Review Paper - doi: 10.3832/ifor0723-006 ©iForest - Biogeosciences and Forestry

Green Infrastructure as a tool to support spatial planning in European urban regions

Raffaele Lafortezza (1), Clive Davies (2), Giovanni Sanesi (1), Cecil C Konijnendijk (3)

The last decades have seen a major shift in the planning and development of ecosystem and landscape management in Europe. First of all, in line with international developments, the life-support services of ecosystems have come to the fore through the application of the concept of "ecosystem services". Secondly, drawing on the principles of landscape ecology linkages between ecosystems are being stressed through the concept of "ecological networks". Thirdly, there is increasing recognition of the beneficial relationship between access to green space and improved public "health and well-being". These services and relationships are being linked together in both academic literature and policy practice in what is termed the Green Infrastructure (GI) approach. It is argued that GI networks are discernible at different scales, and across urban, peri-urban and rural landscapes. Furthermore, GI is considered as supportive of ecological processes whilst simultaneously contributing to better human health and well-being. Moreover, especially in urban regions, GI is being placed at the same level as other essential urban infrastructure. Recognising these developments the authors have devised an updated conceptual framework for the development, management, and analysis of GI networks by focusing on contemporary drivers nested together at the territorial level and with a prominent role for temporal considerations. The latter has hitherto been only weakly presented in the GI discourse. Development of the conceptual model has been informed by reference to examples drawn from across Europe. Finally, directions are provided for future research, and for developing and delivering GI in the emerging context of ecosystem services and human well-being.

Keywords: Green Infrastructure (GI), Ecosystem Services, Territorial Cohesion, Urban Forestry, Human Well-being, European Urban Regions, Urban interface

Objectives

Worldwide, the ways of considering ecosystems and their importance to human societies has undergone dramatic changes during recent decades. It has become increasingly clear that the goods and services provided to urban dwellers by various types of ecosystems are essential (Bowler et al. 2010). The recognition of this linkage between ecosystem services and human well-being leads to a strong case for them to be planned together. The Green Infrastructure (GI) approach appears to offer a way of combining and analysing this linkage. The authors' aim for this paper is to describe a new framework for analysing, developing and delivering GI. This is achieved through addressing the following objectives: (1) discussing the concept of GI in both ecological and social terms; (2) describing a new conceptual framework of GI that could be applied at multiple spatial and temporal scales; (3) providing directions for future research, and for developing and delivering GI in the emerging context of ecosystem services and human well-being.

(1) Dipartimento di Scienze Agro-Ambientali e Territoriali, Università di Bari, v. Amendola 165/A, I-70126 Bari (Italy); (2) Department of Architecture, Planning & Landscape, Claremont Tower, Newcastle University, NE1 7RU Newcastle upon Tyne (UK); (3) Danish Centre for Forest, Landscape and Planning, Faculty of Life Sciences, University of Copenhagen (Denmark)

@ Raffaele Lafortezza (raffaele.lafortezza@uniba.it)

Received: Aug 02, 2012 - Accepted: Dec 04, 2012

Citation: Lafortezza R, Davies C, Sanesi G, Konijnendijk CC, 2013. Green Infrastructure as a tool to support spatial planning in European urban regions. iForest 6: 102-108 [online 2013-03-05] URL: http://www.sisef.it/iforest/contents/?id=ifor0723-006

Communicated by: Renzo Motta

Introducing and defining Green Infrastructure

Benedict & McMahon (2002) define Green Infrastructure (GI) as an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations. Benedict and McMahon also contend that GI is the ecological framework needed for environmental, social and economic sustainability and that it differs from conventional approaches to open space planning because it looks at conservation values and actions in concert with land development, growth management and built infrastructure planning.

Weber et al. (2006) describes Green Infrastructure as the abundance and distribution of natural features in the landscape which, in addition to supporting ecological processes, also contribute to human health and well-being (Tzoulas et al. 2007). Ewers et al. (2009) and Lafortezza et al. (2010) both recognise that Green Infrastructure is becoming a preminent approach for delivering essential goods and services to people whilst simultaneously reversing trends such as landscape and habitat fragmentation.

Taking a practitioner-led consultation approach, Davies et al. (2006) identified a typology of multi-functional open spaces, including formal parks, gardens, woodlands, green corridors, waterways, street trees and open countryside, which when taken together comprised an "environmental resource", which contributes towards sustainable resource management. Green Infrastructure is also presented as the integration and interaction of different services and benefits on the same area, notably through the use of the term "multi-functionality" used to describe the many functions delivered through appropriate management of the same piece of land (Davies et al. 2006). This is seen as key to the efficient and sustainable use of land, especially in the compact and rapidly expanding European cities, where pressures on land are particularly acute (EEA 2006, Poelmans & Van Rompaey 2009).

Ortega-Álvarez & MacGregor-Fors (2009) present Green Infrastructure in structural terms as components that work together to maintain a network of sites supporting ecological and social processes. These components range in size and shape depending upon the type of function or service being provided. Generally, two main components are identified: hubs and links. Hubs act as "anchor" for a variety of ecosystem services, providing source and sink habitats for species dispersing through the landscape (Benedict & McMahon 2002). This component may include elements, such as reserves, parks and open spaces, residual lands, forests and farmlands. Links are the connections binding the ecosystems together, facilitating the flow of ecological processes; links may include, green corridors, green belts and stepping stones (Williamson 2003).

The term GI is appearing more and more frequently in land and planning related topics across different regions, and at different levels, from the city to the supranational level (Mell 2010). However, the term means different things to different people, and can be described and assessed in many different ways (Davies et al. 2006). The GI approach first reached Europe via the UK; Mell (2010) contends that in the UK the focus is embedding it into different areas of planning policy.

