Urban-rural ecological networks and 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 to the study and monitoring of ecological systems. 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.

Keywords: Peri-urban areas; ecological network; spatial network analysis; landscape planning; spatial resilience analysis; planning support

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 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.

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 (Biró 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.

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). Bennet 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.

In operational terms, the analysis of ENs can be referred to graph based modelling techniques that have been proposed under the field of *complex network analysis (CNA)*. CNA applications are based on mechanical statistics approach applied to the wider availability, in the last 15 years, of large data sets and higher processing power. These techniques have assisted analysts in the characterization of complex systems in many realms: biology, engineering, sociology, genomics, environmental planning, and others (Albert and Barabási, 2002; Boccaletti et al., 2006).

In addition, ENs should be inspected by invoking the class of spatial networks. These networks include elements that present a reference to geographical space: in our case, nodes and edges consist of patches and corridors, which display a certain location, extension, width, length, and shape (Dale and Fortin, 2010). The application of spatial networks to modeling ENs is still in its infancy and constitutes a promising field of application. Many studies present similar approaches, as they include, *inter alia*: i) identification of elements (Fortuna et al., 2006; Minor and Urban, 2007; Urban and Keitt, 2001; Urban et al., 2009); and ii) landscape connectivity analysis (Adriaensen et al., 2003; Bunn et al., 2000; Fall et al., 2007; Minor and Urban, 2008; Pascual-Hortal and Saura, 2006).

Advanced spatial analysis is usually adopted to recognize and map ecological patches and corridors through the use of GIS tools including ad hoc routines tailored for network analysis and available in many software programs (Boyd and Foody, 2011; Gurrutxaga et al., 2010; Marulli and Mallarach, 2005; Vuilleumier and Prélaz-Droux, 2002).

Landscape connectivity characterises the analysis of ENs, with a focus on establishing whether two given patches are connected or not. In this respect, meta-population, i.e. the study and identification of typical vegetal and animal target species, is of paramount importance (see, Cartensen et al. 2012; Cartensen and Olsen, 2009; Hepcan et al., 2009; Kissling et al., 2012). Each species is mainly defined by its general behaviour and attitude towards displacement. In this context, a very frequently adopted index is the dispersal distance that measures the maximum length a target species is able to cover. In this sense, two patches are connected if they are located within the dispersal distance of target species in a given EN.

Network theory and modeling for ecological systems

We are interested to model an ecological peri-urban system as a network of relational properties between patches (RO_1). In order to present our model to the largest readership, we first introduce some definitions that are necessary to set the ground of our discussion. We define our model using a graph $G = (E, N)$ that comprises a set of nodes $N(G)$ and edges (i.e. links) $E(G)$ such that each edge e_{ij} connects node i to j. Nodes and edges of ENs can include additional attributes such as dispersal probability between nodes (edge attribute) and the patches' area (node attribute).

The connection between nodes can be unidirectional if $e_{ij} = e_{ji}$ or directional otherwise. Connectivity is an important property of graphs as it allows nodes to reach and be reached by other nodes. A graph is said to be connected if every node is reachable from any other node. Conversely, unconnected graphs are composed by disconnected sub graphs. According to Urban and Keitt (2001), ecologists use a variety of terms to connote connectivity. In our case, it relates to the relational connectivity between patches in an ecological system modelled as a graph. The higher is the connectivity of an ecological network, the higher the capacity of an ecological system to survive, regenerate and grow.

An EN can be represented as a weighted directed spatial network in order to take into account: i) the pattern of seed dispersal from colonized to first neighbor nodes, and ii) the intensity of the relation between each pair of nodes (dispersal probability). In this respect, we consider that the intensity of interactions (i.e. weights) varies depending on the probability that plant seeds are dispersed. We spatially locate each node in its patch's centroid and we use the patch's area as an index of the carrying capacity, habitat quality and productivity (Urban and Keitt, 2001). Our model is a multilayer network (Boccaletti et al., 2014) composed of three graph-layers whose intra layer connections are: *i)* Euclidian distances d_{ij} between nodes i and j, *ii)* dispersal probability p_{ij} , and *iii)* dispersal flux w_{ij} between *i* and *j*. The dispersal probability is expressed as:

$$p_{ij} = f(\beta, d_{ij}) \quad (1)$$

where β is an impedance coefficient which accounts for the impact of space in the propagule dispersal (plant seeds). Dispersal probability can take several forms such as exponential and Gaussian distributions (Clark et al, 1999).

We use the concept of dispersal fluxes in order to take into consideration the capacity of source patches to “colonize” other patches. The dispersal flux from patch *i* to *j* is:

$$w_{ij} = \frac{ap_i}{ap_{tot}} p'_{ij} \quad (2)$$

where ap_i is the area of source patch *i* and ap_{tot} is the area of the habitat under examination. p'_{ij} is the probability of seed dispersal from *i* to *j*, normalized by the sum of *i*’s weights. Furthermore, being the network oriented, $w_{ij} \neq w_{ji}$.

In Appendix 1, the reader can find an examination of network measures discussed for the ENs’ class (RO_2).

Network spatial resilience against attacks

One of the aims of this study is to scrutinize the effect of land uses and of master plans on ecological networks in peri-urban and urban areas. The gain or loss of habitat’s patches is central to landscape change, in general, and land management, in particular (Urban and Keitt, 2001). Our goal is here to understand how an ecological network changes if one or more nodes are removed (RO_3). We benchmark network spatial resilience by evaluating the total residual dispersal capacity $F(T)$ in the network, which accounts for the propagule dispersal level in a network. We calculate the total residual dispersal capacity of a network at time T as follows:

$$F(T) = \sum_{i,j \in N} w_{ij}(T) \tag{3}$$

The higher F is, the higher the movement of propagule in a network, which signals higher biotic activities in the ecosystem.

Connection is key to ecological networks. The effect of fragmentation of an ecosystem reduces biodiversity and severely disrupts the functionalities of ecological networks. Disjoint sub-networks are the direct effect of fragmentation and we measure it by counting the number of connected components in the network, also called weakly connected components (Dijkstra, 1976). The smaller is the number of connected components after removing nodes, the higher is the network's spatial resilience to changes in its organization and biotic interactions.

We study the spatial resilience of ecological networks with a probabilistic and deterministic approach. In the probabilistic approach, we randomly remove nodes in order to evaluate the resilience of the system. In the deterministic approach we consider two strategies: in the first one we deliberately attack strategic nodes (i.e. nodes with high centrality) in order to check if the system would be resilient to extreme conditions. The second one evaluates the effects of master plans (i.e. in terms of land use changes) on ecological networks. The selective attack is implemented according to the probability of a given land use to interfere with the biotic life of an EN. We account for it by calculating the probability of planning interference (*PPI*) of each node *i* as follows:

$$PPI_i = f(A_i, LI_i, \phi_i) \tag{4}$$

where A_i is the area of the patch, LI_i is the land index (i.e. the maximum build volume per unit of surface area) and ϕ_i is a coefficient that accounts for the land use type of patch *i*. *PPI* is directly proportional with its three components. Thus, our hypothesis is that smaller patches are more fragile and have a higher probability to disappear. A higher land index allows landowners to build more in their property and thus our hypothesis is that the higher the *LI* the higher the probability of a patch to disappear. Finally, the coefficient ϕ_i takes into account the effect of different land uses. For example, one should expect that, under the *ceteris paribus* clause, an industrial settlement has a bigger impact than a residential settlement on ecological networks. The assessment of this measure is left to the practitioner that is implementing the analysis and has a good knowledge of the local planning system.

Case study: the ecological network of Nuoro (ENN)

The context of this application is Nuoro, a medium size town (roughly 37,000 inhabitants in 2014) located in central Sardinia, Italy (Figure 1).

Please, place Figure 1 about here

The history of the town reports on strong relationships between population and landscape, characterized by ecosystems belonging to the Mediterranean maquis and fairly high altitude sites (maximum 955 m above sea level), such as the Ortobene peri-urban mountain. The interplay between urban settlement and landscape is characterized by the absence of a clear boundary delimitating urban and rural settings. In this case, peri-urban areas play an important role in biodiversity management, because they are able to reconnect external environments to internal zones encapsulated in the urban fabric. The design and management of an ecological network is crucial for the municipality of Nuoro as the urban settlement is progressively sprawling into the surrounding rural areas. Urban and regional land use plans imply transformations, which affect positively and negatively the ecological network. In this case, a coordination is required, as many examples of municipal ecological network indicate (Jongman et al, 2004).

Target species and dispersal distance

Olive (*Olea europaea*) and Holm oak (*Quercus ilex*) are two of the most characteristic plant species of peri-urban landscape of the town of Nuoro. Both Olive and Holm oak are widely used in the urban and peri-urban green areas such as gardens and street trees and natural areas (abandoned orchards, parks, and unused areas). Thereafter, the choice of those two species allows for the classification of urban and peri-urban areas based on the potential colonization, presence and evolution of them (in Appendix 2, the reader can find a detailed description of the plant species and colonization processes that involve vegetal and animal species in the urban and peri-urban areas of Nuoro).

Our analysis has pointed out that the two plant species (Olive and Holm oak) have multiple possibilities to be efficiently dispersed in the peri-urban area of Nuoro, while a reasonably restricted access of vectors characterizes the urban zone. The highest spreading possibility is for Olive species that in spite of the minor dispersal distance $d_{ij,o}$ (maximum 100 m) is favoured by the high population of frugivorous birds actively feeding Olive fruits. On the contrary, the Holm oak showed a potential wider spreading distance $d_{ij,q}$ (maximum 1,000 m range) but a decidedly lower population of animal vectors and a strongest dependence from ecological corridors.

Data and software used

The construction of the ENN has implied the identification and classification of patches in a pilot area of Nuoro. Geographical information has been drawn from aero-photogrammetric maps and verified through photo-interpretation and field surveys. Orthophoto maps were geo-referenced into the Monte Mario/Italy zone 1 projection (EPSG code: 3003) and released in 2006 by the Autonomous Region of Sardinia (ARS). In addition, we have considered the information provided by the Sardinian Forestry Plan (District level). Land use planning information has been extracted

from the 2009 update of the municipal Master Plan (official Italian name and acronym: Piano Regolatore Generale, PRG) of the town of Nuoro. The Master Plan is a major tool in the Italian urban planning system and regulates land uses over the entire extension of a municipality. It establishes the *jus aedificandi* –i.e. the rules of land modifications- typically through the zoning, a subdivision of municipal territory into homogeneous areas that are attributed certain functions including: residence, historical center protection, urban services provision, agro-industrial production, territorial services, and environmental protection. The plan entered into force for the first time in 1976 and was updated in 2015 by a broader type of Master Plan (official Italian name and acronym Piano Urbanistico Comunale, PUC). Along these decades, the Master Plan was strongly modified and received a multitude of integrations following the international and national evolution of urban policies. During the early 1980s, prominent integrations concerned the design of new areas for public services and agricultural production. Starting from the 1990s, municipal administrations recognized and developed on the strong linkage between the town center and the natural value of the surrounding landscape. Actually, the new Master Plan has incorporated the results of this long evolution process: urban policy issues are well documented and available in the institutional website (reported in the Reference section).
Table 1 reports the metadata of the processed information.

Please, place Table 1 about here

Geographic information has been processed through CAD proprietary software (Autodesk AutoCad) and GIS open source software (QGIS). Spatial network visualization and analysis has been performed through the open source software Gephi (Bastian et al., 2009) and NetworkX (Hagberg et al., 2008).

Building the ENN

Our study has regarded the northern part of Nuoro, where we have sampled a set of 236 patches. Each patch has been classified as reported in Table 2.

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Two patches are connected if their centroids, i.e. barycenter points, lay within a certain dispersal distance. Thus, two patches are connected in the ENN depending on the geometry of their areas: small patches are much more likely to be interconnected than larger ones. In addition, we build a weighted oriented network following the discussion we present in the section 'Network theory and modeling for ecological systems'.

The starting point of our dynamic analysis is an initial scenario corresponding to the current state of the system that includes patches as nodes, only if they currently host at least one target species.

As far as the assessment of dispersal probability function is concerned (see 'case-study' section and appendix 2 for details), we consider a different mathematical expression for the two predominant target species. We modify equation (2) as follows:

$$w_{ij} = \frac{ap_i}{ap_{tot}} (p'_{ij,o} + p'_{ij,q} \cdot 10^{-3}) \tag{5}$$

where $p'_{ij,o}$ is the dispersal probability of Olive and $p'_{ij,q}$ is the dispersal probability of Holm oak. Dispersal capacity of Holm oak was estimated about thousand times weaker than that of Olive (Gómez, 2003; Mulas et al., 2003). For this reason, we have introduced a factor, which accounts for this phenomenon in equation (5).

We have estimated $p'_{ij,o}$ and $p'_{ij,q}$ by using data published in a similar study and the arguments discussed in the 'case-study' section. We have fit the data in Figure 1 by Gómez (2003) with several probability distributions and have found that a log-normal distribution is the best candidate (R^2 = 0.696).

