toronto: The Cardinal Group.

Clerici, N., Weissteiner C. J., Paracchini M.L., Strobl, P., (2011). *Riparian zones: Where green and blue networks meet - Pan-European zonation modelling based on remote sensing and GIS.* JRC Scientific and Technical Report, JRC EUR 24774 EN 2011. ISBN 978-92-79-19799-4. Luxembourg: Office for Official Publication of the European Communities.

Coffman, R.R. & Davis, G. (2005) Insect and avian fauna presence on the Ford assembly plant ecoroof. *Paper presented at the Third Annual Greening Rooftops for Sustainable Communities Conference, Awards and Trade show;* 4-6 May 2005. Washington DC. Toronto: Green Roofs for Healthy Cities.

Cotanza et al. (2008) The Value of Coastal Wetlands for Hurricane Protection. *Ambio* 37(4): 241-8.

Damschen, E.I., Haddad, N.M., Orrock, J.L. *et al.* (2006) Corridors increase plant species richness at large scales. *Science* 313:1284-1286.

Dahdouh-Guebas, F., Jayatissa, L.P., Di Nitto, D. *et al.* (2005) How effective were mangroves as a defence against the recent tsunami? *Current Biology* 15(12): R443-R447.

Danielsen, F., Sørensen, M.K., Olwig, M.F. *et al.* (2005) The Asian tsunami: a protective role for coastal vegetation. *Science* 310(5748): 643.

Davies, Z.G., Wilson, R.J., Coles, S. & Thomas, C.D. (2006). Changing habitat associations of a thermally constrained species, the silver-spotted skipper butterfly, in response to climate warming. *Journal of Animal Ecology* 75(1): 247-256.

de Vriers, S., Verheij, R.A., Groenewegen, P.P. & Spreeuwenberg, P. (2003) Natural environments - healthy environments? *Environmental Planning* 35, 1717-1731.

Defra (2010) *Defra's climate change plan*. London: Department for Environment, Food and Rural Affairs.

Diaz, S., Tilman, D. & Fargione, J. (2005) Biodiversity regulation of ecosystem services. In R Hassan, Scholes, R, & Ash, N. (eds) *Ecosystems and Human well-being: current state and trends: findings in the Condition and Trends Working Group*. Washington: Island Press. pp. 297–329.

Dickie, A. & Thomson, C. (2010) *Initial Assessment of the Costs and Benefits of the National Forest.* London: Defra and The National Forest Company.

Dixon, J.D., Oli, M.K. Wooten, M.C. *et al.* (2006) Effectiveness of a regional corridor in connecting two Florida black bear populations. *Conservation Biology* 20:155-162.

Doswald, N. & Osti, M. (2011) *Ecosystem-based Adaptation and Mitigation: good practice examples and lessons learnt in Europe*. Bonn: Bundesamt für Naturschutz.

Dunn, A.D. (2010) *Siting Green Infrastructure: Legal and Policy Solutions to Alleviate Urban Poverty and Promote Healthy Communities.* Pace Law Faculty Publications Paper 559

Dunn, A.D. (2007) *Green Light for Green Infrastructure.* Pace Law Faculty Publications Paper 494

Dunning, J.B., Jr., R. Borgella Jr., K. Clements, and G.K. Meffe (1995) Patch isolation, corridor effects, and colonization by a resident sparrow in a managed pine woodland. *Conservation Biology* 9:542-550.

Dvorak, B. & Volder, A. (2010) Green roof vegetation for North American ecoregions: A literature review. *Landscape and Urban Planning* 96:197-213.

European Commission (2003) Communication from the Commission to the Council, The European Parliament and the European Economic and Social Committee: A European Environment and Health Strategy COM (2003) 338 final Brussels, 11.6.2003.

Ecologic Institute. (2011) *Background paper: Green Infrastructure – Expert Workshop.* Berlin: Ecologic Institute.

