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Integrating ecological networks into spatial planning
Ecological corridors, green infrastructures and ecosystem services

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Abstract

Ecological networks protect habitats and species endangered from effects of increasing urbanisation. Policies have shifted toward the creation of ecological networks with a focus on the preservation of biodiversity.

Spatial planning and environmental assessments are essential instruments for addressing the integration of ecological networks issues in decision-making processes.

The main objective of this thesis is to propose an expeditious methodological approach to understand by what means ecological corridors could be defined, evaluated, and integrated into planning issues, starting from available data in the literature.

The purpose of the proposed approaches concerns the prioritization of spatial elements, as ecological corridors, which can provide highly biologically valuable areas where species movement should be improved through an implementation of a framework of planning and management regulation.

Least cost methods are suggested to study a "best" solution. These tools can describe linkages design for many species and it can be used to compare linkages design to alternative designs in order to satisfy cost or political constraints.

In this thesis, potential ecological corridors for enhancing connectivity are expected to be managed into a new kind of plan which represents a quite flexible way to bring together available data, expert knowledge and technical support to obtain straightforward information to start planning processes in ecological terms; it could be a strategic way, since it can suggest where planning strategies

to preserve the landscape biological integrity should be implemented in favour of an improved connectivity.

In spatial planning, the adoption of procedures based on the Strategic Environmental Assessment to integrate ecological corridors concepts, during the drafting of the proposed plan, provides a reliable framework where the inclusion of environmental issues into decision-making contributes to building more sustainable and effective results.

Summary

The structure of the thesis

The thesis is organised in six sections; each section is subdivided into paragraphs, that, in turn, are subdivided into sub-paragraphs. The structure of the thesis is specified as follow.

This first section is organised in two paragraphs. After an introduction which deals with preliminary key concepts to read the contents of the thesis, the first paragraph explains the research question, which focuses on the definition of ecological corridors and their implementation into spatial planning, declaring the research objectives. The second paragraph explains working methods to develop this research.

The second section, which deals with a framework of the state of the art on ecological networks and methodologies to implement connectivity issues in spatial planning from a point of view of ecological networks, is organised in five paragraphs. The first paragraph shows a regulative framework on ecological networks, describing: the Convention on Biological Diversity; the Pan-European Ecological Network; the Emerald Network, and the Natura 2000 Network. The second paragraph introduces ecological networks concepts even based on terminology. The third paragraph concerns issues related to ecological networks in spatial planning instruments, focalising on some Italian regions. The fourth paragraph explains the shifting of view from isolated natural protected areas and reticular systems of protected areas, introducing the concept of connectivity. The fifth paragraph provides a set of patterns, models and tools to analyse connectivity issues, in particular, the Least Cost Path method and the Linkage Mapper GIS-tool.

The third section concerns a framework on the thesis focus, in particular, related to concepts about the absence of connective elements in the Natura 2000 Network and consequences in spatial planning. It is organised in three paragraphs. The first paragraph discusses important issues concerning the implementation of connectivity into spatial planning. The second paragraph discusses the concept of spatial planning and environmental planning. The third paragraph concerns with ecological networks, green infrastructure and ecosystem services, in particular showing the role of the Natura 2000 Network.

The fourth section implements some case studies, developed during the research of the doctoral period, and discusses methodologies to define and spatially identify ecological corridors in order to recognise and integrate them into new plans in spatial planning. It is organised in three paragraphs. The first paragraph shows the Sardinian case studies, providing materials, methodologies, results and discussions. The second paragraph discusses the Belgian case study, providing materials, methodologies, results and discussions. The third paragraph shows a final and comparative discussion on case studies.

The fifth section concerns a proposal regarding the introduction of a new scheme of a plan able to integrate ecological network concepts into making-decision processes. It is organised in two paragraphs. The first paragraph concerns important issues to integrate ecological corridors into spatial planning, highlighting the role of ecosystem approaches and the strategic environmental assessment. The second paragraph shows and explains the proposal of a new planning instrument to manage the ecological corridors, highlighting the role of spatial planner and the role of participation.

The sixth section discusses the final conclusions of the thesis and provides some recommendations that spatial planners should take into account to manage the environmental dimension.

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Section 1 – Introduction

In literature, the concept of ecological networks is proposed as an instrument able to support the environmental requalification of anthropized areas, as it would allow a process of regeneration of the territory, starting from the management of conflicts between anthropic and natural flows. The ecological networks can assume a strategic connotation within the multifunctional system of green infrastructures, where the complexity of the planning discipline meets ecological-environmental issues. Since an ecological network is the backbone of green infrastructure, it is able to steer any actions towards the provision of ecosystem services (Kettunen *et al.*, 2007; European Commission, 2013; Čivić *et al.*, 2014).

The integration of ecological networks into the decision-making processes of urban and regional planning has become a necessary condition for conservation policies in order to effective results in a framework of spatial transformation policies. The government of the territory must be involved in these issues at all levels of jurisdiction (Jongman *et al.*, 2004; Todaro, 2010).

The European Union (EU) proposes action plans, concerning the implementation of spatial planning toward ecosystem approaches based on ecological networks, specifically related to the Natura 2000 Network and its ecosystem services[1]. These kinds of approaches would minimize the loss of biodiversity and the degradation of ecosystems, and also could bring good practices that would

1 Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions, "Our life insurance, our natural capital: an EU biodiversity strategy to 2020, {SEC(2011) 540 final}, {SEC(2011) 541 final}", Brussels, 03/05/2011, COM(2011), 244 final. The document can be downloaded from: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0244&from=IT (accessed 31 January 2019).

lead to the fulfilment of socio-economic objectives, and to dialogue between national, regional and local authorities, stakeholders and citizens[2].

In the European Union, the Natura 2000 Network represents the cornerstone of biodiversity conservation policies. Since its establishment in 1992 through the Directive 92/43/EEC (known as "Habitats Directive")[3], which integrates the Directive 79/409/EEC (known as "Birds Directive")[4], the Natura 2000 Network provides an instrument which aims at the conservation of natural and semi-natural habitats, flora and fauna of particular European interest. Furthermore, for the Member States of the European Union, the Natura 2000 Network is the main initiative aimed at maintaining biodiversity, by managing sites as protected areas.

In order to increase the territorial interconnections between the sites belonging to the Natura 2000 Network, the Habitats Directive encourages the Member States to improve ecological coherence by maintaining and creating landscape elements that are important for wild plants and animals (Articles 3 and 10). The Directive says that these elements of the landscape have a linear structure (e.g., rivers) or have interconnection functions (e.g., ponds, scrublands), and are essential for migration, geographical spread and genetic exchange of wild species. Nevertheless, connections have not identified into the structure of the Natura 2000 Network yet.

Protected natural areas are increasingly isolated, within a matrix of human-based landscapes (Jongman *et al*., 2004). This isolation, in addition to influencing the movement of species, can affect the flow of ecological processes necessary

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2 Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – An Action Plan for nature, people and the economy, {SWD(2017) 139 final}, Brussels, 27/04/2017, COM(2017), 198 final. The document can be downloaded from: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52017DC0198&from=IT (accessed 31 January 2019).

3 The Habitat Directive can be found at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31992L0043 (accessed 31 January 2019).

4 The Birds Directive can be found at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31979L0409&from=EN (accessed 31 January 2019).

for the provision of ecosystem services essential for human well-being (European Commission, 2013).

Connectivity is a concept that recognizes habitats and species as integral parts of an interconnected ecological network whose nature must be maintained and protected by actively involving populations (Baudry and Merriam, 1988; Jongman *et al*., 2004). Therefore, connections that include semi-natural and natural landscapes are essential features for several protected areas.

The implementation of ecological networks takes place within a broad legal and regulatory framework. Considering biodiversity, land use and the juridical status of the ecosystem components (biotic and abiotic factors), they are enclosed in a wide system of laws and regulations, in different levels (from international to local).

In order to achieve the objectives of an ecological network, however, to create a solid framework of legal instruments concerning the conservation of nature (as protected areas) is not enough, but neither spatial planning works on the control of land use, rural development or water resources are adequate.

This thesis examines ecological networks and their implementation in order to understand a useful way to integrate them in spatial planning processes. In particular, the Natura 2000 Network is taken into account for this purpose.

Purposes and research question

The industrialisation of agriculture, reorganizations of land use, transport networks and metropolitan areas cause fragmentation of natural areas, deterioration of ecosystems, loss of natural habitats and habitat structures, and extinction of species (as cited in Jongman *et al*., 2004: Stanners and Bourdeau, 1995), especially in the most densely populated areas of Europe.

In many regions, natural habitats patches are isolated as islands on the sea. The smaller and more isolated “habitat islands” are, as a result of the increasing use of land and fragmentation due to road networks, the more likely species will decline. Species survival depends on habitat quality, food availability and the facility to move through the landscape.

The possibility to move in the landscape ensure foraging, rest, shelter, migrations for reproduction or to avoid hostile environments or for dispersal (as cited in Jongman *et al*., 2004: Hansson *et al*., 1992; Bennett, 1998; Van Opstal, 1999).

Thus, land use changes and landscape fragmentation reduce ecological functions degrading ecosystems (Jongman *et al*., 2004; EEA, 2011; European Commission, 2013). Habitat loss and fragmentation threaten the biodiversity, and climate change could exacerbate negative effects on species movement across fragmented landscapes or along river corridors to track suitable conditions.

Ecological networks of isolated protected areas, e.g. Natura 2000 Network, mainly focalised on conservation policy, will be no longer sufficient in order to sustain some species movements.

The implementation of missing corridors in an ecological network should mitigate the effects of land use and climate change by facilitating movements of individuals among suitable patches, providing planned rescue elements in order to avoid local extinction and support genetic exchange by restoring or maintaining ecological processes, and enabling climate change adaptations.

These assets should be taken into account by spatial planning, e.g. into integrated management plans, where nature conservation meets human dimensions.

The purpose of the thesis is to highlight the importance of ecological networks where ecological corridors are defined, spatially identified and planned. These issues can contribute to the conservation and restoration of natural and cultural capital, and spatial planning can address environmental-ecological objectives.

Working methods to develop the research

The thesis shows a way where ecological concepts of ecological networks could achieve the integration into culture and landscape capital, and into planning processes, in particular by focalising on the Natura 2000 Network.

In order to carry out a systematic review, the research strategy has been developed taking into account information involving: 1) breaking down the research questions into keywords, synonyms or phrases; 2) looking for models to implement the research; and 3) understanding whether where it was necessary to employ approaches to modify or broaden or narrow the research.

Intense bibliographic research into literature was carried out through an online search of scientific websites and information platforms.

The main survey involved documents concerning planning and policies, relevant peer-reviewed datasets and models published in scientific articles, conference proceedings, various report and working related to topics of the research, significant issues based on the relationships between biodiversity, ecological networks and planning at various scales.

The keywords involved into the research was: Natura 2000 Network, ecological network(s), ecological corridor(s), connection(s), connectivity, graph theory, least cost analyses, nature conservation, natural and cultural heritage, ecosystem services, landscape, cultural landscapes, green infrastructure strategy, management plans, integrated management, spatial planning, public participation.

Section 2 – State of the art and methodologies

In this chapter, in order to build a conceptual framework, some considerations on ecological networks concerning concepts and terms used in fields of planning, and at European and Italian level, are proposed highlighting the importance of ecological corridors, notwithstanding they are not defined and identified yet.

The framework on ecological networks

In Europe, several regulative instruments recognise that maintaining ecological coherence and connectivity is an important contribution to biodiversity conservation and support climate change adaptations.

The European Landscape Convention, adopted in 2000 by the Council of Europe, provides a European framework for sustainable planning, management and protection of landscapes. The Landscape Convention does not explicitly address ecological coherence and connectivity; anyway, it provides a framework to support these issues in landscape planning and management.

In spatial planning, concepts regarding ecological networks need to be integrated into plans and defined in a shared and univocal way. Nevertheless, if ecological networks have to be understood as instrumental models of reference for the conservation, protection and management of biodiversity within territorial governance processes, a shared and univocal theoretical and lexical definition should be necessary for the purpose of a transposition throughout the national territory (D'Ambrogi and Nazzini, 2013). This implies a systemic approach characterizing all urban-territorial planning instruments, and the linkages between sites have to be spatially identified in order to implement proper plans also within these ecological corridors.

Following, some documents concerning ecological network issues and their implementation are discussed.

The Convention on Biological Diversity

The Nairobi Conference for the Adoption of the Agreed Text of the Convention on Biological Diversity (CBD) was held on 22 May 1992, and «the Convention was opened for signature on 5 June 1992 at the United Nations Conference on Environment and Development (the Rio "Earth Summit"). It remained open for signature until 4 June 1993, by which time it had received 168 signatures. The Convention entered into force on 29 December 1993, which was 90 days after the 30th ratification. The first session of the Conference of the Parties was scheduled for 28 November – 9 December 1994 in the Bahamas»[5].

The Convention is based on three main objectives (Article 1): 1) the conservation of biological diversity; 2) the sustainable use of components of biological diversity; and 3) the fair and equitable sharing of benefits arising out of the utilization of genetic resources. The objectives should include appropriate access to genetic resources and the appropriate transfer of relevant technologies, taking into account all rights over those resources, technologies, and appropriate funding.

In 2010, the Parties of the CBD adopted the Strategic Plan for Biodiversity 2011-2020, a ten-year framework for actions by all countries and stakeholders to safeguard biodiversity and benefits it provides to people. Twenty targets, known as the "Aichi Biodiversity Targets", under five strategic goals, were adopted as a part of the Strategic Plan. In support of the Aichi Biodiversity Targets, national

5 As stated in the official Internet site of the Convention: https://www.cbd.int/history/default.shtml (accessed 31 January 2019).

governments should establish appropriate national objectives and action plans. These National Biodiversity Strategies and Action Plans (NBSAPs) are the keys to fulfil the objectives of the CBD. The Strategic Plan for Biodiversity is based on the vision that «By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people, [with the mission to] take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being, and poverty eradication. To ensure this, pressures on biodiversity are reduced, ecosystems are restored, biological resources are sustainably used and benefits arising out of utilization of genetic resources are shared in a fair and equitable manner; adequate financial resources are provided, capacities are enhanced, biodiversity issues and values mainstreamed, appropriate policies are effectively implemented, and decision-making is based on sound science and the precautionary approach»[6].

In particular, under the Strategic goal C "Improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity", the Target 11 states «By 2020, at least 17 per cent of terrestrial and inland water areas, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes».

6 As reported in the "Annex of Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets. Conference of the Parties to the Convention on Biological Diversity, Tenth meeting Nagoya, Japan, 18-29 October 2010 Agenda item 4.4". This document can be consulted at: https://www.cbd.int/doc/decisions/cop-10/cop-10-dec-02-en.pdf (accessed 31 January 2019).

The above sentence represents a crucial part of the implementation of the Convention; it means that a “well connected” system of protected areas is required and also “integrated” into wider landscapes and seascapes.

Since 2015, the ecological connectivity should be reached as a goal[7] on CBD programs by suggesting activities concerning: the identification and implementation of practical steps to improve the integration of protected areas into broader land- and seascapes, including policy, legal, planning and other measures; the integration of regional, national and sub-national systems of protected areas into broader land- and seascape, *inter alia* by establishing and managing ecological networks, ecological corridors and/or buffer zones, to maintain ecological processes; the development of tools to improve ecological connectivity (such as ecological corridors) linking protected areas; the rehabilitation and restoration of habitats and degraded ecosystems to contribute to building ecological networks, ecological corridors and/or buffer zones (Secretariat of the Convention on Biological Diversity, 2004a).

Thus, the concept of the connectivity in ecological networks plays an important role into policies concerning the best practices on biodiversity, and ecological connections are to be defined to support the achievement of the objectives of the CBD.

The Pan-European Ecological Network

In order to achieve the implementation of the CBD at the European level, during the international conference “Conserving Europe’s Natural Heritage: Towards a European Ecological Network”, held in Maastricht from the 9th to the 12th of November 1993, the implementation of a Pan-European Biological and

7 Goal 1.2 “To integrate protected areas into broader land- and seascapes and sectors so as to maintain ecological structure and function”. Target “By 2015, all protected areas and protected area systems are integrated into the wider land- and seascape, and relevant sectors, by applying the ecosystem approach and taking into account ecological connectivity4 and the concept, where appropriate, of ecological networks” (Secretariat of the Convention on Biological Diversity, 2004b).

Landscape Diversity Strategy (PEBLDS) was proposed. The key element of PEBLDS was the development of a Pan European Ecological Network (PEEN) to support the coherence in biodiversity conservation strategies. PEEN was ratified by 54 Minister of the United Nations Economic Commission for Europe (UNECE) during the "Third Ministerial Conference on Environment for Europe", held in Sofia from the 23rd to the 25th October 1995, implementing PEBLDS concepts.

Nowadays, as Jongman *et al.* (2011) show, the implementation of the PEEN is achieved in three subprojects: Central and Eastern Europe, completed in 2002; South-eastern Europe, completed in 2006; and, Western Europe, also completed in 2006. The methodology implemented to map these three projects is broadly comparable, but data availability, different national databases, technical developments and geographical differences influence the approach; in fact, one of the challenges was to find common denominators for all habitats data in Europe. Each project has been synthesised in a map and the maps differ in terms of ecological coherence and need for ecological corridors. For example, in Central and Western Europe corridors are essential to provide connectivity, while in Northern, Eastern and South-eastern Europe larger, coherent natural areas still exist.

PEEN should include the implementation of national ecological networks and, in particular, the pursuit of international coherence through the development of trans-European ecological corridors in a common approach for biodiversity conservation.