The dispersal probability of Olive and Holm oak are as follows:

$$p'_{ij,o} = 2.09 + \frac{7489.42}{\sqrt{2 \cdot 3.14} \cdot 0.53 \cdot d_{ij}} e^{\frac{-(\ln \frac{d_{ij}}{247.42})^2}{2 \cdot (0.53)^2}} \qquad (6)$$

$$p'_{ij,q} = 2.09 + \frac{748.942}{\sqrt{2 \cdot 3.14} \cdot 0.53 \cdot d_{ij}} e^{\frac{-(\ln \frac{d_{ij}}{24.742})^2}{2 \cdot (0.53)^2}} \qquad (7)$$

We illustrate the weighted ENN in Figure 2, where a spatial weighted representation of the system overlays the orthophoto of the town. Nodes are identified by (blue) dots; weights are thematically represented in different colour and thickness; and patches are mapped out as green coloured areas.

Please, place Figure 2 about here

Analysis of the ENN

This section delves into the description of the topological and weighted network analysis of the ENN (the reader not familiar with these measures may want to refer to appendix 1). Table 3 reports the main topological measures: number of nodes (N) and edges (E), density (D), average shortest path length ($<l>$) and diameter or maximum path length (l_{max}). E is two orders higher than N leading to a very high density, a sign of a strongly interconnected network. The average shortest path length, a measure of cohesiveness among the nodes, is low thus confirming the high interconnectivity in the ENN.

Please, place Table 3 about here

Please, place Figure 3 about here

The last three measures of Table 3 represent a synthetic indication of different aspects of network centrality, which are biased by the high density of the network. Average total degree is 75 and when we spatially plot the distribution of nodes (Figure 3), we clearly observe four clusters: the first one, located in the central part of the study area, includes nodes with high degree; the second and the third ones are located on the east and west side of the first high-degree node cluster respectively. The last one, which spreads across a wider area, is located in the east side of the study area. Our spatial statistical analysis highlights that the most sensible and important area of the ENN includes patches that belong to the first cluster. Those areas play a vital role for the network being composed of highly connected patches, which are also located close to each other. Spread of diseases, fire and any human and natural hazard could arm the preservation of biotic life in the network if patches were compromised in these areas.

The average clustering coefficient (*C*) is also very high but when we look at the spatial distribution of *C*, we see a different scenario (Figure 4): nodes with high clustering coefficient are positioned in the outer south-east and south-west areas where there is a higher local dispersal capacity due to the interconnectivities between near nodes.

Please, place Figure 4 about here

We plot betweenness centrality (*BC)* of each node in Figure 5, which allows us to detect patches that act as bridges and provide the shortcuts in the ENN. The network has a large number of nodes with high *BC,* which is a signal of high resistance to external attacks.

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In the second part of our analysis, we scrutinize the ENN as a weighted network. In table 4, we report the main measures obtained in this analysis.

Please, place Table 4 about here

Please, place Figure 6 about here

While the weight holds the intensity of connections (dispersal capacity) between patches (see Figure 2), the strength (S) is able to appreciate the centrality of a node with respect to the "traffic" implied (Figure 6). In our case, a few nodes stand out as paramount for the biotic life of the network. This is mainly due to the fact that those patches have large areas thus highest dispersal capacity. From this point of view, they can be seen as network reservoirs, which allow for the biotic survival of the system.

Finally, we map out the weighted clustering coefficient (C_w) (Figure 7) and the weighted BC (BC_w) (Figure 8) for each patch. While in the case of C_w peripheral rural patches are those with higher values (as for the case of S), the BC_w is higher for nodes located in the central part of the network.

Please, place Figure 7 about here

Please, place Figure 8 about here

The network analysis has thus so far shown two different categories of nodes equally important for the biotic life of the ENN: nodes localized in its outer edge (i.e. belonging to peri-urban, i.e. rural areas contiguous to the town) show the highest dispersal capacity and enhance the spread of seeds, while nodes in its central part allow for the circulation of biotic flows in the network.

Spatial resilience analysis

Having scrutinized the complex interacting relationships in the ENN, our attention reverses now on its spatial resilience to changes. According to Cumming (2011), spatial resilience refers to the way in which a spatial variation (including connectivity and dispersal) influences the resilience of social-ecological systems. This concept is of paramount importance for ecological networks as it directly links to biodiversity and regional diversity among ecosystems. An ecosystem that is resilient to natural and human disturbances ensures stable functional biotic conditions. From our point of view, we are interested to assess whether the ENN is resilient to human changes and whether the ecosystem will survive to disturbances. From a planning approach, disturbances may result in the loss of patches due to several natural factors (earthquakes, flooding, windstorms, vegetal diseases, etc.) and artificial drivers (building of new settlements, fires, urban forestry activities, biologic treatments, etc.), that hinders the development of the target species and the dispersal process.
We have scrutinized the resilience of the ENN to exogenous attacks by simulating the loss of patches. We have assessed the response of the ENN to three approaches illustrated in Table 5.

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According to the first approach, we perform a stochastic selection, where nodes are randomly and progressively removed at each step. Furthermore, in order to reduce the error of our stochastic model, we apply a Monte Carlo approach (Ripley, 1987). We repeat the experiment 1,000 times and consider the most probable state provided by the average value at each step. With respect to the variables describing the resistance/resilience, we evaluate the effect of nodes' removal by calculating the total residual dispersal capacity $F(T)$ (Formula 3) and the number of connected components in the ENN. The other two approaches imply a preferential selection of the nodes to be attacked and successfully eliminated. The second approach deterministically assesses the adaptability of the system when it loses more important nodes. We remove nodes in descending order of BC. The third approach implies the removal of nodes due to another deterministic criterion, namely the level of influence of the Master Plan of Nuoro over the ENN in descending order of PPI (equation 4).

Figure 9 and 10 illustrate the results of our analysis developed according to the first approach. The horizontal axis represents the percentage share of removed nodes at each step, while the vertical axis reports the total residual capacity $F(T)$, on the left, and the number of connected components on the right.

Please, place Figure 9 about here

The total residual dispersal capacity is fitted by a polynomial curve of second degree (R^2=0.99) which signals a gradual loss of total dispersal capacity. The system conserves 50% of its dispersal capacity after removing 30% of nodes and about one third of its dispersal capacity after removing 50% of its nodes. These results are complemented by the analysis of connected components. We found that the cut point for the ENN to have more than one connected components is 90% of removed nodes. After removing 98% of total nodes, we found that the network had only three connected components. These results are in line with previous studies that showed that co-evolving systems of interlaced human and natural activities are resilient to external shocks (Gunderson, 1999). Figure 10 visualizes the process of node removal and the progressive loss of nodes and links in the network. We have decided to remove the spatial reference of nodes in order to focus our attention on the topological features of the network.

Please, place Figure 10 about here

In Figure 11, we show the results of the study developed according to the second approach involving a preferential attack of central nodes. We removed 53% of the total number of nodes (we removed nodes with no null *BC*). The drop in the total dispersal capacity is much higher in this test. The network loses more than 50% of its total dispersal capacity after removing 5% of its nodes and splits in two sub networks (connected components). The 5% threshold characterizes a 10% loss of dispersal capacity by removing one more percent of nodes. Other relevant thresholds are at 3, 10 and 18%. After removing 10% of the most central nodes, the network has a residual dispersal capacity 90% lower than its initial dispersal capacity.

Please, place Figure 11 about here

The third approach evaluates the impact of human activities (i.e. land use and master planning) by removing nodes according to the impact of the Master Plan of Nuoro on the ENN. In Figure 12, we illustrate the results of resilience analysis according to *PPI*-based node removal.

Please, place Figure 12 about here

We observe a slower decay of $F(T)$ compared to the *BC*-based removal illustrated in Figure 11: the network conserves 50% of its functionality after removing around 50% of nodes. The *BC*-based removal follows an exponential decay (R^2 = 0.96) while the PPI-based removal a linear trend (R^2 = 0.99) in the first part (50% removed nodes) and a polynomial trend in the second part (R^2 = 0.95). We thus conclude that the effect of the Master Plan of Nuoro on the ENN is intermediate between a random attack and preferential *BC*-based attack. The latter findings open a wider discussion on the effect of human settlements and land planning on ecological networks. In the next section we will discuss the results obtained in this study with emphasis on the role that network modelling should/can assume in monitoring ecological systems. Results presented in the previous two sections, have in fact shown that the loss of certain nodes/patches could turn out to be very dangerous and disruptive for the survival of an ecological network. Targeted and planned actions could substantially mitigate and avoid the loss of those patches if put in place.

Discussion

In this section, we discuss the results obtained in this study focusing on the Research Objectives described in the introduction.

With respect to RO_1 concerning the building of the ecological network modeling, we have formulated a series of hypotheses while modeling our ecological system as a spatial network (Hagen et al, 2012). We have considered nodes representing the centroids of natural patches, which host two vegetal target and the relative vector bird species (Gómez, 2003; Rey and Alcántara, 2000). The interactions among those species create a complex system of relationships intertwined by differently intense dispersal relations that we have further considered and coded as weighted edges in the network. The model (ENN) has been calibrated considering two vector species that transport plant seeds between patches. Links' weights provide with a measure of probability of seed dispersal between two given patches. The ENN has been thus constructed to consider the complex relations in the peri-urban fringe of Nuoro and the exchanges between external rural and internal urban landscapes of the municipality. These circumstances allow us to develop on a relevant local example of universal scenarios characterizing contemporary landscapes.

We have investigated RO_2 regarding centrality (inspired by, *inter alia*, the study of Minor and Urban, 2008) by selecting three network measures able to describe the criticality of nodes as pivoting elements. In particular, we have developed on the *BC* analysis, which represents the global inter-centrality of nodes acting as bridges and offering shortcuts to flows of biotic materials (in this case, the seeds). In addition, centrality measures have been calculated taking into account the weights of the connections and allow to locate the most influential/critical patches in the network. The analysis of BC_w (see Figure 8) clearly indicates that five zones of the ENN are critical and deserve a particular protection and planning regime.

As far as RO_3 about spatial resilience properties is concerned, we have studied the reaction of ecological networks to progressive node removal (Urban and Keitt, 2001). In our case, we have simulated different scenarios by taking into account three types of potential hazards to simulate different sorts of dangerous events. We have demonstrated that the ENN currently is able to resist to random attacks on its nodes. By contrast, the ENN becomes soon very fragile when disturbed by preferential attacks addressed to the nodes with the highest networking dispersal capacity (*BC*). This evidence confirms what we have observed above: the preservation of nodes with the highest *BC* is crucial for the survival of the ENN. In addition, we have illustrated how the ENN is resilient to targeted attacks aimed to nodes exposed to higher probability of removal due to the interference generated by the Master Plan. In this respect, we note that the ENN under planning regulations is more resilient than it would be without any Master Plan.

Considering RO_4 about planning support and monitoring through ecological network analysis, we have demonstrated that modelling an ecological system, as a spatial network, would allow practitioners for an immediate detection of the most crucial nodes and a simulation of the effect of external disturbances (i.e. human activities). With respect to similar investigations (Urban and Keitt, 2001), our work is original, since it detects the perturbations induced by master plans and leads to useful indications on the ecological effectiveness of given planning regimes. We have illustrated how network modeling offers the possibility to monitor the characteristics of a complex ecological system. A few simple variables and concepts prove useful for understanding the collective resistance/vulnerability and formulating possible strategies for the protection and enhancement of ecological networks.

Conclusions and outlook

This paper has recalled the major research streams attaining biodiversity conservation, which includes, *inter alia*, the design, construction, and maintenance of ecological networks (Jongman et al., 2004). We have presented an approach to the study of ecological networks in landscape planning and recalled fundamental concepts, such as target species and dispersal distance that have allowed us to understand, model and describe the main determinants that impact on the dynamics of an ecological network, i.e. the colonization of new green areas and patches. We have connected the analysis of these issues with researches on graphs and, in particular, spatial networks (Dale and Fortin, 2010). Similarly to other studies (Gómez, 2003) green areas represented by patches' centroids are interlaced by connections featured with a weight describing the probability of mutual colonization. We have built the ecological network of Nuoro (ENN) on a pilot set of 236 patches connected according to the spatial distribution and dispersal pattern of two target plant species: Olive and Holm oak. We have applied spatial network analysis on the ENN to describe its characteristics in the current state and to dynamically monitor its resilience against hypothetical random and deterministic attacks. The analysis has focused in particular on network centrality of patches through three measures: degree, clustering coefficient, and betweenness centrality. These indicators are able to locate the most critical patches providing the whole system with informational resistance and shortcuts. The dynamic analysis refers to the assessment of the level of resilience measured through two relevant proxies, namely the residual dispersal capacity, and the number of connected components.

We have directed our analyses to four Research Objectives illustrated in the Discussion section and have demonstrated that network modelling provides planners with a set of simple and meaningful variables (i.e. centrality measures) and concepts (i.e. resilience to external disturbances). The discussion on the ROs is useful as it provides with a synthetic rationale of the scientific premises and peculiar contributions developed in this paper.

Although this research has already demonstrated a number of valuable findings, we call for further work on some empirical questions. The opportunity to monitor the effect of different planning dispositions in time and space needs additional work. The study of the 2015 update of the Master Plan of Nuoro can be applied with a comparative and dynamic perspective. For our case study, recent contacts with the administration of the municipality of Nuoro have been directed to launching the project of an ecological network and a dedicated municipal environmental and planning observatory. Furthermore, the current pilot system presented in this study covers the northern sector of the town of Nuoro including 236 patches. We plan to extend our analysis to the whole municipality comprehending both rural and urban areas. Patches have been detected through the presence of target species using two instruments: field survey and orthophoto interpretation. As the first is always the most reliable assessment of current state of the patches, we will verify every patch colonization state through direct field work.