Ecologic Institute. (2011) *Green infrastructure – Expert workshop (07.09.2011) Summary of working groups.* Berlin: Ecologic Institute.

EEA (2011a) *Green Infrastructure and territorial cohesion. The concept of green infrastructure and its integration into policies using monitoring systems.* EEA Technical Report No 18/2011. Luxembourg: Publications Office of the European Union, 2011

EEA (2011b) *An experimental framework for ecosystem capital accounting in Europe.* EEA technical report No 13/2011 Luxembourg: Publications Office of the European Union, 2011

EEA (2011c) *Landscape Fragmentation in Europe: a joint EEA-FOEN report.* EEA Report No 2/2011. Luxembourg: Publications Office of the European Union, 2011

EFDAC pattern map viewer (2011). Forest pattern map viewer for forest pattern map products and indicator query, accessible at http://efdac.jrc.ec.europa.eu/pattern/map/

Ervin, J., K. J. Mulongoy, K. Lawrence, E. *et al.* (2010) *Making Protected Areas Relevant: A guide to integrating protected areas into wider landscapes, seascapes and sectoral plans and strategies.* CBD Technical Series No. 44. Montreal, Canada: Convention on Biological Diversity, 94pp.

Estreguil C. and Caudullo G. (2011a). *Fragmentation of natural lands in Europe. An insight into pattern.* JRC Pubsy registration 64570. Luxembourg: Publications Office of the European Union

Estreguil C. and Caudullo G. (2011b). Indicator 4.7. Landscape forest spatial pattern. In Criterion 4: Maintenance, Conservation and Appropriate Enhancement of Biological Diversity in Forest Ecosystems. In: FOREST EUROPE, UNECE and FAO (2011): State of Europe's Forests 2011. Status and Trends in Sustainable Forest Management in Europe. Ministerial Conference on the Protection of Forests in Europe. Oslo: Forest Europe.

EU Working Group on Green Infrastructure (2011) *Task 1: Scope and objectives of Green Infrastructure in the EU. Recommendations.* Brussels: European Commission.

EU Working Group on Green Infrastructure (2011) *Task 2: How to put Green Infrastructure in place on the ground. Recommendations.* Brussels: European Commission.

EU Working Group on Green Infrastructure (2011) *Scoping Document.* Brussels: European Commission.

Faber-Taylor, A., Kuo, F.E. & Sullivan, W.C. (2001) Coping with ADD. The surprising connection to green play settings. *Environment and Behavior* 33: 54-77.

Felson, A.J. & Pickett, S.T.A. (2005) Designed experiments: new approaches to studying urban ecosystems. Frontiers in *Ecological Environment* 3(10): 549-556.

Fernandez, M, Moreno, V, Picazo, I., Torres, A. & Martinez, B. (2008) *Valoracion de los costes indirectos de gestion de la Red Natura 2000 en Espana.* Madrid: Dirrecion General de Medio Natural y Politica Forestal, Ministerio de Medio Ambiente y Medio Rural y Marino. Unpublished.

Finnish Centre of Excellence in Metapopulation Biology (2011) *Leaflet on Zonation Conservation Planning Software.* Helsinki: University of Helsinki. Downloadable from http://www.helsinki.fi/bioscience/consplan/software/Zonation/Introduction.html

Fisher *et al.* (2009) Defining and classifying ecosystem services for decision making. *Ecological Economics* 68:643-653.

Fluri, P., & Fricke, R. (2005) L'apiculture en Suisse: etat et perspectives. *Revue Suisse d'agriculture* 37(2):81-86.

Forest Research (2010) *Benefits of green infrastructure*. Farnham: Forest Research.

Foster, J., Lowe, A. & Winkelman, S. (2011) *The Value of Green Infrastructure for Urban Climate Adaptation.* Washington DC: Center for Clean Air Policy.

Frankham, R., Ballou, J.D., Eldridge, M.D.B. *et al.* (2011) Predicting the Probability of Outbreeding Depression *Conservation Biology* 25(3):465–475.

