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# Urban–rural ecological networks for landscape planning

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ABSTRACT

Urban–rural landscape planning research is nowadays focusing on strategies and tools that support practitioners to design local areas where human and natural pressures interfere. A prominent framework is provided by ecological network studies, whose design regards the combination of a set of green areas and patches (nodes) interconnected through environmental corridors (edges). Ecological networks are key for biodiversity protection and enhancement, as they are able to counteract fragmentation, and to create and strengthen relations and exchanges among otherwise isolated elements. Biodiversity evolution, indeed, depends on the quantity and quality of spatial cohesion of natural areas. In this paper, we propose a methodological framework based on network modelling for the study and modelling of ecological networks. We use network properties and centrality measures (degree, clustering coefficient, and betweenness centrality) and take into account the intensity of the dispersal capacity by introducing the corresponding weighted centrality measures. We simulate the dynamics of ecological networks by monitoring the residual dispersal capacity and the number of connected components from three perspectives: random attacks, deterministic attacks according to decreasing betweenness centrality and influence of master plans. We demonstrate that spatial network analysis is useful to monitor the performance of ecological networks and support decision-making, management, and planning.

The proposed methodology is applied to the case study of the peri-urban and urban areas of the town of Nuoro (Italy). Patches (nodes) have been selected among the ecosystems with target vegetal species Holm oak and cultivated and wild Olive while the connecting corridors (links) enable for seed dispersal.


## 1. Introduction

The development of human settlements has often caused severe interferences with local ecosystems that result in loss of biodiversity (Swingland, 2013). In this respect, uncontrolled pace of building activity and erosion of public spaces and green areas are major determinants (Jongman, 2004). Nowadays planners are faced with urban landscapes often in need of policies directed to the conservation of biodiversity (Forman, 1995). A prominent strategy able to satisfactorily meet these needs is to preserve and manage ecological networks, i.e. systems of green areas interlaced through corridors. In a number of cases, local authorities have successfully adopted programs based on ecological networks approach in order to counteract biodiversity decrease and facilitate the reintroduction of certain vegetal and animal target species in peri-urban and urban landscapes (Jongman et al., 2004). The analysis of the structure and behavior of ecological networks is often based on graph theory, a discipline that has recently received renewed interest due to the development of complex network analysis and to the availability of new tools, large data sets and computational power (see Dale and Fortin, 2010).

This paper provides a methodological framework for the modelling and study of ecological networks in peri-urban settings. Our approach can be adopted as a monitoring tool able to support practitioners to design master plans while enhancing and protecting ecological networks. In particular, we detail this study

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on four research objectives (ROs). $RO_1$ investigates the general debate about ecological system modelling and whether network modelling is a suitable approach to study ecological systems in peri-urban areas. $RO_2$ delves into the analysis of suitable network measures to scrutinize ecological systems. $RO_3$ investigates the spatial resilience of ecological networks to resist and adapt to external disturbances, thus able to deliver ecosystem services. $RO_4$ concerns the implementation of ecological network modelling as monitoring system in planning.

The argument is presented as follows. In the second and third sections, we debate the current literature and methodologies regarding biodiversity conservation strategies and ecological network analysis, management, and planning. In the fourth section, we discuss the cornerstones of complex network analysis and principles underlying the assessment of spatial resilience under random and preferential attacks. From the fifth to the ninth section, we focus on the case study of the municipality of Nuoro (Italy). In the fifth section, we detail the case study and the main spatial, environmental and ecological characteristics. In the sixth section, we build the ecological network while in the seventh and eighth section, we characterize the topological and weighted network by focusing on centrality measures and assess the spatial resilience of the system under different scenarios. In the ninth section, we discuss the results obtained with respect to the ROs and in the tenth section summarize the main findings and conclusions of our study.

## 2. Biodiversity and ecological networks

For much of the 20th century biodiversity conservation, understood in its classical meaning as the variety of life found in a place (Swingland, 2013), has found an effective tool in the establishment of natural protected areas (Boardman, 1981). However, over the past forty years, the validity of the concept of protected area has been in a crisis due to the excess of conventional "conservation islands" (MacArthur and Wilson, 1967; Boardman, 1981; Rodrigues et al., 2004; Hoekstra et al., 2005). Moreover, scholars have acknowledged the negative effects that landscape fragmentation causes on biodiversity (Forman, 2003; Jongman, 2004; Wiegand et al., 2005; EEA, 2011; Modica et al., 2012; Romano and Zullo, 2012; Fahrig, 2013; Vizzari and Sigura, 2015). At the same time, the emergence of theories on metapopulation (Levins, 1969), polarization of the landscape (Rodoman, 1974), and source-sink (Pulliam, 1988) have pioneered the conservation biology and the concept of landscape connectivity as tools to improve the vitality of the population and the species richness (Noss and Coperrider, 1994; Gilbert-Norton et al., 2010).

