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Multifunctional and Multiscale Aspects of *Green Infrastructure* in Contemporary Research

Multifunkcjonalność *zielonej infrastruktury* we współczesnych badaniach

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Abstract
This paper provides information on the definition and benefits *of green infrastructure*, outlines the *green infrastructure* solutions and technics and their influence on multifunctionalty and multiscale of current research. Examples of *green infrastructure* practices include green, blue, and white roofs; hard and soft permeable surfaces; green alleys and streets; urban forestry; green open spaces such as parks and wetlands. *Green infrastructure* approaches help to achieve sustainability and resilience through practices such as among many others: urban forestry, and water conservation. This paper evaluates benefits of selection of particular *green infrastructure* solutions on the background of broader ecological context.

Key words: *green infrastructure,* connectivity, urban structure

Streszczenie
Idea *zielonej infrastruktury* jest jednym z najważniejszych kierunków tworzących nową jakość w zarządzaniu środowiskiem przyrodniczym. *Zielona infrastruktura* oprócz funkcji ekologicznej ma wpływać na poprawę: warunków zdrowotnych, poprawę poszczególnych komponentów środowiska, a nawet kontrolować rozwój przestrzenny miasta. Niektórzy badacze przyjmują założenie że *zielona infrastruktura* powinna być traktowana równorzędnie z techniczną.
Celem artykułu jest określenie rodzajów *zielonej infrastruktury* w strefie zurbanizowanej ze szczególnym uwzględnieniem obszarów wielofunkcyjnych, które dzięki swojej atrakcyjności przyrodniczej i krajobrazowej, wynikającej z różnorodnych form użytkowania, mogą zapewnić optymalną ilość i jakość terenów rekreacyjnych. We współczesnych badaniach zauważa się, że strefy wielofunkcyjne w obrębie których preferowane są metody użytkowania gruntów, chroniące różnorodne biologicznie ekosystemy, zatrzymując czysta wodę, zabezpieczając przed erozją, powodziami służyć mogą różnorodnym potrzebom mieszkańców miast. W artykule prezentowane są zasady rządzące funkcjonowaniem zielonej infrastruktury, szczególnie najważniejsza z nich dotycząca poprawy łączności między istniejącymi obszarami przyrodniczymi, w celu przeciwdziałania ich fragmentacji i zwiększenia ich ekologicznej spójności.

Słowa kluczowe: *zielona infrastruktura*, łączność ekologiczna, środowisko zurbanizowane

Introduction

Habitat fragmentation affects numerous ecological process across multiple scales, including changes in abiotic regimes, shifts in habitat use, altered population dynamics, and changes in species compositions (Schweiger et al., 2000). Patch size has been identified as a major feature influencing the existence of plant and animal communities.
The main challenge in spatial development is to find the basis to build a hierarchic system of functioning of green areas. Current studies show how important it is to work on different scales of green areas – from single parcels to the whole continent in order to

maintain ecosystem integrity (Burgi, Herperger, Schneeberger, 2004). The hierarchic structure of green areas and extent of vegetation in urban environment have an impact on temperature, humidity and surface run-off. Groundwater levels are gradually falling across all European countries. New housing developments influence fragmentation of habitat and species isolation (Forman, 1995; Mazza et al., 2011). One of the development priorities is to maintain and expand municipal forests and to improve the ecological network between the cities and its suburban neighborhood. In order to preserve the most valuable virtues of the environment and to prevent its further deterioration, the need to find solutions for building an environmentally functioning web (*green infrastructure*) is growing. *Green infrastructure* may be most successful when it functions at multiple scales in tandem. In the Toronto's *Greening the Portlands* project in Ontario *major parks*, *minor parks*, *wide corridors*, *narrow corridors* and *development parcel landscapes* create the basis of *green Infrastructure* (*Portland's Green Infrastructure,* 2010).

Green Infrastructure definition

In landscape ecology, the mosaic model of green areas describes the spatial configuration of landscapes. The model uses landscape elements and on the basis of theirs correlation define landscape structure: patches corridors, and the matrix. A patch, which provide multiple functions, is a homogeneous nonlinear area that differs from its surroundings. A corridor is a linear area of a particular land cover type that is different in content and physical structure from its context (Forman, 1995; Ahern, 2007). The matrix represents the dominant land cover type (Forman, 1995; Forman, Gordon, 1986).