The Emerald Network

The 19th of September 1979, the Council of Europe developed the Convention on the Conservation of European Wildlife and Natural Habitats, known as "Bern Convention" and it came into force the 1st of September 1982.

The Bern Convention is a binding international legal instrument concerning nature conservation, and it covers most of the natural heritage of the European continent and some States of Africa. The Council of Europe, by the development of the Bern Convention, binds parties to the protection of habitats and species of European concern, promoting cooperation between countries for the protection of migratory species.

During these years, many Recommendations were established and adopted. In particular, in 1989, three operative recommendations (Recommendations n° 14, 15 and 16) were focused on the development of a network of areas under the Bern Convention. Specifically, Recommendation n° 16 proposes the establishment of Areas of Special Conservation Interest (ASCIs). By virtue of this, the Standing Committee recommended Parties to define ASCIs, within their territory or under their responsibility, to ensure that the necessary and appropriate conservation measures are taken for each area.

Later, the Recommendation n°25, adopted in 1991, concerning the conservation of natural areas outside protected areas, addresses the Bern Convention by encouraging the conservation and, where necessary, the restoration of ecological corridors, habitats types and landscape features that are important for wildlife conservation.

In 1996, by developing the Resolution n°3 «European states which are observer states in the Standing Committee of the Bern Convention [was invited] to participate in the network and designate ASCIs».

Therefore, an ecological network was created in compliance with Recommendation n° 16 (1989) and Resolution n° 3 (1996). This ecological network was called "Emerald Network" and it was adopted in 1998 by amending the Convention to integrate the Emerald Network into the text of the Bern Convention.

The Emerald Network, set up under the Bern Convention, can be viewed as a supplement of the Natura 2000 Network (see next paragraph): the Natura 2000 Network is the EU contribution to the Emerald Network as per the EU is a Contracting Party to the Bern Convention. The Emerald Network, based on the same principles of the Natura 2000 Network, represents the *de facto* extension to non-EU countries.

The Natura 2000 Network

The 21st of May 1992, the Council of the European Communities adopted the Council Directive 92/43/EEC concerning the conservation of natural habitats and of wild fauna and flora, to promote the maintenance of biodiversity, taking account of economic, social, cultural and regional issues. This European directive is also known as "Habitats Directive" and represents the basis of nature conservation policy in Europe.

Article 3 of the Habitats Directive establishes that:

«1. A coherent European ecological network of special areas of conservation shall be set up under the title Natura 2000. This network, composed of sites hosting the natural habitat types listed in Annex I and habitats of the species listed in Annex II, shall enable the natural habitat types and the species' habitats concerned to be maintained or, where appropriate, restored at a favourable conservation status in their natural range. The Natura 2000 network shall include the special protection areas classified by the Member States pursuant to Directive 79/409/EEC.

2. Each Member State shall contribute to the creation of Natura 2000 in proportion to the representation within its territory of the natural habitat types and the habitats of species referred to in paragraph 1. To that effect each Member State shall designate, in accordance with Article 4, sites as special areas of conservation taking account of the objectives set out in paragraph 1.

3. Where they consider it necessary, Member States shall endeavour to improve the ecological coherence of Natura 2000 by maintaining, and where appropriate developing, features of the landscape which are of major importance for wild fauna and flora, as referred to in Article 10».

Article 10 says that «[the] Member States shall endeavour, where they consider it necessary, in their land-use planning and development policies and, in particular, with a view to improving the ecological coherence of the Natura 2000 network, to encourage the management of features of the landscape which are of major importance for wild fauna and flora. Such features are those which, by virtue of their linear and continuous structure (such as rivers with their banks or the traditional systems for marking field boundaries) or their function as stepping stones (such as ponds or small woods), are essential for the migration, dispersal and genetic exchange of wild species».

Currently, the Natura 2000 Network cover the 18.2% of EU territory, which amounts to 4,346,742 km^2, and consists of 24,127 Sites of Community Importance (SCIs), which should be converted in Special Areas of Conservation (SACs), and 5,616 Special Protection Areas (SPAs)[8]. No indication on ecological corridors has been provided yet.

The paradigm of the concept of the ecological network

In territorial scenarios based on ecosystem relations, the strategic concept of ecological network allows to mitigate the biological problems related to the high pressure exerted by human activities on natural components, impacting and causing variations and fragmentation of ecosystems matrix, linked to the use of inadequate agricultural and forestry practices, to pollution, to the spread of exotic species, to urbanization and to the realization of infrastructures.

Even though various documents describe how ecological networks can be defined in legal ways, no one document explains by what means the network can be related to planning issues and what shape it should have.

8 Data provided by the Natura 2000 Barometer. The Natura 2000 Barometer provides an overview on the Natura 2000 Network of sites under the Birds and the Habitats Directives, in terms of information on area and site numbers; it can be consulted at: https://www.eea.europa.eu/data-and-maps/dashboards/natura-2000-barometer (accessed 31 January 2019).

Bennett (1991, 2000, 2002) states the first concept regarding the shape of an "ecological network"; it can be associated with EECONET (European ECOlogical NETwork) project. This acronym was defined on 1991 by IEEP (Institute for European Environmental Policy), in collaboration with IUCN (International Union for Conservation of Nature), WCMC (World Conservation Monitoring Centre), *Landbouwuniversiteit* Wageningen, and the *Universidad Complutense* Madrid, with the support of the *Ministerie van Landbouw*, *Natuur en Voedselkwaliteit* of the Netherlands Government. EECONET was discussed in the report "Towards a European Ecological Network" (Bennett, 1991).

The implementation of EECONET was also discussed during the international conference "Conserving Europe's Natural Heritage: Towards a European Ecological Network" held in Maastricht, from the 9th to 12th November 1993. In this conference, the development of the PEBLDS was established as per EECONET requirements on the conservation of European important species, habitats, and ecosystems through the implementation of the PEEN. Nowadays, the acronym EECONET is also used to identify the PEEN.

The diagrammatic representation of the spatial configuration of an ecological network proposed by Bennett (2004), as shown in Figure 1, is composed by:

- core areas: the conservation of biodiversity takes primary importance;
- corridors: vital ecological or environmental connections are ensured by maintaining physical (though not necessarily linear) linkages between the core areas; they can be:
    - linear corridors (such as a hedgerow, forest strip or river);
    - stepping stones, consisting of an array of small habitat patches that individuals use during the movements for shelter, feeding and resting;
    - various forms of interlinked landscape matrices that allow individuals to survive during movement between habitat patches;

- buffer zones: protection of the network from potentially damaging external influences and essential transitional areas characterized by compatible land uses;
- sustainable-use areas: opportunities are exploited within the landscape mosaic for the sustainable use of natural resources together with the maintenance of most ecosystem services.

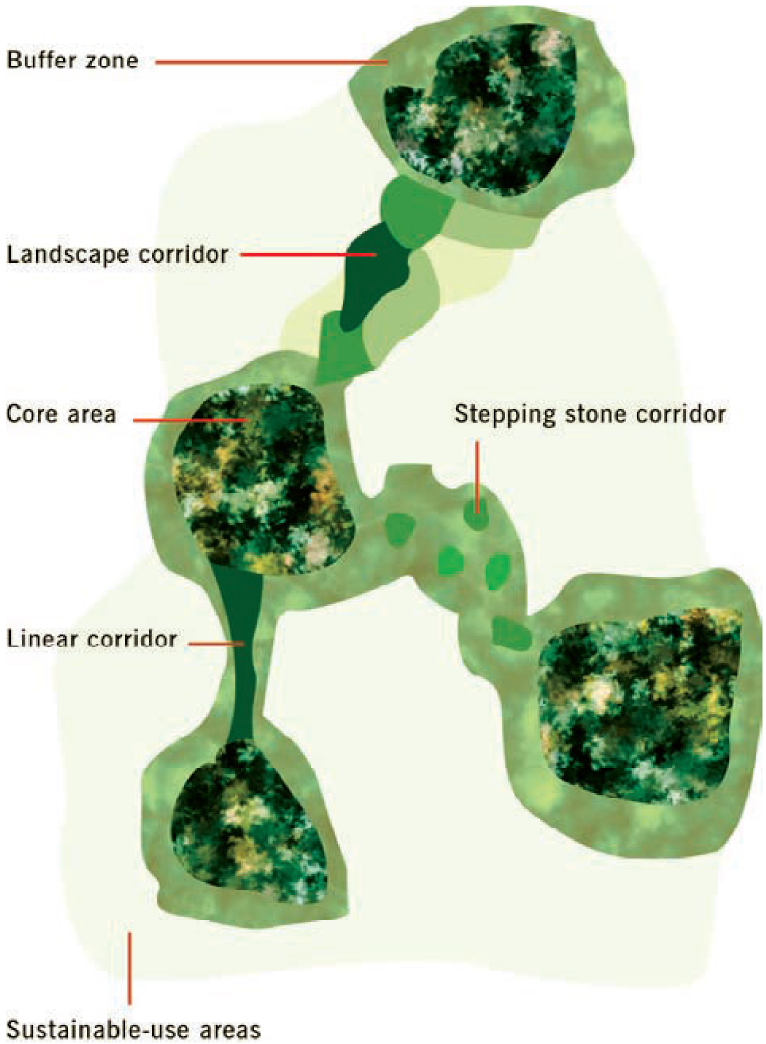

Figure 1 – Conceptual spatial model of an ecological network (Bennett, 2004).

Terminology in the field of ecological network

In the early 1990s, the term "ecological network" gained favour in Europe and has been used in the most important international issues in recent years, including IUCN's World Conservation Congresses, the World Summit on Sustainable Development's Plan of Implementation and the CBD Conferences of the Parties, including the programme of work on protected areas.

However, several terms are used to describe the model of an ecological network, even in a regional or national setting, and in the scientific literature, collecting a wide variation in terminology which may cause confusion due to parallel evolutions in ecological-network models (Bennett and Mulongoy, 2006).

A variety of terms to describe ecological networks are used (Bennett and Mulongoy, 2006; Todaro, 2010), for instance: green network (Ratih *et al*., 2016), interwoven biotope system (Bennett, 2001), reserve network (Nalle *et al*., 2002), territorial systems of ecological stability (Moyzeová *et al*., 2015), wildlands network (Noss, 2003). Other different terms are undoubtedly used in programmes concerning ecological networks, conservation strategies and spatial planning[9].

Furthermore, different terminology may be even found about the term "ecological corridor" (Bennett and Mulongoy, 2006; APAT, 2003), for instance: biological corridor (Rosenberg, 1995), biodiversity corridor (West *et al.*, 2016), conservation corridor (United States Department of Agriculture, 2004), [regional] corridor (Dixon *et al*., 2006), ecological greenways (Bryant, 2006), green corridor (Aziz *et al.*, 2014), connectivity areas (Worboys *et al.*, 2016), wildlife corridor (Jones *et al.*, 2012).

Although a large, sometimes inappropriate, use of terminologies is evident, the problem of the unambiguous definition of ecological corridors within an eco-

9 Next paragraph shows some ways to consider ecological networks in spatial planning.

logical network conceptually exists (ISPRA, 2010). Moreover, the Habitat Directive cites terms as “ecological network” and “coherent” but does not clarifies “spatial” or “functional” definitions related to linkages between protected areas (Biondi *et al*., 2012). For this purpose, the European Commission drafted guidelines to better interpret Article 6, maybe the most important of the Habitat Directive, because of related conservation issues and spatial planning (European Commission, 2000).

Therefore, in order to maintain the permeability of the landscape-ecological matrix, a shared concept of ecological corridors, thus the connectivity that they offer, is required. In this way, by integrating concepts related to ecological networks into instruments of spatial planning and governance can be feasible, since a high degree of continuity is generally linked to a low degree of fragmentation and, consequently, a reduced risk of extinction of a species.

Ecological networks in spatial planning

Spatial planning and decision making in the framework of ecological networks are issues that involve a multidisciplinary effort to define the study context, habitats and species of interest, levels of ecological organization. Works focused on these issues, should concern structural (on ecosystems units and their connections), functional (on the study of the populations involved and their behaviour) and geographical analyses (on the characterization of different areas and identification of specific conservation measures) (Leone, 2014).

Depending on specific functions to be privileged, at least four ways to understand ecological networks can be defined (APAT, 2003; Guccione *et al*. (2010):

- ecological network as an interconnected habitat system, to safeguard biodiversity;

- ecological network as a system of parks and reserves, involved in a coordinated system of infrastructures and services;
- ecological network as a landscape system, with priority support for perceptive and recreational use;
- ecological network as a multi-purpose ecosystem scenario, supporting sustainable development.

  Each one of these ways to understand ecological network can have a different vision to inform spatial planning. As specified by APAT (2003), the main interests of each of these four visions can be resumed as follow.

The first case focuses on ecological networks as one tool to protect biodiversity. The nodes of this structure are not mandatory protected areas legally established, but patches of habitats. The main objective is to protect and maintain species. This type of network can be interested from a local to a regional scale.

The second case focuses on ecological networks as instruments composed of spatial elements (for example, infrastructures and services). This structure needs to be coordinated by policies and governance. This is not an alternative option of the first, but it is a form, necessary but not sufficient, to define appropriate tools for spatial planning.

The third case concerns the ecological network as a tool to protect the landscape in terms of aesthetic and cultural services. The main structures of this network are conceived in local scales (urban and extra-urban).

The fourth case is based on the concept of rupture between ecosystems and territory. This caesura causes, not only the loss of biodiversity but even many spatial problems such as hydrogeological risks, loss of primary functions (e.g. microclimate changes, self-purification, recharging groundwater, intrinsic control of pests and disease, oxygen production, etc.). The structure of this network works on various scales, also involving the reconnection of the natural mosaic.

All four of these systems are not reciprocal to each other, rather they can contribute in a complementary way in spatial planning processes in ecological networks.

In accordance with the concepts of frameworks discussed above, a connected system of protected areas and integrated into wider landscapes and seascapes appears a condition to make best practices in a sustainable spatial planning process concerning ecological networks. Indeed, the CBD promote the implementation of "well connected" system of protected areas "integrated" into wider landscapes and seascapes, and the connectivity is the key of this action since it is able to define policies concerning best practices on biodiversity, and ecological connections.

PEEN, Emerald Network and Natura 2000 encourage the implementation of coherent ecological networks throughout the European continent.

In particular, Article 6(1) of the Habitats Directive, in relation to the Natura 2000 sites, introduces management plans. These plans are defined "appropriate" and "specific", and, in accordance with the principle of integration of the environment in other Community policies to contribute to the coherence of the network, they need to be «integrated with other development plans». In terms of nature and biodiversity, to ensure the long-term survival of the most precious and the most endangered species and habitats, drawing up appropriate and specific plans is not enough. They must be integrated into other development plans, but in order to reach all planned sets of conservation objectives included into integrated policies, the mutual interconnection of sites in an ecological network plays an important role in decision making.

The management of landscape elements, both nodal and connective, cannot be organised in a locked system of strictly protected natural reserves, where human activities are precluded.

A spatial network, which integrates landscape connective elements that are of primary importance for wild fauna and flora, can address sustainable approaches in ecological and economic terms. Besides, the only identification of connective elements on thematic maps of natural environments does not necessarily correspond to their functional effectiveness, because it depends both on intrinsic factors (corridor area, width, location from core areas, environmental quality, type of surrounding matrix), and extrinsic factors (behaviour of species that can, potentially, use these elements) (APAT, 2003; Province of Bergamo, 2008; Leone, 2014).

A new generation of planning tools, as criteria based on the ecological network, should be taken into greater consideration, in particular by giving a territorial weight to the principle of connectivity. In this field, a huge number of data, monitoring systems and researches are required to better implement a good planning process.

Ecological networks in Italy

Italy adopted issues coming from the Habitats Directive through the Decree of the President of the Italian Republic [*Decreto del Presidente della Repubblica,* DPR] N. 357/1997. In this decree, Italy formally adopts the Natura 2000 Network and its structure. Article 2(1-p) of the DPR transposes Article 10 of the Habitats Directive concerning landscape connective elements. Article 2 defines “areas of functional ecological connection”, that should be the so-called ecological corridors in Italy.

Readers, by analysing this national legislation, can notice that in order to make Natura 2000 more environmentally coherent, planning in ecological networks should integrate those elements of the landscape that are of primary importance for wild fauna and flora. Ecological corridors can, therefore, be interpreted as connective elements which, by linear and continuous structure or by linking role, are essential for migration, geographical distribution and genetic exchange of wild species, and takes on fundamental importance in the field of nature, biodiversity, habitats and species.

For several years, the Institute for the protection and environmental research [*Istituto Superiore per la Protezione e la Ricerca Ambientale*, ISPRA] studied aspects of planning related to the ecological networks. On the implementation of the ecological network within spatial planning tools, ISPRA[10] shows a positive trend through a data monitoring on the implementation of the ecological network concepts within spatial planning instruments (D'Ambrogi *et al.*, 2015).

Technical innovations in planning approaches and the development of management models are required to focus with attention on principles of ecological connectivity of a specific territory. Italy certainly does not excel and still applies theoretical rather than applicative dimensions (ISPRA, 2010).

There are several ecological theories and disciplines whose goal is the evaluation of connectivity for susceptible species and groups (e.g. the theory of biogeography applied to fragmented terrestrial contexts and protected areas; the metapopulation theory or planning environmental and landscape ecology[11]) (Battisti, 2004).

Professional skills involved in these multidisciplinary wide range issues are required: planners, designers, landscapers, naturalists, and other. Research activities can improve knowledge in these fields; in fact Italian institutions activated

10 In this regard, data from previous ISPRA monitoring can be consulted. They are available from the address: http://www.isprambiente.gov.it/it/progetti/biodiversita-1/reti-ecologiche-e-pianificazione-territoriale (accessed 31 January 2019).