The National Planning Policy Framework for England 2012 (Department of Communities and Local Government, UK) stipulates that "Local Plans should take account of climate change over the longer term, and that when new development is brought forward in areas which are vulnerable, care should be taken to ensure that risks can be managed through suitable adaptation measures, including through the planning of Green Infrastructure" (Bonan 2008).

At a European scale GI has been defined as a "concept addressing the connectivity of ecosystems, their protection and the provision of ecosystem services, while also addressing mitigation and adaptation to climate change" (EEA 2011). The European Commission EU, DG Environment Biodiversity Unit (EU 2010) see the concept as "central to the overall objective of ecosystem restoration, which is now part of the European Union's 2020 biodiversity target. It also promotes integrated spatial planning by identifying multifunctional zones and by incorporating habitat restoration measures and other connectivity elements into various land-use plans and policies, such as linking peri-urban and urban areas or in marine spatial planning policy".

It is clear that those conceptualising Green Infrastructure including Benedict & McMahon (2002), Weber et al. (2006), Davies et al. (2006) and Tzoulas et al. (2007) all see the link between ecological and social factors as crucial to the Green Infrastructure approach, but this is not necessarily reflected in practice as illustrated by the review of examples examined in this research (Tab. S1 in Appendix 1). In these examples the predominant characteristic is spatially driven landscape management undertaken within the constraints of territorial planning and social and ecological outcomes are bi-products rather than co-products of the approach (Sanesi et al. 2009).

The literature review does however indicate that there is relatively little consideration being given to temporal considerations. This suggests that there is insufficient recognition of the correlation between the delivery of land-use public policy and land management practice and the positive or negative impact of these on performance of Green Infrastructure through time (Walmsley 2006).

Green Infrastructure and Ecosystem Services

Ecosystems, through their normal functioning, provide a range of goods and services important for human well-being, which are collectively called ecosystem services (Nelson et al. 2008, Raudsepp-Hearne et al. 2010, Rounsevell et al. 2010). Ecosystem services, such as cleaning the air, filtering water, cycling nutrients, generating soils, regulating climate, sequestering carbon, etc. are all provided by forest areas, wetlands, and other natural ecosystems (Costanza et al. 1997, Weber et al. 2006). The concept of ecosystem services is regarded as encompassing a paradigm shift from pure ecosystem conservation to a focus on conserving ecosystem functionality (de Groot et al. 2002).

A recent report by Forest Research (2010) provides an overview of the main ecosystem services that can be attributed to GI and their associated components using the classification created by the Millennium Ecosystem Assessment (MEA 2005). From the report, it is clear that GI may influence the capacity of ecosystem to provide services across a range of landscape scales (Feld et al. 2009). For example, GI can mitigate risks from climate change by protecting urban regions against floods and other negative effects of changing weather patterns (Keim et al. 2006, Krause et al. 2011).

One of the challenges to ecosystem functionality and the provision of ecosystem services is the increasing fragmentation of landscapes and ecosystems (Lafortezza et al. 2010). Mounting levels of urbanization and transport infrastructure have created a network of barriers that results in a patchwork of land uses and isolate open space areas. Consequently natural ecosystems have become scattered across the landscape and displaced by new land-use developments (Geneletti 2004, Lafortezza & Brown 2004, Lafortezza et al. 2008). According to the PLUREL project (Piorr et al. 2011) more than a quarter of European landscapes are directly affected by urban land use; over the period 2000-2006, peri-urban (discontinuous) areas grew four times faster than continuous urban areas. The trend towards urban living is set to continue: by 2020 approximately 80 % of Europeans will be living in urban areas (Lyytimäki et al. 2008, Lyytimäki & Sipilä 2009, Piorr et al. 2011).

From a social perspective, landscape fragmentation exacerbates social and economic divisions and the alienation of man from nature (Benedict & McMahon 2002). This calls for approaches and strategies that overcome fragmentation and enhance functionality, including the development of structural and functional linkages among ecosystems through networks of ecological and human-based components (Lindenmayer & Fischer 2007, Pataki et al. 2011). A range of measures exist that can enhance such linkages while reducing the effect of landscape fragmentation. These measures take different names and definitions according to the scale at which land-use planning is undertaken: from local to regional/national/trans-national level (von Haaren & Reich 2006, Weber et al. 2006, Gill et al. 2008, Leibenath et al. 2010).

Improving the functional and spatial connectivity of landscapes is a prerequisite to its ability to mitigate and adapt to climate change and in turn to increase the value of the goods and services that ecosystems provide (Grimm et al. 2008, Griffith et al. 2009, Hodgson et al. 2009, Lafortezza el al. 2008, 2009). In respect of spatial connectivity there is increasing research on the subjects of landscape fragmentation and connectivity (*e.g.*, Geneletti 2004, Hodgson et al. 2009). Landscape fragmentation occurs when areas of continuous natural ecosystems are broken up into smaller elements as a result of new landscape developments and changes (Lafortezza et al. 2010), creating new edges between land cover types (Collinge 1996, Fahrig 2003). Isolated, fragmented populations are more sensitive to climate change (Collingham & Huntley 2000, Sanesi et al. 2007). Recent studies on landscape ecology have clearly brought a new light on the subject of connectivity and suggested several measures for conserving biological and landscape diversity (Kindlmann & Burel 2008, Heller & Zavaleta 2009). At the landscape scale level, GI is one of the possible measures in tackling biodiversity conservation and other ecosystem services, such as recreation and accessibility to natural resources.

At the local and regional scale, strategies to counteract spatial fragmentation take the form of greenways, green belts, and green networks (Li et al. 2005, Ribeiro & Barão 2006, Goddard et al. 2010). These are land-use planning designations designed to protect and enhance areas of unmanaged and managed urban green-space, naturally regenerating brownfield land and undeveloped, forest or agricultural land. Urban Planners see concepts such as greenways, green belts, and green networks as a way to improve accessibility to green and open spaces close to where they live, and to link together rural and urban areas (Walmsley 1995, Espeseth & Cassens 1996, Zhang & Wang 2006).