The ecological network, which aim is to maintain the integrity of environmental processes is a model that has developed over the past 30 years. It promotes the sustainable use of natural resources in order to reduce the impacts of human activities on biodiversity and/or to increases the biodiversity value of managed landscapes (Bennett, 2004). This coherent system of ecological components include: core areas (hubs), where the conservation of biodiversity takes primary importance, corridors (linear linkages between core areas), which help to maintain vital ecological or environmental connections, mix land used buffer zones (transitional areas), which protect the network from external influences and finally sustainable-use areas. Core areas (hubs) as origin or destination for wildlife and ecological processes play essential role within the *green infrastructure*. Not limited by the size or scale they incorporate: large protective areas (national parks, wildlife reserves), managed native landscapes (national forests), working lands (private farms and forests), regional parks and preserves of regional ecological significance and community parks (Benedict Mc Mahon, 2002). In the coherent, self-regulating network of *green infrastructure*, corridors as a physical linkages between the core areas are essentially devices to maintain or restore a degree of coherence in fragmented ecosystems. Bennet and Mulongoy (2006), who distinguished three physical forms of corridors: a linear corridor (examples: hedgerow, forest strip or river), stepping stones (examples: ponds, small woods), consisting of small patches of habitat that animals use during movement for shelter, feeding and resting and other various forms of interlinked landscapes, widen the term *corridor* to describe many different kinds of measures, including first of all landscape linkages (examples: marine linkages, sea-river linkages) but also recreational routes (example: greenways) and entire ecological networks (example: coastal systems). The concept of a buffer zone created in the 1930s as an integral part of the management approach in UNESCO's *Man and Biosphere Programme* become an important conservation instrument in the 1970s. Buffer zones can act as protected and transition areas in which sustainable resource management practices can be developed. Ecological networks develops conservation actions to ecosystem processes, create coherent network of habitat patches and extend biodiversity conservation through compatible forms of land use (Bennet, Mulongoy, 2006). The ecological network evolved out of developments in ecological theory, primarily MacArthur and Wilson's island biogeography and metapopulation theory in which habitat fragmentation increases the vulnerability of species populations by limiting opportunities for dispersal, migration and genetic exchange (MacArthur, Wilson, 1967). Important for the subsequent ecological network model was Diamond proposition of configuration of the nature reserves introduced in 1975, now partly included in the principles IUCN's *World Conservation Strategy*, according to which reserves should be as large, round as possible and located as close as possible to each other.

Connectivity is a property of landscapes which illustrates the relationship between landscape structure and function (examples: water flow, nutrient cycling and the maintenance of biological diversity, Leitão et al., 2006; Ahern, 2007). In urban highly modified landscapes connectivity is greatly reduced and manifest in fragmentation – the separation and isolation of landscape elements.

The principle of connectivity is included in the EU's most important biodiversity conservation legislation, the 1979 *Birds Directive* and the 1992 *Habitats Directive.*

Convention on the Conservation of Migratory Species of Wild Animals (the Bonn Convention) protects the transboundary linkages used by migratory species. Under the Convention, a series of agreements and memoranda of understanding have been adopted by UE member states with the aim of conserving threatened migratory species and theirs habitats. These create the background for representative system of protected areas throughout the EU – Natura 2000, which increasing constantly and now cover approximately 17 percent of the EU's territory. Natura 2000 as the crucial part of *European Green Infrastructure* constitute a reservoir of biodiversity that can be drawn upon to repopulate and revitalize degraded environments and catalyze the development of GI. This will also help reduce the fragmentation of the ecosystem, improving the connectivity between sites in the Natura 2000 network and thus achieving the objectives of Article 10 of the *Habitats Directive* (1992). In Central and Eastern Europe, several national ecological-network programs developed in the 1980s (with the first *Estonian Network of Ecologically Compensating Areas* elaborated in 1983). Now Ecological networks in Central and Eastern Europe are being developed in three main ways: through framework of the *Pan-European Biological and Landscape Diversity Strategy* (adopted in 1995, through national or regional government programs and through various NGO projects). In *Western Europe TEN (Transnational Ecological Network)* – a cooperative project between regional governments in the United Kingdom, the Netherlands, Germany and Denmark helps to maintain and enhance ecological integrity on wetlands and aquatic ecosystems. One of the newest ecological network at the international level in Europe is *Green Belt* (launched in 2004) stretching along the entire border region of the former Iron Curtain. In North America the principal ecological network *(Widland Project)* was launched in 1991 and helps to protect and restore the natural heritage through the establishment of a connected system of *wildlands*, that is *reserve networks* including core areas, corridors and buffer zones – examples: USA: *The Southern Rockies Wildlands Network*, Canada: *The Bow Valley Wolf Corridor* (Noss, 1993; Bennet, Mulongoy, 2006).