Appendix 1

Network measures for ecological systems

One of the measures that quantify the compactness of a graph is the *diameter* (l_{max}) which measures the highest number of edges that separate any pair of nodes. The set that includes the edges connecting two nodes is called path (l). The path l_{ij}, that connects two nodes i and j with the minimum number of edges, is the shortest path.

We mathematically formalize an ecological network using an adjacency matrix A, where diagonal elements a_{ii} are equal to zero (no self-loops are admitted: a patch cannot be connected to itself) and off-diagonal elements a_{ij} are equal to 1, if nodes i and j are connected, and 0 otherwise.

Network theory and modelling has a vast literature on measures that have been used in different fields to study networks' structure and understand, explain, and predict systems' behaviours. In this appendix, we set the methodological ground and delve into network centrality (RO_2) that we use to investigate ecological networks.

Topological and weighted degree centrality

Centrality is a core topic in network analysis since it allows one to identify nodes that play a primary role in the network. We are interested to characterize network centrality in an ecological habitat for both weighted and un-weighted graphs. Node degree (k) is the simplest measure of centrality and provides a very basic quantification of the structural (topological) importance of patches in the habitat: the higher is the degree k of a node, the higher is the dispersal capacity of the patch and thus the contribution in keeping the biological functions of the habitat active. The un-weighted (topological) degree k for node i is expressed as follows:

$$k_i = \sum_{j \in \vartheta} a_{ij} \tag{1.1}$$

where ϑ is the set of *j* nodes connected to *i*.

Because we model ecological systems as oriented graphs, one can distinguish between in-degree k^{in} (received dispersal activities) and out-degree k^{out} (forwarded dispersal activities). Both k^{in} and k^{out} are paramount for a habitat life as nodes with high k^{out} ensure dispersal activities today while nodes with high k^{in} are those with highest probability to be colonized and be active part of the network in future. The in-degree is the sum connections onto node *i*:

$$k_i^{in} = \sum_{j=\vartheta} a_{ij} \tag{1.2}$$

The out-degree is the total number of connections coming from node *i*:

$$k_i^{out} = \sum_{j\in\vartheta} a_{ji} \tag{1.3}$$

The sum of in-degree k^{in} and out-degree k^{out} is equal to the total degree *k*:

$$k_i = k_i^{in} + k_i^{out} \tag{1.4}$$

The weighted form of the network provides richer information and considers flows rather than a simple binary description of nodes' interactions. Similarly to degree *k* in the un-weighted case, we can define the strength for the total in-flow (s^{in}) and total out-flows (s^{out}) from each node. Their algebraic description can be written as follows:

$$s_i^{in} = \sum_{j\in\vartheta} w_{ij} \tag{1.5}$$

$$s_i^{out} = \sum_{j \in \vartheta} w_{ji} \tag{1.6}$$

$$s_i = s_i^{in} + s_i^{out} \tag{1.7}$$

Strength *s* allows one to evaluate nodes' importance according to the strongest direct effects from and to other nodes (Urban and Keitt, 2001).

Clustering coefficient (C)

Modeling an eco-system as a network allows us to go one-step further in our quantitative analysis by not only considering the single patch but also quantifying the structural organization of the network. The clustering coefficient accounts for the fraction of interconnected neighbors of a given node. We expect that the higher the clustering coefficient, the higher is the dispersal capacity of a node because it is well connected to densely interconnected nodes (clusters or cliques), instead of being randomly connected to other nodes. The clustering coefficient can better describe how fast dispersal activities propagate across the network. The clustering coefficient (*C*) for a node *i* in an undirected and un-weighted network reads as follows:

$$C_i = \frac{2t_i}{k_i(k_i - 1)} \tag{1.8}$$

where t_i denotes the number of triangles around *i*. In order to account for the dispersal flow in the network, we use the weighted *C* as proposed by Barrat et al. (2004):

$$C_i^w = \frac{1}{s_i(k_i - 1)} \sum_{j,k} \frac{\hat{w}_{ij} + \hat{w}_{ik}}{2} a_{ij} a_{jk} a_{ik} \tag{1.9}$$

where the weight $\hat{w}_{ij}$ between node *i* and *j* is obtained as the average value between the links' weight in the oriented graph $\hat{w}_{ij} = \frac{w_{ij} + w_{ji}}{2}$.

Betweenness centrality (BC)

Betweenness centrality (*BC*) is another measure of node centrality, which accounts for the fraction of shortest paths that pass through a given node *i*. A patch with high *BC* is an important intermediary for seed dispersal in ecological networks. Thus, a patch could serve as a bridge between clusters of nodes (sub graphs) and interconnect parts of the habitat otherwise disconnected which would have been doomed to disappear trough time. Freeman (1977) has formalized *BC* as follows:

$$BC_r = \sum_{i,j \in N} \frac{\rho(i,j,r)}{\rho(i,j)} \tag{1.10}$$

where $\rho(i,j,r)$ is the number of shortest paths passing through node *r* and $\rho(i,j)$ is the total number of shortest paths in the graph. The shortest path between two given nodes in the network can be calculated only if the given nodes belong to the same sub graph (if the network is composed of disconnected sub graphs). A common strategy used to find the shortest path between two nodes is the Dijkstra algorithm (1959), which finds the path with the least cost. In network modelling a weight associated to a link is usually seen as impedance between two nodes (i.e., spatial distance). In our model, the weight w_{ij} associated to an edge e_{ij} represents the strength of interaction (dispersal flow) between patches. For this reason, when we calculate *BC* we inverse the edge weights (dividing 1 by the weight). This implies that a stronger edge gets a lower cost than a weaker edge (Newman, 2001).

Appendix 2

Vegetal species in Nuoro.

Olive is a peculiar component of the agricultural landscape by means of the cultivated variety (*O. europaea* var. *sativa*). Orchards are more or less traditional in the planting and managing system and the case of abandoned cultivations is present. Dissemination from cultivated plants may produce feral seedlings but also the wild variety (*O. europaea* var. *sylvestris*) is widely present in the peri-urban natural areas and may be active in the natural colonization of abandoned areas (Mulas, 1999; 2009, 2012; Mulas et al., 2002). Following the evolution of the vegetation cover, the affirmations of olive seedling generate the shrub or tree form of the species as component of the Mediterranean maquis (Mulas et al., 2001; 2005). Holm oak is the main component of most developed forests widely growing in the hills around the urban area of Nuoro. Moreover, the pure Holm oak forest is the climax natural vegetation cover of the Nuoro land hills (Mulas et al., 2004a). Olive and Holm oak frequently establish a natural equilibrium (Mulas et al., 2003). Olive is a colonizing species of burned or degraded soils by means of wild or feral seedlings. Seed spreading is highly efficient thanks to many birds or small mammalians (Mulas et al., 2003; 2004b). Seedlings slowly developed as bushes showing a fundamental function of soil protection and enhancing vegetation cover evolution. Olive bushes or trees also play a role in the affirmation of the subsequent colonization of Holm oak. This species, in fact, needs the shade of other bushes or trees and that is the case of the mature Mediterranean maquis. Because of the seed larger size and tender texture, the seedling spreading of Holm oak is less efficient than Olive. However, after colonization, Holm oak is very competitive with respect to other plant species and a significant reduction of biodiversity may be easily measurable in mature forests (Mulas et al., 2003).

Seed dispersal process in Nuoro.

With the aim to analyze this potential network system and to elaborate a corresponding functional model, a first definition of potential patches and corridors has been designed and presented in Table 2.1. This is a minimal systematic key of land description proposed for the first step of the soil cover classification.

Please, place Table 2.1 about here

The most active seed dispersal vector of the Holm oak seeds is the European jay (*Garrulus glandarius*) (Gómez, 2003; Pons and Pausas, 2007). The average dispersal distance of the bird is 250 m, with a recorded maximum of 1,000 m (Table 2.2).

Please, place Table 2.2 about here

Less effective as seed dispersers are the rodents, with some different species like woodmouse (*Apodemus sylvaticus*) and garden dormouse (*Eliomys quercinus*) (Gómez et al., 2008). Rodents are also active in the seed dispersal of Olive but the maximum dispersal distance of these vectors is of few meters. More efficient as olive seed disperser are many frugivorous birds, like Common Starling (*Sturnus vulgaris*), Song Thrush (*Turdus philomenos*), Blackcap (*Sylvia atricapilla*), Sardinian Warbler (*Sylvia melanocephala*) (Rey and Alcántara, 2000; Alcántara and Rey, 2003). The most probable maximum distance of seed dispersal by these birds is of 100 m because they swallowed olive fruits whole, regurgitating the stones 20-50 minutes later (Bass et al., 2006). Wild big mammalians and livestock, like pigs, sheep, goats and cattle, feed both Holm oak and Olive seeds. However, these vectors efficiently disperse only olive seeds. In addition, the European fox (*Vulpus vulpus*) may be a possible disperser of olive seeds for a maximum distance of 50 km (Bass et al., 2006).

References

Adriaensen, F., Chardon, J.P., De Blust, G., Swinnen, E., Villalba, S., Gulinck, H., Matthysen, E., 2003. The application of "least-cost" modelling as a functional landscape model. Landsc. Urban Plan. 64, 233-247.

Albert, R., Barabási, A.L., 2002. Statistical mechanics of complex networks. Rev. Mod. Phys. 74, 47-97.

Alcántara, J.M., Rey, P. J., 2003. Conflicting selection pressure on seed size: evolutionary ecology of fruit size in a bird-dispersed tree, Olea europaea. J. Evol. Biol. 16, 1168-1176.

Barrat, A., Barthélemy, M., Pastor-Satorras, R., Vespignani, A., 2004. The architecture of complex weighted networks. Proc. Natl. Acad. Sci. 11, 3747-3752.

Bass, D.A., Crossman, N.D., Lawrie, S.L., Lethbridge, M.R., 2006. The importance of population growth, seed dispersal and habitat suitability in determining plant invasiveness. Euphytica 148, 97-109.

Bastian, M., Heymann, S., Jacomy, M., 2009. Gephi: an open source software for exploring and manipulating networks, 3rd International AAAI Conference on Weblogs and Social Media, May 17 - 20, 2009, San Jose, California.

Bennett, G., 2004. Guidelines on the application of existing international instruments in developing the Pan-European Ecological Network (Nature and Environment Series, No. 124). Council of Europe Publishing, Strasbourg.

Bennett, G., Mulongoy, K., 2006. Review of experience with ecological networks, corridors and buffer zones (Technical Series, No. 23). Secretariat of the Convention on Biological Diversity, Montreal.

Birò, E., Bouwma, I., Grobelnik, V., 2006. Indicative map of the Pan-European Ecological Network in South-Eastern Europe (Technical background document). European Centre for Nature Conservation, Tilburg.

Bloemmen, M. and van der Sluis, T. (Eds.) 2004. European corridors – examples studies for the Pan European Ecological Network (Alterra Report N° 1087). Wageningen, Alterra.

Boardman, R., 1981. International Organisation and the Conservation of Nature. Macmillan, New York.

Boccaletti, S., Bianconi, G., Criado, R., Del Genio, C. I., Gómez-Gardeñes, J., Romance, M., Zanin, M., 2014. The structure and dynamics of multilayer networks. Physics Reports 544(1), 1-122.

Boccaletti, S., Latora, V., Moreno, Y., Chavez, M., Hwang, D. U., 2006. Complex networks:

Structure and dynamics. Physics reports 424(4), 175-308.

Boitani, L., Falcucci, A., Maiorano, L., Rondinini, C., 2007. Ecological networks as conceptual frameworks or operational tools in conservation. Conserv. Biol. 21(6), 1414-1422.

Boyd, D.S., Foody, G.M., 2011. An overview of recent remote sensing and GIS based research in ecological informatics. Ecol. Inform. 6, 25-36.

Bunn, A.G., Urban, D.L., Keitt, T.H., 2000. Landscape connectivity: A conservation application of graph theory. J. Environ. Manag. 59, 265-278.

Carstensen, D.W., Dalsgaard, B., Svenning, J.-C., Rahbek, C., Fjeldså, J., Sutherland, W.J., Olesen, J.M., 2012. Biogeographical modules and island roles: a comparison of Wallacea and the West Indies. J. Biogeogr. 39, 739-749.

Carstensen, D.W., Olesen, J.M., 2009. Wallacea and its nectarivorous birds: nestedness and modules. J. Biogeogr. 36, 1540-1550.

Clark, J.S., Silman, M., Kern, R., Macklin, E., HilleRisLambers, J., 1999. Seed dispersal near and far: patterns across temperate and tropical forests. Ecol. 80, 1475-1494.

Crooks, K. R., Sanjayan, M., 2006. Connectivity Conservation, Conservation Biology Book Series. Cambridge University Press, Cambridge.

Cumming, G.S., 2011. Spatial resilience in social-ecological systems. Springer, New York and Dordrecht.

Dale, M.R.T., Fortin M.-J., 2010. From graphs to spatial graphs. Annu. Rev. Ecol. Evol. Syst. 41, 21-38.

Damschen, E.I., Haddad, N.M., Orrock, J.L., Tewksbury, J.J., Levey, D.J., 2006. Corridors increase plant species richness at large scales. Sci. 313, 1284-1286.