Frumkin, H. (2002) Urban sprawl and public health. *Public Health Reports* 117(3): 201-217.

Funk, A., Reckendorfer, W., Kucera-Hirzinger, V., Raab, R. and Schiemer, F. (2009). Aquatic diversity in a former floodplain: remediation in an urban context. *Ecological Engineering* 35(10): 1476-1484.

Ganesan, A. (2008) The impact of natural products upon modern drug discovery. *Current Opinion in Chemical Biology* 12(3): 306-317.

GHK Consulting, Christie M, ADAS, IEEP, Minter R and the Research Box (2011) *Benefits of Sites of Special Scientific Interest.* London: Defra.

Gilbert-Norton, L., Wilson, R., Stevens, J.R. & Beard, K.H. (2009) A Meta-Analytic Review of Corridor Effectiveness. *Conservation Biology* 24(3):660-668.

Gill, S.E., Handley, J.F., Ennos, A.R. and Pauleit, S. (2007) Adapting cities for climate change: the role of green infrastructure. *Built Environment* 33(1):115-133.

Grimm, N.B., Morgan Grove, J., Pickett, S.T.A. & Redman, C.J. (2000) Integrated Approaches to Long-term Studies of Urban Ecological Systems. *Bioscience* 50(7): 571-584.

Haddad, N.M., Bowne, D.R., Cunningham, A. et al. (2003) Corridor use by diverse taxa. *Ecology* 84:609-615.

Harrison, P.A., Vandewalle, M., Sykes, M.T. et al. (2010) Identifying and prioritising services in European terrestrial and freshwater ecosystems. *Biodiversity Conservation* 19(10): 2791-2821.

Hanski, I. (1999) *Metapopulation ecology*. Oxford: Oxford University Press.

Hartig, T., Evans, G.W., Jamner, L.D., Davis, D.S. & Gärling, T. (2003) Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology* 23:109-123.

Heidt, V. & Neif, M. (2008) Benefits of urban greenspace for improving urban climate. In: M.E. Carreiro, Y.C. Song and J. Wu (eds) *Economy, planning and management of urban forests: international perspectives.* New York: Springer. pp 336-345.

Henwood, K. (2002) *Issues in health development: Environment and health: Is there a role for environmental and countryside agencies in promoting benefits to health?* London: Health Development Agency.

Hepcan, S., Hepcan, C.C., Bouwma, I.M. et al. (2009) Ecological networks as a new approach for nature conservation in Turkey: A case study of the Izmir Province. *Landscape and Urban Planning* 90:143-154.

Hladnik, D. & Pirnat, J. (2011) Urban forestry - Linking naturalness and amenity: The case of Ljubljana, Slovenia. *Urban Forestry and Urban Greening* 10(2):105-112.

Hoctor, T.S., Allen, W.L., Carr, M.H. et al. (2007) Land Corridors in the Southeast: Connectivity to Protect Biodiversity and Ecosystem Services. *Journal of Conservation Planning* 4: 90-122.

Horwood, K. (2011) Green infrastructure: reconciling urban green space and regional economic development: lessons learnt from experience in England's north-west region. *Local Environment* 16(10):963-975.

Hostetler, M., Allen, W. & Meurk, C. (2011) Conserving urban biodiversity? Creating green infrastructure is only the first step. *Landscape and Urban Planning* 100:369-371.

Humpel, N., Owen, N. & Leslie, E. (2002) Environmental factors associated with adults' participation in physical activityEnvironmental factors associated with adults' participation in physical activity. *American Journal of Preventative Medicine* 22(3):188-199.

Humpel, N., Owen, N., Leslie, E. et al. (2004) Associations of location and perceived environmental attributes with walking in neighbourhoods. *American Journal of Health Promotion* 18: 239-242.