When land-use planning occurs at the larger scale, new strategies are needed to organize and link together the spatial assemblage of ecosystems that support regionally significant processes and provide services across whole landscapes (Yu et al. 2006, Weber et al. 2006). An emerging approach is to consider the landscape as an overall system of ecosystems in which single components interact with each other through a multitude of ecosystems and landscape elements that contribute to create a Green Infrastructure (Benedict & McMahon 2002, Weber et al. 2006, Wickham et al. 2010).

Human health, well-being and Green Infrastructure

Green Infrastructure (GI) is considered as supportive of ecosystem services whilst simultaneously contributing to many health benefits which encompass physical, psychological and socio-economic outcomes (Diener 1984, Diener et al. 1999, Lafortezza et al. 2009). Health benefits derived from GI exist not just at the local level, but also at the neighborhood, city and regional levels. For example, GI supports human health and well-being of local communities through the presence of more cohesive places to live, work and recreate and connection to nature (Forest Research 2010). Recent studies have proposed GI as a way of engaging people with the rural landscape (Espeseth & Cassens 1996) as the management of GI can provide cultural, ecological, and psychological linkages between people and the environment.

Forest Research (2010) grouped the many potential health and well-being benefits of GI into three main categories: (1): increased life expectancy and reduced health inequality; (2): improvements in levels of physical activity and health; (3): promotion of psychological health and mental well-being. Improvements in physical activity and health and the promotion of psychological health and well-being have been grouped together under the term "Green Exercise" (Petty et al. 2007). The creation and management of GI in connection with territorial planning can be used to enhance landscape connectivity, and hence provide greater access to individuals to undertake green exercise. An example of this is the creation of new cycle-ways through tree-lined corridors which link residential areas to employment sites and retail centres.

Green Infrastructure and territorial planning

Green Infrastructure (GI) differs from other approaches in landscape planning because it considers ecological and social values in combination with other land use developments (Aegisdóttir et al. 2009). Used in connection with territorial planning different types of landscape elements may enhance connectivity (Collinge 1996, Mata et al. 2005) and purposely support the restoration of landscapes to provide optimal habitats and conduits for species (Kindlmann & Burel 2008).

The various policies, plans and related activities incorporated in GI are carried out at spatial scales from the local neighborhood through the regional scale to the trans-national. The buildings blocks of GI such as tree lined streets and neighborhood parks exist at a local scale, but the linkage of these creates synergies and higher level effects that have significance at a scale greater than the local (Konijnendijk et al. 2004, Davies et al. 2006). The implications of this on planning are considerable and suggest that GI plans should be nested at a variety of spatial scales from the local to international level, each having a relationship with the next tier. This key point is picked up by the EEA (2011) which identifies three spatial groups (i): local, neighbourhood and village scale; (ii): town, city and district scale; (iii): city-region, region and national scale.

Plan nesting is common in all forms of Government with strategic approaches lying on top of delivery plans at smaller scales. The authors believe that that the city region, an urban conurbation and its adjacent wildland urban interface, appears to be an especially useful level to consider GI planning. The city-region is large enough to be strategic with identifiable ecological hubs and links yet not too large to be remote from community level activities and local delivery plans that consider green-space as public amenity.

Green Infrastructure framework

The EEA report (EEA 2011) proposes that Green Infrastructure (GI) may act as a: (a) strategically planned and delivered network of high-quality green spaces and other environmental features; (b) delivering multifunctional benefits; (c) helping to deliver placemaking; and (d) delivering "smart" conservation. It also proposes that GI benefits could be presented in terms of ecosystem services as this provides a relatively consistent and effective language that also has growing resonance with policymakers and other stakeholders. However, GI includes the spatially explicit delivery of ecosystem services - this is the difference and added value compared to the more general and implicit description of ecosystem services. As an example this can be seen through catchment management protection of water resources through changed land management practices such as new afforestation upstream of cities. Hence GI can be used to show benefits and deficits on local, regional and national levels, and therefore is closely linked to planning, decision-making and policymaking.

To support the process of developing and delivering GI, we propose a conceptual Green Infrastructure Framework (GIF) embracing a multi-functional, multi-scale and temporal approach (Fig. 1) which advances the EEA guiding principles and focuses afresh on the link between ecological and social factors argued by Benedict & McMahon (2002), Weber et al. (2006), Davies et al. (2006) and Tzoulas et al. (2007).

The proposed GIF consists of five main blocks each one corresponding to a specific function or bundle of functions. Each block is directly or indirectly linked to the others to mark the interrelation between the various functions and benefits related to GI. Following the guidelines from the Millennium Ecosystem Assessment (MEA 2005), the GIF focuses particular attention on the linkages between ecosystem services and human well-being.

Human well-being refers to a set of basic elements for a good life, freedom to act and make choices, good social relations and security (MEA 2005). Recent studies demonstrated how human well-being is dependent upon multiple and often interrelated ecosystem services (Tzoulas et al. 2007, Karjalainen et al. 2010): for example changes in regulating services, such as climate fluctuation, could affect the rate of floods and landslides thus having negative effects on people's sense of security and well-being.

In addition to ecosystem services and well-being, the framework considers as key functions of GI those related to biodiversity, social and territorial cohesion, and sustainable development (James et al. 2009, EEA 2011).

Biodiversity concerns the variability among living organisms and includes diversity within and between species and diversity of ecosystems (MEA 2005). High levels of biodiversity can mitigate disturbances, making ecosystems more resilient and likely to provide services in the long term (Bunker et al. 2005). GI can provide habitats for a wide range of species thus supporting biodiversity at ecosystem and landscape levels (Martínez et al. 2010, EU 2010).