Many definitions of *green infrastructure* (GI) have been developed. It is therefore difficult to cover all aspects in one sentence. The following definition was used for the purposes of the Communication from the Commission to the European Parliament paper (Brussels, 6.05.2013): *a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services*. According the Commission: *it incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings*. According to Naumann (2011) it *is the network of natural and semi-natural areas, features and green spaces in rural and urban, terrestrial, freshwater, coastal and marine areas*. Originally, *green infrastructure* was identified with parkland, forests, wetlands, greenbelts, or floodways in and around cities that provided improved quality of life or ecosystem services such as water filtration and flood control (Mc Mahon, 2000). Now *green infrastructure* is more often related to environmental or sustainability goals that cities are trying to achieve through a mix of natural approaches. The development of GI across the world is well known. In the 1990's, Florida, Maryland and several initiated programs to strategically identify, protect and restore interconnected systems of conservation land and other sites of ecological value. The President's Council on Sustainable Development (USA) in report *Towards a Sustainable America* (1999) identified *green infrastructure* as one of five strategic areas that provide a comprehensive approach for sustainable community development. Over the last 20 years, new examples of GI projects have been carried out and there is a wealth of experience demonstrating that the approach is flexible and cost-effective. GI projects are carried out on a local, regional, national or transboundary scale. The concept of *green infrastructure* is endorsed in the Milton Keyes and South Midlands Sub-Regional Strategy and *The Northamptonshire Green Infrastructure Project* (*River Nene Regional Park*, 2005). *Green infrastructure* is highlighted as an important resource to support the *Northwest's Regional Economic Strategy*, published in 2006 (case studies: Mersey Waterfront Regional Park, St Helen's Urban Fringe).

Benefits of *green infrastructure*

Green infrastructure utilize the natural retention and infiltration capabilities of plants. In urban and suburban highly modified landscapes green infrastructure could bring a lot of benefits, among them: biodiversity enrichment, reduced and delayed stormwater runoff volumes, enhanced groundwater recharge, lowered incidents of combined storm and sewer overflows (CSOs), Urban Heat Island mitigation, reduced energy demands and GHG emissions. Incorporation of trees and vegetation in urban landscapes contribute to improvement of air quality, human health and creates additional wildlife habitat and recreational space. Plants can naturally filter and break down many common pollutants found in stormwater. Finally, as it is suggested in a number of case studies, *green infrastructure* can increase surrounding property values through converting degraded parts of cities into more greener and clean space (Foster et al., 2011).

The superior role of *green infrastructure* in flood protection is invaluable. Restoration of floodplain forests can deliver many ecological benefits as: maintaining the water table, preventing erosion and reduction of pollutants by filtering the water. Introduction of riparian woodland, protection forests in mountainous and restoration of coastal wetlands combined with infrastructure can decrease disaster risk. *Green infrastructure* mitigates the negative effects of fragmentation of the landscape through better integration of urban land use areas with ecosystems.

Green Infrastructure is based on principle that maintaining, enhancing nature connectivity and natural processes and integrating nature into spatial planning add multiple benefits for human society. In the context of this in *COM(2013) 249 final, The European Economic and Social Committee and the Committee of the regions Green Infrastructure (GI) — Enhancing Europe's Natural Capital* (2013) *green infrastructure* is identified as one of the investment priorities, contributing to regional policy and sustainable growth in Europe. GI have significant potential to strengthen regional and urban development, through encouraging business investments and creating jobs.

Social aspects of *green infrastructure*

Between 2009 and 2011, the UK National Ecosystem Assessment (UK NEA) analysed the natural environment in terms of its benefits for society. The UK NEA found that the well-being of society depends on the range of services provided by ecosystems which include: soil formation, photosynthesis, supplying food, fibre and fuel, regulated air quality and climate, controlled erosion as well as non-material benefits for people, for instance: recreation (*Green Infrastructure…,* 2013). To understand the term well-being, it is crucial to take into consideration its broad range of biological, sociological, economic and environmental factors. This term was used by WHO (1948) to introduce definition of health and public health.