Hutchings (2002) *The opportunities for woodland on contaminated land. Information Note 44.* Edinburgh: Forestry Commission.

IEEP and Alterra (2010). *Reflecting environmental land use needs into EU policy: preserving and enhancing the environmental benefits of "land services": soil sealing, biodiversity corridors, intensification / marginalisation of land use and permanent grassland. Final report to the European Commission, DG Environment on Contract ENV.B.1/ETU/2008/0030.* Brussels: European Commission.

Jaeger, J.A.G., Bertiller, R., Schwick, C. *et al.* (2008) Implementing Landscape Fragmentation as an Indicator in the Swiss Monitoring System of Sustainable Development (MONET) *Journal of Environmental Management* 88:737-751.

Jaeger, J.A.G., Madrinan, L.F., Soukup, T. et al. (2011) *Landscape fragmentation in Europe. Joint European Environment Agency - Federal Office for the Environment report. EEA Report No 2/2011* Luxembourg: Publications Office of the European Union, 2011.

James, P., Tzoulas, K., Adams, M.D. et al. (2009) Towards an integrated understanding of green space in the European built environment. *Urban Forestry & Urban Greening* 8:65-75.

Jongman, R.H.G., Bouwma, I.R., Griffioen, A. *et al.* (2011) The Pan European Ecological Network: PEEN. *Landscape Ecology* 26:311–326.

Karieva, P., Watts, S., McDonald, R. & Boucher, T. (2007) Domesticated nature: shaping landscapes and ecosystems for human welfare. *Science* 316:1866-1869.

Kazemi, F. Beecham, S. & Gibbs, J. (2011) Streetscape biodiversity and the role of bioretention swales in an Australian urban environment. *Landscape and Urban Planning* 101:139-148.

Kellert, R. & Wilson, E.O. (1993) *The biophilia hypothesis.* Washington D.C: Island Press.

Kim, J. & Kaplan, R. (2004) Physical and psychological factors in sense of community. *Environment and Behavior* 36(3): 313-340.

Kingston, D.G. (2011) Modern natural products, drug discovery and its relevance to biodiversity conservation. *Journal of Natural Products* 74(3): 496-511.

Korpela, K. & Hartig, T (1996) Restorative qualities of favourite places. *Journal of Environmental Psychology* 16: 221-233.

Korpela, K., Hartig, T., Kaiser, F. & Fuhrer, U. (2001) Restorative experience and self-regulation in favourite places. *Environment and Behavior* 33: 572-589.

Kuo, F.E. (2001) Coping with poverty: Impacts of environment and attention in the inner city. *Environment and Behavior* 33: 5-34.

Kuo, F.E. & Sullivan, W.C. (2001) Agression and violence in the inner city. Effects of environment via mental fatigue. *Environment and Behavior* 33: 543-571.

Institute for European Environmental Policy (2012) *Green infrastructure implementation and efficiency*. London: Institute for European Environmental Policy.

Layke, C. (2009) *Measuring Nature's Benefits: A status report and action agenda for improving ecosystem services indicators. Mainstreaming Ecosystem Services – Policy Series No.2. External Review Draft.* Washington DC: World Resources Institute (WRI).

Lee, I.-M., Rexrode, K.M., Cook, N.R. et al. (20010 Physical activity and coronary heart disease in women. *Journal of the American Medical Association* 285(11): 1447-1454.

Lees, A.C. & Peres, C.A. (2008) Conservation Value of Remnant Riparian Forest Corridors of Varying Quality for Amazonian Birds and Mammals *Conservation Biology* 22(2): 439-449.

Liu, K. & Baskaran, B. (2003) Thermal Performance of Green Roofs through Field Evaluation. *Proceedings of 1st North American Green Roof Conference: Greening Rooftops for Sustainable Communities,* Chicago. 29-30 May (2003) Toronto: The Cardinal Group.

LIFE (2010) *LIFE building up Europe's green infrastructure. Addressing connectivity and enhancing ecosystem functions.* Luxembourg: Publications Office of the European Union.