Social and territorial cohesion is a multi-faceted concept covering different phenomena related to people cooperation and territorial integration in cross-border and transnational regions (Friedkin 2004, EEA 2011). In this view, social and territorial cohesion deals with the social processes that affect individuals within territories, such as social participation and community engagement which draw people together to work for the benefit of others (Chiesura 2004). Following this perspective, GI can foster social and territorial cohesion between communities, promote polycentric and balanced territorial development, and encourage integrated development in cities, rural and specific areas.

Sustainable development can be defined as the process of balancing the fulfilment of hu-

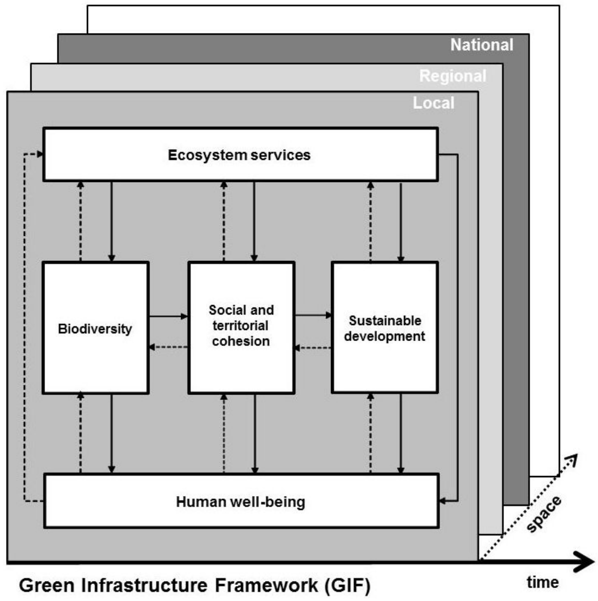

Fig. 1 - The Green Infrastructure Framework (GIF) consists of five main blocks each one corresponding to a specific function or bundle of functions. Each block is directly or indirectly linked to the others to mark the interrelation between the various functions and benefits related to Green Infrastructure

man needs with the protection of the natural environment. Sustainable development refers to the management of renewable resources without compromising the availability of these resources for future generations and the survival of other species and natural ecosystems (Freedman & Knight 2004). GI supports the sustainable provision of ecosystem goods and services while enhancing biodiversity (EC 2010). GI also promotes regional development in countries and regions.

A GI that supports ecosystem services, biodiversity, social and territorial cohesion and sustainable development creates the environmental settings for human well-being and community health (Tzoulas et al. 2007).

Besides multi-functionality, the GIF brings a multi-scale perspective to the subject of GI as envisioned by the EEA (2011). In other words, the framework recognizes the importance of the scale at which land-use planning is undertaken and supports the idea of having the same approach and bundle of functions applied at different spatial and temporal scales (Fig. 1). In this view, the GIF can support long-term plans and decisions on new GI from local to regional, national, and trans-national level.

Through the framework, existing GI and its functionality can be assessed. Moreover, the framework may assist planners and managers in developing GI plans and delivering multiple benefits to communities (Forest Research 2010). At the local scale the GI components are coarsely defined units of individual green-spaces. As the scale increases the resolution becomes progressively finer and a network is revealed.

The time axis indicates that the model develops through time; if the GI components are progressively establishing (*e.g.*, growing connections, increase biomass) the services and benefits can be considered as increasing as established landscapes provide greater ecosystem services than new ones (Chazdon 2008). If the GI components are declining the reverse is true. The time axis is neither a measure nor proxy for improvement or decline; it is indicating whether within any given time frame, the strategies and projects in place are driving improvement or decline in GI networks. The time axis can be large since GI networks establish and decline over long time-frames. Major events (*e.g.*, storms) and driving forces (*e.g.*, forest fire), which may be natural or human influenced, can change the status of the GI rapidly.

Review of examples of GI approaches in Europe

To contextualise the Green Infrastructure Framework (GIF) a review of case studies in Europe was undertaken through a combination of study methods including a document review, web analysis, desk study and review of public sector strategies at the regional, national and international level (see Tab. S1 in Appendix 1). Two starting points were identified for continent wide discussion on Green Infrastructure (GI) in Europe.

The first is Europe's Natura 2000 network which encompasses more than 25 000 sites, spread over 27 member countries, covering almost a fifth of the European territory. Conservation of landscape features that support species movement and dispersal is particularly important as a means of supporting the coherence of the Natura 2000 network (Kettunen et al. 2007). However, many studies and reports argued that such network might not establish its coherence as much of Europe's landscape is highly fragmented and under intensive land use, transport routes and urban sprawl (EEA 2010, Krause et al. 2011). The Natura 2000 network can be interpreted as GI cells that already provide ecosystem services, such as food, air quality, carbon sequestration, flood management, water treatment, local climate conditions, soil erosion prevention, etc. (EEA 2010), but the system benefits at a continental scale could be greater if there was more network connectivity between them.

The European Landscape Convention which is aimed at the protection, management and planning of landscapes as well as raising awareness of a living landscape is another GI consideration. Importantly, the Convention is not only aimed at designated landscapes but also ordinary landscapes both in urban and rural areas (Wikipedia 2011). Since GI includes the landscape scale approach many examples of GI transnational and national programmes in Europe can be found. As the landscape scale becomes more finely delineated towards the city or local level the linkage between different landscape units becomes more pronounced. There appear to be significant benefits to be gained from a GI approach, both in terms of planning landscape enhancements, using green spaces to buffer the most sensitive areas closer to urban settlements (*e.g.*, wild-land urban interface).

Among the examples of GI projects in Europe, the authors considered twelve examples across four levels of spatial (planning) scale: transnational, national, city-region and urban (Tab. S1 in Appendix 1). For each example, the main documents describing the vision and objectives were reviewed. Using the authors Green Infrastructure Framework (GIF), each example was then analysed according to five functions/bundle of functions: (i) ecosystem services; (ii) biodiversity; (iii) social cohesion; (iv) sustainable development; and (v) human well-being. It was then reported whether or not the example gave indications on such functions. By using the GIF as an analytical lens the following observation were made.