Dawson, D., 1994. Are habitat corridors conduits for animals and plants in a fragmented landscape? A review of scientific evidence (English Nature Research Report, No. 94). English Nature. Retrieved April 15, 2014 from http://publications.naturalengland.org.uk/publication/148102.

Diamond, J.M., 1975. The island dilemma: lessons of modern biogeographic studies for the design of nature reserves. Biol. Conserv. 7(2), 129-146.

Dijkstra, E.W., 1959. A note on two problems in connexion with graphs. Numerische Mathematik 1, 269-271.

Dijkstra, E.W., 1976. A Discipline of Programming. Prentice Hall, New York.

EEA, 2011. Green infrastructure and territorial cohesion. EEA (European Environment Agency), Copenhagen.

Fahrig, L. (2013). Rethinking patch size and isolation effects: the habitat amount hypothesis. Journal of Biogeography, 40, 1649–1663. doi:10.1111/jbi.12130

Fall, A., Fortin, M.-J., Manseau, M., O'Brien, D., 2007. Spatial graphs: principles and applications for habitat connectivity. Ecosyst. 10, 448-461.

Fichera CR, Laudari L, Modica G (2015). Application, validation and comparison in different geographical contexts of an integrated model for the design of ecological networks. Journal of Agricultural Engineering, 46: 52. DOI: 10.4081/jae.2015.459

Fichera, C.R., Laudari, L., Modica, G., 2010. From the construction of an ecological network to the definition of an environmentally sustainable planning model for periurban space. In: XVII World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR) on "Sustainable Biosystems through Engineering". Québec City, Canada, June 13-17, 2010.

Foppen, R.P.B., Bouwma, I.M., Kalkhoven, J.T.R., Dirksen, J., Van Hopstal, S., 2000. Corridors of the Pan-European Ecological Network: Network, concepts and examples for terrestrial and fresh water vertebrates. European Centre for Nature Conservation, Tilburg.

Forman, T.T., 1995. Land Mosaics. The Ecology of Landscapes and Regions. Cambridge University Press, New York.

Forman, T. T. 2003. Road Ecology: Science and Solutions. Island Press

Fortuna, M.A., Gómez-Rodríguez, C., Bascompte, J., 2006. Spatial network structure and amphibian persistence in stochastic environments. Proc. R. Soc. B 273, 1429-1434.

Freeman, L.C., 1977. A set of measures of centrality based on betweenness. Sociom. 40, 35-41.

Gilbert-Norton, L., Wilson, R., Stevens, J.R., Beard, K.H., 2010. A meta-analytic review of corridor effectiveness. Conserv. Biol. 24, 660-668.

Gómez, J.M., 2003. Spatial patterns in long-distance dispersal of Quercus ilex acorns by jays in a heterogeneous landscape. Ecogr. 26, 573-584.

Gómez, J.M., Puerta-Piñero, C., Schupp, E.W., 2008. Effectiveness of rodents as local seed dispersers of Holm oaks. Oecologia 155, 529-537.

Gunderson, L., 1999. Resilience, flexibility and adaptive management - antidotes for spurious certitude? Conserv. Ecol. 3(1), 7(1-9).

Gurrutxaga, M., Lozano, P.J., del Barrio, G., 2010. GIS-based approach for incorporating the connectivity of ecological networks into regional planning. J. Nat. Conserv. 18, 318-326.

Hagberg, A., Schult, D., Swart, P., 2008. Exploring Network Structure, Dynamics, and Function using NetworkX. In: Varoquaux, G., Vaught, T., Millman, J. (Eds.), Proceedings of the 7th Python in Science conference (SciPy 2008). SciPy Organizers, Pasadena (CA), pp. 11-15.

Hagen, M., Kissling, W.D., Rasmussen, C., De Aguiar, M.A.M., Brown, L.E., Carstensen, D.

W., Alves-Dos-Santos, I., Dupont, Y.L., Edwards, F.K., Genini, J., Guimarães, P.R., Jenkins, G.B., Jordano, P., Kaiser-Bunbury, C.N., Ledger, M.E., Maia, K.P., Darcie Marquitti, F.M., Mclaughlin, Ó., Morellato, L.P.C., O'Gorman, E.J., Trøjelsgaard, K., Tylianakis, J.M., Morais Vidal, M., Woodward, G., Olesen, J.M., 2012. Biodiversity, Species Interactions and Ecological Networks in a Fragmented World. Adv. Ecol. Res. 46, 89-210.

Hepcan, Ş., Hepcan, Ç.C., Bouwma, I.M., Jongman, R.H.G., Özkan, M.B., 2009. Ecological networks as a new approach for nature conservation in Turkey: A case study of İzmir Province. Landsc. Urban Plan. 90, 143-154.

Hobbs, R.J., 1992. The role of corridors in conservation: solution or bandwagon? Trends Ecol. Evol. 7(11), 389-392.

Hoekstra, J., Boucher, T., Ricketts, T., Roberts, C., 2005. Confronting a biome crisis: Global disparities of habitat loss and protection. Ecol. Lett. 8(1), 23-29.

Jetz, W., Carbone, C., Fulford, J., Brown, J.H., 2004. The scaling of animal space use. Sci. 306(5694), 266-268.

Jongman, R., 2004. The context and concept of ecological networks. In: Jongman, R., Pungetti, G. (Eds.), Ecological Networks and Greenways Concept, Design and Implementation. Cambridge University Press, Cambridge, pp. 7-33.

Jongman, R.H.G., 1995. Nature conservation planning in Europe: developing ecological networks. Landsc. Urban Plan. 32(3), 169-183.

Jongman, R.H.G., Külvik, M., Kristiansen, I., 2004. European ecological networks and greenways. Landsc. Urban Plan. 68, 305-319.

Kissling, W.D., Dormann, C.F., Groeneveld, J., Hickler, T., Kühn, I., McInerny, G.J., Montoya, J.M., Römermann, C., Schiffers, K., Schurr, F.M., Singer, A., Svenning, J.-C., Zimmermann, N.E., O'Hara, R.B., 2012. Towards novel approaches to modelling biotic interactions in multispecies assemblages at large spatial extents. J. Biogeogr. 39, 2163-2178.

Lambeck, R.J., 1997. Focal Species: A Multi-Species Umbrella for Nature Conservation. Conserv. Biol. 11(4), 849-856.

Levins, R., 1969. Some demographic and genetic consequences of environmental heterogeneity for biological control. Bull. Entomol. Soc. Am. 71, 237-240.

MacArthur, R.H., Wilson, E.O., 1967. The Theory of Island Biogeography. Princeton University Press, Princeton.

Marulli, J., Mallarach, J.P., 2005. A GIS methodology for assessing ecological connectivity: application to the Barcelona Metropolitan Area. Landsc. Urban Plan. 71, 243-262.

Minor, E.S., Urban, D.L., 2007. Graph theory as a proxy for spatially explicit population models in conservation planning. Ecol. Appl. 17(6), 1771-1782.

Minor, E.S., Urban, D.L., 2008. A Graph-Theory Framework for Evaluating Landscape

Connectivity and Conservation Planning. Conserv. Biol. 22(2), 297-307.

Modica, G., Vizzari, M., Pollino, M., Fichera, C.R., Zoccali, P., Di Fazio, S., 2012. Spatio-temporal analysis of the urban–rural gradient structure: an application in a Mediterranean mountainous landscape (Serra San Bruno, Italy). Earth Syst. Dyn. 3, 263–279. doi:10.5194/esd-3-263-2012

Mulas, M., 1999. Characterisation of olive wild ecotypes. Acta Horticulturae 474, 121-124.

Mulas, M., 2009. Domesticazione delle forme selvatiche di Olea europea L. per la produzione di biomasse legnose [Domestication of wild relatives of Olea europaea L. for woody biomass production], Atti del Terzo Convegno Nazionale sulle Piante Mediterranee “Le Piante Mediterranee nelle Scelte Strategiche per l’Agricoltura e l’Ambiente”. Bari, 27 settembre/1 ottobre 2006. Ital. J. Agron., Supplement issue IV, 4: 77-84.

Mulas, M., 2012. Study, collection and characterization of oleaster genetic resources. Acta Horticulturae 948, 135-142.

Mulas, M., Cauli, E., Francesconi A.H.D., 2002. Advances in the study of wild olive genetic resources. Acta Horticulturae 586, 121-124.

Mulas, M., Cauli, E., Francesconi, A.H.D., 2001. Valorizzazione delle forme selvatiche di Olea europaea L. per gli usi forestali della specie. [Evaluation of Olea europaea L. wild relatives for the forestry use of the species] Monti e Boschi, LII(2), 47-54.

Mulas, M., Congia, A., Cauli, E., 2004b. Colonizzazione da parte di specie della macchia mediterranea di aree interessate da attività mineraria superficiale nel Sulcis-Iglesiente. [Land colonization by Mediterranean maquis species of abandoned mines in Sulcis-Iglesiente area] Italus Hortus 11(4), 291-294.

Mulas, M., Deidda, P., Chessa, I., 2005. Risorse dei sistemi vegetali mediterranei, [Plant resources of Mediterranean systems] Atti della Giornata di studio su “Polifunzionalità delle specie vegetali della macchia mediterranea”. Firenze, 11 marzo 2004. I Georgofili, Serie VIII, 1, 131-150.

Mulas, M., Fadda, A., Cauli, E., Sulis, S., 2004a. Caratterizzazione di selezioni di leccio (Quercus ilex L.) provenienti da popolazioni della Sardegna Centrale. [Characterization of Holm Oak (Quercus ilex L.) selections from populations of Central Sardinia]. Italus Hortus 11(4), 225-227.

Mulas, M., Perinu, B., Ruiu, E.P., 2003. Ecologia delle forme selvatiche di Olea europaea L. in una formazione a macchia mediterranea, [Wild Olea europaea L. ecology in a maquis plant cover] Atti del III Congresso Nazionale SISEF “Alberi e Foreste per il Nuovo Millennio”, Viterbo, 15-18 ottobre 2001, pp. 159-165.

Newman, M.E.J., 2001. Scientific collaboration networks. II. Shortest paths, weighted networks, and centrality. Phys. Rev. E 64, 016132(1-7).

Noss, R.F., Coperrider, A.Y., 1994. Saving Nature’s Legacy: Protecting and Restoring Biodiversity. Defenders of Wildlife. Island Press, Washington, DC.

Nuoro (1976). Piano Regolatore Generale, PRG (Master Plan). Bollettino Ufficiale della Regione Autonoma della Sardegna 12 (1976). [in Italian].

Oliver, M., Piatti, G. (Eds.), 2008. World Heritage and Buffer Zones, International Expert Meeting on World Heritage and Buffer Zones Davos, Switzerland, 11-14 March, Davos, Switzerland. UNESCO World Heritage Centre, Paris (France).

Opdam, P., Steingröver, E., Van Rooij, S., 2006. Ecological networks. A spatial concept for multi-actor planning of sustainable landscapes. Landsc. Urban Plan. 75, 322-332.

Pascual-Hortal, L., Saura, S., 2006. Comparison and development of new graph-based landscape connectivity indices: towards the priorization of habitat patches and corridors for conservation. Landsc. Ecol. 21(7), 959-967.

Pons, J., Pausas, J.G., 2007. Acorn dispersal estimated by radio-tracking. Oecologia 153, 903-911.

Pulliam, H., 1988. Sources, Sinks and Population regulation. Am. Nat. 132, 652-661.

Rey, P.J., Alcántara, J.M., 2000. Recruitment dynamics of a fleshy-fruited plant (Olea europaea): connecting patterns of seed dispersal to seedling establishment. J. Ecol. 88, 622-633.

Ripley, B. D., 1987. Stochastic Simulation. New York: Wiley & Sons.

Rodoman, B., 1974. Polarisation of landscape as a management agent in the protection of biosphere and recreational resources. Resursy, Sreda, Rasselenije. Nauka, Moscow, pp. 150-163.

Rodrigues, A.S.L., Andelman, S.J., Bakarr, M.I., Boitani, L., Brooks, T.M., Cowling, R.M., Fishpool, L.D.C., da Fonseca, G.A.B., Gaston, K.J., Hoffmann, M., Long, J.S., Marquet, P.A., Pilgrim, J.D., Pressey, R.L., Schipper, J., Sechrest, W., Stuart, S.N., Underhill, L.G., Waller, R.W., Watts, M.E.J., Yan, X., 2004. Effectiveness of the global protected area network in representing species diversity. Nat. 428, 640-643.

Romano B., Zullo F., 2012. Landscape fragmentation in Italy. Indices implementation to support territorial policies. In: Campagna M., De Montis A., Isola F., Lai S., Pira C., Zoppi C. (Eds.), Planning Support Tools: Policy analysis, Implementation and Evaluation: 399-414. Franco Angeli, Italy

Shafer, C.L., 1990. Nature Reserves. Island Theory and Conservation Practice. Smithsonian Institution Press, Washington and London.

Simberloff, D., 1988. The contribution of population and community biology to conservation science. Annu. Rev. Ecol. Evol. Syst. 19, 473-511.

Simberloff, D., Farr, J.A., Cox, J., Mehlman, D.W., 1992. Movement corridors: conservation bargains or poor investments? Conserv. Biol. 6(4), 493-504.