11 Landscape ecology is the study of structure, function, and change in a heterogeneous land area which contains interacting ecosystems. Landscape ecology focuses on 1) the spatial relationships among landscape elements, 2) the flows of energy, mineral nutrients, and species among the elements, and 3) the ecological dynamics of the landscape mosaic through time. In particular, landscape ecology is concerned with the effects of both natural and human disturbances on the landscape (Forman, 1986).

conceptual paths on ecological networks in 1998, when the Ministry of University and Scientific Research [*Ministero dell'Università e della Ricerca Scientifica*] financed a two-year program of national interest [*Programma biennale di interesse nazionale*, PRIN] called "Planeco" (Planning in Ecological Network), and proposed research units of the University of L'Aquila, Camerino and Chieti with the aim of implementing territorial planning methodologies based on environmental continuity structures; then, in 2002, the Ministry of the Environment, Nature Conservation Service [*Ministero dell'Ambiente, Servizio Conservazione della Natura*], commissioned the scheme of the National Ecological Network [*Rete Ecologica Nazionale*, REN] and the same Ministry, in parallel, promoted a further opportunity for national study on the APE project [*Appennino Parco d'Europa* (*Appennini* Park of Europe)].

In particular, the REN should be an operative tool, able to address spatial planning and natural resources management policies at the national level. It is a global network that takes into account Italian vertebrates. The main objective of the project was the identification of a network of mosaics of areas of different value and conservation priorities, highlighting linking elements between key areas, with the purpose to minimise fragmentation of habitats and areas where species are present. In this project, a database of 504 species was built: 81 freshwater fish, 34 amphibians, 43 reptiles, 244 birds and 102 mammals (Boitani *et al.*, 2002).

Into the regional level of planning, there are not many Italian regions that have included ecological networks in current regulatory provisions (Ciabò *et al.*, 2015). Some examples, also cited by Guccione *et al*. (2010), are given below.

The Public Administration of Emilia Romagna Region, through the Regional Law [*Legge regionale*, LR] N. 6 of 02/17/2005, regulates the management of the regional system of protected natural areas and sites of the Natura 2000 Network and, in Article 7, asks the identification of areas of ecological connection to provinces in coordination of municipal levels.

The Public Administration of Umbria Region implemented the first experience concluded in Italy concerning an entire regional administrative district at the scale 1:10,000. It approves, through the Decree of the Regional council [*Decreto della Giunta Regionale*, DGR] N. 2003 of 30/11/2005, the Umbria Region Ecological Network project [*Rete ecologica della Regione Umbria*, RERU], included in Law N. 13 of 26/06/2009, indicating in Article 27 the ecological network as the main content of provincial coordination territorial plans.

The Public Administration of Lombardy Region, through the DGR N. 8/8515 of 26/11/2008, and definitively through the DGR N. 8/10962 of 30/12/2009, approves the design of its regional environmental network (RER). This network addresses the regional plan into a framework of priority naturalistic sensitivities; it plays the role of guidelines in spatial planning.

The Public Administration of Marche Region, through the LR N. 2 of 05/02/2013, establishes the discipline of the ecological network of Marche (REM). It promotes interventions to support ecological connections and the valorisation of the ecosystem services requiring the transposition of these actions into other planning instruments.

The Public Administration of Piedmont Region, through the DGR N. 52/1979 of 31/07/2015, implemented its own methodology to design the Piedmontese ecological network, already exposed in the LR N. 19 of 29/06/2009. Arts. 53-54, Chapter I of Title IV, highlight the importance of ecological links and establish that the ecological corridors should be reported in spatial planning instruments at any level.

In Sardinia Region, concepts related to a regional ecological network are mentioned in the Regional landscape plan [*Piano paesaggistico regionale*, PPR]. Article 34 of the Technical Rules [*Norme tecniche di attuazione*, NTA] encourages the identification of areas to design ecological corridors and their integration within the management plans in a unique system of areas of the Natura 2000

Network, the Ramsar sites and landscape and environmental enhancement criteria. In these articles, the PPR shows the intention to systematize the Natura 2000 sites and other protected areas through ecological corridors; however, it delegates the implementation of the ecological corridors to other planning instruments. In fact, Article 106 states that, during the phase of adjustment of the provincial urban planning, the sites containing natural habitats, flora and fauna species of community interest, and relative rules of protections have to be integrated in provincial planning (Paragraph 2); furthermore, provincial planning regulations have to identify and regulate ecological corridors, in order to build a network of connections between protected areas, biotopes and natural areas, rivers and springs (Paragraph 7). The concept of ecological corridors assumes the strategic implication of tool in a wide area. Despite the presence of 31 SPAs, 34 SCIs, 53 SACs, 3 overlapping of SPAs&SCIs and 3 SPAs&SACs[12], no ecological corridor has been defined in Sardinia yet.

Isolated natural protected areas or reticular system?

Island theory is the best-known theory in population dynamic. This theory explains that, in isolated areas, an equilibrium can be reached between the immigration of new species and the rate of species extinction (MacArthur *et al.*, 1967). The original theory was born to describe population dynamics in real islands, but the main idea can be applied to the dynamics of some species. In particular, the dynamic equilibrium depends on two factors: the area of the island and the distance between them. The greater the distance, the lower the number species which can colonise the island; the smaller the island, the lower the number of species that it can support. Issues related to the effects on population (e.g. dimension of isolated areas, distances or landscape fragmentation) are a specific concern of metapopulation theory. Metapopulation dynamics are driven by extinctions and

12 Statistics derived from Natura 2000 data available at: https://www.eea.europa.eu/data-and-maps/data/natura-9 (accessed 31 January 2019).

recolonization of habitat and the time for which a species can survive is influenced by the behaviour of species, the structure of the landscape and the quality of the habitat.

These theories, however, are based on the problematic issue of ecological insularisation of protected areas, that needs to be overcome.

The IUCN provide a definition of "protected area" as defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve long-term conservation of nature with associated ecosystem services and cultural values[13]. In this definition, the scale needle points in the direction of concepts of "conservation of nature", rather than "conservation of biodiversity" as in past concepts.

Therefore, the sites of an ecological network can be understood as isolated protected areas without connection with others. These sites can be affected by effects related the isolation.

Since a network structure is composed by nodes and linkages, significant importance must be given to connective elements of the network, that are links between sites; if connective elements are not taken into account networks lose its intrinsic value (Todaro, 2010, 2011). Actually, different existing ecological networks, also legally established, do not identify the whole structure of the network; indeed, they are constituted only by nodes, that are sites of protected areas, but all connective elements are not defined yet.

Natural protected areas are increasingly isolated within human-dominated landscapes (and seascapes). This isolation affects species movement and ecological processes. These issues affect, in turn, the provision of ecosystem services

13 This definition was presented in the IUCN World Conservation Congress held in Barcelona (Spain) from the 5th to the 14th of October 2008. In this event, around 6,600 leaders from government, public sectors, non-governmental organizations, business, agencies and social organizations discussed, debated and agreed on solutions for the world's most pressing environmental issues.

that are essential for human well-being. In the concept of connectivity, habitats and species functions are recognised as part of an interconnected network to maintain and protect nature. Connections in semi-natural and natural landscapes are an essential feature for protected areas. In order to design a complete ecological network, all sites need to be connected by proper landscape elements that ensure landscape connectivity. The space of ecological corridors can be defined, in turn, as a protected area with a connective function. This means that different types of land may benefit from nature conservation, even though their use and management as a recreation area, a military domain, or a managed farm. The focus does not primarily and explicitly on the preservation of biological diversity but can address connectivity issues in the network.

«Maintaining natural connections in landscapes was not considered of conservation importance before the 1970s because the consequences of chopping up natural habitats with development were not immediate. […] ruminations about island biogeography, as the new science would be called, raised similar questions about fragmented habitats, which essentially are islands in transformed landscapes. […] Habitat fragments lose species after they are isolated because these islands are no longer part of a larger natural system. […] What we learned was that conservation depends not only on protection but also on connections (Lovejoy *et al.*, 2015).

Changes in environmental conditions, either due to natural events or human activities, lead many species to rely on their ability to colonise new areas. For this reason, the connectivity of a landscape is important and is expressed physically in ecological networks. Consequently, a response of various conservationists and conservation authorities has been the shift from conservation strategies based on existing natural "islands", increasingly isolated, to the adoption of policies based on conservation and restoration of interconnected natural areas (as cited in Jongman *et al*., 2004: Farhig and Merriam, 1985; Arts *et al*., 1995).

Connectivity issues in ecological networks

Since the vision of a spatial planner is related to the space organization to enhance, restore or create landscapes, the work plan is the landscape in the faceting of its definitions. Article 1 of European Landscape Convention (Florence, 20/10/2000) defines «landscape means an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors». From a biological point of view, landscapes are defined as one of the lower levels of ecological organisation within regional ecosystems (i.e. biomes) (Wiens, 2002). Landscapes are commonly organized in discrete elements termed patches, which can be defined as relatively homogeneous areas that differ from their surroundings (Forman, 1995). There is a landscape heterogeneity, in particular in spatial distribution and arrangement of patches. At the level of landscape scale, the meaning of the term "connectivity" is mainly focused on the definition of Taylor *et al.* (1993) as the degree to which the landscape facilitates or impedes movement among resource patches.

In fact, the main topic of this manuscript is that landscape patterns can promote connectivity for species, communities and ecological processes, and, thus, they are key elements in nature conservation. Consequently, the emphasis is focused on landscape connectivity issues rather than corridors *per se*, but ecological corridors are that elements to be integrated into spatial planning.

Bennett (2004) explains corridors are essentially devices to maintain or restore a degree of coherence in fragmented ecosystems, in the sense of functional linkages between sites. Linking isolated patches can increase the viability of local species populations in several ways: by allowing individual animals access to a larger area of habitat in order to forage, to facilitate the dispersal of juveniles or to encourage the recolonization of "empty" habitat patches; by facilitating seasonal migration; by permitting genetic exchange with other local populations of the same species; by offering opportunities for individuals to move away from a habitat that is degrading or from an area that is under threat; by securing the integrity of physical environmental processes that are vital to the requirements of certain species.

Corridors play the role of ecological connections in spatial restitching in favour of the mobility of species. However, dealing with these elements of primary importance for fauna and flora, in landscape ecology there is a significant difference between physical-territorial and ecological-functional aspects. In particular, the term “ecological connection” indicates the concept of contiguity (connectedness) as a physical adjacency between ecosystem types and/or populations. Instead, the term “ecological connectivity” indicates a more complex meaning since two components must be taken into account: one, structural, depends on the spatial arrangement of ecosystem typologies, from their physical continuity, from the presence, typology and dimension of elements, of natural or anthropic origin; the other, functional, related to the scale of perception of species, to its ecological and behavioural requisites, including its degree of specialization (Baudry *et al.*, 1988; Battisti, 2004; D’Ambrogi *et al.*, 2015).

Structural connectivity has become increasingly measurable by researchers and policymakers, as geographic information systems (GIS) and remote sensing tools have become widely available, accessible and scalable. However, functional connectivity is not easily measurable by using the movements of individual organisms. Thus, the topic becomes logistically more complicated (Rudnick *et al.*, 2012).

Connectivity can have several forms: flyways for migratory species including stepping stones, but also terrestrial or river corridors; the most obvious terrestrial corridors are forest corridors, but they can also include wetland or river related corridors or mountain corridors (Jongman *et al.*, 2011).

Connectivity is a task of national or regional authorities. The implementation of connectivity issues is constrained by the lack of knowledge on ecological requirements of species and habitats. For this purpose, Article 18 of the Habitats Directive aims to improve researches and exchange of information saying that «particular attention shall be paid to scientific work necessary for the implementation of Articles 3 and 10, and transboundary cooperative research between member states shall be encouraged».

Theoretically, a network consists of the combination of a set of nodes and linkages. The structure of an ecological network should consider nodes as protected areas (i.e Natura 2000 sites) interconnected through specific connective elements in the landscape, that are the so-called ecological corridors. Thus, an ecological corridor has two meaning: the first, a physical feature, which provide connectedness in the landscape, physically connecting core habitats; and, the second, a biological function, which is the landscape connectivity as the ability of the target species or assemblages to disperse across a landscape (Baudry and Merriam, 1988). The former does not imply the success of the second, while the latter does. Actually, ecological networks have an important lack, that is the absence of connective elements. Furthermore, a critical point is to know how different species differently perceive a landscape, and in what way the level of connectivity varies between species and between communities. Doubtless, an invariant concept is that in a landscape or area with high connectivity, species can move without obstacle between suitable habitats; otherwise, in a landscape with low connectivity, species are prevented from moving between suitable habitats. Additionally, a particular landscape or region may, at the same time, provide high connectivity for some species, and low connectivity for others (Bennett, 1998, 2003).

Patterns, models and tools to analyse connectivity issues

In order to identify areas that provide the greatest potential for increasing connectivity for species, landscape connectivity analysis can be an advantageous decision tool for prioritizing restoration prospects. Common products of connectivity analyses are maps of predicted core areas, linkage zones, or barriers. These maps can be the basis for management actions (Rudnick *et al.*, 2012).

Several tools can be used to map and analyse connectivity issue, and each has unique strengths and weaknesses, and several methods and tools have been developed and implemented with the purpose to address connectivity concepts in ecological networks and find the best placement for ecological corridors.

Since many informatics tools are produced in scientific researches, they can be freely found on the Internet on specific sites that disseminate experiences related to ecological corridors. For instance, the website "Conservation Corridor"[14] provides a summary of major tools currently in use or in development.

Currently, a huge number of tools is GIS-based. The most part consists of free tools, often, based on GIS open source. They are developed to model wildlife or ecological corridors, connectivity, or habitat, and they are discussed in the peer-reviewed literature in studies concerning connectivity and corridors. The most part of tools uses algorithms of Least cost path (LCP).

GIS tools for connectivity, corridor, or habitat modelling

In 1969, when McHarg (1969, 2007) presented his book "Design with Nature", he laid the analogical bases for current modern GIS. Since the development of ever more efficient computer systems has increased computing power, modern GISs provide a broad range of powerful spatial modelling and analysis features.

14 The website is accessible at: http://conservationcorridor.org/corridor-toolbox/websites/ (accessed 31 January 2019).

Users (such as planners, engineers, biologists) by using GIS can produce maps, analyse cell-based raster data, implement integrated raster/vector analysis; obtain new information from existing data, query information across multiple data layers, and integrate cell-based raster data with traditional vector data sources.

A large number of analytical approaches concerning ecological corridors are implemented in a GIS environment (e.g. Least-cost analysis, Factorial least-cost paths, Circuit theory, Graph theory, Resistant kernel) to support planners in mapping and prioritizing landscape connections. Specific data for each approach are required, and they often require input from biologists to define model parameters. Additionally, different objectives and different outcomes are produced by each approach (Rudnick *et al.*, 2012).

GIS-based modelling tools are constantly evolving, as researchers and professionals are identifying the best ways to improve existing tools. There are tools able to model connectivity not only in terrestrial landscapes (Table 1 from 1 to 6) but also in the fluvial or marine environment (e.g. Marine Geospatial Analysis Tool[15]).

In Table 1 (from 1 to 6)[16] are listed commonly used terrestrial-oriented tools. They can be used to model either functional or structural connectivity. Each tool requires specific input data sets to develop landscape permeability models or connectivity for specific species. The most part of tools uses algorithms of Least cost path.

15 Marine Geospatial Ecology Tools (MGET) is a free, open-source geoprocessing toolbox. It can help to solve marine researches, conservation, and spatial planning problems. MGET plugs into ArcGIS®. Further information available at: http://mgel.env.duke.edu/mget (accessed 31 January 2019).

16 Table 1 reports data coming from http://conservationcorridor.org/corridor-toolbox/programs-and-tools/ (last accessed: 31 January 2019).

Table 1 (Part 1/6) – Patterns, models and tools.

Tool	Author(s)	Published	Description	Used for	Input Data	Compatibility	Website
Circuitscape	Brad McRae (The Nature Conservancy), Viral Shah, Tanmay Mohapatra	2006	Circuitscape is an open-source program that uses circuit theory to model connectivity in heterogeneous landscapes. Its most common applications include modelling movement and gene flow of plants and animals, as well as identifying areas important for connectivity conservation.	Calculating multiple corridors between distinct nodes. Analysing gene flow.	Resistance layer (raster or network of nodes)	ArcGIS®	circuitscape.org
FunConn	Dave Theobald (Colorado State University)	2006	FunConn is a toolbox for ArcGIS that allows users to create terrestrial habitats and landscape network models. The habitat model is based on species' vegetation affinities, so a landcover layer is a minimal dataset required to run the model. No sampling data is required. The Analysis toolset allows for graph-theoretic or network-type analyses to be executed on landscape networks for modelling least-cost paths between fragmented habitats.	Modelling complex landscape networks without using sample data. Focusing on functional connectivity across a large landscape. Creating maps of habitat quality.	Landcover layer (raster)	Stand-alone	wiki.landscape-toolbox.org/doku.php/tools:funconn
Zonation	Conservation Biology Informatics Group, University of Helsinki, Finland	2006	Zonation produces a hierarchical prioritization of the landscape based on the occurrence levels of biodiversity features in sites (cells) by iteratively removing the least valuable remaining cell while accounting for connectivity and generalized complementarity. Zonation identifies areas important for retaining habitat quality and connectivity for multiple species, indirectly aiming at species' long-term persistence.	Individuals working in systematic conservation planning, spatial conservation prioritization, reserve/site selection, reserve network design, land use planning. Synthesizing data across multiple species and biodiversity features. Identifying potential barriers to conservation plans. Planning for climate change.	Biodiversity feature layer (raster) ex. habitat type, vegetation distribution, willingness to sell, ecosystem services	ArcGIS®	https://www.helsinki.fi/en/researchgroups/metapopulation-research-centre/software#section-14300
Conefor	Santiago Saura (Polytechnic University of Madrid) and Josep Torné (University of Lleida)	2007	Conefor is a software package that allows quantifying the importance of habitat areas and links for the maintenance or improvement of landscape connectivity. It is conceived as a tool for decision-making support in landscape planning and habitat conservation, through the identification and prioritization of critical sites for ecological connectivity.	Measuring habitat availability (reachability) at the landscape scale. Converting distances between patches to connectivity indices. Detailed analysis for specific target species. Functional connectivity assessment.	Calculations of effective distances (ex. with Circuitscape, Linkage Mapper)	Stand-alone	conefor.org

Table 1 (Part 2/6) – Patterns, models and tools.