Social and territorial cohesion features throughout all the examples. On closer analysis the socially cohesive elements vary according to the scale of the project, for instance the social and territorial cohesion between populations across country boundaries is the principle requirement at the transnational scale and by contrast within and between local communities at the scale of urban programmes. Given the strength of the relationship it is possible with confidence to conclude that the relationship between GI and social and territorial cohesion is already seen as a "strong rationale" and "policy driver" for those developing GI projects at all spatial levels.

The relationship between biodiversity and GI was the second strongest relationship (10 out of 12) and appears to be universally sought for at the City region, national and transnational level, however the relationship at the urban programme level is much weaker. This suggests that social cohesion and biodiversity considerations are stronger for those actively developing projects at the urban programme level and also confirms earlier practitioner led observations (Davies et al. 2006). This observation also supports the position of those arguing with local politicians for a greater level of understanding on the benefits to communities of being "close to nature".

Sustainable development and GI is focused on the city region and urban programme level. This can be explained by the fact that the land-use policy planning system is used in most European countries to direct and moderate on all forms of development (*e.g.*, housing, industry, energy infrastructure). This is generally delegated to city and local authority administrations although sometimes, as in the case of the UK, with national guidance.

Human well-being and GI is strongly focused on the urban programme scale. This can be explained by the fact that most urban health interventions seek to raise the health expectations of those disadvantaged communities who through their lifestyle, educational attainment or housing conditions have considerably lower life expectations and lower age mortality than the urban average. Green improvements are known to lead to an improvement in human health and lower the costs of primary health care and it appears from this analysis that this relationship is understood by those developing urban green infrastructure projects.

The least consistent relationship is that between GI and ecosystem services. There is no apparent trend. It is thought that the few connections found between GI and ecosystem services might reflect the influence of policy makers or practitioners who are already aware of the relationship between ecosystem services and GI and that wider knowledge amongst the professions remains low. Given the clear link now being made between the two (EC 2010, EU 2010, EEA 2011) and the notable link that the GI approach can be a major planning and implementation tool to maintain and enhance ecosystem services to urban populations; there would appear to be a strong case for the European Union to be strongly investing in the training of key urban professionals, applied research projects and pathfinder projects in member states where results will lead to a change in practice. A description of the examples is reported in the supplementary material (Appendix 2).

In summary the investigation revealed that one of the most effective ways to build up GI is through an integrated approach to spatial planning (EU 2010). Policies that adopt a spatial planning approach can improve landscape coherence and connectivity inside and outside protected areas and help establishing multifunctional landscapes. Therefore, GI should not be interpreted in a narrow sense, but as a means to illustrate that habitats, species and landscapes must be part of a functionally coherent network that delivers valuable services and goods (EU 2010).

Discussion and conclusion

Europe is a densely populated continent and much of the land is in active use (EC 2010). Land-use changes are having considerable effects on ecosystem services and human well-being and as a result landscapes and ecosystems in Europe are under pressure. Within Europe and in the context of Green Infrastructure (GI), there is a good deal of policy making and practitioner led activity at all levels; international, national, city region and local. There is evidence that funders and the agencies leading these activities have designed their initiatives to address the ecosystem consequences of environmental pressure. In this respect the GI approach is a notable contribution to the planning of ecological connections at many scales which meld with urban form to offer the prospect of a more sustainable landscape for well-being and biodiversity. This analysis is considered the major reason why the GI approach has been taken up rapidly by planning systems in many countries and by the European Union. Since developing and delivering GI involves the adoption of an integrated territorial planning approach supporting not only ecological coherence between protected and unprotected areas, but also a wide range of functions and benefits to society then key challenges can be identified for the European Union's environmental policy agenda. The principle one is how to integrate ecological networks (Natura 2000 sites) into a broader GI that maintains ecological functions in combination with multi-functional land uses (Bennett & Mulongoy 2006).

In a practical sense the city-region level appears to offer an especially attractive scale for GI planning by being capable of strategic significance and relevant to local communities at the same time. However, GI can be discerned at all levels with the local level possessing the coarsest resolution, where individual component such as "green-spaces" are readily identifiable through to the international "continental" level, where the resolution is at its finest. This implies that only by linking GI plans together hierarchically it is possible to ensure a seamless transition through the different scales of resolution.

The European experience of GI has much to offer to other continents, not least because the approaches taken in Europe have proven highly adaptive to national and regional requirements. Whilst the idea of GI did not originate in Europe, it is perhaps in Europe where the approach has received such a high level of attention, experimentation and research interest. The challenge for researchers is not so much what to include but what to leave out of the discourse.

In researching examples of GI initiatives across Europe and then combining those with the results of a detailed literature review new insights start to appear. This has led to the development of a proposed new Green Infrastructure Framework (GIF). This is offered to policy makers and researchers for use and further exploration. The GIF is seen as a unifying human centred approach to multi-scale (spatial and temporal) planning for "ecosystem" and "well-being" services. The framework model operates at all spatial scales and is "nested" and can be allied to the key opportunities identified by the EEA (2011). The inclusion of a time axis places the planning of GI into the temporal dimension of improvement and/or degradation or indeed both as some elements may be progressing whilst others are contracting at the same time. The GIF is built upon existing GI criteria including ecological hubs, links and multi-functionality in land-use management but adds "drivers" for GI planning; ecosystem services, human well-being, social cohesion, biodiversity and sustainable development. A well rounded GI plan should be expected to deliver on all these drivers at different scales and through time.

The prospect also exists that as the costs and benefits of ecosystem services become ever more accepted within decision making and resource allocation, resources in support of the GI approach will also be strengthened.