Smith, D.J., 2004. Impact of roads on ecological networks and integration of conservation and transportation planning: Florida as a case study. In: Jongman, R., Pungetti, G. (Eds.), Ecological

Networks and Greenways Concept, Design and Implementation. Cambridge University Press, Cambridge, pp. 73-91.

Steiner, F.R., 2008. The Living Landscape, Second Edition: An Ecological Approach to Landscape Planning. Island Press, Washington, DC.

Swingland, I.R., 2013. Biodiversity, Definition of. In: Encyclopedia of Biodiversity, Second Edition, Volume 1. Elsevier, Amsterdam (The Netherlands), pp. 399-410.

Urban, D.L., Keitt, T., 2001. Landscape connectivity: a graph-theoretic perspective. Ecol. 82, 1205-1218.

Urban, D.L., Minor, E.S., Treml, E.A., Schick, R.S., 2009. Graph models of habitat mosaics. Ecol. Lett. 12(3), 260-273.

Van Rooij, S.A.M., Van Der Sluis, T., Steingrover, E.G., 2003. Networks for Life. Development of an Ecological Network for Persiceto (Emilia-Romagna, Italy) (Report No. 729). Wageningen, The Netherlands: Alterra, Green World Research.

Verboom, J., Pouwels, R., 2004. Ecological functioning of networks: a species perspective. In: Jongman, R., Pungetti, G. (Eds.), Ecological Networks and Greenways Concept, Design and Implementation. Cambridge University Press, Cambridge, pp. 56-72.

Vizzari, M., Sigura, M., 2015. Landscape sequences along the urban–rural–natural gradient: A novel geospatial approach for identification and analysis. Landsc. Urban Plan. 140, 42–55. doi:10.1016/j.landurbplan.2015.04.001

Vuilleumier, S., Prélaz-Droux, R., 2002. Map of ecological networks for landscape planning. Landsc. Urban Plan. 58(2-4), 157-170.

Watts, K., Eycott, A.E., Handley, P., Ray, D., Humphrey, J.W., Quine, C.P., 2010. Targeting and evaluating biodiversity conservation action within fragmented landscapes: an approach based on generic focal species and least-cost networks. Landsc. Ecol. 25(9), 1305-1318.

Wiegand, T., Revilla, E., Moloney, K.A., 2005. Effects of habitat loss and fragmentation on population dynamics. Conserv. Biol. 19, 108-121.

Websites.

Apulia. Rete Ecologica Regionale (Regional Ecological Network). http://paesaggio.regione.puglia.it/index.php/lo-scenario-strategico/cinqueprogetti/reteecologica.html [last accessed August 9, 2015].

Emilia Romagna. Rete Ecologica Regionale (Regional Ecological Network). http://ambiente.regione.emilia-romagna.it/parchi-natura2000/sistema-regionale/rete-ecologica [last accessed August 9, 2015].

European Commission. Natura 2000 Network. http://ec.europa.eu/environment/nature/natura2000/index_en.htm [last accessed August, 9 2015].

Lazio. Rete Ecologica Regionale (Regional Ecological Network). http://arplazio.it/pp~id-43+sx-+dx-+alto-+id_settore-3+id_pp-.htm [last accessed August 9, 2015].

Liguria. Rete Ecologica Regionale (Regional Ecological Network). http://www.ambienteinliguria.it/lirgw/eco3/ep/linkPagina.do?canale=/Home/020natura/020retenatura2000/030reteecologicaregionale [last accessed August 9, 2015].

Lombardy. Regional Ecological Network. http://www.reti.regione.lombardia.it/cs/Satellite?c=Page&childpagename=DG_Reti%2FDGLayout&cid=1213602060172&p=1213602060172&pagename=DG_RSSWrapper [last accessed August 9, 2015].

Marche. Rete Ecologica Regionale (Regional Ecological Network). http://www.ambiente.marche.it/Ambiente/Biodiversit%C3%A0ereteecologica/Biodiversit%C3%A0/ReteEcologicaRegionale.aspx [last accessed August 9, 2015].

Nuoro. Piano Urbanistico Comunale, PUC (Master Plan). http://www.comune.nuoro.it/index.php/Cittadino/Territorio_e_Urbanistica/7418/PUC_(Piano_Urbanistico_Comunale)_definitivo_della_Citt%C3%A0_di_Nuoro.htm [last accessed September 21, 2015].

Tuscany. Siti di Importanza Regionale e i siti di interesse regionale (Sites of Regional Importance and Sites of Regional Interest). http://www.regione.toscana.it/enti-e-associazioni/ambiente/biodiversita/-/asset_publisher/eonjZadAbVH6/content/siti-di-importanza-regionale-sir-e-i-siti-di-interesse-regionale-sir-;jsessionid=2D52939863281080404F2F23EF23C2F3.web-rt-as01-p2 [last accessed August 9, 2015].

Veneto. Rete Ecologica Regionale e Biodiversità (Regional Ecological Network and Biodiversity). http://www.regione.veneto.it/web/ambiente-e-territorio/reti-ecologiche [last accessed August 9, 2015].

Umbria. Rete Ecologica Regionale (Regional Ecological Network). http://www.regione.umbria.it/ambiente/rete-ecologica-della-regione-umbria-reru- [last accessed August 9, 2015].

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Table 1

Description	**Format**	**Scale**	**Spatial Resolution**	**Year**	**Source**
Aerophotogrammetric map of Nuoro	AutoCad drawing (*.dwg)	1:10,000	—	1998	ARS
RGB Orthophoto	*.Geotiff	—	0.50 m x 0.50m	2006	ARS
Sardinian Forestry Plan	*.pdf	1:250,000	—	2007	ARS
Master Plan of Nuoro	*.shp	Various	—	2009	Province of Nuoro

Table 2

N	Classification	Olive (*Olea europaea*)	Holm oak (*Quercus ilex*)
1	Olive orchard	Dominant cultivated	Absent, possible colonization
2	Green area	Present cultivated	Absent, possible colonization
3	Green area	Absent, possible colonization	Present as young plants
4	Green area	Present cultivated	Absent, possible colonization
5	Green area	Present cultivated	Established
6	Green area	Present cultivated	Established
7	Green area	Absent, possible colonization	Established
8	Green area	Absent, possible colonization	Established
9	Green area	Absent, possible colonization	Established
10	Natural area	Initial colonization	Absent, possible colonization

Table 3

N	***E***	***D***	**<*l*>**	l_{max}	**<*K*>**	**<*C*>**	**<*BC*>**
236	17,717	0.63	1.62	5	75.08	0.67	0.0027

Table 4

$<w>$	$<s>$	$<C_w>$	$<BC_w>$
0.1234	8.1211	0.0018	0.0067

Table 5

N	Type of attack	Selection criterion	Main variables describing resilience
1	Random	Stochastic, Monte Carlo	Total residual dispersal capacity, number of connected components
2	Preferential 1	Deterministic, Decreasing BC	Total residual dispersal capacity, number of connected components
3	Preferential 2	Deterministic, Decreasing influence of master planning (Master Plan of Nuoro)	Total residual dispersal capacity, number of connected components

Table 2.1

Zone	Patch Classification	Olive (*Olea europaea*)	Holm Oak (*Quercus ilex*)
Peri-urban	1) Natural area or rangeland	Absent	Absent
	2) Olive orchard	Dominant as cultivated or abandoned tree	Absent
	3) Natural area or rangeland	Present as initial colonization by seedlings	Absent
	4) Natural area or rangeland	Affirmed as shrub component of maquis	Absent
	5) Natural area or rangeland	Affirmed as shrub and tree	Present as initial colonization by seedlings
	6) Pure or mixed forest	Absent	Present or dominant as mature tree
Urban	7) Abandoned area	Present or potentially colonizable area	Absent
	8) Natural area/green area	Affirmed as shrub component of maquis or urban green	Absent or present as young plants
	9) Natural area/green area	Absent	Present or dominant as mature tree
	10) Corridors	Street trees, way borders and other forms of natural communications.	Street trees, way borders and other forms of natural communications.

Table 2.2

Vector Species	**Olive (*Olea europaea*)**	**Holm Oak (*Quercus ilex*)**
Jay (*Garrulus glandarius*)	Unknown	1,000 m
Common Starling (*Sturnus vulgaris*); Song Thrush (*Turdus philomenos*); Blackcap (*Sylvia atricapilla*); Sardinian Warbler (*Sylvia melanocephala*);	100 m	Unknown
Rodents: woodmouse (*Apodemus sylvaticus*); garden dormouse (*Eliomys quercinus*)	7.5 m	7.5 m
Sheep (*Ovis aries*), goat (*Capra aegagrus hircus*), cattle (*Bos taurus*), pig (*Sus scrofa*)	2,000 m	Unknown
Fox (*Vulpus vulpus*)	50 km	Unknown

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Figure 4 Thematic mapping of the Clustering Coefficient (*C*). The image in the background is an orthophoto released in 2006 by the Autonomous Region of Sardinia.
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Figure 11 Second approach to ENN resilience analysis: effects of *BC*-based preferential nodes' removal.
Figure 12 Third approach to ENN resilience analysis: effects of *PPI*-based preferential nodes' removal.