What is more, vegetation has a positive impact on human health. In the research it is suggested that urban green spaces can create a stronger sense of community (Kim, Kaplan, 2004). There is close relationship between longevity, health and access to green space (Tzoulas et al., 2007). Boulevards, squares, parks, green roofs and walls in cities creates attractive landscapes for leisure and recreation. Vegetation provides cooling and cleaner air, mitigates the urban heat island effect and creates more spaces for living creatures. It should be also mentioned that green areas of high quality can have a positive impact on land and property markets as well as create job opportunities (*Green Infrastructure...,* 2013). Finally, well managed network of green areas may encourage business investment. Green infrastructure solutions, especially in coastal areas, increase tourism economy, create attractive wetland habitats close to human settings and improve the development of leisure facilities. Easily accessible nature gives opportunities for physical activity, relaxation and healthy living. New green areas encourage social interaction, provide a range of educational opportunities based on close relationship of local communities surrounded by the natural environment. Furthermore, river valleys, waterways, pedestrian and cycle paths, offer sustainable transport routes.

Economic aspects of *green infrastructure*

Green infrastructure provides long lasting and sustainable benefits, for instance saving money, cleaner air as well as groundwater recharge. New York City 2010 Green Infrastructure Plan includes precised calculations (total annual benefits) for every acre of green infrastructure connected with reduced energy demand and CO_2 emissions, improved air quality, as well as increased property value. Statistics presented in Bird's study (2004) concerning five major UK cities show more than £ 1.8 million savings for UK National Health Service (if 20% of the population within 2 km of an 8-20 ha green area used that space to reach a target of 30 min., activity, lasting 5 days a week, Tzoulas et al., 2007). Green alleys, rain barrels and tree planting are estimated to be 3-6 times more effective in managing storm water per $1000 invested than grey infra-structure methods. Green infrastructure methods, which clearly illustrate this correlation, were implemented in Portland (US) as Green Streets projects; which cost $8 million. It was estimated, that they enabled saving of $250 million in hard infrastructure costs (Foster et al., 2011). Philadelphia, which has been implementing green infrastructure solutions since 2006, and saved approximately $170 million so far (Foster et al., 2011). The value of green roofs has been estimated to be 40% higher than a conventional roof due to storm water management, reduced electricity costs and improved air-quality. Green roofs give energy savings up to 15-45% of annual energy consumption (Foster et al., 2011). Urban trees enable further additional savings for city inhabitants. They have positive impact on carbon and storm water storage (trees can reduce runoffs in urban areas by up to 17%). It was estimated that the value of street trees in Washington, D.C. reached around $10.7 million annually, for all benefits (Foster et al., 2011). In Atlanta, GA (USA) trees provide $833 million in storm water management benefits (Foster et al., 2011). The benefits of green infrastructure in mitigating climate changes are also visible, which has positive economic consequences. Studies carried out in Manchester (UK) have shown that additional 10% of green cover in high density areas would keep surface temperatures at a level below historical baseline (Gill et al., 2007; Foster et al., 2011). Green infrastructure helps to achieve greater urban sustainability and resilience, as well as builds stronger communities based on diversity, flexibility and self-sufficiency.

Multifunctionality and multiscale research

The ecological network concept has been introduced into spatial management with an idea to create a landscape strategy at broad scales which will include continents, nations and regions (Jongman, Pungetti, 2004). The concept aimed primary at maintaining biodiversity has been rarely applied in urban contexts (Ahern, 2007). The multi-scaled research involves assessment and planning of landscape patterns and ecological processes at multiple scales. According Ahern (2007) in urban environments the appropriate scales are: the metropolitan region or city, the districts or neighborhoods, and individual sites. Application of *green infrastructure* approaches range in scale from large centralized public *macro* projects (example: *Staten Island Bluebelt project*, 2003, incorporating 16 small urban watersheds into water management system) to small scattered *micro* applications on private properties (example: rain barrels to collect stormwater). Benefits of *green infrastructure* multifunctionality include among others: better management of storm-water runoff, decrease of combined storm and sewer overflows (CSOs), water capture and conservation and purification, flood prevention and mitigation of urban heat island (UHI) effects.

Multiscale approach of *green infrastructure* could include vertical integration, where various functions are applied in one location (examples: wildlife crossings under/over roads, infiltration systems beneath building or parking lots, or green roofs on buildings (Ahern, 2007). *Green infrastructure* stormwater system could incorporates green roofs, infiltration wells, vegetated bioswales, small ponds and created wetlands. New York City integrated the extensive existing wetlands into their water management plans. In Staten Inland Bluebelt project the stormwater system joins sanitary sewer system, and a separate stormwater system using existing wetlands. The Bluebelt project implementation effects in reduce of the quantity and velocity of runoff, and remove of contaminants from the runoff by introducing aquatic plants for bioremediation. This multiscale project integrates watersheds, subwatersheds and isolated wetlands (Ahern, 2007).