Acknowledgements

We are grateful to the two referees for their constructive comments on the manuscript. This study was carried out within the project PRIN 2009 "in_FLAMING: Developing innovative models and techniques for integrated fuel management for fire prevention in Mediterranean and temperate forests" (national coordinator: P. Corona) funded by the Italian Ministry for Education, University and Research.

References

Aegisdóttir HH, Kuss P, Stöcklin J (2009). Isolated populations of a rare alpine plant show high genetic diversity and considerable population differentiation. Annals of Botany 104: 1313-1322. - doi: 10.1093/aob/mcp242

Benedict MA, McMahon ET (2002). Green infrastructure: smart conservation for the 21st century. Renewable Resources Journal 20: 12-17. [online] URL: http://www.greeninfrastructure.net/sites/greeninfrastructure.net/files/GI_RR.pdf

Bennett G, Mulongoy KJ (2006). Review of experience with ecological networks, corridors and buffer zones. Technical Report n. 23, Secretariat of the Convention on Biological Diversity, Montreal, Canada, pp. 100.

Bonan GB (2008). Forests and climate change: forcings, feedbacks, and the climate benefits of forests. Science 320: 1444-1449. - doi: 10.1126/science.1155121

Bowler DE, Buyung-Ali L, Knight TM, Pullin AS (2010). Urban greening to cool towns and cities: a systematic review of the empirical evidence. Landscape and Urban Planning 97: 147-155. - doi: 10.1016/j.landurbplan.2010.05.006

Bunker DE, DeClerck F, Bradford JC, Colwell RK, Perfecto I, Phillips OL, Sankaran M, Naeem S (2005). Species loss and aboveground carbon storage in a tropical forest. Science 310: 1029-1031. - doi: 10.1126/science.1117682

Chazdon RL (2008). Beyond deforestation: restoring forests and ecosystem services on degraded lands. Science 320: 1458-1460. - doi: 10.1126/science.1155365

Chiesura A (2004). The role of urban parks for the sustainable city. Landscape and Urban Planning 68: 129-138. - doi: 10.1016/j.landurbplan.2003.08.003

Collinge SK (1996). Ecological consequences of habitat fragmentation: implications for landscape architecture and planning. Landscape and Urban Planning 36: 59-77. - doi: 10.1016/S0169-2046(96)00341-6

Collingham YC, Huntley B (2000). Impacts of habitat fragmentation and patch size upon migration rates. Ecological Applications 10: 131-144. - doi: 10.1890/1051-0761(2000)010[0131:IOHFAP]2.0.CO;2

Costanza R, d'arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M (1997). The value of the world's ecosystem services and natural capital. The value of the world's ecosystem services and natural capital. Nature 387 (6630): 253-260. - doi: 10.1038/387253a0

Davies C, MacFarlane R, McGloin C, Roe M (2006). Green infrastructure planning guide, pp. 45. [online] URL: http://www.scribd.com/doc/33007993/Green-Infrastructure-Planning-Guide

de Groot RS, Wilson MA, Boumans RMJ (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41: 393-408. - doi: 10.1016/S0921-8009(02)00089-7

Diener E (1984). Subjective well-being. Psychological Bulletin 95 (3): 542-575. - doi: 10.1037/0033-2909.95.3.542

Diener E, Suh EM, Lucas RE, Smith HL (1999). Subjective well-being: three decades of progress. Psychological Bulletin 125 (2): 276-302. - doi: 10.1037/0033-2909.125.2.276

EC (2010). Green infrastructure. Summary report, Nature and Environment, leaflet no. KH-32-10-314-EN-C. [online] URL: http://ec.europa.eu/environment/nature/info/pubs/docs/greeninfrastructure.pdf

EEA (2006). Urban sprawl in Europe - the ignored challenge. Report no. 10, European Environment Agency, Copenhagen, Denmark, pp. 60.

EEA (2010). The European environment - state and outlook 2010: synthesis. Report, European Environment Agency, Copenhagen, Denmark, pp. 228.

EEA (2011). Green Infrastructure and territorial cohesion. The concept of Green Infrastructure and its integration into policies using monitoring systems.Technical Report no. 18/2011, European Environment Agency, Copenhagen, Denmark. [online] URL: http://www.eea.europa.eu/publications/green-infrastructure-and-territorial-cohesion/at_download/file

EU (2010). LIFE building up Europe's green infrastructure: addressing connectivity and enhancing ecosystem functions. Technical Report, European Commission, Environment Directorate-General, Brussels, Belgium, pp. 60.

Espeseth RD, Cassens KM (1996). Greenways. Those long, skinny, green parks. Illinois Parks and Recreation 27: 35-36.

Ewers RM, Kapos V, Coomes DA, Lafortezza R, Didham RL (2009). Mapping community change in modified landscapes. Biological Conservation 142: 2872-2880. - doi: 10.1016/j.biocon.2009.06.022

Fahrig L (2003). Effects of habitat fragmentation on biodiversity. Annual Review of Ecology, Evolution and Systematics 34: 487-515. - doi: 10.1146/annurev.ecolsys.34.011802.132419

Forest Research (2010). Benefits of green infrastructure. Report by Forest Research, Contract no. WC0807, Farnham, UK, pp. 42. [online] URL: http://ec.europa.eu/environment/nature/info/pubs/docs/greeninfrastructure.pdf

Feld CK, Martins da Silva P, Paulo Sousa J, de Bello F, Bugter R, Grandin U, Hering D, Lavorel S, Mountford O, Pardo I, Pàrtel M, Ràmbke J, Sandin L, Bruce Jones K, Harrison P (2009). Indicators of biodiversity and ecosystem services: a synthesis across ecosystems and spatial scales. Oikos 118: 1862-1871. - doi: 10.1111/j.1600-0706.2009.17860.x

Freedman B, Knight J (2004). Sustainable development. Gale Encyclopaedia of Science (3rd edn). Detroit, Michigan, USA.

