Ecological Engineering 120 (2018) 23–35

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Green and brown infrastructures support a landscape-level implementation of ecological engineering

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ARTICLE INFO

Keywords:
Brown infrastructure
Buffer zones
Constructed wetlands
Ecological network
Ecosystem services
Green infrastructure
Landscape planning
Land-use conflict

ABSTRACT

The green infrastructure (GI) is a network of natural and semi-natural areas with environmental features that is designed and managed to deliver a wide range of ecosystem services. The concept has roots in the former hierarchical system of ecological networks. There are several examples of GIs, but details of their implementation at a landscape level are often missing or they have been used non-systematically. Here, we demonstrate opportunities for landscape-level implementation of GIs based on spatial analysis through the application of ecological engineering or other measures. Using maps and expert evaluations of different land-use types, we created a methodology for national-scale determination of Estonia's GI. Based on spatially explicit datasets (e.g., land cover, soils, topography, roads), we determined the proportions of greenness and brownness (primarily anthropogenic) landscape indices. Areas with the highest greenness values served as the GI's core areas, whereas areas with the greatest anthropogenic composition represented the brown infrastructure. Identification and classification of hotspots where the two infrastructures are in conflict (e.g., construction, mining areas, roads, settlements, airports, power lines, wind turbines) revealed locations where ecological engineering and other measures are needed to mitigate or eliminate the conflict. Developing spatially explicit models of the conflicts between the infrastructures represents a new approach in landscape planning and environmental management that links coarse-scale landscape planning and regional landscape plans with more detailed local landscape plans that support the design of site-specific ecological engineering and other measures. We demonstrate that the implementation of GIs is inseparably connected with ecological engineering and landscape-scale planning.

1. Introduction

1.1. Historical background

In recent decades, the concept of a green infrastructure (GI, the network of natural and semi-natural components of a landscape) has become increasingly important in environmental planning and management, both internationally (UNEP, 2014) and at a national level in the development of policy agendas (e.g., in France, Grenelle Environment, 2010; in the UK, DCLG, 2012; in the United States, EPA, 2014). However, the early development of this idea can be traced back to the ecological networks described in the theories of Heinrich von Thünen, Walter Christaller, and Edgar Kant. Von Thunen (1826) proposed the first conceptual scheme for the optimization of land-use patterns in agricultural landscapes. Christaller (1933) introduced the theory of central places, then enlarged the concept to the whole region, and Estonian geographer Edgar Kant (1935) implemented it for the first time at a national level (Tammiksaar et al., 2018). The next major step was by Russian geographer Rodoman (1974), whose theory of polarized landscapes showed the role of the network of natural and semi-natural land uses as a counterbalance to human-engineered infrastructure.

In the second half of the last century, landscape planning practices in several European countries incorporated elements of nature conservation and environmental management (Haber, 1973; Olschowy, 1981; Sukopp and Weiler, 1988; Prendergast et al., 1993). Specific and detailed concepts, as well as national ecological network plans based on

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https://doi.org/10.1016/j.ecoleng.2018.05.019
Received 2 March 2018; Received in revised form 14 May 2018; Accepted 14 May 2018

those concepts, were developed in a number of Central and Eastern European countries, such as Slovakia (Ružička and Miklós 1982; Miklós, 1989,1996), Estonia (Jagomägi, 1983; Mander et al., 1988), the Czech Republic (Buček et al., 1986; Buček and Lacina, 1992), and Lithuania (Kavaliauskas, 1994, 1995).

As a logical development of country-scale ecological networks, 54 European countries endorsed the establishment of the Pan-European Ecological Network in 1995 as a part of the Pan-European Biological and Landscape Diversity Strategy (Jongman et al., 2011). The two major instruments to build the network were the European Union's (EU) Natura 2000 Network for 27 EU member states and the Emerald Network (an extension of Natura 2000 to non-member states). Under the name "Greenways", systems and concepts analogous to those in the EU network were developed in the United States (Ahern, 1995) and Australia (Hobbs, 2002). In Estonia, the concept was not implemented in legal practice after the country regained its independence in 1991. Only in the mid-1990s, when new legislation and modes of policy-making were initiated, was it possible for Estonia to bring the ecological network ideology into the public decision-making process (Sepp et al., 2001). Through these reforms, the concept of ecological networks has been incorporated into new spatial planning and environmental legislation. For example, Estonia's Planning Act (Government of Estonia, 2015) emphasizes the importance of green networks and designates green networks at national, county, and municipal levels.

Ecological networks (Fig. 1) are based on the concepts of core areas (i.e., central nodes in the network), ecological corridors (i.e., continuous connections between the nodes), stepping stones (i.e., non-continuous corridors), buffer zones (i.e., barriers between natural and anthropogenic areas), and restoration areas (i.e., anthropogenic areas that are being managed to make them more natural). The networks are designed and managed in such a way as to preserve biological diversity and to maintain or restore ecosystem services through the interconnectivity among the network's physical elements within the landscape (Jongman et al., 2011).