Figure 1

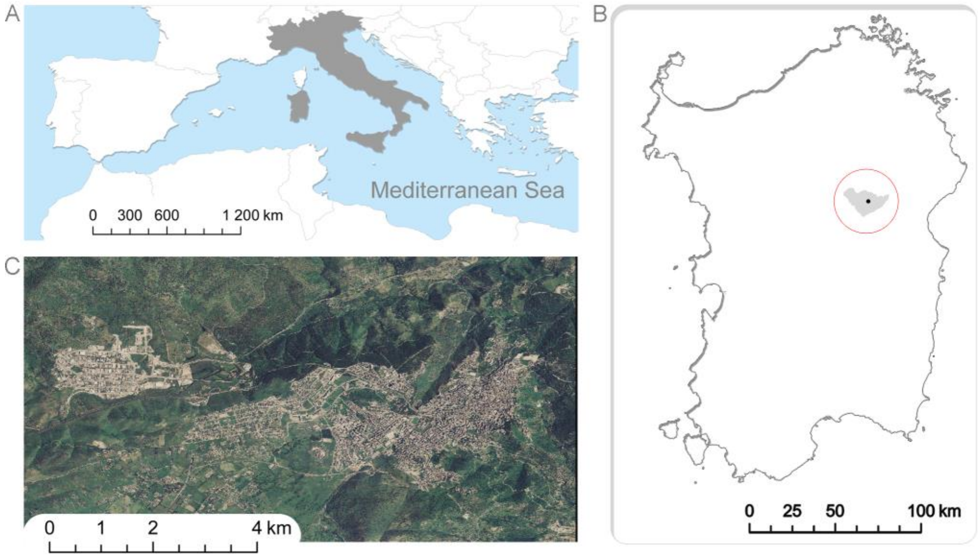


Figure 2

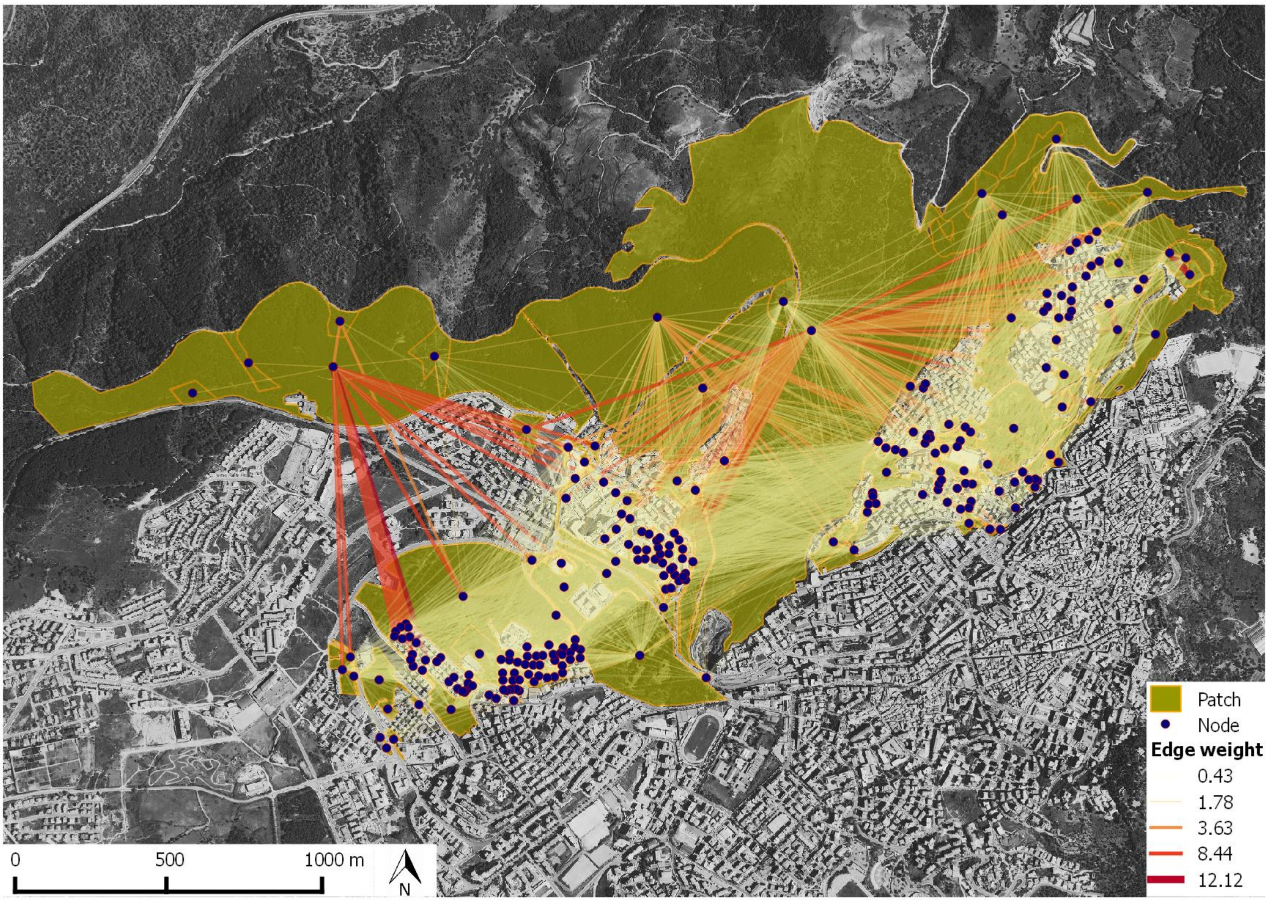


Figure 3

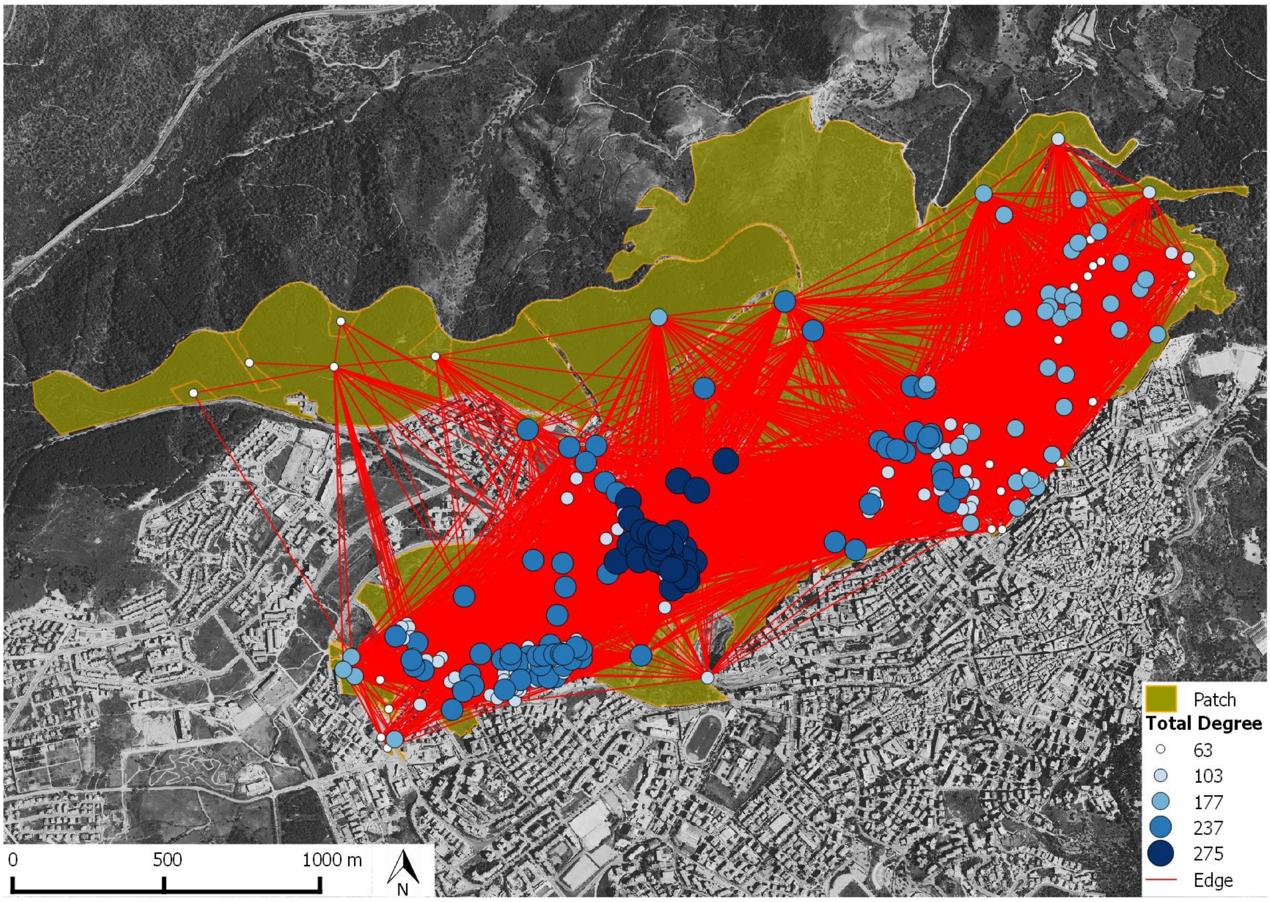


Figure 4

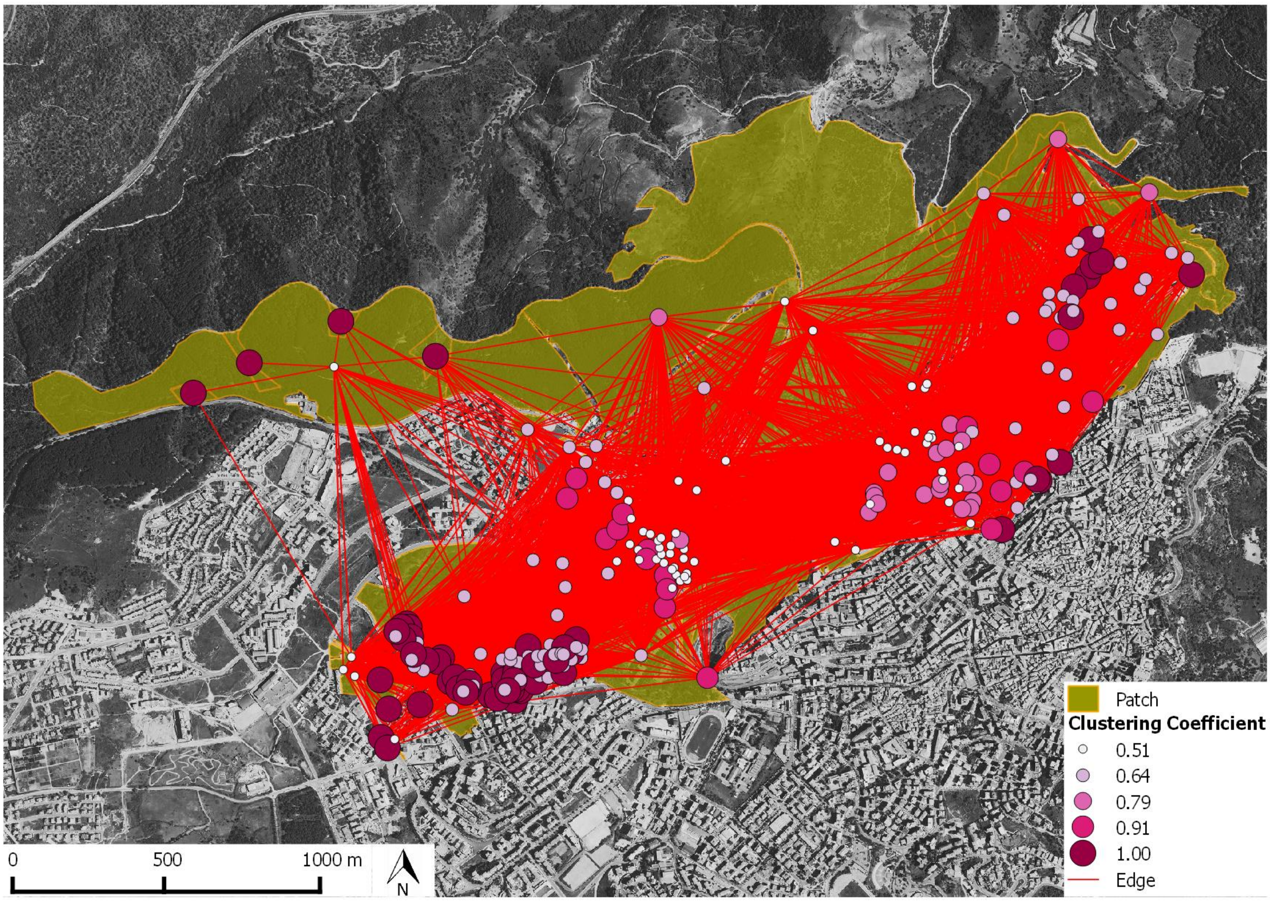
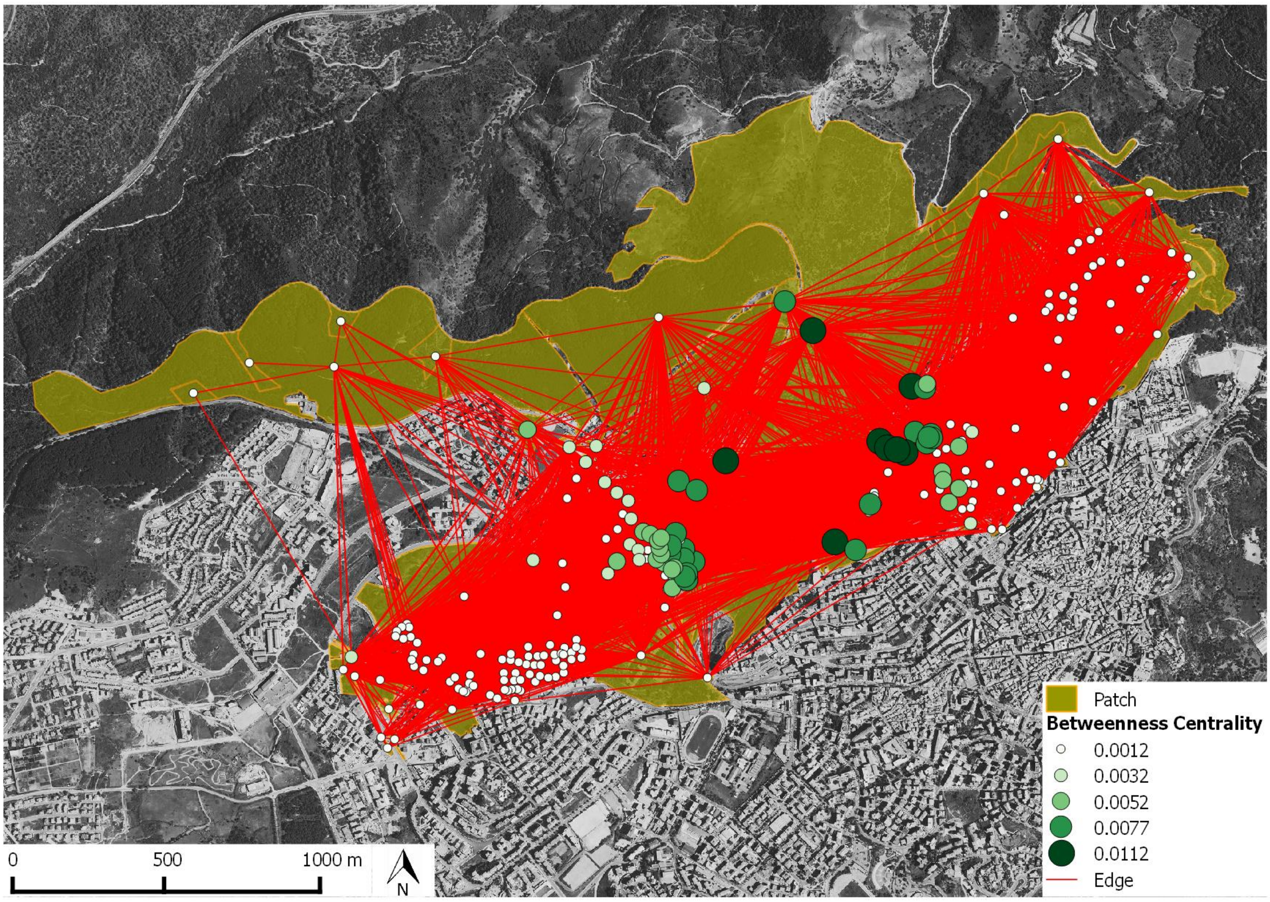

Patch
Clustering Coefficient
0.51
0.64
0.79
0.91
1.00
Edge
0
500
1000 m
N

Figure 5



Patch
Betweenness Centrality
0.0012
0.0032
0.0052
0.0077
0.0112
Edge
0
500
1000 m
N