Tool	Author(s)	Published	Description	Used for	Input Data	Compatibility	Website
Corridor Design	Dan Majka (The Nature Conservancy), with Paul Beier	2007	The site developers aim to transfer everything they've learned about designing wildlife corridors to the general public to facilitate better conservation, science, and dialogue.	Inexperienced users who need step-by-step guidance in planning for connectivity. Use of CorridorDesigner, a basic ArcToolbox toolbox for creating corridor models.	None	Stand-alone	corridordesign.org
Connect: Landscape Connectivity Modeling Toolbox	Ian Breckheimer and Austin Milt (University of North Carolina)	2010	Connect is a set of tools that help researchers and conservation planners model landscape connectivity for multiple wildlife species in complex heterogeneous landscapes. Connect also allows users to combine single-species models of animal movement to identify areas of the landscape that facilitate the movement of multiple species. Connect packages three cutting-edge connectivity modelling and conservation planning tools, Circuitscape, NetworkX, and Zonation into a user-friendly geoprocessing toolbox for ESRI ArcGIS 9.3.	Combining movement data for several target species to generate multi-species connectivity maps. Identifying areas where connectivity can be effectively restored. Assessing the impact of alternative-use scenarios. Adaptive management.	Resistance layer (raster)	ArcGIS®	unc.edu/depts/geog/lbe/Connect/index.html
Connectivity Analysis Toolkit	Carlos Carroll (Klamath Center for Conservation Research)	2010	The Connectivity Analysis Toolkit provides conservation planners with newly-developed tools for both linkage mapping and landscape-level 'centrality' analysis. The Toolkit allows users to develop and compare three contrasting centrality metrics based on input data representing habitat suitability or permeability, in order to determine which areas, across the landscape as a whole, would be priorities for conservation measures that might facilitate connectivity and dispersal. The Toolkit also allows application of these approaches to the more common question of mapping the best habitat linkages between a source and a target patch.	Ranking the importance of sites in the landscape as "gatekeepers" for movement. Mapping linkages between a source and target patches.	Habitat quality layer (raster)	Stand-alone	klamathconservation.org/science_blog/software/

Table 1 (Part 3/6) – Patterns, models and tools.

Tool	Author(s)	Published	Description	Used for	Input Data	Compatibility	Website
Linkage Mapper	Washington Wildlife Habitat Connectivity Working Group	2010	Linkage Mapper uses GIS maps of core habitat areas and resistance to identify and map linkages between core areas. The tool identifies adjacent (neighbouring) core areas and creates maps of least-cost corridors between them. It then mosaics the individual corridors to create a single composite corridor map.	Calculating single composite corridors between core areas. Identifying pinch-points (by combining with Circuitscape via Pinchpoint Mapper). Detecting barriers to facilitate restoration planning (via Barrier Mapper). Mapping corridors along climatic gradients (via Climate Linkage Mapper)	Core habitat areas layer (raster) Resistance layer (raster)	ArcGIS®	circuitscape.org/linkagemapper
UNICOR	Erin Landguth, Brian Hand, Joe Glassy (University of Montana, Computational Ecology Lab)	2011	UNICOR (Universal Corridor Network Simulator) is intended for use by land managers as well as the research community and will be a valuable tool for the study of conservation biology, by increasing our understanding of species connectivity in fragmenting future landscapes. The results can be used to designate sites as a potential source or sink populations, identify corridors, barriers, and population connectivity of keystone patches, and characterize zones for species persistence, vulnerability, and isolation.	Identifying movement corridors and barriers to movement. Designating sites as a potential source or sink populations.	Resistance layer (raster) Point locations for each population/individual location	Stand-alone	github.com/ComputationalEcologyLab/UNICOR
Grainscape	Paul Galpern (University of Calgary), Andrew Fall and Micheline Manseau	2012	Grainscape is a package in R developed for landscape connectivity analyses. Given a landscape resistance surface, functions in this package create grains of connectivity and minimum planar graph models that can be used to calculate effective distances for landscape connectivity at multiple scales. Distributed with SELES (Spatially Explicit Landscape Event Simulator) software.	Creating a simple map of how patches can be connected. Modelling connectivity for highly mobile organisms that are not obligate patch occupants.	Proficiency in RLandscape raster with associated resistance values	R	grainscape.r-forge.r-project.org

Table 1 (Part 4/6) – Patterns, models and tools.

Tool	Author(s)	Published	Description	Used for	Input Data	Compatibility	Website
Graphab	Jean-Christophe Foltête and Gilles Vuidel (University of Franche-Comté)	2012	Graphab is a software application for modelling ecological networks using landscape graphs. It is composed of four modules for: constructing graphs, including loading initial landscape data and identifying patches and links; computing connectivity metrics from graphs; integrating graph-based connectivity metrics into species distribution models; and, visual and cartographic interfacing.	Creating linkages between individual patches. Computing connectivity metrics	Landcover layer (raster)	Stand-alone	thema.univ-fcomte.fr/productions/graphab/en-home.html
Gnarly Landscape Utilities	Andrew Shirk (University of Washington), Brad McRae (The Nature Conservancy), Jim Platt (The Nature Conservancy)	2013	Gnarly Landscape Utilities is an ArcGIS toolbox designed to support some of the less-glamorous tasks involved with connectivity modelling. It includes tools for creating resistance and habitat layers and core area mapping.	Creating resistance layers and habitat layers. Mapping core areas.	Excel spreadsheet of values for raster classes	ArcGIS®	circuitscape.org/gnarly-landscape-utilities
MulTyLink	Raul Brás, J. Orestes Cerdeira, Diogo Alagador, and Miguel B. Araújo	2013	MulTyLink is an open source application designed to select connectivity linkages for distinct types of habitats, under a cost-efficient protocol. Since areas that can be used as linkages for one type of habitats may be barriers for other types, MulTyLink implements methods to optimise the selection of linkages free of barriers for every type of habitat. MulTyLink was conceived as a decision-support tool to be used in spatial conservation planning.	Determining how different types of barriers will affect linkages in the landscape. Importing and visualizing empirical richness patterns.	Resistance layer (text)	ArcGIS®	pascal.iseg.utl.pt/~rbras/MulTyLink/
The Yale Framework	Yale School of Forestry & Environmental Studies Working Group (led by Oswald Schmitz)	2013	The Yale Climate Adaptation Framework is a flexible portfolio of six spatially explicit adaptation options that help adjust the way land use planning can be done for a climate future. The framework crosses three ecological scales (i.e., species, ecosystems, and landscapes) used in different levels of planning with six adaptation approaches. Maintaining and restoring ecological connectivity is a cornerstone adaptation approach in the Framework.	Exploring potential methods for planning for connectivity. Introductory data sets that can be helpful to planners. Climate change focus	None	Stand-alone	yale.databasin.org

Table 1 (Part 5/6) – Patterns, models and tools.

Tool	Author(s)	Published	Description	Used for	Input Data	Compatibility	Website
Connecting Landscapes	LandScope America (a collaborative project of NatureServe and the National Geographic Society)	2014	This web-based guidance is intended for natural resources and conservation practitioners that need to model, assess, and plan for connectivity. While it is geared toward those that are relatively new to connectivity practice, experienced practitioners may also find value in this site to learn about new methods, tools, and resources or to contribute such information to this site; it is designed to be self-populating by the connectivity community of practice.	Inexperienced users who need step-by-step guidance in planning for connectivity. Individuals needing to determine what type of data is needed to map connectivity.	None	Stand-alone	landscope.org/focus/connectivity
FRAG-STATS	Kevin McGarigal (University of Massachusetts, Amherst)	1995 (last updated 2015)	FRAGSTATS is a spatial pattern analysis program for quantifying the structure (i.e. composition and configuration) of landscapes. The landscape subject to analysis is user-defined and can represent any spatial phenomenon. FRAGSTATS simply quantifies the spatial heterogeneity of the landscape as represented in either a categorical map (i.e. landscape mosaic) or continuous surface (i.e. landscape gradient).	Computing general landscape metrics. Flexibility in defining and scaling landscapes.	Landscape grid (raster)	Stand-alone	http://www.umass.edu/landeco/research/fragstats/fragstats.html
Guidos-Toolbox	Peter Vogt (Joint Research Centre, European Commission)	2008 (version 2.4 released 2015)	GuidosToolbox (Graphical User Interface for the Description of image Objects and their Shapes) is a free software collection with a variety of modules targeted to investigate several spatial aspects of raster image objects, such as pattern, connectivity, fragmentation, cost, etc. The MSPA (Morphological Spatial Pattern Analysis) module automatically detects connecting pathways and can be combined with Conefor for connectivity analysis.	Image analysis of raster files Structural connectivity assessment. Cost analysis including detection of least cost path and user-driven cost ranges.	Raster image (ex. land cover classes, resistance layer, etc.)	Google Earth®	forest.jrc.ec.europa.eu/download/software/guidos

Table 1 (Part 6/6) – Patterns, models and tools.

Tool	Author(s)	Published	Description	Used for	Input Data	Compatibility	Website
Condatis	David W. Wallis and Jenny A. Hodgson (University of Liverpool)	2015	Condatis is a decision support tool to identify the best locations for habitat creation and restoration to enhance existing habitat networks and increase connectivity across landscapes. It is designed for landscape-scale studies of connectivity over successive generations of species and works particularly well for habitats that are well-defined and patchy.	Map out directional connectivity over a landscape. Pick out most effective sites for habitat creation. Test climate change resilience. Run several comparable colonization scenarios.	Habitat layer(s) (ESRI Grid format or TIFF file)	-	condatis.org.uk
LandScape Corridors	Spatial Ecology and Conservation Lab (LEEC), Universidade Estadual Paulista, Brazil	2017	LandScape Corridors (LSCorridors) uses a resistance surface map to generate multiple corridors between multiple source-target locations inside the map. To accomplish that, it uses species habitat requirement information and a least-cost path algorithm. The package also includes stochasticity at different levels and enables different simulation methods.	Calculating multiple corridors between multiple source-target patches. Incorporating species habitat requirement information. Incorporating stochastic variation.	Source-target patches layer (raster) Resistance layer (raster)	GRASS GIS	github.com/LEEClab/LS_CORRIDORS/wiki

The Least Cost Path method

Graph theory is a part of the network theory. It defines a network as a graph *G* which is a set of *V(G),* called *vertices*, and *E(G)*, called *edges* which connect two or more vertices, as described in Tutte (2001). In this manuscript, since the terminology is not standardised yet, "nodes" is the term used to define the *V(G)* set and "link" to *E(G)*. Applying search algorithms (e.g. Dijkstra, 1959), LCP methods allow to analyse all paths of the network and predict least-cost way computed as the minimum cost path (link) between two, or more, patches (nodes), taking into account landscape resistance values which represent the opposition to species movement from a source point to a destination point. LCP method requires two main input: a landscape resistance surface, and core areas defining nodes of the network to be connected.

In this way, a spatial composition of the landscape is simplified in a raster where cells represent resistances, and species are assumed to perceive a cost while they move from a site to another.

LCP methods have been implemented in several studies aiming at the identification of potential ecological corridors and the prioritization of patches among protected areas (Adriaensen *et al.*, 2003; Beier *et al.*, 2009; Beier *et al.*, 2011; Sawyer *et al.*, 2011; Zeller *et al.*, 2012; EEA, 2014; Lee *et al.*, 2014; Liquete *et al.*, 2015; Rayfield *et al.*, 2016; Lechner *et al.*, 2017; Pietsch, 2017) to design best paths to connect structure elements in the landscape. LCP methods are often integrated with GIS-tool.

Even though LCP approach is discouraged by Beier *et al.* (2008) since it is unlikely that animals can identify optimal routes between nodes and these routes are sensitive to a pixel size of raster representing cost values, LCP approach is largely used in the scientific field. Indeed, several software and methods are based on LCP algorithms, for instance: CircuitScape (Shah *et al.*, 2008); Connectivity Analysis Toolkit – CAT (Carroll *et al.*, 2012); Linkage Mapper (McRae *et al.*, 2011); UniCor (Landguth *et al.*, 2012); and, the approach presented by Panzacchi *et al.* (2016). Further, Ribeiro *et al.* (2017) describe a new similar approach for corridor design by using the software LSCorridors[17]. This software is implemented on LCP approaches to identify potential corridors between two or more patches. Each identified corridor is the expression of a single path of least resistance between patches. This approach is similar to other "least cost corridor" approaches (Adriaensen *et al.*, 2003; McRae *et al.*, 2011; Pinto *et al.*, 2012).

Linkage Mapper

Linkage Mapper[18] is a GIS-tool developed to analyse regional habitat connectivity. This tool requires two inputs: a source layer and a friction/resistance layer. It can be implemented in ArcGIS®.

The first input is a polygonal shapefile that represents patches to be connected; they can be nodes of the ecological network or single patches into the nodes (it depends on the scale of the analysis).

The second input is a raster map which provides for each cell two types of basic information: a resistance value and data concerning spatial position and orientation. Resistance values define the cost of movement in relation to attributes of the land cover type in the cell. The movement is assumed as a cost, that is the resistance that species face to the movement (e.g. energy spent for moving, mortality risk, negative powerful effect on future reproductive potential).

In Linkage Mapper the model is based on the following steps:

1) adjacent core areas are identified;
2) a network of core areas is defined by using adjacency and distance data;

17 This software can be downloaded from https://github.com/LEEClab/LS_CORRIDORS/wiki (accessed 31 January 2019).

18 This software can be downloaded from http://www.circuitscape.org/linkagemapper (accessed 31 January 2019).

3) Cost Weighted Distance analyses (CWD[19]) and LCP algorithms are implemented; and,
4) least-cost corridors are identified and represented into a single map, by a single CWD-based raster map for all core areas (as shown in Figure 2).

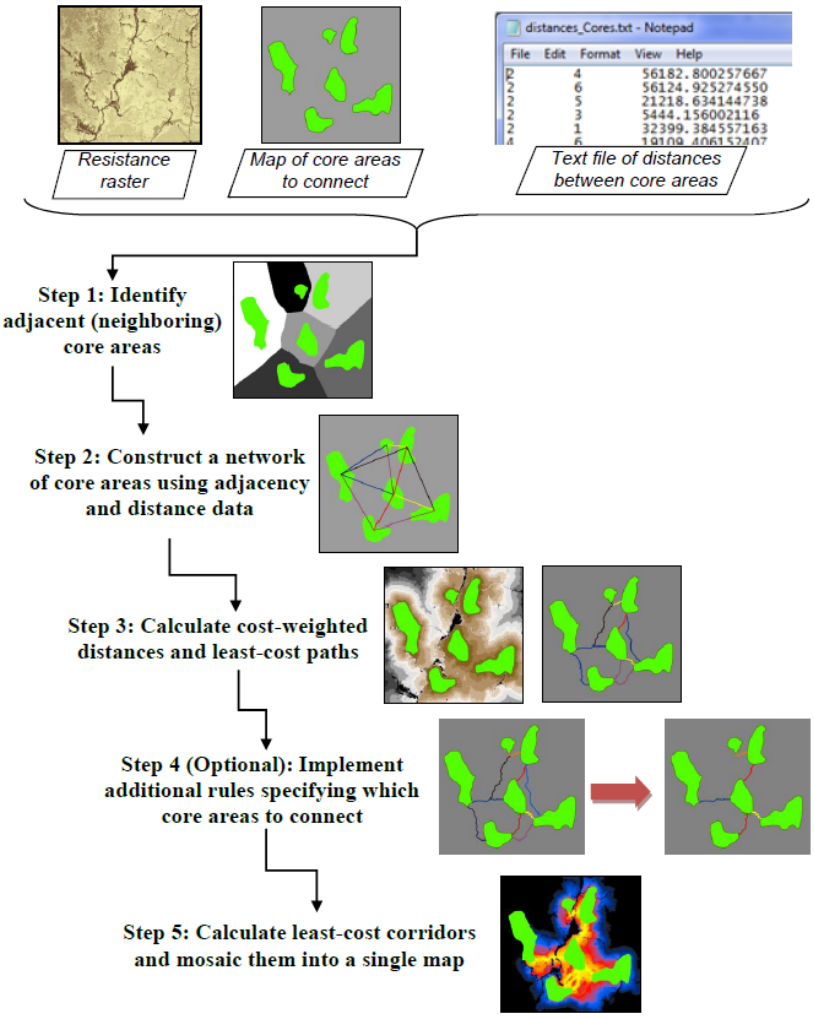

Figure 2 – The logic map of the model implemented in Linkage Mapper. Source: McRae et al., 2011.

19 CWD values indicates the cumulative weighted distance between two core areas in terms of length units (km).

The algorithm identifies directions that require the least effort to move from a cell to another, thus the lowest cost in terms of species movement.