Loreau, M., Naeem, S., Inchausti, P. et al. (2001) Ecology – Biodiversity and Ecosystem functioning: current knowledge and future challenges. *Science* 294:804-808.

Lucius, I. Dan, R. & Caratas, D. (2011) *Green Infrastructure: Sustainable Investments for the Benefit of Both People and Nature.* SURF-nature project publication.

Lundholm, J., MacIvor, J.S, MacDougall, Z. & Ranalli, M. (2010) Plant Species and Functional Group Combinations Affect Green Roof Ecosystem Functions. *PLoS ONE* 5(3): e9677.

Lyytimäki, J., Petersen, L.K., Normander, B.& Bezáák, P. (2008) Nature as nuisance? Ecosystem services and disservices to urban lifestyle. *Environmental Sciences* 5(3): 161-172.

MA (2005) *Ecosystems and human well-being: synthesis. Milllenium Ecosystem Assessment*. Washington, DC: Island Press.

Mabelis, A.A. & Maksymiuk, G. (2009) Public Participation in green urban policy: two strategies compared. *International Journal of Biodiversity Science & Management.* 5(2):63-75.

Mabry, K. E. & G. W. Barrett (2002) Effects of corridors on home range sizes and interpatch movements of three small mammal species. *Landscape Ecology* 17:629-636.

MacArthur, R.H. & Wilson, E.O. (1967) *The theory of island biogeography.* Princeton, New Jersey: Princeton University Press.

Maestre, F.T., Quero, J.L., Gotelli, N.J. *et al.* (2012) Plant Species Richness and Ecosystem Multifunctionality in Global Drylands. *Science* 335 (6065): 214-218 .

Mazza L., Bennett G., De Nocker L. et al. (2011) *Green Infrastructure Implementation and Efficiency.* Final report for the European Commission, DG Environment on Contract ENV.B.2/SER/2010/0059. London: Institute for European Environmental Policy.

McDonald, L.A., Allen, W.L., Benedict, M.A. & O'Conner, K. (2005) Green Infrastructure Plan Evaluation Frameworks. *Journal of Conservation Planning* 1:6-25.

Milder, J.C. (2007) A framework for understanding conservation development and its ecological implications. *Bioscience* 57(9):757-768.

Mills, J., Courtney, P., Gaskell, P., Reed, M. & Ingram, J. (2010) *Estimating the incidental socio-economic benefits of environmental stewardship schemes. Final Report.* Gloucester: Countryside and Community Research Institute.

Minor, E.S. & Urban, D.L. (2008) A Graph-Theory Framework for Evaluating Landscape Connectivity and Conservation Planning. *Conservation Biology* 22(2):297-307.

Moffat A.J., Pediaditi, K. & Doick, K.J. (2010). Monitoring and evaluation practice for brownfield regeneration to greenspace initiatives. A meta-evaluation of assessment and monitoring tools. *Landscape and Urban Planning* 97: 22-36.

Morris, J. & Camino, M. (2010) *Economic Assessment of Freshwater, Wetland and Floodplain Ecosystem Services, Report to the Economics Team of the UK National Ecosystem Assessment, Cranfield University.* Cambridge: UK National Ecosystem Assessment.

Naumann, S., McKenna D., Kaphengst, T. *et al.* (2011a). *Design, implementation and cost elements of Green Infrastructure projects. Final report.* Brussels: European Commission.

Naumann, S., Anzaldua, G., Berry, P. *et al.* (2011b): Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe. Final report to the European Commission, DG Environment, Contract no. 070307/2010/580412/SER/B2. Brussels; European Commission.

Nelson, E., Mendoza, G., Regetz, J. *et al.* (2009) Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment* 7(1):4-11.

Nielsen, T.S. &Hansen, K.B. (2007) Do green areas affect health? Results from a Danish survey on the use of green areas and health indicators. *Health and Place* (13): 839-850.