In this scientific and cultural context, the concept of "ecological network" (EN) has been introduced as a conservation tool for recovery and maintenance of ecological connectivity and environmental continuity (Levins, 1969; Simberloff, 1988; Dawson, 1994; Jongman, 1995; Forman, 1995).

The validity of scientific theory and the arguments behind this conservation strategy has been widely debated by various scholars (Diamond, 1975; Shafer, 1990; Hobbs, 1992; Simberloff et al., 1992; Dawson, 1994; Crooks and Sanjayan, 2006; Gilbert-Norton et al., 2010). In particular, the effectiveness of ecological networks, as tools able to maintain and improve landscapes and habitats spatially integrated, is increasingly accepted as an appropriate approach for improving natural ecosystems' quality and protecting biodiversity (Van Rooij et al., 2003; Verboom and Pouwels, 2004; Smith, 2004; Damschen et al., 2006; Crooks and Sanjayan, 2006; Gilbert-Norton et al., 2010; Hagen et al., 2012). More recently, ecological networks tools play a central role in landscape planning (Opdam et al., 2006; Steiner, 2008), also according to an ecological and functional integration approach (Fichera et al., 2010, 2015).

Although identified in different ways, also depending on the reference spatial scale and priority goals, the constituent elements of an ecological network are: (i) core areas, (ii) corridors, and (iii) buffer zones (Jongman, 1995; Bennett, 2004). Core areas or patches are zones of high natural value for the conservation of habitats, species and landscapes. Although the criteria for their identification are not homogeneous, such areas may be divided into two main types (Birò et al., 2006): institutional natural protected areas (Boitani et al., 2007); areas with particular characteristics (in terms of vegetation, size and spatial configuration etc.) suitable for the survival of certain species (Lambeck, 1997; Jetz et al., 2004; Watts et al., 2010). Corridors are physical connections between core areas to ensure the ecosystems self-regulation by allowing the spreading of species. The corridors can be distinguished on the basis of: (i) structure: continuous or discontinuous (stepping stones); (ii) function: migration, commuting, and dispersal corridors (Foppen et al., 2000); and (iii) characteristics that led to their identification (naturalness, bio permeability, etc.). Buffer zones are areas around the core areas and around the connecting elements, designed to protect network elements from exogenous disturbance originating from neighboring areas (Jongman, 2004; Oliver and Piatti, 2008).

In their implementation, ecological networks can be classified according to three basic approaches (Fichera et al., 2015): (i) physiographic approaches, centered on maintenance and strengthening of the spatial structure of the different existing ecosystems; (ii) functional approaches, oriented to the management of ecological processes (i.e. the regeneration of vital habitats for the target species that represent the local biodiversity); and (iii) planning approaches, centered on a multifunctional planning perspective: ecological, recreational, aesthetic, etc. In this paper, we mainly adopt the type (ii) approach.

These classical criteria are recently being integrated in the concept of green infrastructure (EEA, 2011), a complex and wide-ranging approach where ecological networks, as well as ensuring environmental features and the maintenance of biodiversity, are configured as guidelines for a proper ecological landscape planning.

## 3. Ecological networks in landscape planning

The construction and development of ENs is one of the prominent strategies able to counteract the decrease of biodiversity level in contemporary landscapes (Hagen et al., 2012). Bennett and Mulongoy (2006) reviewed a number of ecological networks from various locations around the world: relevant examples of on-going experiences include the Southern Rockies Wildlands Network in the United States, the Arakawa River Ecological Network in Japan, the East-Australasian Shorebird Site Network in Western Pacific, and the Tri-Dom Ecological Network in Africa. In a European perspective, Bloemmen and van der Sluis (2004) focused on a number of ENs and relevant jeopardized species, such as the Eurasian Lynx in Northern Europe, the brown bear in Italy, the Brent goose in the arc from France to Northern Russia, and the Eurasian crane all over the continent. ENs developed at different institutional levels have gained an increasing importance as possible common action in landscape planning towards nature conservation also in the context of European integration (Jongman et al., 2004). Beyond the green infrastructure, Natura 2000 network is one the main concepts that inspires the design and institution of ENs in Europe. In this respect and given the focus of this paper, Italy is very active. Regional administrations are responsible for the implementation of ENs: relevant examples include the regional ecological networks (RENs) of Apulia, Emilia Romagna, Lazio, Liguria, Lombardy, Marche, Tuscany, Veneto, and Umbria. In many cases, the REN constitutes a cornerstone for local landscape protection policy and planning.