Linkage Mapper computes least-cost corridors as the sum of CWD based on the raster maps related to pairs of core areas[20]. For instance, if A and B are two core areas, the least-cost corridors are normalized according to the equation (1) (McRae *et al.*, 2011).

$$NLCC_{AB} = CWD_A + CWD_B - LCD_{AB} \tag{1}$$

Where:

$NLCC_{AB}$ is the normalised least-cost corridor connecting core areas A and B,

CWD_A is the cost-weighted distance from core area A,

CWD_B is the cost-weighted distance from core area B, and

LCD_{AB} is the cost-weighted distance accumulated by moving along the potential least-cost path connecting the two core areas.

In section 4 some case studies are based on the implementation of the GIS-tool Linkage Mapper.

20 In weighted-distance analysis, the minimum sum of cell "costs" between a given cell and the closest designated source area are calculated for each cell. This determine the weighted distance shown in resulting maps, in terms of length units (km), which estimates the efforts for species to move in terms of the cumulative effect of landscape barriers or the total weighted distance. In order to define least-cost corridors, the "cost" of moving between two designated source areas is evaluated by calculating, for each cell, the cumulative weighted distance between the given cell and the two sources. The least-cost corridor resulting in maps shows the relative linkage value across the landscape between two source areas (Singleton et al., 2002).

Section 3 – Important issues concerning the implementation of connectivity into spatial planning

In recent years, land managers have to face an important challenge concerning the design and implementation of land-use strategies able to ensure the conservation of natural resources in relation to land use demands. This is a challenge which involves government agencies, responsible for the administration and management of large areas of land, but also community groups and individuals, managers of small parcels of land in fragmented landscapes.

The integration of both natural and anthropic spaces in ecological networks is useful to protect and enhance the biodiversity, and connective elements into the landscape allow to create or strengthen relations among all elements of the network.

Spatial planning approaches, that introduce biophysical, economic and socio-cultural effects from ecosystem services, should be integrated starting from the concept of ecological networks.

The strategical function of an ecological network is to mitigate anthropic pressures on the environment, which cause impacts, changes on ecosystems and fragmentation (Pereira *et al.*, 2011). The identification of ecological corridors ensures movements of wild fauna and flora species, but they need to be supported by a methodological approach to be identified, and then to be regulated in spatial planning.

The Convention on Biological Diversity, which defines an ecosystem as “a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit”, suggests implementing ecosystem-based approaches which integrate the management of land, water and living resources, to promote conservation and sustainable uses.

Ecosystems' resilience can be increased by ensuring the permanence of species within their respective natural ecosystems and enabling the movement and spread. By guarantying ecological connectivity within landscapes, in particular, improving existing ecological networks, negative impacts of fragmentation can be reduced. Thus, connectivity issues support both ecosystems functions and ESs provisioning, so their socio-economic benefits (Kettunen *et al.*, 2007).

However, the major issue concerning the Natura 2000 Network is that any kind of link between its sites did not have ever recognised, so they require analyses regarding connectivity concepts as well as methodologies to identify physically a set of ecological corridors.

Improving connectivity for all species, as well as maintaining their long term evolutionary advantage, is a challenging task (Samways *et al.*, 2010). However, different species have different habitat requirements and they can perceive and respond to a landscape at different spatial scales. In this way, an ecological network may be a permeable matrix for different groups of species or a barrier for some other species. Connectivity in an ecological network could be experienced very differently by different species (Urban *et al.*, 2009).

Approaches based on the behaviour of species, that is a functional connectivity, are species- and context-specific issue and they can be difficult to meet connectivity needs of all species and processes within any one implementation, since studies on functional connectivity require complex phenomena often difficult to sample, experiment on, and describe synthetically (Bélisle, 2005).

Urban *et al.* (2009) suggests implementing an approach based on analyses graphs independently for several species, and then overlay or intersect the solutions to find locations that are important to several species.

As suggested in Massa (2001), in spatial planning a framework study on ecological corridors could be as the workflow below:

- building a thematic map based on land uses or land covers;
- identifying a focal species, or a focal group species, in the study area;
- defining the relationship between land uses and species;
- defining and designing the potential connectivity;
- implementing potential corridors in management or spatial planning.

Relations between land use and species

In literature, different methods with different purposes can be found. They aim to identify ECs and to implement connectivity analyses. Some authors keep the focus on particular vertebrates species (i.e. Pereira *et al.*, 2011, for *Emys orbicicularis*; Loro *et al.*, 2015, for *Capreolus capreolus*), or particular birds (Mazaris *et al.*, 2013, for *Gyps fulvus*, *Aquila chrysaetos*, *Neophron percnopterus*, *Aquila pomarine*), or particular habitat (i.e. Foltête *et al.*, 2014, for a pond network), others aim to develop a multiple species connectivity (i.e. Sahraoui, 2017, concerning the construction of a virtual species; Cushman *et al.*, 2013, implementing an approach concerning some focal species; Urban *et al.*, 2009, suggesting a multispecies applications by overlaying multiple graphs generated for different species). They show useful outcomes to implement quantitative analyses concerning target species or habitat, but, in order to integrate ecological networks into processes related to spatial planning, the definition of ECs is required. Sites are already protected by several specific policies, but the elements of the landscape which could connect protected areas have to be still identified.

The spatial identification of ECs is an important foundation of protection and long-term conservation of biodiversity functions on the basis of prioritization of spatial elements (Snäll *et al.*, 2016) that show low resistance to species movements.

In order to implement approaches focused on connectivity analyses and the identification of ECs, information concerning the association of species and habitat types is required.

The association of species and habitat types to ecosystems allows to build statistics, indicators and maps issues related to nature conservation, and, in particular, understand issues on land use and species, useful to integrate ecological network in spatial planning. For instance, in the conceptual framework of "Mapping and Assessment of Ecosystems and their Services" (MAES)[21], Roscher *et al.* (2015) propose a database of associations of species and habitat types linked to MAES ecosystems types. This allocation of species and habitat per ecosystem (an example is shown in Figure 3) is completed for each of the nine terrestrial biogeographical regions (according to the Habitats Directive) and each marine region (according to the Marine Strategy Framework Directive).

In their report, each species is sorted per species group and then per name, and each habitat is sorted per Natura 2000 code. They link species and main ecosystem classifying characteristics of links between species and main ecosystems as follows: P, preferred ecosystem: species usually use this ecosystem during most of its life cycle or its largest population is linked to this; S, suitable ecosystem: species regularly occur, but it is not their preferred ecotype; O, occasional ecosystem: the species lives sometimes, but only marginally or a small part of the species population uses this ecosystem.

21 Further information on MAES can be found at https://biodiversity.europa.eu/maes (accessed 31 January 2019). All data on MAES can be downloaded from https://www.eea.europa.eu/data-and-maps/data/linkages-of-species-and-habitat#tab-european-data (accessed 31 January 2019).

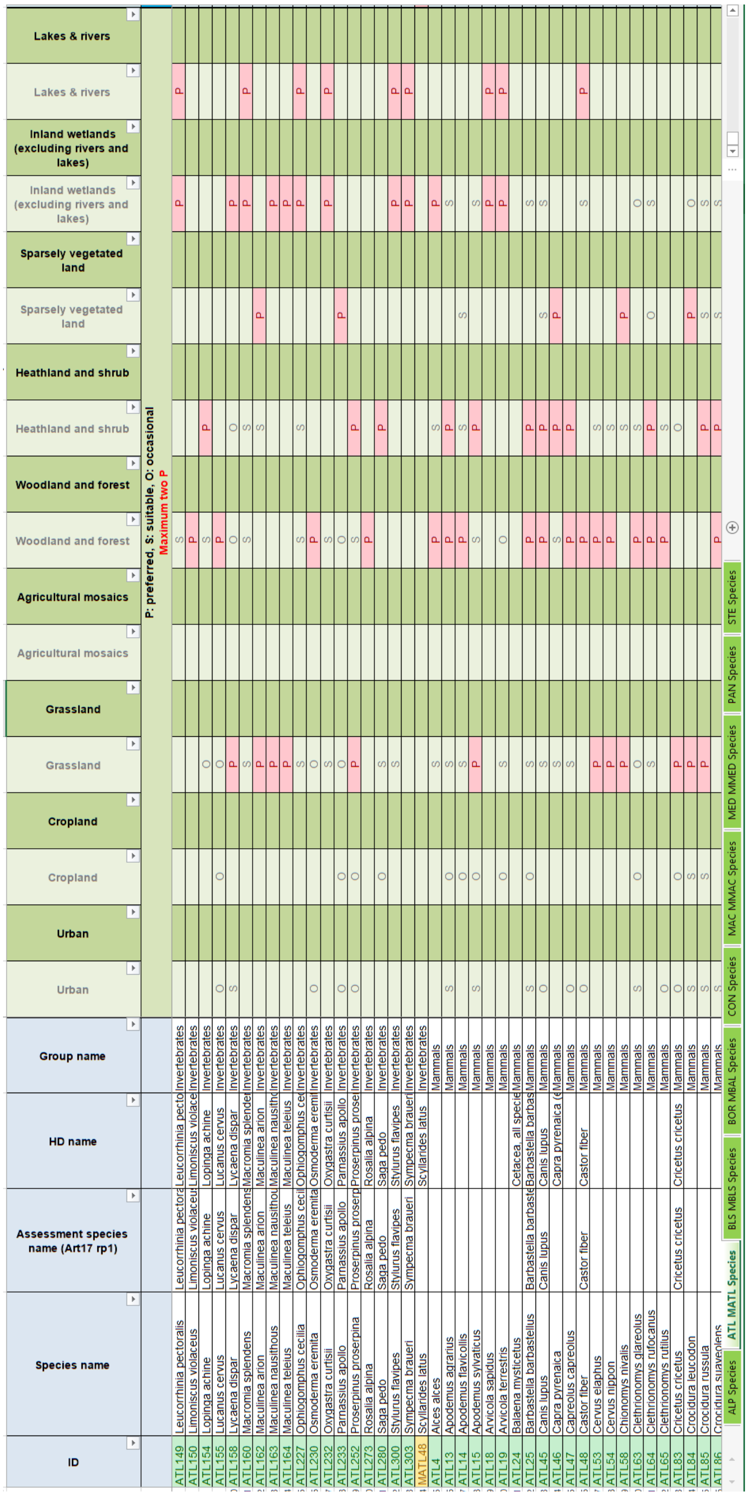

Figure 3 – A screenshot of a part of the spreadsheet concerning species and ecosystems association.

MAES ecosystem types are the aggregation of either habitat types or land cover classes. A cross-linkages (Figure 4) between different typologies can be used to check equivalence between current MAES ecosystem types, EUNIS[22] habitats level 1 and the Corine[23] Land Cover (CLC) classification (EEA, 2013).

MAES typology of ecosystems		Representation of habitats (functional dimension by EUNIS level 1 and MSFD for marine ecosystems)	Representation of land cover (spatial dimension)
Major ecosystem category (level 1)	**Ecosystem type (level 2)**		
Terrestrial	**Urban**	**J Constructed industrial & other artificial habitats**	Urban, industrial, commercial and transport areas, urban green areas, mines, dump and construction sites
	Cropland	**I Regularly or recently cultivated agricultural, horticultural & domestic habitats**	Annual and permanent crops
	Grassland	**E Grasslands & land dominated by forbs, mosses or lichens**	Pastures and (semi-) natural grasslands
	Agricultural mosaics (*)	**X Habitat complexes limited to** Crops shaded by trees, Intensively-farmed crops interspersed with strips of semi-natural vegetation, Pasture woods (with a tree layer overlying pasture), Mosaic landscapes with a woodland element (bocages)	
	Woodland and forest	**G Woodland, forest & other wooded land**	Forests
	Heathland and shrub	**F Heathland, scrub and tundra**	Moors, heathland and sclerophyllous vegetation
	Sparsely vegetated land	**H Inland unvegetated or sparsely vegetated habitats**	Open spaces with little or no vegetation (bare rocks, glaciers and beaches, dunes and sand plains included)
	Wetlands	**D Mires, bogs and fens**	Inland wetlands (marshes and peatbogs)
Freshwater	**Rivers and lakes**	**C Inland surface waters**	Water courses & bodies incl. coastal lakes (without permanent connection to the sea)
Marine	**Marine inlets and transitional waters**	Pelagic habitats: Low/reduced salinity water(of lagoons) Variable salinity water (of coastal wetlands, estuaries and other transitional waters) Marine salinity water (of other inlets) Benthic habitats: Littoral rock and biogenic reef, Littoral sediment Shallow sublittoral rock and biogenic reef Shallow sublittoral sediment	Coastal wetlands: Saltmarshes, salines and intertidal flats Lagoons: Highly restricted connection to open sea, reduced, often relatively stable, salinity regime Estuaries and other transitional waters: Link rivers to open sea, variable, highly dynamic salinity regime. All WFD transitional waters included Fjords/sea lochs: Glacially derived, typically elongated and deep; marine salinity regime Embayments: Non-glacial origin, typically shallow, marine salinity system Pelagic habitats in this type include the photic zone,benthic habitats can include it or not
	Coastal	Pelagic habitats: Coastal waters Benthic habitats: Littoral rock and biogenic reef Littoral sediment Shallow sublittoral rock and biogenic reef Shallow sublittoral sediment	Coastal, shallow-depth marine systems that experience significant landbased influences. These systems undergo diurnal fluctuations in temperature, salinity and turbidity, and are subject to wave disturbance. Depth is up to 50-70 meters. Pelagic habitats in this type include the photic zone, benthic habitats can include it or not
	Shelf	Pelagic habitats: Shelf waters Benthic habitats: Shelf sublittoral rock and biogenic reef Shelf sublittoral	Marine systems away from coastal influence, down to the shelf slope. They experience more stable temperature and salinity regimes than coastal systems, and their seabed is below wave disturbance.Depth is up to 200 meters. Pelagic habitats in this type include the photic zone, benthic habitats are beyond the photic limit (aphotic)

Figure 4 – A screenshot of a part of the spreadsheet of cross-linkages.

Spatial planning and environmental planning

Enhancing the interconnectivity of natural protected areas and establishing a permeable landscape should be considered as a strategic way to ensure the diversity of and connectivity between natural areas, allowing for species migration and survival under climate changes. These issues must be factored into the management of the Natura 2000 Network (European Commission, 2009).

Ecological networks are based on policy objectives, and approaches are derived from these objectives. These networks do not have to coincide necessarily

22 European nature information system, EUNIS, is a part of the European Biodiversity data centre (BDC). It brings together European data from several databases and organisations into three interlinked modules on Natura 2000 sites, species and habitat types. EUNIS provides also a specific habitat classification. Further information can be found at https://eunis.eea.europa.eu/index.jsp (accessed 31 January 2019).

23 Corine is the acronym of *COoRdination de l'INformation sur l'Environnement* [Coordination of the information concerning the environment]. Further information can be found at http://www.eea.europa.eu/publications/COR0-landcover (accessed 31 January 2019).

with ecological structures since nature conservation is the main objective for policies. The ecology conservation is an implicit issue in nature conservation. However, nature conservation is based on ecological principles, but they can be interpreted differently because of differences in national or regional policies and decision making between different land use interests (Jongman *et al.*, 2001).

Spatial planning approaches need to integrate ecological concepts based on ecological networks, in order to build a consistent methodological framework and, even more, to understand where planners should spatially operate. In this methodological approach is needed to identify the most optimal patches in the landscape to define ecological corridors to improve the connectivity of an ecological network.

Ecological corridors are often constituted by habitat patches between protected areas that can be used by species to move from a site to another. Natural vegetations or extensively-used agricultural areas compose most land-based habitats (Bakker *et al.*, 2015).

The use of connective elements in the landscape, as ecological corridors, can be related not only to biological diffusions but also to touristic functions or agrarian productions. However, these issues should be integrated into a planning logic and, thereafter, a framework of rules, that takes into account compatible or interfering uses with biological functions, has to be built (Romano, 1997).

Recently, the United Nations Environment Programme (UNEP)[24] proposed the development of a Connectivity Conservation Strategy[25] in order to achieve the CBD Strategic Plan for Biodiversity, in particular, Aichi Biodiversity Targets

24 The UNEP is the leading global environmental authority that sets the global environmental agenda, promotes the coherent implementation of the environmental dimension of sustainable development within the United Nations system, and serves as an authoritative advocate for the global environment. Further information can be found at https://www.unenvironment.org/ (accessed 31 January 2019).

25 Further information can be found at http://beta.unep-wcmc.org/news/unep-launches-global-connectivity-conservation-project (accessed 31 January 2019).

5, 11, 12, 14 and 15. This strategy has the task of assisting authorities in integrating considerations into national land-use (and seascape planning processes). The project of the strategy consists of three phases. In the first phase, a global database-hub will collate information on existing connectivity conservation initiatives at different scales and a map of connectivity conservation areas will be built in order to inform a global analysis of potential areas for scaling up connectivity conservation at the landscape and seascape scale. In the second phase, practical guidelines will be developed to support the recognition, establishment, and implementation of connectivity conservation areas to conserve large, functioning ecological landscapes and seascapes. In the third phase, technical support for decision makers and stakeholders will be implemented in priority areas to establish connectivity conservation areas.

In May 2016, the International Union for Conservation of Nature – World Commission on Protected Areas (IUCN[26]-WCPA[27]) released a draft concerning guidelines on definition, types, selection criteria and governance of areas of connectivity conservation Guidelines (Worboys *et al.*, 2016). These guidelines are useful for defining important areas for connectivity issues. They support the recognition and spatial delineation of areas of connectivity conservation, that can be understood as ecological corridors.