Figure 6

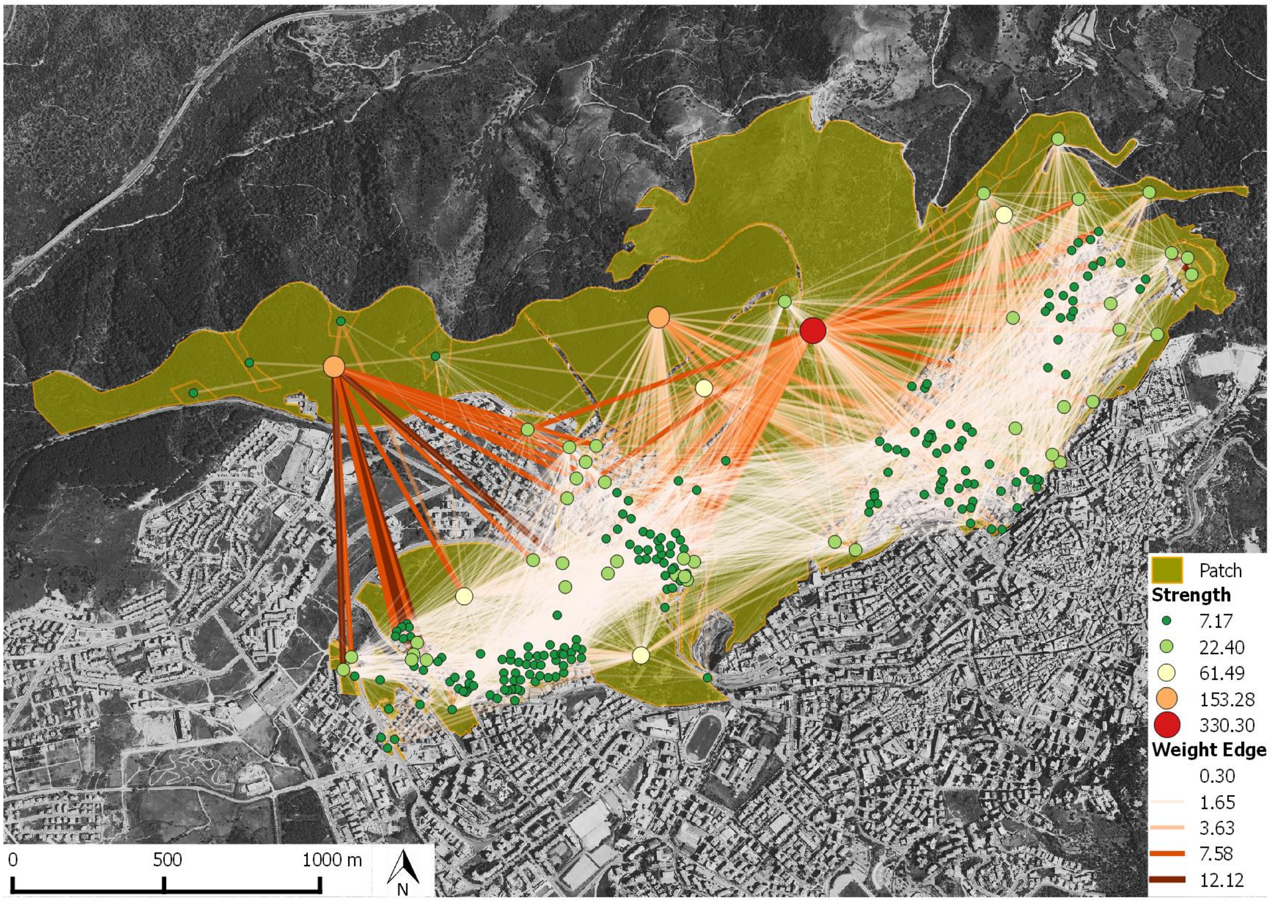

Patch
Strength
7.17
22.40
61.49
153.28
330.30
Weight Edge
0.30
1.65
3.63
7.58
12.12
0
500
1000 m
N

Figure 7

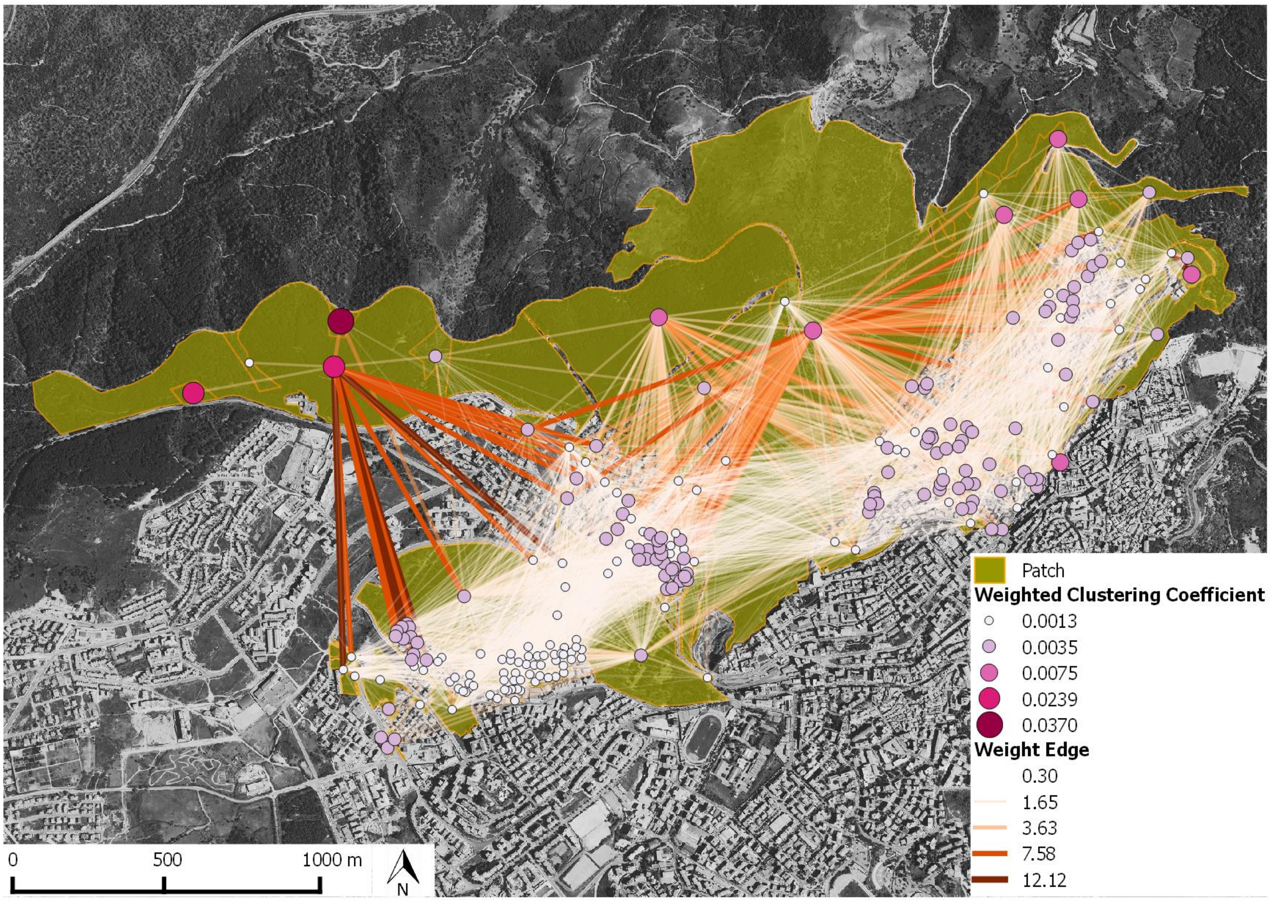

Patch
Weighted Clustering Coefficient
0.0013
0.0035
0.0075
0.0239
0.0370
Weight Edge
0.30
1.65
3.63
7.58
12.12
0
500
1000 m
N

Figure 8

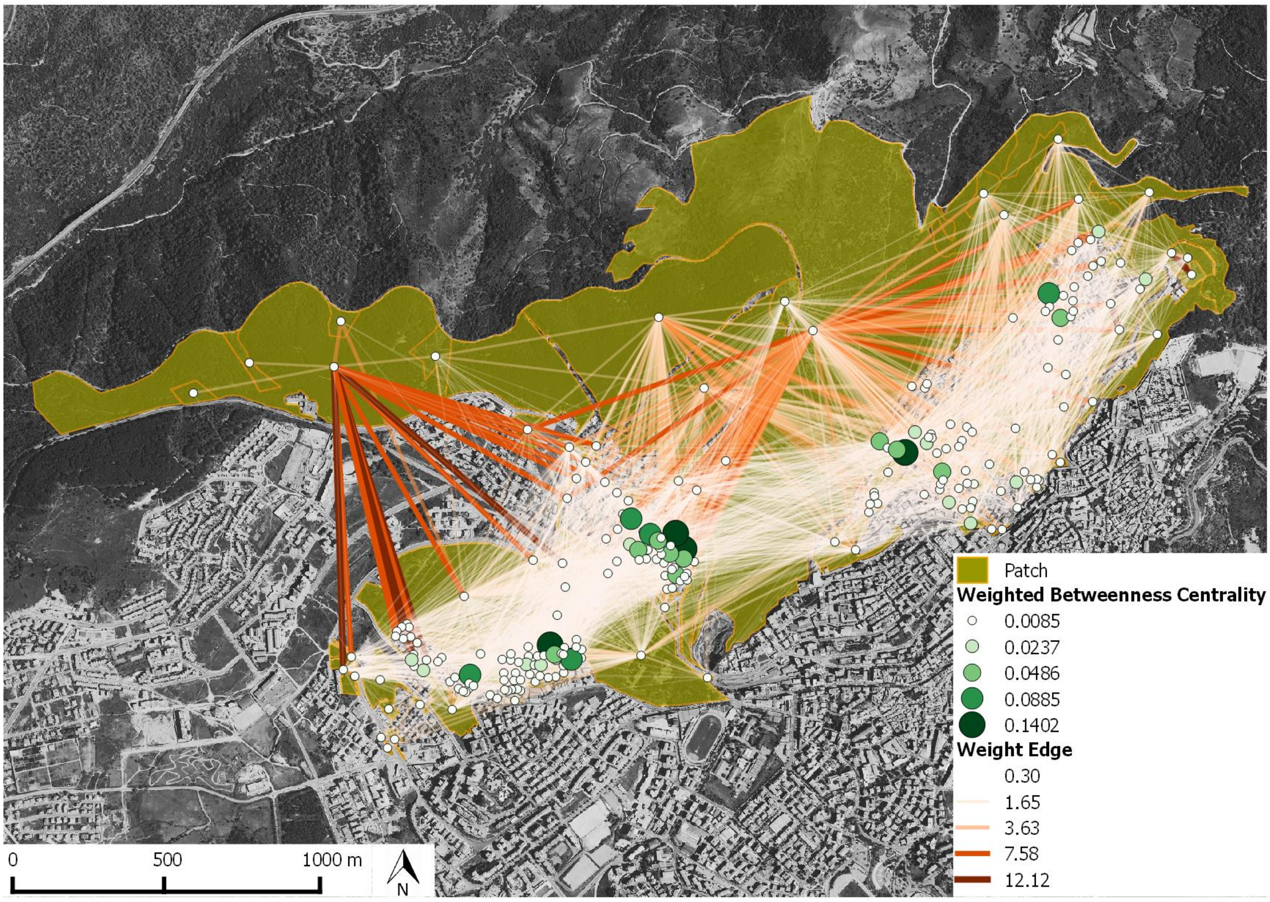
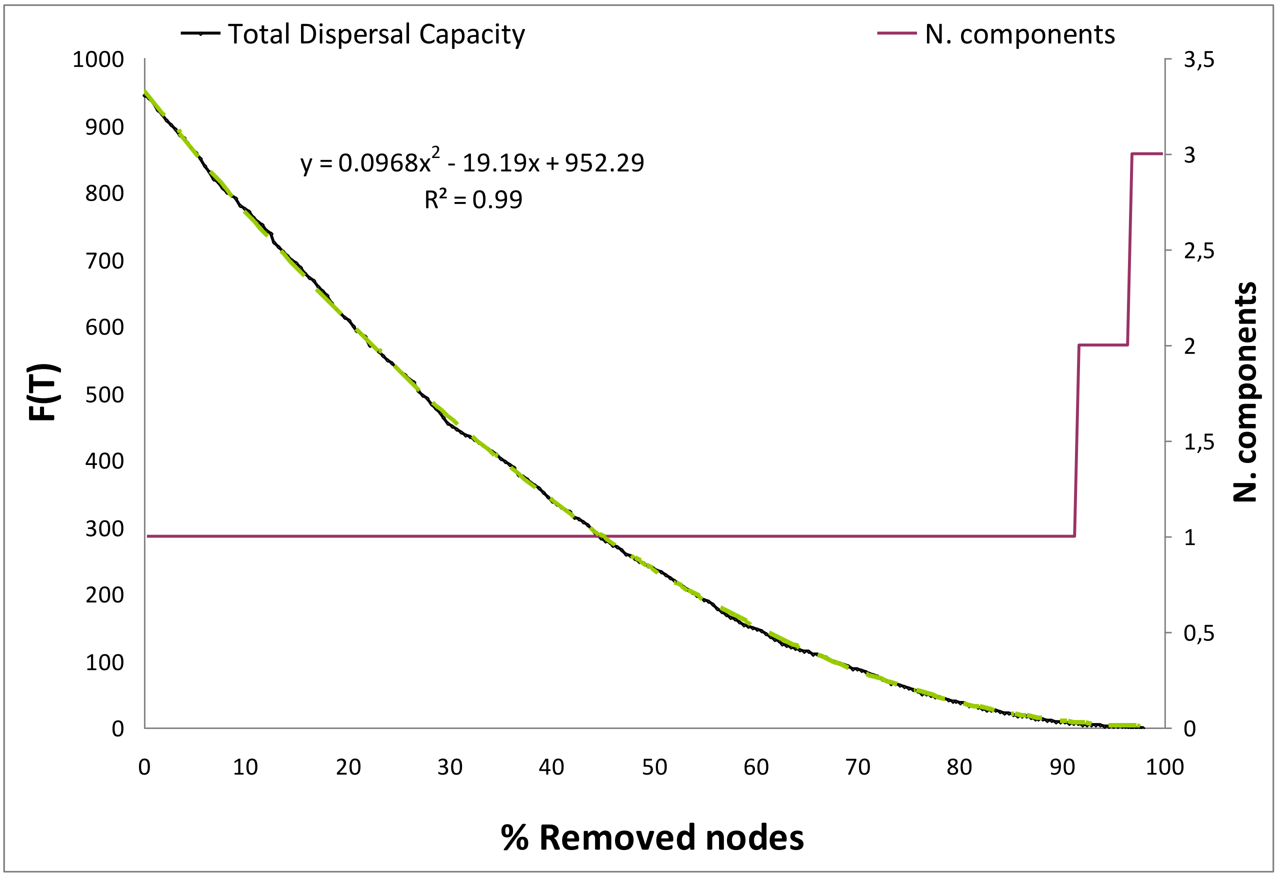