Nowak, D.J. (1994) *Air pollution removal by Chicago's urban forest, Chicago's Urban Forest Ecosystem. Results of the Chicago Urban Forest Climate Project.* Radnor, PA: U.S. Department of Agriculture.

Oberndorfer, E., Lundholm, J., Bass, B. et al. (2007) Green roofs as Urban Ecosystems: Ecological Structures, Functions ad Services. *Bioscience* 57(10): 823-833.

Opdam, P. Steingröver, E. & van Rooij, S. (2006) Ecological networks: a spatial concept for multi-actor planning of sustainable landscapes. *Landscape and Urban Planning* 75:322-332.

Orsega-Smith, E., Mowen, A.J., Payne & L.L., Godbey, G. (2004) The interaction of stress and park use on psycho-physiological health in older adults. *Journal of Leisure Research* 36 (2), 232-256.

Pataki, D.E., Carreiro, M.M., Cherrier, J. *et al.* (2011) Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions. *Frontiers in Ecology and Environment* 9(1):27-36.

Payne, L.L., Orsega-Smith, E., Godbey, G. & Roy, M. (1998) Local parks and the health of older adults: results from an exploratory study. *Parks and Recreation* 33(10): 64-71.

Pearce, F. (2012) Corridors of Uncertainty. *Opinion. New Scientist.* 2850

Pérez, G., Rincón, L., Vila, A., González, J.M. & Cabeza, L.F. (2011) Behaviour of green facades in Mediterranean continental climate. *Energy Conversion and Management* 52(4): 1861-1867.

Pikora, T., Giles-Corti, B., Bull, F., Jamrozik, K. & Donovan, R. (2003) Developing a framework for assessment of the environmental determinants of walking and cycling. *Social Science and Medicine* 56: 1693-1703.

Pino, J. & Marull, J. (2012) Ecological networks: Are they enough for connectivity conservation? A case study in the Barcelona Metropolitan Region (NE Spain) *Land Use Policy.* 29:684-690.

Primavera, J.H. (2005) Mangroves, fishponds and the quest for sustainability. *Science* 310 (5745): 57-59.

Pyke, C., Warren, M.P., Johnson, T. et al. (2011) Assessment of low impact development for managing stormwater with changing precipitation due to climate change. *Landscape and Urban Planning* 103:166-173.

Qureshi, S., Kazmi, S.J.H. & Breuste, J.H. (2010). Ecological disturbances due to high cutback in the green infrastructure of Karachi: Analyses of public perception about associated health problems. *Urban Forestry and Urban Greening* 9(3):187-198.

Rayment, M., Pirgmaier, E, De Ceuster, G, et al. (2009). *The economic benefits of environmental policy. A project under the framework contract for economic analysis* ENV.G.1/FRA/2006/0073 – 2nd. Amsterdam: Institute for Environmental Studies.

Rey Benayas, J.M., Newton, A.C., Diaz, A. & Bullock, J.M. (2009) Enhancement of Biodiversity and Ecosystem Services by Ecological Restoration: A Meta-Analysis. *Science* 325(5944): 1121-1124.

Ruijgrok, E.C.M. (2006) *Kentallen Waadering Natuur, Water, Bodem En Lanschap. Hulpmiddel Bij Mkba's*. Rotterdam: Witteven en Bos.

Saura, S., Estreguil, C., Mouton, C. & Rodriguez-Freire, M. (2011) Network analysis to assess landscape connectivity trends: Application to European forests (1990-2000) *Ecological Indicators* 11:407-416.

Schrader, S. and Boning, M. (2006). Soil Formation on green roofs and its contribution to urban biodiversity with emphasis on Collembolans. *Pedobiologia* 50(4), 347-356.

Sesso, H.D., Paffenbarger, R.S., Ha, T. & Lee, I.-M. (1999) Physical activity and cardiovascular disease risk in middle-aged and older women. *American Journal of Epidemiology* 150(4): 408-416.