In this way, ecological corridors can assume the definition of spatial elements that support the connectivity of habitats and their protection, since an area of

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26 The IUCN is a membership Union uniquely composed of both government and civil society organisations. It provides public, private and non-governmental organisations with the knowledge and tools that enable human progress, economic development and nature conservation to take place together. It harnesses the experience, resources and reach of its 1,300 Member organisations and the input of some 13,000 experts. Further information can be found at https://www.iucn.org/ (accessed 31 January 2019).

27 The WCPA is the world's premier network of protected area expertise. It is administered by IUCN's Global Programme on Protected Areas and has over 2,000 members, spanning 140 countries. Their mission is to develop and provide scientific and technical advice and policy that promotes a representative, effectively managed and equitably governed global system of marine and terrestrial protected areas, including especially areas of particular importance for biodiversity and ecosystem services. Further information can be found at https://www.iucn.org/theme/protected-areas/wcpa (accessed 31 January 2019).

connectivity conservation is defined as «A recognised, large and/or significant spatially defined geographical space of one or more tenures that is actively, effectively and equitably governed and managed to ensure that viable populations of species are able to survive, evolve, move and interconnect within and between systems of protected areas and other effective area-based conservation areas. The vision and purpose of an Area of Connectivity Conservation is to connect protected areas and other effective area-based conservation areas and to maintain or restore ecosystem function and ecological and evolutionary processes of species and ecosystems across (and between) landscapes, freshwater-scapes or seascapes for biodiversity conservation in areas that may also be used and occupied for a variety of human purposes, so that people and other species are able to survive and to adapt to environmental change, especially climate change» (Worboys *et al.*, 2016).

In the previous definition, important foundations are that these areas should be “recognised”, “spatially defined” and “governed and managed”. Thus, planners can have a key role in these issues, since they can propose, working in multidisciplinary teams, methods to recognise and spatially define areas as ecological corridors, and, then, they can implement a normative framework to govern and manage this space into various type of planning (e.g. both spatial and environmental).

Ecological networks, green infrastructure and ecosystem services

In scientific literature, the concept of ecological network assumes different meanings depending on the interpretation which can be translated in different ways of implementation. From an ecological point of view, the network is an interconnected system of habitats to safeguard biodiversity, with particular attention on potentially threatened species. The geometry of the network has a structure based on the recognition of central areas (core areas), protection zones (buffer zones) and connection areas (corridors) that allow the exchange of individuals between areas, in order to reduce extinction risks of individual local populations. Ecological networks are instruments aimed at mitigating the phenomenon of habitat fragmentation and, in their ecological-functional approach, to guarantee the permanence of ecosystem processes and connectivity for sensitive species.

Over the years, the concept of ecological network has undergone an evolution that has led it to become part of the current green infrastructure model. Actually, the current concept of green infrastructure is strictly related to delivery ecosystem services. Indeed, the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions (GI) (COM (2013) 249 final), defines a green infrastructure as «[A] strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings. […] The work done over the last 25 years to establish and consolidate the network means that the backbone of the European green infrastructure is already in place. [The Natura 2000 network] is a reservoir of biodiversity that can be drawn upon to repopulate and revitalize degraded environments and catalyse the development of green infrastructure. This will also help reduce the fragmentation of the ecosystems, improving the connectivity between sites in the Natura 2000 network and thus achieving the objectives of Article 10 of the Habitats Directive» (European Commission, 2013).

Green infrastructure can contribute to ecosystem health in various ways by its elements and components. For instance, at urban and peri-urban scale, the overall vegetation cover (natural, semi-natural and artificial) can include different habitats, thus they can contribute to the conservation of biological diversity (as cited in Tzoulas *et al*., 2007: Bratton, 1997 and Flores *et al*., 1998).

Ecosystem services are the benefits people obtain from ecosystems, which the Millennium Ecosystem Assessment (2003) describes in four types of service: provisioning (e.g. food and water), regulating (e.g. regulation of floods, drought, land degradation, and disease), cultural (e.g. recreational, spiritual, religious and other non-material benefits) and supporting (e.g. soil formation and nutrient cycling).

Recent debates on the relationship between biodiversity and ecosystem services discuss whether the strengthening of nature conservation reasoning can be driven by emphasizing the role of species and habitats in supporting ecosystem services (Bastian, 2013; Čivić *et al.*, 2014).

Harrison *et al.* (2014) provide a systematic literature review by analysing linkages between biodiversity and ecosystem services. They show that the majority of relationships between biodiversity and ecosystem services cited in 530 studies were positive (i.e. the services of water quality regulation, water flow regulation, mass flow regulation and landscape aesthetics were improved by increases in community and habitat area).

Liquete *et al.* (2015) argue that green infrastructure is a spatial structure of a network consisting of protected areas which need to be taken care.

Urban and regional planning can develop and manage issues related to green infrastructure and their delivery ecosystem services (Čivić *et al.*, 2014). Moreover, green infrastructures are important to restore biodiversity, reduce ecosystems fragmentation, and improve their capacity to deliver ecosystem services (European Commission's Directorate-General Environment, 2012; EEA, 2014; Liquete *et al.*, 2015).

Tzoulas *et al*. (2007), by citing Opdam (2006), claim that green infrastructure can help to maintain the integrity of habitat systems and may provide the physical basis for ecological networks issues; furthermore, ecological networks can alleviate ecological impacts of habitat fragmentation. Thus, biodiversity conservation is an integral part of sustainable landscapes in green infrastructure.

The environmental protection via habitat management and restoration make possible to increase ecosystem services (as cited in Vihervaara, 2012: Srivastava and Vellend, 2005; Balvanera *et al.*, 2006; Cardinale *et al.*, 2006; Rafaelli, 2006; Hector and Bagchi, 2007; Benayas *et al.*, 2009).

Several studies are showing that multi-functional use of natural and semi-natural ecosystems and landscapes have not only ecologically more sustainable, and socio-culturally results, but they can have economically more beneficial results (de Groot *et al.*, 2010; Bastian, 2013; Castro *et al.*, 2015).

The resilience of ecosystems can be increased by ensuring the permanence of species within their respective natural ecosystems and allowing movement and dissemination. Therefore, by ensuring ecological connectivity within landscapes, by improving existing ecological networks, negative impacts of fragmentation can be reduced, and, at the same time, functions of supplying ecosystem services are also guaranteed as socio-economic benefits (Kettunen *et al.*, 2007; Čivić *et al.*, 2014).

In this view, ecological corridors can support multi-functional land uses ensuring task to restore biodiversity, reducing ecosystems fragmentation, improving the capacity to deliver ecosystem services of involved landscape elements.

Unfortunately, a coherent and integrated approach to implementing the practical application of the concept of ecosystem and landscape functions in planning, management and decision-making is still lacking (de Groot *et al.*, 2010).

The role of the Natura 2000 Network

The Natura 2000 Network represents the core of green infrastructures framework in Member States.

The Natura 2000 Network, taking into account Article 10 of the Habitats Directive, should be ecologically and functionally connected by landscape elements, connecting habitats with the purpose to support biodiversity conservation and enhancement. These connective elements form the ecological corridors. The completion of the ecological network, improving the coherence by the implementation of ecological corridors, can increase in the supply of ecosystem services (Kettunen *et al.*, 2007; Samways *et al.*, 2010), since this issue well implemented the Natura 2000 Network can be the backbone of a further green infrastructure (European Commission, 2010).

The EU Biodiversity Strategy to 2020 (COM(2011)244) is aimed at protecting and improving the state of biodiversity in Europe for the next decade. In 2011 the European Commission adopted this Strategy with a headline target of «halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, and restoring them in so far as feasible while stepping up the EU contribution to averting global biodiversity loss». Furthermore, the vision of the Strategy proposes «[by] 2050, European Union biodiversity and the ecosystem services it provides — its natural capital — are protected, valued and appropriately restored for biodiversity’s intrinsic value and for their essential contribution to human wellbeing and economic prosperity, and so that catastrophic changes caused by the loss of biodiversity are avoided».

The Strategy identifies six targets which cover the main factors for biodiversity loss and which will reduce the greatest pressures on nature. Target 2 of the EU Biodiversity Strategy to 2020 claims «[by] 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15 % of degraded ecosystems». Thus, it focuses on maintaining and enhancing ecosystem services and restoring degraded ecosystems by incorporating green infrastructure in spatial planning. Realising this Target can contribute to the EU's sustainable growth objectives and to mitigating and adapting to climate change while promoting economic, territorial and social cohesion and safeguarding the EU's cultural heritage. Furthermore, better functional connectivity between ecosystems within and between Natura 2000 areas and in the wider countryside can be ensured.

Natura 2000 can play a key role for Strategy implementation, for example, in climate change mitigation and adaptation (e.g. through habitat protection and restoration), in development of EU green infrastructure as a reservoir of biodiversity and, moreover, Natura 2000 Network is also a key attribute of the EU's natural capital and forms an integral part of the EU's endeavours towards establishing a green economy.

More specifically, the completion and appropriate management of the Natura 2000 Network forms an integral part of the Strategy and all crucial actions identified include securing adequate financing for the conservation measures required for Natura 2000 sites at both EU and national/regional level.

The aim of the Habitats Directive is to promote the maintenance of biodiversity, by taking into account economic, social, cultural and regional requirements. The Habitats Directive makes a contribution to the general objective of sustainable development; whereas, in certain cases, the maintenance of biodiversity may require the maintenance or the encouragement of human activities. Thus, the provision of ecosystem services is an indirect target that Natura 2000 can pursue. Within this perspective, which sees the centrality of human communities and benefits that these can derive from an environment in a good state of conservation, the preservation of biodiversity through the maintenance of ecological connectivity is one of the tools to guarantee ecosystems health and able to provide a broad spectrum of ecosystem services.

The Natura 2000 sites, as protected areas in an ecological network, are the key elements of effective biodiversity policy, but they are not sufficient. The integration of protected areas into landscape policies, enhancing and restoring connectivity among site, between sites and with the wider environment, has a decisive role. For this purpose, a multi-functional landscape is required to integrate management issues into spatial planning to achieve ecosystems conservation since ecosystems and habitats are becoming increasingly fragmented mostly through land-use changes and intensification. Green infrastructure concepts can integrate biodiversity policies into many sectors (e.g. agriculture, transport, land use, energy policy) but the Natura 2000 Network constitutes the backbone of green infrastructures, since the maintenance of landscape features, as part of green infrastructures, is vital for the existence and movement of wild flora and fauna, in particular, thinking about pressures associated with climate change, and these structures need to be integrated in decisions on land use planning.

Several ecosystem services depend on natural and semi-natural ecosystems, in addition to ecological forms of land use. If ecosystems were destroyed or converted to more intensive use, not only biological diversity but also many ecosystem services would be lost or reduced (as cited in Bastian, 2013: IEEP, 2002; Schweppe-Kraft, 2008).

Since connectivity analyses constitute a scientific tool to evaluate and maintain ecological functionality between Natura 2000 sites, the European Commission (2010) suggests a methodology based on connectivity concepts to guarantee that the Natura 2000 network is taken into account to build a functional and coherent ecological network with its connective elements and, at the same time, a green infrastructure. This methodology consists of three steps, as follows.

1) Connectivity analysis between Natura 2000 sites.
   In this first step, the ecological coherence between the Natura 2000 sites is evaluated in terms of connectivity. The selection of species and/or habitats to be used in modelling is very important, since a connectivity analysis for

all the species present in the study is technically difficult. Common or equivalent methodologies are useful for implementing exportable and repeatable cases.

2) Definition of ecological corridors and high permeability areas.
   In this second step, a landscape analysis based on the results of the connectivity analysis can be useful to define a set of ecological corridors and areas with high permeability between the Natura 2000 sites. At this stage, areas of conflict over connectivity, which may act as obstacles or barriers for species and habitats, may already be identified.
3) Implementation of ecological corridors and high permeability areas.
   In this step, the results of the two previous steps should be shared with the appropriate stakeholders (farmers, land planners, etc., always trying to follow a bottom-up approach) in order to implement the ecological network composed of ecological corridors and high permeability areas. At this stage, financial issues can be answered. If all issues are resolved and the network of protected areas is properly interconnected, it can be said that the backbone of the green infrastructure has been implemented.

In the chapter "Section 4 – Case studies", some cases try to implement methodologies by following suggestions coming from this chapter in order to obtain outcomes to be integrated into spatial planning.

In the chapter "Section 5 – Proposals to integrate ecological corridors into spatial planning", a scheme of a new plan is proposed to take into account connectivity issues.

Section 4 – Case studies

Spatial planning approaches need to integrate ecological concepts based on ecological networks, in order to build a consistent methodological framework and, even more, to understand where planners can spatially operate.

Ecological corridors often consist of natural vegetations or agricultural areas. These land uses compose most land-based habitats patches between protected areas that species can use to move from a site to another (Bakker *et al.*, 2015).

In order to assist land management processes, several approaches are proposed to identify and assess optimal corridors to enhance the connectivity among landscape elements by using least-cost path methods which require a map of landscape resistance.

The aim of this section is to provide and to optimize the connectivity of landscape structural elements and provide an assessment of properties of ecological landscape networks, as that these considerations can be integrated into planning strategies.

Some case studies are presented as an implementation of methodological approaches to identify the most optimal patches in the landscape, in order to define ecological corridors and improve the connectivity of an ecological network. Three case studies are implemented in Sardinia (Italy), and a case in Flanders (Belgium).

The first Sardinian case study regards the local context of the Metropolitan City of Cagliari and it is implemented taking into account only a single species, the *Euleptes Europaea*. The main target, in this case, is to analyse relationships between land uses and species behavioural starting from data available in the literature.

The second case completes the first case by the implementation of a multi-species approach to identify ecological corridors within the Metropolitan City of Cagliari.

The third case represents an extension at the regional scale and applies a method to spatially define regional ecological corridors. It regards the region of Sardinia and it is implemented on multispecies purposes.

The last case is implemented in the Flemish Region (Belgium) which establishes a regional ecological network. This network conceives spaces of ecological connections, but they are not implemented yet. For this purpose, the Flemish Region can be further implementation of methodologies of Sardinian cases.

Sardinian case studies

The specific objective aims at drafting a map of corridors by the identification of most important geographical locations that could be useful to maintain connectivity among core habitat and facilitate movement of different species.

The results obtained in these case studies can be useful to integrate ecological concepts into spatial planning taking into account the ecological networks framework.

Some common materials used in these case studies are explained in the next paragraph; other materials are introduced in specific case studies.

Main materials

Geographical database of land covers of Sardinia

The Autonomous Region of Sardinia [*Regione Autonoma della Sardegna*, RAS], in 2008, published a geographical database of Sardinian land covers.

Shapefiles of areal and linear elements are included in the database[28]. The areal elements are identified by CLC classes, up to level 5 (the classification was adapted to the local situation considering the standard code of the CLC). The linear elements represent a potential hydrographic network (e.g. canals and waterways, rivers, streams and ditches), and the transportation network (railway and road networks). The land cover map is built at the 1:25,000 scale.

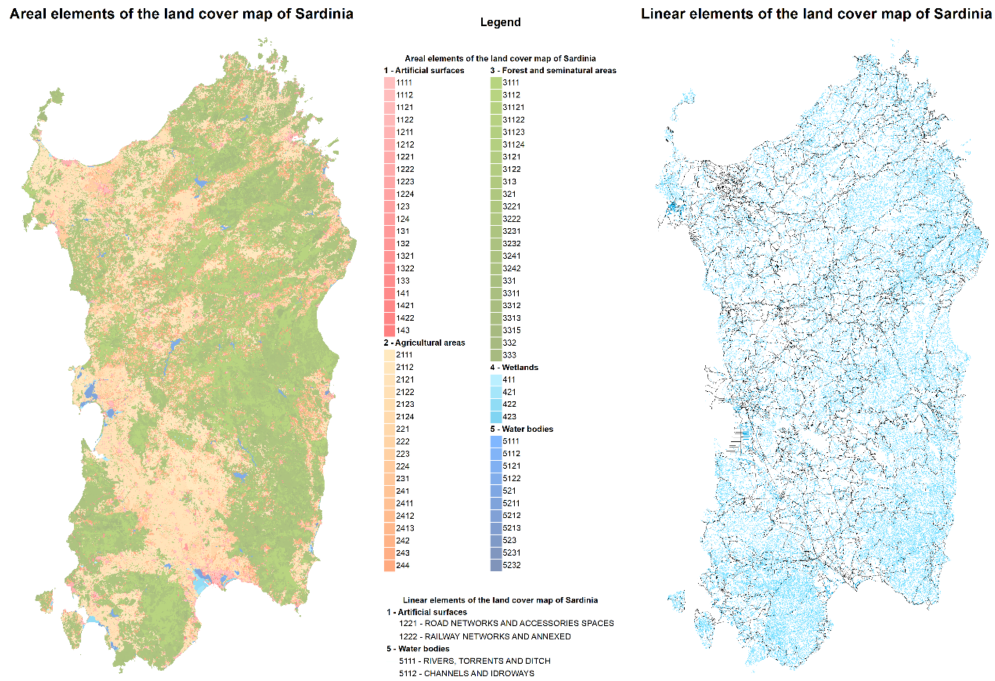

Figure 5 – The maps of areal and linear elements in the geodatabase of land cover of Sardinia.