Friedkin NF (2004). Social cohesion. Annual Review of Sociology 30: 409-425. - doi: 10.1146/annurev.soc.30.012703.110625

Geneletti D (2004). Using spatial indicators and value functions to assess ecosystem fragmentation caused by linear infrastructures. International Journal of Applied Earth Observation and Geoinformation 5: 1-15. - doi: 10.1016/j.jag.2003.08.004

Gill SE, Handley JF, Ennos AR, Pauleit S, Theuray N, Lindley SJ (2008). Characterising the urban environment of UK cities and towns: A template for landscape planning. Landscape and Urban Planning 87: 210-222. - doi: 10.1016/j.landurbplan.2008.06.008

Goddard MA, Dougill AJ, Benton TG (2010). Scaling up from gardens: biodiversity conservation in urban environments. Trends in Ecology and Evolution 25: 90-98. - doi: 10.1016/j.tree.2009.07.016

Griffith B, Scott M, Adamcik R, Ashe D, Czech B, Fischman R, Gonzalez P, Lawler J, McGuire AD, Pidgorna A (2009). Climate change adaptation for the US national wildlife refuge system. Environmental Management 44: 1043-1052. - doi: 10.1007/s00267-009-9323-7

Grimm NB, Foster D, Groffman P, Grove JM, Hopkinson CS, Nadelhoffer KJ, Pataki DE, Peters DP (2008). The changing landscape: ecosystem responses to urbanization and pollution across climatic and societal gradients. Frontiers in Ecology and the Environment 6: 264-272. - doi: 10.1890/070147

Heller NE, Zavaleta ES (2009). Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological Conservation 142: 14-32. - doi: 10.1016/j.biocon.2008.10.006

Hodgson JA, Thomas CD, Wintle BA, Moilanen A (2009). Climate change, connectivity and conservation decision making: back to basics. Journal of Applied Ecology 46: 964-969. - doi: 10.1111/j.1365-2664.2009.01695.x

Karjalainen E, Sarjala T, Raitio H (2010). Promoting human health through forests: Overview and major challenges. Environmental Health and Preventive Medicine 15: 1-8. - doi: 10.1007/s12199-008-0069-2

Keim RF, Skaugset AE, Weiler M (2006). Storage of water on vegetation under simulated rainfall of varying intensity. Advances in Water Resources 29: 974-986. - doi: 10.1016/j.advwatres.2005.07.017

Kettunen MTA, Tucker G, Jones A (2007). Guidance on the maintenance of landscape features of major importance for wild flora and fauna - Guidance on the implementation of Article 3 of the Birds Directive (79/409/EEC) and Article 10 of the Habitats Directive (92/43/EEC). Institute for European Environmental Policy, IEEP, Brussels, Belgium, pp.114.

Kindlmann P, Burel F (2008). Connectivity measures: a review. Landscape Ecology 23: 879-890. - doi: 10.1007/s10980-008-9245-4

Konijnendijk CC, Sadio S, Randrup TB, Schipperijn J (2004). Urban and peri-urban forestry in a development context - Strategy and implementation. Journal of Arboriculture 30: 269-275.

Krause B, Culmsee H, Wesche K, Bergmeier E, Leuschner C, (2011). Habitat loss of floodplain meadows in north Germany since the 1950s. Biodiversity and Conservation 20: 2347-2364. - doi: 10.1007/s10531-011-9988-0

James P, Tzoulas K, et al (2009). Towards an integrated understanding of green space in the European built environment. Urban Forestry and Urban Greening 8: 65-75. - doi: 10.1016/j.ufug.2009.02.001

Lafortezza R, Brown RD (2004). A framework for landscape ecological design of new patches in the rural landscape. Environmental Management 34: 461-473. - doi: 10.1007/s00267-002-2009-z

Lafortezza R, Corry RC, Sanesi G, Brown RD (2008). Visual preference and ecological assessments for designed alternative brownfield rehabilitations. Journal of Environmental Management

89: 257-269. - doi: 10.1016/j.jenvman.2007.01.063

Lafortezza R, Carrus G, Sanesi G, Davies C (2009). Benefits and well-being perceived by people visiting green spaces in periods of heat stress. Urban Forestry and Urban Greening 8: 97-108. - doi: 10.1016/j.ufug.2009.02.003

Lafortezza R, Coomes DA, Kapos V, Ewers RM (2010). Assessing the impacts of fragmentation on plant communities in New Zealand: scaling from survey plots to landscapes. Global Ecology and Biogeography 19: 741-754. - doi: 10.1111/j.1466-8238.2010.00542.x

Leibenath M, Blum A, Stutzriemer S, (2010). Transboundary cooperation in establishing ecological networks: The case of Germany's external borders. Landscape and Urban Planning 94: 84-93. - doi: 10.1016/j.landurbplan.2009.08.002

Li F, Wang R, Paulussen J, Liu X (2005). Comprehensive concept planning of urban greening based on ecological principles: a case study in Beijing, China. Landscape and Urban Planning 72: 325-336. - doi: 10.1016/j.landurbplan.2004.04.002

Lindenmayer DB, Fischer J (2007). Tackling the habitat fragmentation panchreston. Trends in Ecology and Evolution 22: 127-132. - doi: 10.1016/j.tree.2006.11.006

Lyytimäki J, Petersenb LK, Normanderb B, Bezákc P (2008). Nature as a nuisance? Ecosystem services and disservices to urban lifestyle. Environmental Sciences 5: 161-172. - doi: 10.1080/15693430802055524

Lyytimäki J, Sipilä M (2009). Hopping on one leg - the challenge of ecosystem disservices for urban green management. Urban Forestry and Urban Greening 8: 309-315. - doi: 10.1016/j.ufug.2009.09.003

Martínez S, Ramil P, Chuvieco E (2010). Monitoring loss of biodiversity in cultural landscapes. New methodology based on satellite data. Landscape and Urban Planning 94: 127-140. - doi: 10.1016/j.landurbplan.2009.08.006

Mata C, Hervás I, Herranz J, Suárez F, Malo JE (2005). Complementary use by vertebrates of crossing structures along a fenced Spanish motorway. Biological Conservation 124: 397-405. - doi: 10.1016/j.biocon.2005.01.044

Mell IC (2010). Green Infrastructure: concepts, perceptions and its use in spatial planning. PhD thesis, Newcastle University, Newcastle, UK.