Nowadays, pursuant to the *Convention of Biological Diversity* approved in Rio de Janeiro in 1992, protection of biological diversity is directed at the whole natural space, most of all at terrains used by man, and even at terrains transformed by him significantly, such as towns. This must be taken into account in model considerations. Protection of biological diversity and use of its elements in a sustainable way are strictly interrelated. Within urbanized areas it is important to maintain enclaves of different types of unused habitats (swamps, mid-field afforestation, peat bogs, basins of surface waters, water courses, river valleys, mid-field balks, etc.).

Change and regulation of riverbeds also results in a change of water management throughout the whole river valley. A large majority of rivers have been modified by dams and other engineering works. In Europe, floodplain losses approach 95% (Tockner, Stanford, 2002). Groundwater levels are gradually falling across all the EU countries. The need to protect remaining floodplain systems and to restore degraded river valleys has grown in recent decades (Ward et al, 1999). In agglomeration scale *green infrastructure* projects could include wetlands buffering areas against river flooding for regional infrastructure and housing. The use of a wetland system, which store and release water gradually also helps communities to buffer against drought.

Planting and maintaining trees in urban settings deliver multiple benefits for resilience, adaptation, and climate mitigation. Trees filter storm-water runoff, prevent from flooding, improve water quality and clean the air through absorbing pollutants. In urban environment trees protect buildings from wind damage, and regulate heat island effects through shading and evaporation. Trees absorb and reduce various pollutants found in the cities, including particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), and ground-level ozone (O_3).

GIS in *green infrastructure* research

Usage of GIS to identify *green infrastructure* in a Multi-State Region was introduced in the *Southeastern Ecological Framework Project* (2002). The key task of the project was to identify ecological significant areas and connectivity in the southeast region of the United States. The states included in the project are Florida, Georgia, Alabama, Mississippi, South Carolina, North Carolina, Tennessee, and Kentucky. The project was conducted in 1999-2000 by the University of Florida GeoPlan Center and sponsored by the US Environmental Protection Agency Region 4.

Consistent, reliable data are essential for effectively deploying *green infrastructure*. Information is needed about the extent and condition of ecosystems, the services they provide and the value of these services so that ecosystem services are correctly valued and then priced if appropriate, to promote GI solutions in spatial planning and decision-making processes in relation to infrastructure. Traditional land conservation and *green infrastructure* planning both focus on environmental restoration and preservation, but *green infrastructure* also concentrates on the pace, shape, and location of development and its relationship to important natural resources and amenities. The innovation of usage GIS in *green infrastructure* models is connected with creation GIS based analysis which allow to indicate habitat patches and connect them across multiple jurisdictions, scales and landscape types. GIS programs could be used to identify vital ecological areas and linkages prior to development in suburban and rural landscapes and identify a *green infrastructure* network that connects these primary ecological areas, indicate *green infrastructure* classification and assessment and finally to introduce the model of *green infrastructure* and test of its impact on the environment and its biodiversity. GIS programs are generally used to describe form, configuration, and composition of the landscape pattern and are considered to cover principal aspects of structural landscape assessment of crucial ecological meaningfulness. Crucial dataset are: CORINE Land cover (CLC), LIDAR scan data converted to 1 m resolution raster model-layers: DEM (Digital Elevation Model), vegetation height (trees, shrubs), buildings (vector layer of buildings), Urban Atlas (GMES/Copernicus), online aerial photography datasets, Street View photography and orthophotomaps. Online aerial photography datasets, and especially the Bird's Eye photography and the Street View photography can be invaluable as a supplement. All of the GI mapping using would carried out in ESRI's ArcGIS Desktop.

Green infrastructure projects through introducing new green areas has an important role in enhancing stormwater infiltration rates and reducing the volume of runoff flowing to urban sewer systems. The natural infiltration capabilities of green infrastructure technologies can increase groundwater recharge. On the other hand vegetation provide natural water storage and flood protection by slowing the passage of flowing waters and reducing sedimentation Green cover constitute a buffer zone for pollutants being transported to surface waters. *The Cambridge Sustainable Drainage Design and Adoption Guide* introduces SuDS methods such as: ponds and wetlands, retention and infiltration basins, swales and filter strips, filter drains, canals, rills and channel systems. In ECOS CENTRE (60 ha urban park in Northern Ireland) reed-bed water treatment technology helps to deal with waste in a sustainable way, willow coppice is used to produce biomass fuel. The reed-bed system implemented in is also used for Swindon Borough Council to filter surface water with low-level contaminants running off the urban forest. On urban areas green infrastructure can mitigate the effects of urban heat islands, reduce energy demand and as an effect improve the air quality and human health. Greenways, parks, urban forests, wetlands, and various forms of green infrastructure provide increased access to recreational space and wildlife habitat. Enhancing the surface of green roofs in cities has important impact on the level of reducing of rainwater. Consultants *for Greening for Growth project* in London's Victoria Business Improvement District (BID) identified that fitting 25 ha of green roofs could deal with 80,000 m^3 of rainwater each year (Green Infrastructure…, 2013).