The monitoring system

Since 2008, the RAS has implemented a monitoring system related to the conservation status of habitats and species of Community interest in Sardinia (AGRISTUDIO, 2011). This monitoring system studies each Natura 2000 site in Sardinia. For each site, one or more map was built. In each map, each CLC cover,

28 The database can be downloaded from http://www.sardegnageoportale.it/index.php?xsl=2420&s=40&v=9&c=14480&es=6603&na=1&n=100&esp=1&tb=14401 (accessed 31 January 2019).

present in the site, is associated with values of habitat suitability, specific for each species existing in the site. The number of annexed maps in the monitoring system is 368.

The conceptual scheme is shown in Figure 6: on the left, the framework of the Natura 2000 sites subdivided in maps; on the centre; an example of a representation of a map; on the right, the table of CLC code intersections with species existing in the site and the specific values of habitat suitability. The maps of monitoring system take into account only the inner part of the Natura 2000 sites.

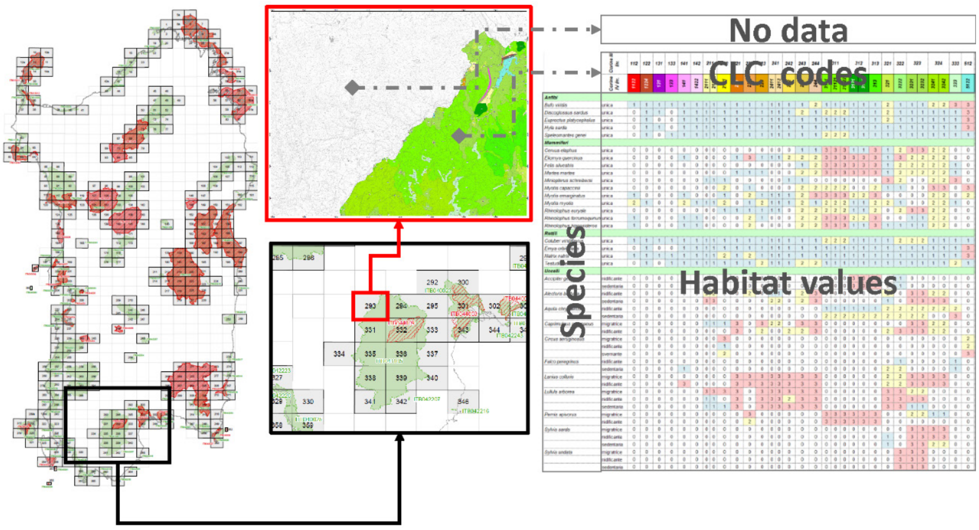

Figure 6 – The conceptual scheme of the monitoring system.

The maps of monitoring system take into account only the inner part of the Natura 2000 sites. The methodology used to classify species-specific values of habitat suitability with CLC codes have been derived from the REN (Boitani *et al.*, 2002). In the REN, the list of analysed fauna species does not include all species listed in the Habitats Directive and contained in the standard data forms[29] of the Natura 2000 sites. For this reason, in the monitoring system, the habitat

29 Last update can be downloaded from: https://www.eea.europa.eu/data-and-maps/data/natura-9 (accessed 31 January 2019).

suitability values are not identified for all species existing in Sardinia, and the CLC evaluation does not include all species.

The suitability values are defined as follows: 0 (unsuitable), spatial elements that do not meet the ecological requirements of species; 1 (low suitability), spatial elements that support the presence of species discontinuously (through time); 2 (average suitability), spatial elements that support the presence of species, even though they are not their optimal locations; 3 (high suitability), spatial elements that are the best locations for permanent presence of species.

The first case study: the *Euleptes Europaea* in the Metropolitan City of Cagliari

This case study is based on the spatial context of one of the most populated areas in Sardinia: Cagliari and its extended hinterland. The Metropolitan City of Cagliari[30], recently established, consists of 17 municipalities where 16 sites of the Natura 2000 Network are included (Figure 7). During the drafting of new metropolitan plans, the new authority should adopt a new spatial plan able to address smart management in the metropolitan area. In this context, the role of the Strategic Environmental Assessment (SEA)[31] is essential.

SEA is an important process which allows to insert environmental issues into planning and formulate objectives of environmental sustainability. The implementation of this ecological concepts into public policy and governance, based on the sustainability theory, can bring the Metropolitan City of Cagliari to be aware of its environmental heritage.

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30 The Metropolitan City of Cagliari was officially established under the provisions of Sardinian Regional Law N. 2/2016.

31 Issues related to the SEA are discussed in the paragraph "The strategic environmental assessment", page 108.

Study area

The Metropolitan City of Cagliari is located on the southern coast of Sardinia and includes 17 municipalities: Assemini, Cagliari, Capoterra, Decimomannu, Elmas, Maracalagonis, Monserrato, Pula, Quartu Sant'Elena, Quartucciu, Sarroch, Selargius, Sestu, Settimo San Pietro, Sinnai, Uta, Villa San Pietro.

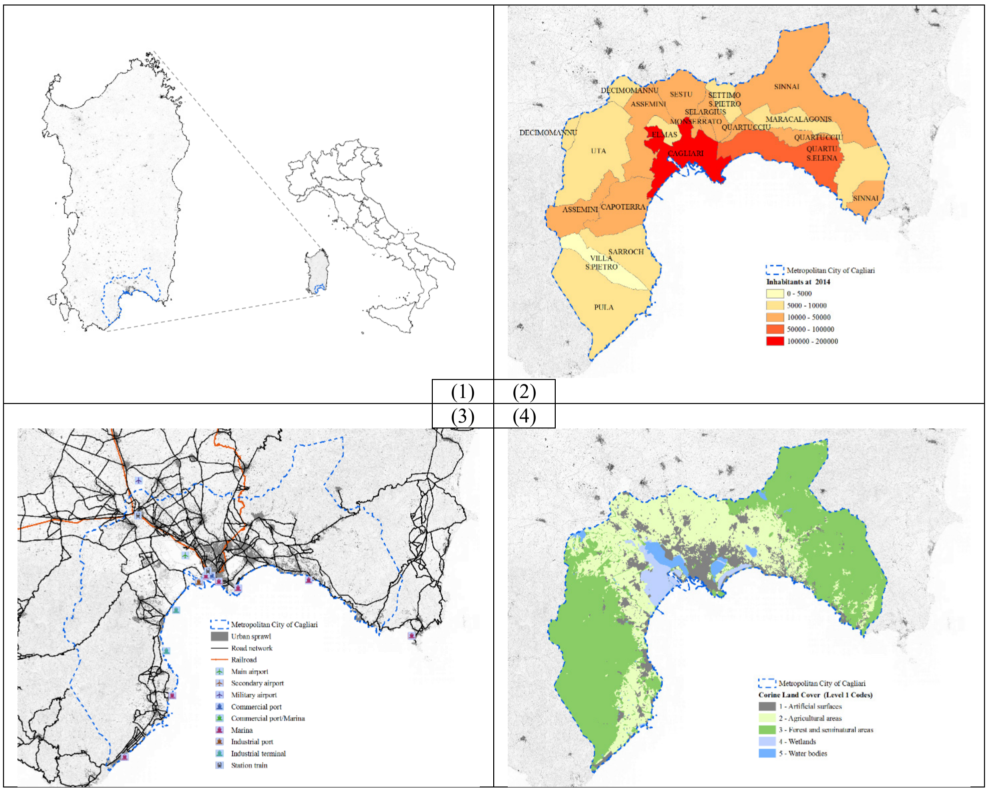

Figure 7 – The metropolitan area of Cagliari. In (1), the geographical position in Italy; in (2), the 17 municipalities classified by population; in (3), the main transport network; in (4), the land use based on CLC level 1.

The population is approximately 430,000 inhabitants[32], and Cagliari and Quartu Sant'Elena are the municipalities with the highest number of inhabitants. The total area amounts to 1,247 km^2, about the 5% of the Sardinian surface area. In the metropolitan context, there are some of the most important strategic

32 Data based on ISTAT (*Istituto nazionale di statistica* [National Institute of Statistics]) http://demo.istat.it/ (accessed 31 January 2019).

transport poles for Sardinia's Island, such as ports (marina, commercial and industrial port) and airports (main, secondary and military airports), as shown in Figure 7 (panel 3).

Methodology

In this case study, a dual approach, linked to spatial and ecological aspects, is applied to analyse the metropolitan area of Cagliari. This proposed approach consists in building a habitat suitability map within the metropolitan area, based on species-specific suitability values related to specific land covers.

In order to define and design ecological corridors in a study area, several studies (Massa, 2001; Boitani *et al*., 2002; Marull *et al*., 2005) base their works on thematic maps supporting relations between land uses and species. In this sense, this qualitative approach is applied to the area of the Metropolitan City of Cagliari.

The habitat suitability map was built by using data of the monitoring system (AGRISTUDIO, 2011); as described in the previous paragraph, the monitoring system studies only the inner part of the Natura 2000 sites.

The methodology consists of three steps:

1) choosing the species;
2) defining the relation between land covers and species;
3) building a habitat suitability map based on land uses or land covers.

In the first step, the chosen species is the *Euleptes Europaea*. The previous scientific name of this species was *Phyllodactylus Europaeus* and in Italian is known as *Tarantolino*.

The *Euleptes Europaea* is an endemic reptile species of the west-central Mediterranean. This species mainly lives in coastal areas and especially in Corsica (France) and Sardinia (Italy). It prefers habitat in arid and rocky areas, such as cliffs, boulders and stone walls in agricultural land, and it can be relatively abundant within suitable habitat. This species may survive in abandoned houses, but avoids areas of maquis vegetation, woodland and urban areas.

The *Euleptes Europaea* is a nocturnal species and eats insects, spiders and vegetables. In Sardinia this species is locally threatened by habitat loss due to fires, picking recreational purposes and urbanization (Corti *et al.*, 2009).

The *Euleptes Europaea* is mentioned in the standard data forms of seven Natura 2000 sites within the Metropolitan City of Cagliari: ITB040021, ITB041106, ITB042216, ITB042241, ITB042242, ITB042243, ITB043055.

In particular, the choice of this species is based on information reported in the Prioritised Action Framework (PAF) for the Natura 2000 Network of the Sardinia Region, in the program from 2014 to 2020 (RAS, 2014, p. 41). In accordance with Article 17 of the Habitats Directive, the conservation status of some species is assessed in the PAF for the whole Sardinia. This assessment follows these definitions of Conservation status, agreed at the Community level:

- "FV – *Favorevole* [Favourable]": species able to thrive without any change of management and strategies currently in place.
- "U1 – *Sfavorevole/inadeguato* [Unfavourable/inadequate]": species that require a change of management policies, but not endangered.
- "U2 – *Sfavorevole/cattivo* [Unfavourable/bad]": species in serious danger of extinction (at least locally).
- "XX – *Sconosciuto* [Unknown]": inadequate information to make a judgment.

Table 2 – The assessment of the conservation status of the Euleptes Europaea. Source: RAS (2014).

Species	**Range**	**Population**	**Habitat**	**Future Prospects**	**Overall Assessment**
Euleptes Europaea	FV	U1	U2	U2	U2

Table 2 shows the conservation status of the *Euleptes Europaea* in critical conditions. Thus, the choice of this species was determined by this critical status.

In the second step, after having chosen the species, a table reporting all CLC codes and specific habitat suitability values is necessary.

The table of habitat values of the *Euleptes Europaea* is built by aggregating all maps of the monitoring system and associating all CLC codes where the species is mentioned. This table allows identifying land covers which can be suitable for the species and can be used in its potential movement. Land covers, in the maps of the monitoring system, are referred only to the inner part of the Natura 2000 sites where the species is mentioned. However, habitat suitability values can be associated also in the external part by using the geodatabase of the land covers of RAS.

In the third step, by doing a spatial join between shapefiles of land covers and the table of habitat suitability, a map of habitat suitability of the *Euleptes Europaea* is built. In this way, suitable elements for the species can be highlighted in a map to investigate where the species can face resistance to a potential movement.

Results

Data and materials, described above, allow designing the habitat suitability map shown in Figure 8, with four sectors, highlighting the most suitable patches in the metropolitan landscape for the *Euleptes Europaea*. Sector 1 represents the habitat suitability map: in red, areas with zero value; in yellow, areas with low suitability; and, in green, areas with average suitability. Sector 2 shows the Natura 2000 sites where the *Euleptes Europaea* is mentioned in standard data forms transmitted to the European Community on 2015. Sector 3 shows all sixteen Natura 2000 sites within the metropolitan area. Sector 4 shows a qualitative potential species-specific “ecological corridor” in green dashed line.

This approach, based on habitat suitability values, analyses relationships between species and environment and, therefore, they represent a powerful tool to support spatial planning. A habitat suitability assessment constitutes an initial basis to plot the potential distribution of single species in the study area (Boitani *et al.*, 2002).

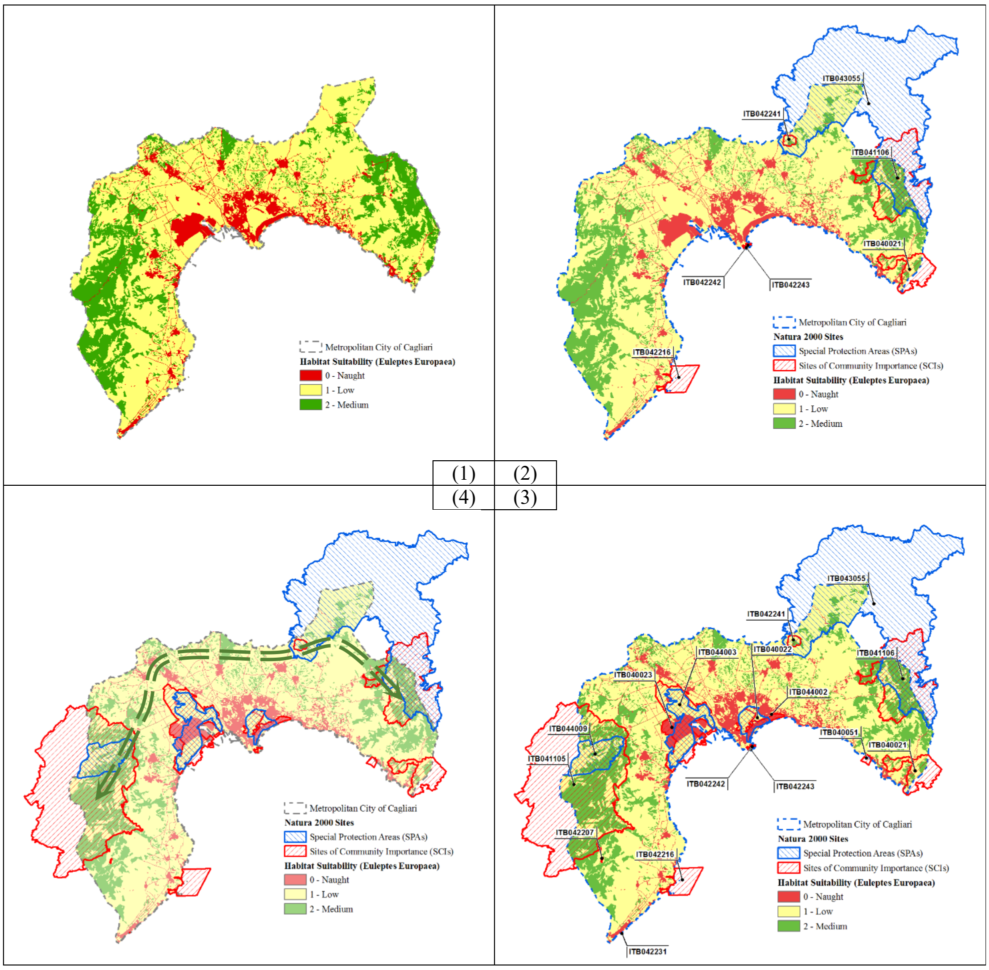

Figure 8 – The Habitat suitability map for the Euleptes Europaea in the Metropolitan City of Cagliari.

The study area can be subdivided into more-suitable and less-suitable patches in the landscape by implementing this methodology. Furthermore, less-suitable elements can represent the main resistance for the species. This resistance describes the physical effects that can interfere with flows of species, energy, and material (Forman, 1995, p. 279; EEA, 2014).

The Metropolitan City of Cagliari shows the highest concentration of transport infrastructures in the central zone (Figure 9). From an ecological and functional point of view, these physical elements can constitute an insurmountable obstacle in species movement.

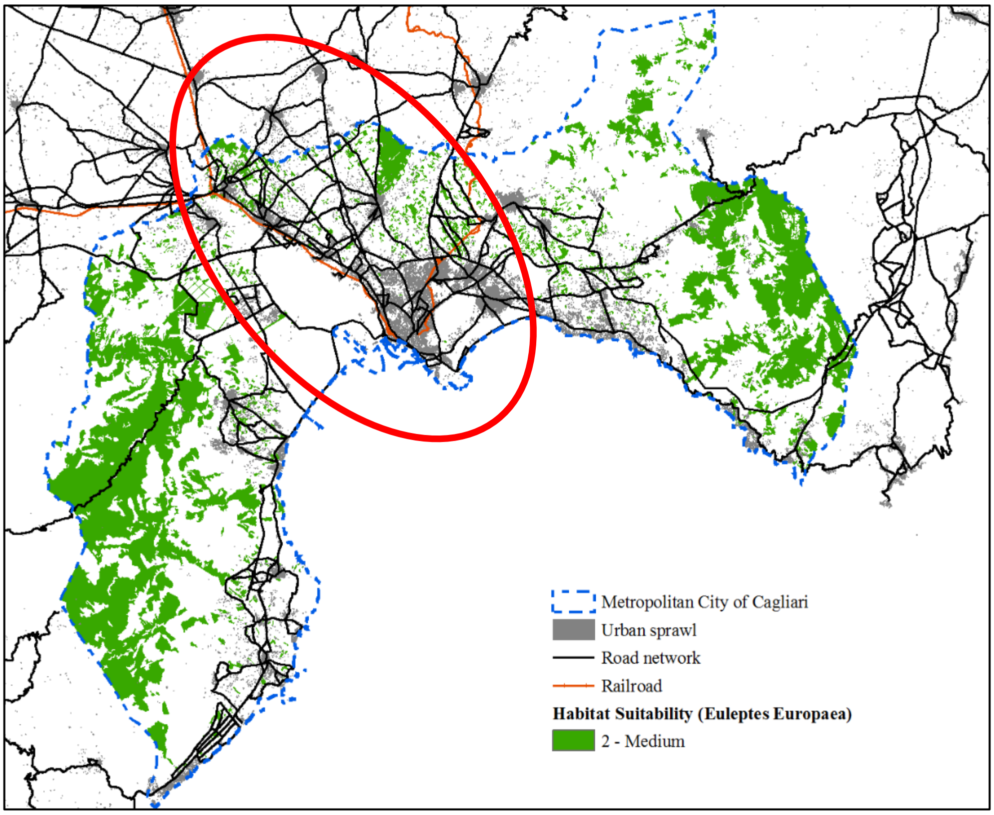

Figure 9 – The main critical area in the metropolitan area of Cagliari is identified by the central zone where the transport network is highly concentrated.