Smith, M.A. & Green, D.M. (2005) Dispersal and the metapopulation paradigm in amphibian ecology and conservation: are all amphibian populations metapopulations? *Ecography 28*:110-128.

Susca, T., Gaffin, S.R. & Dell'Osso, G.R. (2011) Positive effects of vegetation: Urban heat island and green roofs. *Environmental Pollution* 159(8-9): 2119-2126.

Sutherland, G.D., Harestad, A.S., Price, K. & Lertzman, K.P. (2000) Scaling of natal dispersal distances in terrestrial birds and mammals. *Conservation Ecology* 4(1): 16.

Sustainable Development Commission (2010) *Sustainable development: the key to tackling health inequalities.* London: Sustainable Development Commission.

Tackenberg, O., Poschlod, P. & Bonn, S. (2003) Assessment of wind dispersal potential in plant species. *Ecology Monograms.* 73:191-205.

Takano, T., Nakamura, K. & Watanabe, M. (2002) Urban residential environments and senior citizen longevity in megacity areas: the importance of green spaces. *Journal of Epidemiology and Community Health* 56(12): 913-916.

Tanaka, A., Takano, T., Nakamura, K. & Takeuchi, S. (1996) Health levels influenced by urba residential conditions in a megacity - Tokyo. *Urban Studies* 33: 879-894.

TEEB (2010) *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB.* Geneva: United Nations Environment Programme.

TEEB (2010) *The Economics of Ecosystems and Biodiversity for Local and Regional Policy Makers*. Geneva: United Nations Environment Programme.

Ten Brink, B.J.E. & Tekelenburg, T. (2002). *Biodiversity: how much is left? The Natural Capital Index framework (NCI). Bilthoven*: RIVM.

Ten Brink P., Badura T., Bassi S. et al. (2011) *Estimating the Overall Economic Value of the Benefits provided by the Natura 2000 Network*. Final Synthesis Report to the European Commission, DG Environment on Contract ENV.B.2/SER/2008/0038. London: Institute for European Environmental Policy.

Thompson, J.D., Mathevet, R., Delanoë, O. et al. (2011) Ecological solidarity as a conceptual tool for rethinking ecological and social interdependence in conservation policy for protected areas and their surrounding landscape. *Comptes Rendus Biologies* 334:412-419.

Tzoulas, K., Korpela, K., Venn, S. et al. (2007) Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landscape & Urban Planning* 81:167-178.

United Nations (2001). World Urbanization Prospects: The 1999 Revision. New York: United Nations.

Vandermeulen, V., Verspecht, A., Vermeire, B. et al. (2011) The use of economic valuation to create public support for green infrastructure investments in urban areas. *Landscape and Urban Planning* 103:198-206.

Van der Windt, H.J. & Swart, J.A.A. (2008) Ecological corridors, connecting science and politics: the case of the Green River in the Netherlands. *Journal of Applied Ecology* 45:124-132.

Van Renterghem, T. & Botteldooren, D. (2009) Reducing the acoustical façade load from road traffic with green roofs. *Building and Environment.* 44(5): 1081-1087.

Vergnes, A., Le Viol, I. & Clergeau, P. (2011) Green corridors in urban landscapes affect the arthropod communities of domestic gardens. *Biological Conservation* 145(1):171–178.

Vimal, R., Mathevet, R. & Thompson, J.D. (2011) The changing landscape of ecological networks. *Journal for Nature Conservation* 20(1): 49–55.

Vittoz, P. & Engler, R. (2007) Seed dispersal distances: a typology based on dispersal modes and plant traits. *Botanica Helvetica*. 117: 109–124.

Vos, C.C., Baveco, J.W. & van der Veen, M. (2005) *Robuuste Verbindingen (Robust corridors)*. Wageningen: Alterra.