Examples of *green infrastructure* technological practices include:

1. eco-roofs: green roofs (roofs partially or completely covered with plants or trees), blue roofs (non-vegetated source of control that detain stormwater), and white roofs – cool roofs (flat roofs that have been painted white);
2. hard and soft permeable surfaces;
3. green alleys and streets;
4. urban forestry;
5. green open spaces (examples: parks, wetlands);
6. wastewater treatment system.

Green alleys incorporate various technical solutions to achieve better stormwater management, heat and energy reduction goals. These solutions include: permeable and reflective pavements (allowing water allow water to soak back into the ground), introducing of rain-gardens (installed in artificial depressions to capture rainwater), downspout disconnects and rain-barrels, tree-planting, landscaping and bio-swales (artificially contained vegetation), cisterns, eco-roofs (green, blue, white) and recycled materials (*Chicago Green Alley Handbook*, 2010). Studies have shown that permeable pavement with porous layer of soil underneath can reduce runoff volume by 70 to 90%. The goal is to produce runoff characteristics in cityscapes that are similar to those in a meadow or a forest (Foster et al., 2011). The downspouts disconnects are incorporated in water collection or slow dispersion system, such as a cistern (for storage) or a rain garden (for slow dispersion). It is a method of controlling rainwater management system and reducing CSO danger (Foster et al., 2011). In Chicago, in 2007, 30 green alleys with permeable pavement and reflective concrete had been installed, together with 200 catch-basins in various parts of the city. The central goal was to slow the rate of stormwater runoff along alleys through allowing water to soak into the surrounding neighborhoods more naturally (*Chicago Green Alley Handbook,* 2010).

Current questions

The current research assume that *green infrastructure* is the framework for conservation and development and we need to design *green infrastructure* systems strategically to connect across urban, suburban, rural and wilderness landscapes and incorporate green space elements and functions at the state, regional, community and parcel scales.

The main research questions are:

1. To identify vital ecological areas and linkages prior to development in suburban and rural landscapes and identify a green infrastructure network that connects these primary ecological areas.
2. To identify opportunities for the restoration and enhancement of naturally functioning systems in already developed areas.
3. To provide a mechanism to identify green areas used for multiple functions: including ecological, recreational, cultural, aesthetic and other uses.
4. To develop an understanding of the spatial scale issues involved in analyzing the ecological connectivity.
5. To create a scientific system of analysis for *green infrastructure* identification in urban and suburban areas.

6. To calculate the economic and social benefits of *green infrastructure* practices to reduce the barrier against its implementation.

Green infrastructure models have an important role in air conditioning, improving the microclimate and overall softening of the urban heat island effect. The present questions included are how to improve the understanding of the links between biodiversity (species/habitats) and the condition of the ecosystem (vitality, resilience and productivity) and between the condition of the ecosystem and its capacity to deliver ecosystem services and how to provide a mechanism to balance environmental social and economic factors.

Conclusions

Green infrastructure is a strategic approach to land conservation that addresses the ecological and social impacts of urban sprawl and consumption and fragmentation of landscape. It is described as *natural life support system* which creates *an interconnected network of waterways, wetlands, woodlands, wildlife habitats and other natural areas; greenways, parks and other conservation lands; working farms, ranches and forests; and wilderness and other open spaces* (Benedict, Mc Mahon, 2006).

In many major urbanized areas, green space is rapidly disappearing. Accelerated consumption of land for growing cities and fragmentation of landscape caused by urban sprawl are primary conservation challenges. Creation of more isolated patches of green areas and decrease of wetlands and riparian zones restrict the biodiversity and reduces their capacity to control floods. Shrinking natural habitats lose its ability to filter out toxins, excess nutrients, and support wildlife and plant species. In this highly modified environment *green infrastructure* provide a framework for smart growth. Better usage of existing infrastructure (*gray, green, blue*) can help to create more compact, mix used and healthy communities.