Patch
Weighted Betweenness Centrality
0.0085
0.0237
0.0486
0.0885
0.1402
Weight Edge
0.30
1.65
3.63
7.58
12.12
0
500
1000 m
N

Figure 9



Total Dispersal Capacity
N. components
y = 0.0968x2 - 19.19x + 952.29
R² = 0.99
F(T)
N. components
% Removed nodes
1000
900
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
3,5
3
2,5
2
1,5
1
0,5
0

Figure 10

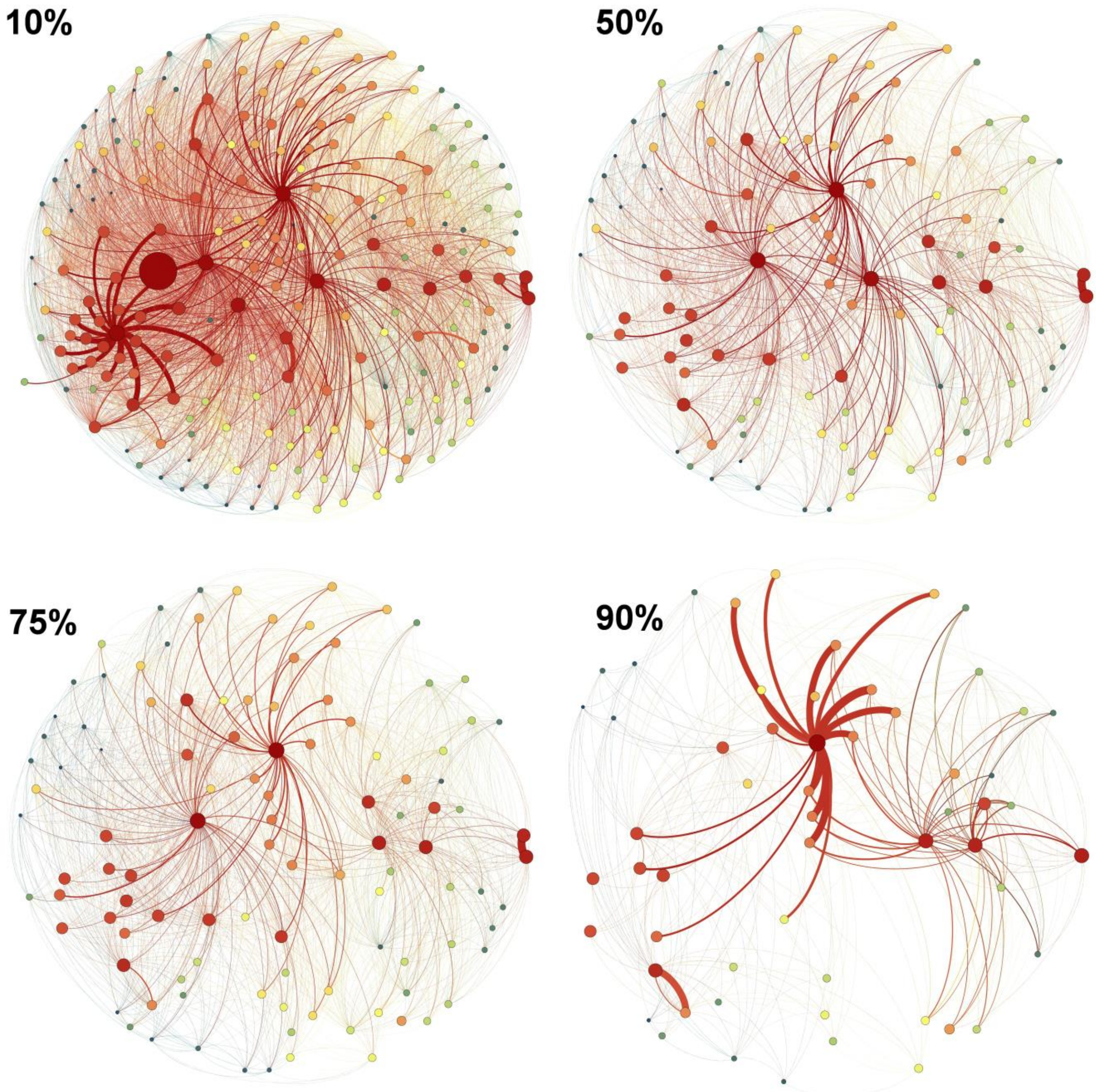
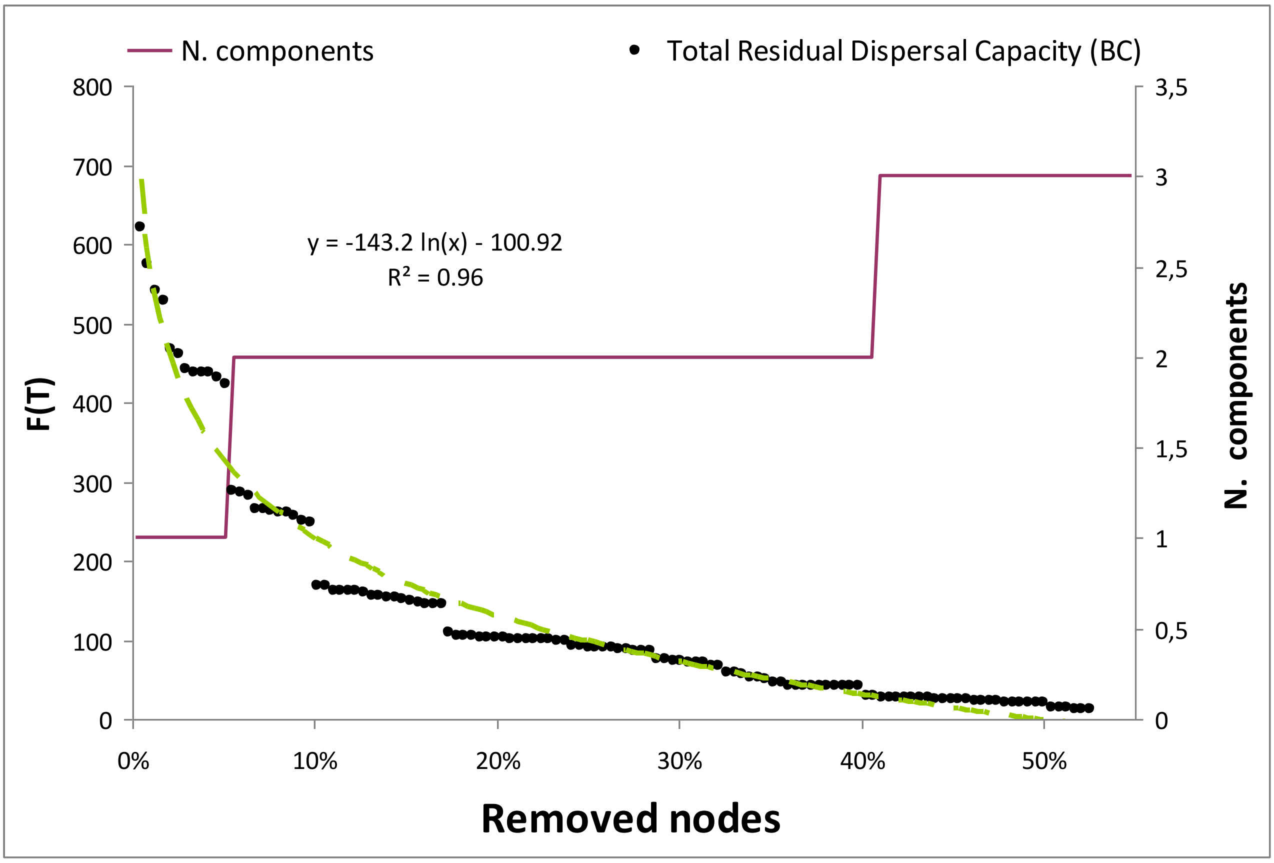
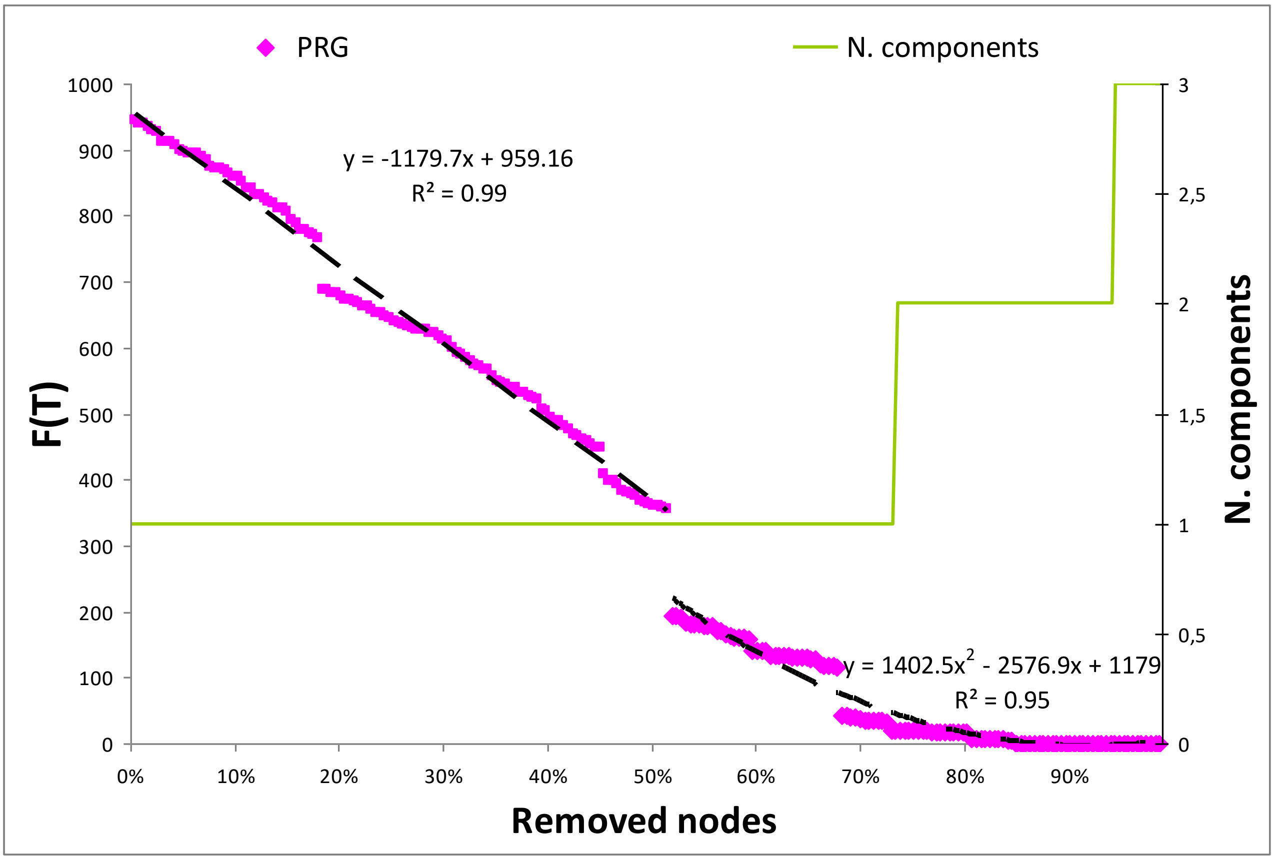


Figure 11



N. components
Total Residual Dispersal Capacity (BC)
800
700
600
500
400
300
200
100
0
F(T)
y = -143.2 ln(x) - 100.92
R² = 0.96
3,5
3
2,5
2
1,5
1
0,5
0
N. components
0%
10%
20%
30%
40%
50%
Removed nodes



PRG
N. components
F(T)
1000
900
800
700
600
500
400
300
200
100
0
y = -1179.7x + 959.16
R² = 0.99
y = 1402.5x2 - 2576.9x + 1179
R² = 0.95
3
2,5
2
1,5
1
0,5
0
N. components
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
Removed nodes