Wannamethee, S.G. & Shaper, A.G. (1999) Physical activity and the prevention of stroke. *Journal of Cardiovascular Risk* (6), 213-216.

Weber, T., Sloan, A. & Wolf, J. (2006) Maryland's Green Infrastructure Assessment: Development of a comprehensive approach to land conservation. *Landscape and Urban Planning* 77 (1-2):94-110.

Weber, T. (2007) *Ecosystem services in Cecil County's Green Infrastructure: Technical Report for the Cecil County Green Infrastructure Plan.* Maryland: The Conservation Fund.

Wei, M., Kampert, J.B., Barlow, C.E. et al. (1999) Relationship between low cardiorespiratory fitness and mortality in normal-weight, overweight and obese men. *Journal of the American Medical Association* 282(16):1547-53.

Whitford, V., Ennos, A.R. & Handley, J.F. (2001) City form and natural processes: indicators for the ecological performance of urban areas and their application to Merseyside, UK. *Landscape Urban Planning* 20(2): 91-103.

WHO (1948) Preamble to the Constitution of the World Health Organisation as adopted by the International Health Conference, New York, 19-22 June 1946; signed on 22 July 1946 by the representatives of 61 states and entered into force on 7 April 1948.

Wright, H. (2010) Understanding green infrastructure: the development of a contested concept in England. *Local Environment* 16(10): 1003-1019.

Wong, N., Chen, Y., Ong, C. & Sia, A. (2003) Life cycle costs analysis of rooftop gardens in Singapore. *Building and Environment* 38:499-509.

Zaghi, D., Calaciura, B., Spinelli, O. *et al.* (2010) Literature study on the impact of biodiversity on human health. Comunità Ambiente Srl, report for the European Commission (Directorate General Environment).

Zandersen, M., & Tol, R.S.J. (2009) A meta-analysis of forest recreation values in Europe. *Journal of Forest Economics* 15(1-2):109-130.

This In-depth Report is published by the European Commission's Directorate-General Environment and edited by the Science Communication Unit, the University of the West of England (UWE), Bristol. Email: sfep.editorial@uwe.ac.uk

All images reproduced with permission from the following sources:

Front cover: ©istockphoto.com/frankreporter

Figure 1: Benefits of Natura 2000. From ten Brink *et al.*, 2011, adapted from Braat and ten Brink *et al.* (2008).

Figure 2: Reprinted from *Landscape and Urban Planning Journal*, 81: 167-178, Tzoulas *et al.,* Conceptual framework linking Green Infrastructure, Ecosystem and Human Health , 2007, with permission from Elsevier.

Figure 3: Contribution of Ecosystems and Biodiversity to Human Wellbeing. From ten Brink P., Badura T., Bassi S. *et al.* (2011) Estimating the Overall Economic Value of the Benefits provided by the Natura 2000 Network.

Figure 4: The Total Economic Value (TEV) framework in the context of Natura 2000. From ten Brink *et al.*, 2011, adapted from Braat and ten Brink *et al.* (2008).

Tables 1-3: Naumann, Sandra, McKenna Davis, Timo Kaphengst, Mav Pieterse and Matt Rayment (2011): *Design, implementation and cost elements of Green Infrastructure projects*. Final report to the European Commission, DG Environment, Contract 070307/2010/577182/ETU/F.1, Ecologic institute and GHK Consulting.

About Science for Environment Policy

Science for Environment Policy is a free news and information service from the European Commission's Directorate-General Environment, which provides the latest environmental policy-relevant research findings.

In-depth Reports are a new feature to the service, which report on the latest relevant science for policy issues in question. The service also publishes a weekly News Alert and regular Thematic Issues, which are delivered by email to subscribers and provide accessible summaries of key scientific studies.

For more information or to subscribe to the News Alert and Thematic Issues, please email: sfep@uwe.ac.uk or visit: http://ec.europa.eu/environment/integration/research/newsalert/index_en.htm