Green infrastructure practices (such as green roofs, green alleys etc.) included in local governments strategies have impact on sustainability and quality of life of local communities. They are seen as main potential tools in climate adaptation. Broader implementation of *green infrastructure* solution is connected with uncertainty involved in economic and social costs and benefits for local governments (Foster et al., 2011). *Green infrastructure* planning should be the first step in the land-use planning and design process. It should be coordinated with planning for *blue and gray infrastructure* – roads, bike trails, water, electric, telecommunication and other essential community support systems. Integrated planning *green and gray infrastructure*) and design should connect the two in a more sustainable network.

References

1. AHERN J. Green infrastructure for cities: The spatial dimension in: *Cities of the Future Towards Integrated Sustainable* Water and Landscape Management, eds. Novotny V., Brown P., IWA Publishing, London 2007, p. 267-283
2. BEATLEY T., *Green Urbanism, Learning from European Cities*, Island Press, Washington D.C. 2000.
3. BENETT G., *Integrating Biodiversity Conservation and Sustainable Use: Lessons Learned From Ecological Networks*, Gland/Cambridge, IUCN 2004.
4. BENETT G., MULONGOY K. *Review of Experience with Ecological Networks, CBD Technical Series* No. 23, Secretariat of the Convention on Biological Diversity 2006.
5. BENEDICT M., McMAHON E., *Green Infrastructure: Linking Landscapes and Communities*, Island Press, Washington, D.C. 2006.
6. BENEDICT M., McMAHON E., 2002 Green Infrastructure: Smart Conservation for the 21st Century, in: *Renewable Resources Journal*, Autumn Edition, p. 12-17, http://www.sprawlwatch.org/greeninfrastructure.pdf.
7. BIRD W., 2004, Natural Fit. Can green space and biodiversity increase levels of physical activity?, in: R. *Soc. Protect. Birds*, p. l.
8. BÜRGI M.; HERSPERGER A.M.; SCHEEBERGER N., 2004, Driving forces of landscape change – current and new directions, in: *Landsc. Ecol.* 19.
9. *The Cambridge Sustainable Drainage Design and Adoption Guide*, https://www.cambridge.gov.uk/sites/www.cambridge.gov.uk/files/docs/SUDS-Design-and-Adoption-Guide.pdf.
10. *Chicago Green Alley Handbook 2010*, http://www.cityofchicago.org/dam/city/depts/cdot/Green_Alley_Handbook_2010.pdf.
11. COM(2011) 17 final, *Regional Policy contributing to sustainable growth in Europe 2020*, Commission staff working document, European Commission SEC(2011) 92 final, http://ec.europa.eu/regional_policy/sources/docoffic/official/communic/sustainable/swd_sec2011_92.pdf.
12. *Communication from the Commission to the European Parliament paper*, Brussels, 6.05.2013, COM(2013) 249 final. *The European Economic and Social Committee and the Committee of the regions Green Infrastructure (GI) — Enhancing Europe's Natural Capital,* http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2013:0249:FIN:EN:PDF.
13. *Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora*.
14. FORMAN R.T.T., *Land Mosaics*, Cambridge University Press, Cambridge 1995.