1.2. Current status of green infrastructures

The present environmental policies in Europe and the United States are based on the green infrastructure concept, and integrate the biodiversity targets from the ecological network concept, but also emphasize other ecosystem services. In Europe, green infrastructures are strategically planned networks of natural and semi-natural areas with environmental features that are designed and managed to deliver a wide range of ecosystem services. They incorporate green spaces (or "blue" spaces if aquatic ecosystems are also present) and other physical features in both terrestrial areas (including coastal, urban, and rural settings) and marine areas (EC, 2012; Davies and Lafortezza, 2017). The infrastructure is an interconnected network of green spaces that conserves natural ecosystem values and functions to provide associated benefits to human populations (Benedict and MacMahon, 2002, 2006). Maintaining the provision of ecosystem services through the development of green infrastructures is therefore increasingly recognized as a strategy to cope with changing future conditions. Thus, this represents a tool for providing ecological, economic, and social benefits through natural solutions, while also helping us to understand the benefits that nature offers to human society and helping to mobilize investments that sustain and enhance these benefits (EC, 2013; EEA, 2014). In the United States, green infrastructures include a strong component of stormwater management, especially in urban areas (EPA, 2010, 2014; Copeland, 2016). Often, the extensive man-made infrastructure (sometimes called "grey infrastructure") only fulfills single functions such as drainage or transportation, whereas nature often provides multiple solutions that are also cheaper, more robust, and economically and socially more sustainable (EEA, 2014).

Green infrastructure can be also considered as a kind of counterbalance against the anthropogenic infrastructure – the human-engineered structures such as settlements, paved surfaces, roads, power lines, and mining areas. Because of their conceptual distance from natural systems, intensively managed agricultural fields can be

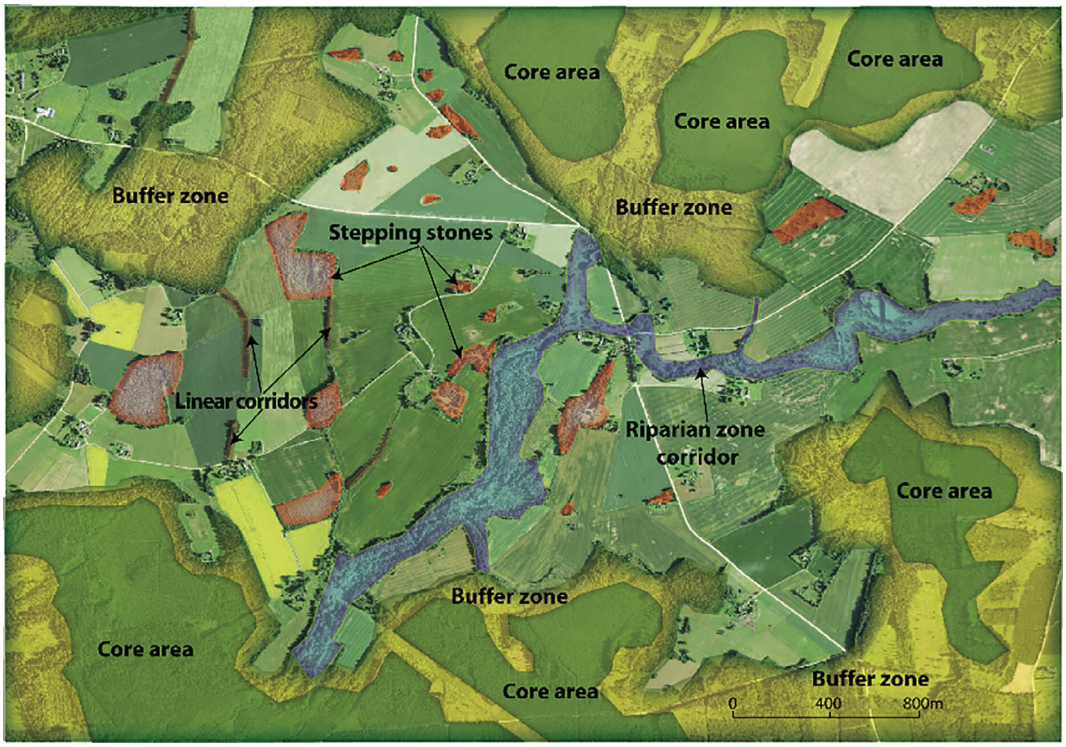

Fig. 1. An example of ecological networks – a predecessor of the green infrastructure concept. The aerial photo shows the main elements of such networks: core areas, linear and stepping-stone corridors, and buffer zones. The photo was extracted from an aerial orthophoto of southeastern Estonia (58°01′N, 27°26′E), and depicts a rural mosaic landscape. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)