MEA (2005). Ecosystems and human well-being: synthesis. Millennium Ecosystem Assessment, Island Press, Washington, DC, USA, pp. 155.

Nelson E, Polasky S, Lewis DJ, Plantinga AJ, Lonsdorf E, White D, Bael D, Lawler JJ (2008). Efficiency of incentives to jointly increase carbon sequestration and species conservation on a landscape. Proceedings of the National Academy of Sciences USA 105 (28): 9471-9476. - doi: 10.1073/pnas.0706178105

Ortega-Álvarez R, MacGregor-Fors I (2009). Living in the big city: Effects of urban land-use on bird community structure, diversity, and composition. Landscape and Urban Planning 90: 189-195. - doi: 10.1016/j.landurbplan.2008.11.003

Pataki DE, Carreiro MM, Cherrier J, Grulke NE, Jennings V, Pincetl S, Pouyat RV, Whitlow TH, Zipperer WC (2011). Coupling biogeochemical cycles in urban environments: Ecosystem services, green solutions, and misconceptions. Frontiers in Ecology and the Environment 9: 27-36. - doi: 10.1890/090220

Petty J, Peacock J, Hine R, Sellens M, South N, Griffin M (2007). Green Exercise in the UK countryside: effects on health and psychological well-being, and implications for policy and planning. Journal of Environmental Planning and Management 50 (2) 211-231. - doi: 10.1080/09640560601156466

Poelmans L, Van Rompaey A (2009). Detecting and modelling spatial patterns of urban sprawl in highly fragmented areas: a case study in the Flanders-Brussels region. Landscape and Urban Planning 93: 10-19. - doi: 10.1016/j.landurbplan.2009.05.018

Piorr A, Ravetz J, Tosics I (2011). Peri-urbanisation in Europe: towards a european policy to sustain urban-rural futures. Academic Books - Life Sciences, University of Copenhagen, Denmark, pp. 144. [ISBN 978-87-7903-534-8]

Raudsepp-Hearne C, Peterson GD, Bennett EM (2010). Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. Proceedings of the National Academy of Sciences USA 107: 5242-5247. - doi: 10.1073/pnas.0907284107

Ribeiro L, Barão T (2006). Greenways for recreation and maintenance of landscape quality: five case studies in Portugal. Landscape and Urban Planning 76: 79-97. - doi: 10.1016/j.landurbplan.2004.09.042

Rounsevell M, Dawson T, et al (2010). A conceptual framework to assess the effects of environmental change on ecosystem services. Biodiversity and Conservation 19: 2823-2842. - doi: 10.1007/s10531-010-9838-5

Sanesi G, Lafortezza R, Marziliano PA, Ragazzi A, Mariani L (2007). Assessing the current status of urban resources in the context of Parco Nord, Milan, Italy. Landscape and Ecological Engineering 3: 187-198. - doi: 10.1007/s11355-007-0031-2

Sanesi G, Padoa-Schioppa E, Lorusso L, Bottoni L, Lafortezza R (2009). Avian ecological diversity as an indicator of urban forest functionality. results from two case studies in Northern and Southern Italy. Arboriculture and Urban Forest 35: 80-86. [online] URL: http://home.dei.polimi.it/melia/ecologia/2010/AUF_09.pdf

Tzoulas K, Korpela K, Venn S, Yli-Pelkonen V, Kazmierczak A, Niemela J, James P (2007). Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. Landscape and Urban Planning 81: 167-178. - doi: 10.1016/j.landurbplan.2007.02.001

von Haaren C, Reich M (2006). The German way to greenways and habitat networks. Landscape and Urban Planning 76: 7-22. - doi: 10.1016/j.landurbplan.2004.09.041

Walmsley A (1995). Greenways and the making of urban form. Landscape and Urban Planning 33: 91-127. - doi: 10.1016/0169-2046(95)02015-L

Walmsley A (2006). Greenways: multiplying and diversifying in the 21st century. Landscape and Urban Planning 76: 252-290. - doi: 10.1016/j.landurbplan.2004.09.036

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. - doi: 10.1016/j.landurbplan.2005.02.002

Wickham JD, Riitters KH, Wade TG, Vogt P (2010). A national assessment of green infrastructure and change for the conterminous United States using morphological image processing. Landscape and Urban Planning 94: 186-195. - doi: 10.1016/j.landurbplan.2009.10.003

Wikipedia (2011). Free encyclopedia. Web site. [online] URL: http://en.wikipedia.org/wiki/European_Landscape_Convention

Williamson KS (2003). Growing with green infrastructure. Heritage Conservancy, Doylestown, PA, USA, pp. 20. [online] URL: http://164.156.7.76/ucmprd2/groups/public/documents/document/dcnr_002286.pdf

Yu K, Li D, Li N, (2006). The evolution of greenways in China. Landscape and Urban Planning 76: 223-239. - doi: 10.1016/j.landurbplan.2004.09.034

Zhang L, Wang H (2006). Planning an ecological network of Xiamen Island (China) using landscape metrics and network analysis. Landscape and Urban Planning 78: 449-456. - doi: 10.1016/j.landurbplan.2005.12.004

Supplementary Material

Appendix 1

Tab. S1 - Case studies and projects of Green Infrastructure in Europe investigated in this study.

Link: Lafortezza_723@suppl001.pdf

Appendix 2 - Overview of urban, city-region, national and transnational Green Infrastructure programmes considered.

Link: Lafortezza_723@suppl002.pdf