15. FORMAN R.T.T., GORDON M., *Landscape Ecology*, John Wiley, New York 1986.
16. FOSTER J., LOWE A., WINKELMAN S., The value of Green Infrastructure for urban climate adaptation. Final report, The Center for Clean Air Policy, Washington, DC 2011, http://www.ccap.org/docs/resources/989/Green_Infrastructure_FINAL.pdf
17. GILL S, HANDLEY J., ENNOS A., PAULEIT S., 2007, Adapting Cities For Climate Change, in: *The Role Of The Green Built Environment* vol. 33, No. 1, http://www.fs.fed.us/ccrc/topics/urbanforests/docs/Gill_Adapting_Cities.pdf.
18. *Green Infrastructure. An integrated approach to land use 2013*, Landscape Institute Position Statement London, http://www.landscapeinstitute.org/PDF/Contribute/2013GreenInfrastructureLIPositionStatement.pdf.
19. HOPKINS M.I.W., 2001, Exploring the links between urban morphology and urban ecology, in: *Urban Morphology* 5, 1. p. 51-53.
20. JONGMAN R., PUNGETTI G., *Ecological Networks and Greenways: Concept, Design, Implementation*, Cambridge University Press, Cambridge 2003.
21. KIM J., KAPLAN R., 2004, Physical and psychological factors in sense of community. New Urbanist Kentlands and Nearby Orchard Village, in: *Environ. Behav.* 36, p. 313-340.
22. LEITÃO A.B., MILLER J., AHERN J., and McGARIGAL K., *Measuring Landscapes: A Planner's Handbook*. Island Press, Washington 2006.
23. McMAHON E., 2000, Looking Around: Green Infrastructure, in: *Planning Commission Journal Burlington*, Vermont no. 37, p.4-7.
24. MAZZA L., BENNETT G., De NOCKER L., GANTIOLER S., LOSARCOS L., MARGERISON C., KAPHENGST T., McCONVILLE A., RAYMENT M., BRINK P., TUCKER G., VAN DIGGELEN R., *Green Infrastructure Implementation and Efficiency, Final report for the European Commission*, DG Environment on Contract ENV.B.2/SER/2010/0059, Institute for European Environmental Policy, Brussels and London 2011.
25. MCCARTHUR R.H., WILSON E.O., *The Theory of Island Biogeography*, Princeton University Press, Princenton 1967.
26. MELL IC , 2007, Green infrastructure Planning: What are the costs for Health and Wellbeing? In: *Journ. of Environ., Culture, Economic and Social Sustainability* vol. 3, no 5, p. 117-124.
27. NAUMANN S., McKENNA D., KAPHENGST T. et al. ,2011, *Design, implementation and cost elements of Green Infrastructure projects*, Final report. Brussels: European Commission, http://ec.europa.eu/environment/enveco/biodiversity/pdf/GI_DICE_FinalReport.pdf.
28. *New York City's 2010 Green Infrastructure Plan*, http://www.nyc.gov/html/dep/pdf/green_infrastructure/NYCGreenInfrastructurePlan_ExecutiveSummary.pdf.
29. New York City DEP, *The Staten Island bluebelt: A natural solution to storm water management*, 2003, http://www.ci.nyc.ny.us/html/dep/html/news/bluebelt.html.
30. *The Northamptonshire Green Infrastructure Project 2005, Planning Sustainable Communities – A Green Infrastructure Guide for Milton Keynes & the South Midlands*, The Countryside Agency, http://www.riverneneregionalpark.org/images/PDF_Files/River_Nene_Regional_Park/Publications/GI_Leaflet6.pdf.
31. *Northwest's Regional Economic Strategy*, 2006, The Northwest RDA, http://www.nwda.co.uk.
32. NOSS R.F., Wildlife Corridors, in: *Ecology of Greenways*, eds. Smith, D.S., Hellmund, P.C., Univ. of Minnesot., Minneapolis 1993, p. 43-68.
33. *Portland's Green Infrastructure: Quantifying the Health, Energy, and Community Livability Benefits*, City of Portland Bureau of Environmental Services 2010, http://www.portland oregon.gov/bes/article/298042.
34. *Southeastern Ecological Framework Final Report*, 2002, Planning and Analysis Branch, U.S. Environmental Protection Agency, Region 4, Atlanta, http://www.geoplan.ufl.edu.
35. SCHWEIGER E. W., DIFFENDORFER J.E., HOLT R.D., PIEROTTI R., GAINES M.S., 2000, The interaction of habitat fragmentation, plant, and small mammal succession in an old field, in: *Ecological Monographs* 70, p. 383-400.
36. TOCKNER K., STANFORD J.A., 2002 , Riverine flood plains: present state and future trends, in: *Environ. Conserv*. 29, p. 308-330.
37. *Towards a Sustainable America – Advancing Prosperity, Opportunity, and a Healthy Environment for the 21st Century, 1999*, The President's Council on Sustainable Development, U.S. Government Printing Office, http://clinton2.nara.gov/PCSD/Publications/tsa.pdf.
38. TZOULAS K., KORPELA K., VENN S., YLI-PELKONEN V., KAŹMIERCZAK A., NIEMELA J., JAMES P., 2007, Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review, in: *Landscape and Urban Planning* 81, p. 167-178.
39. WARD J.V., TOCKNER K., SCHIEMER F, 1999, Biodiversity of floodplain river ecosystems: ecotones and connectivity, in: *Regul. Rivers: Res. Manage.* 15, p.125-130.
40. WHO, *City Health Profiles: A review of progress*, WHO Europe 1998.
41. WOLF K., *City Trees and Property Values*, Seattle 2007, http://www.cfr.washington.edu/research.envmind/Policy/Hedonics_Citations.pdf.