Furthermore, the Environmental Report of the Master Plan of the Province of Cagliari (Province of Cagliari, 2011) describes a critical issue concerning the wetland system, located in middle position in the area of Cagliari. The area circumscribed in red in Figure 9 is threatened by urban and industrial pressure. These factors can influence the quality and ecological functions due to the settlement growth, compromising the surrounding environment.

Since the reduction and fragmentation of natural habitats are critical issues involving biodiversity, planning processes can mitigate intensive farming practices, excessive urbanisation and infrastructure networks. In ecological fields, spatial planning plays an important role in conservation policies and strategies (Ferretti *et al.*, 2013).

Discussion

Planners, by analysing habitat suitability maps, can make proper decisions, since maintaining physical-spatial and ecological-functional continuity within the natural environment is an appropriate strategy implementable into planning processes. This issue can help to mitigate fragmentation effects improving better ecological connectivity (Battisti, 2004).

A qualitative approach, based on habitat suitability of a specific species, is proposed in order to highlight land patches for potential movements through the metropolitan area of Cagliari. This habitat suitability map allows to put in evidence relationships between species and environment. An important basis to assess the potential distribution of each species in the metropolitan area can be used in this sense. This issue can relate to the Natura 2000 Network management, both as nodal and as connective elements, in planning in metropolitan areas.

However, the species behaviour in land patches depends on its biological perception, and its mobility on its ecological profile. The functional connectivity is species-specific and there are no “universal corridors” to support all movement through fragmented habitats or an exclusive valid scale to study ecological connectivity (Gurrutxaga *et al*., 2010).

In this analysis, fauna suitability maps can show suitable land patches that can host fauna species of Community interest, not only in the Natura 2000 sites but within the metropolitan area. These assumptions are useful for management and plans in the metropolitan area to integrate issues concerning an eco-environmental dimension.

The implementation of ecological network concepts into metropolitan spatial planning processes, through the identification of connective elements, can mitigate critical aspects.

Furthermore, the management plans of the Natura 2000 sites within the metropolitan area are site-specific and they are not related to other management plans of nearby sites. They do not assess external elements that can mitigate critical conditions, and they do not address the concept that species can migrate from one to another site.

From a point of view of a metropolitan ecological network, the integration of these concepts can be done in a SEA process that should be a comprehensive assessment based on the knowledge of ecological issues in the study area. In this way, a network model, regarding functions of species in relation to dynamic, structural, and ecological characteristics can be implemented in spatial planning (MATTM, 2009).

In this case study, the analysis is related to only a species, chosen for its weaknesses. The knowledge of all weaknesses of species existing in the metropolitan area can address the metropolitan planning to protect important elements for environmental reinforcement and improvement.

The second case study: multispecies ecological corridors in the Metropolitan City of Cagliari

This second case study concerns a methodological approach to identify ecological corridors between the Natura 2000 sites within the metropolitan area of Cagliari. This approach is based on the prioritization of functional land patches related to their potential role to maintain and enhance biodiversity, identifying the most suitable patches to be included in an ecological corridor on the basis of their accessibility.

The prioritization of spatial elements as ecological corridors needs to define their spatial configuration and connectivity. This issue requires the identification of a spatial structure to protect biodiversity functions and their long-term-persistence (Snäll, 2016).

The identification of priority spatial elements as ecological corridors has been done by using the GIS-tool Linkage Mapper based on concepts of the LCP algorithm and CWD analyses.

A similar method is implemented by Lee *et al.* (2014), introducing in their basis also the value of ecosystem services.

Study area

The study area includes the Metropolitan City of Cagliari, three extensions concerning coastal landscape units of the PPR, and the boundaries of the Natura 2000 sites located in the Metropolitan City (Figure 10).

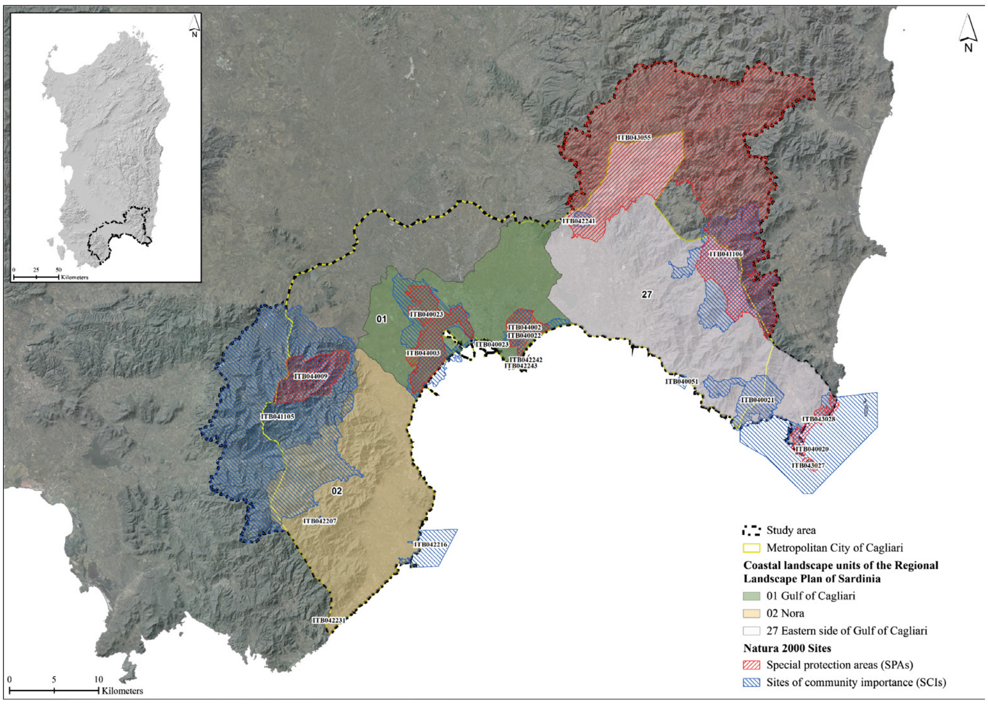

Figure 10 – The study area: the Metropolitan City of Cagliari and its extensions related to the Natura 2000 sites and the PPR units.

The size of the study area is about 1,786 km^2; thirty municipalities and nineteen Natura 2000 sites are included in the study area.

Materials

In this case study, the land cover map of Sardinia and the Sardinian regional monitoring system (AGRISTUDIO, 2011), as presented in the previous paragraph, are the main materials. Furthermore, the concepts of ecological integrity are introduced in this study. The implementation of the case study involves the GIS-tool Linkage Mapper.

The map resolution set in this study is 625 m^2 per pixel (a pixel has 25 m per side), which is the optimal resolution for the Land Cover Map of Sardinia.

The Ecological Integrity Values

Burkhard *et al.* (2009, 2012) proposed a study concerning a matrix of qualitative values of 44 land covers. The matrix is based on the capacity of land covers to provide ecosystem services on a scale from 0 (no relevant capacity) to 5 (very highly relevant capacity). In this matrix, on the base of land covers, they assess seven indicators related to the ecological integrity. These indicators represent the main components of the ecosystem functionality, by describing structures and processes relevant for the long-term functionality and the self-organizing capacity of ecosystems.

In this way, the values of ecological integrity are related to structures, as numbers and characteristics of species (biotic diversity) and physical habitat components (abiotic heterogeneity), and processes concerning ecosystem energy budgets (exergy capture), matter budgets (nutrient storage and loss) and water budgets (biotic water flows and metabolic efficiency).

The basic concept of their involvement in this study is that high values of ecological integrity are found as regards different land cover types, whereas very low or no relevant capacities correspond to land cover types characterised by significant anthropic impacts (e.g., urbanized fabric, industrial or commercial areas, mining sites and landfills). Thus, the assumption is that land patches with high values of ecological integrity provide suitable habitats for different species and they are effective in supporting species movement. Under this perspective, this ecological index assumes the meaning of “suitability value”.

Linkage Mapper

The GIS-tool Linkage Mapper is used to obtain a map of potential species movement, starting from a vector map of core habitat areas and a raster map of movement resistance and implementing LCP algorithms. In this case, the Natura 2000 sites within the study area are assumed as core habitat areas. The resistance map is explained in the paragraph of the methodology. The cells in the raster represent values reflecting the energetic cost, difficulty, or mortality risk of moving across the landscape.

Linkage Mapper produces final maps of accumulated movement resistance between specific core areas by using CWD analyses (McRae *et al.*, 2011).

Methodology

Approaches based on LCP allows prioritizing patches to define ecological corridors between the Natura 2000 sites. Several studies are based on LCP algorithms (Adriaensen *et al.*, 2003; Beier *et al.*, 2009; Beier *et al.*, 2011; Sawyer *et al.*, 2011; Zeller *et al.*, 2012; EEA, 2014; Lee *et al.*, 2014; Liquete *et al.*, 2015; Rayfield *et al.*, 2016; Lechner *et al.*, 2017; Pietsch, 2017). Sawyer *et al.* (2011) state that the LCP approach is mostly used to analyse, and design habitat corridors based on the identification of the impacts of habitats on species movement.

The LCP algorithm (as shown by Adriaensen *et al.*, 2003) requires two raster layers (a source layer and a friction/resistance layer) as model inputs. In this case study, in the source layer are contained the spatial aggregation of all Natura 2000 sites within the study area. The resistance layer represents, in each cell of a grid, a resistance value which depends on the land cover type in the cell. The resistance values reflect the effects of morphological characteristics of the landscape on species movement and, in terms of mortality and obstacle to species, energy, and material flows (Forman, 1955; EEA, 2014; Graves *et al.*, 2014; Lechner *et al.*, 2017).

Resistance parameters can be retrieved in the relevant literature or estimated through data concerning habitats uses (e.g. habitat suitability values). Since the habitat suitability values represent the probability of a habitat being used by a particular species (Boitani *et al.*, 2002; Wang *et al.*, 2008), and, generally, habitat suitability indexes are defined through expert opinions (Zeller *et al.*, 2012; Graves *et al.*, 2014), the inverse value of habitat suitability parameters can be used to compute resistance value and design a resistance map, such required by the LCP method (Forman, 1955; EEA, 2014; Graves *et al.*, 2014; Lechner *et al.*, 2017). Similarly, LaRue and Nielsen (2008, as cited in Zeller *et al.*, 2012) suggest setting resistance values as the inverse value of habitat suitability values.

In this study, the resistance raster map, representing negative attitudes as regards contribution to landscape fragmentation, is built through the following steps.

1) Designing a habitat suitability map: global habitat suitability values related to CLC codes are derived by the monitoring system (AGRISTUDIO *et al.*, 2011). After having aggregate all habitat suitability values of all maps of the monitoring system, a global table is created. All species listed in all maps of the monitoring system are reported in the rows of this table; in the columns, all CLC codes are registered. In this table, a CLC code can have various habitat suitability values depending on the species. In order to calculate a global habitat suitability value, a weighted parameter is defined by calculating the weighted mean value by columns (Figure 11). Then, this weighted value is associated with CLC codes of land covers map of Sardinia (page 64), by geoprocessing in GIS, and, by doing so, a global habitat suitability map is implemented in the whole study area (the initial habitat suitability values are referred to the only inner part of the Natura 2000 sites).

2) Building the ecological integrity map: the ecological integrity values of Burkhard *et al.* (2009, 2012) are associated, by geoprocessing in GIS, with CLC codes of the map of land covers of Sardinia (page 64), and the map is completed.
3) Inverting raster maps: since the purpose is to obtain a map of resistances, the value in the previous raster maps are inverted (Forman, 1955; EEA, 2014; Graves *et al.*, 2014; Lechner *et al.*, 2017) by implementing geoprocesses in GIS.
4) Rescaling inverted raster maps: McRae *et al.* (2011) suggest, in order to implement the GIS-tool Linkage Mapper in a good way, that the resistance raster must include resistances represented by positive numbers (integers or floating point) and recommend to scale resistance maps in a range from 1 to 100, so that values of 1 represent ideal habitat and 100 the highest resistance.
5) Summing inverted rescaled raster maps: in order to work with a resistance map representing, on the one side, a global perception scale of species, and, on the other side, a morphological perception coming from land uses and the ecosystem services that they supply, a final resistance map is created and rescaled as above. These resistance values, as characteristics of the cell, allow dividing the study area into more-suitable and less-suitable elements. The less-suitable elements could be considered the most resistant (Graves *et al.*, 2014).
6) Loading in Linkage Mapper the shapefile of core areas related to the Natura 2000 sites and the resistance raster map (obtained according to the procedure described above), to implement a connectivity analysis.
7) Classifying the resulting raster map of the normalized cumulated CWD values, in order to define a spatial boundary of the ecological corridors, in ten deciles and selecting the first decile as a threshold value for a land parcel to be included in the ecological corridors set.

Species	*Bufo viridis*	*Discoglossus sardus*	*Euproctus platycephalus*	*Hyla sarda*	*Speleomantes flavus*	*Speleomantes genei*	*Speleomantes imperialis*	*Speleomantes supramontis*	*Barbastella barbastellus*	*Cervus elaphus*	*Eliomys quercinus*	*Felis silvestris*	*Glis glis*	*Pipistrellus kuhli*	*Pipistrellus pipistrellus*	*Plecotus auritus*	*Rhinolophus euryale*	*Rhinolophus ferrumequinum*	*Rhinolophus hipposideros*	*Rhinolophus mehelyi*	*Tadarida teniotis*	*Vulpes vulpes*	*Algyroides fitzingeri*	*Archaeolacerta bedriagae*	*Chalcides ocellatus*	*Coluber viridiflavus*	*Emys orbicularis*	*Euleptes europaea*	*Hemorrhois hippocrepis*	*Natrix natrix*	*Podarcis sicula*	*Testudo hermanni*	
Type	A	A	A	A	A	A	A	A	M	M	M	M	M	M	M	M	M	M	M	M	M	M	R	R	R	R	R	R	R	R	R	R	
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512	3	3	3	3	1	1	1	1	3	0	0	0	0	2	2	2	0	0	0	0	3	0	1	1	1	1	3	1	1	3	1	1	1.31
511	1	2		2	2													0	0	0		0	1		1	1	3	1	1	3	1	1	1.18
423	0	0		0											0					0					0	0	0	0			0		0.00
422	0	0		0							0			0	0				0		0	0	0		0	0	0	0	0		0	0	0.00
421	1	1	1	1	1		1							0	0			0	0	0	0	0	1		1	1	2	1	1		1	1	0.71
411	2	2	2	2		1	1	1	2		0	0	0	2	2			0	0	0	2	0	1		1	1	3	1	1		1	1	1.12
333	3	1	1	1	1	1	1	1	0	0	0	1	0	1	1	0	0	0	0	0	0		1	2	1	1	1	1	1	1	2	2	0.84
332	0	0	0	0	2	2		2	0	0	0	1	0	0	0		0	0	0	0	3	0	2	1	1	1	1	1	1	1	1	1	0.70
331	1	1	1	1		1	1	1	0	0	0	0	0	0	0		0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0.60
324	2	1	1	1	1	1	1	1	3	2	2	2	1	3	3	2	2	2	2	2	0	3	2	1	1	1	1	1	1	1	2	1	1.56
323	1	1	1	1	1	1	1	1	0	3	2	2	3	0	0	2	3	1	1	0	0	3	3	1	3	2	1	1	2	1	3	1	1.44
322	1	1	1	1	1	1	1	1	2	2	3	2	1	2	1	1	2	0	1	0	0	2	1	1	1	2	1	1	2	1	3	1	1.28
321	2	2	2	1	1	1	1	1	1	1	1	1	0	2	1	0	0	0	1	0	0	3	1	2	2	1	1	1	1	1	2	1	1.09
313	1	1	1	1	1	1	1	1	3	3	3	3	3	1	2	3	2	3	3	3	0	3	1	1	1	1	1	1	1	1	1	1	1.66
312	1	1	1	1	1	1	1	1	2	1	3	3	1	1	1	3	1	2	1	1	0	2	1	1	1	1	1	1	1	1	1	1	1.25
311	1	2	1	1	1	2	2	2	3	3	3	3	3	1	2	3	2	3	3	3	0	3	1	1	1	2	1	2	2	1	1	1	1.88
244	2	1	1	1	1	1	1	1	2	1	2	2	1	2	2	2	2	2	2	1	0	3	1	1	1	1	1	1	1	1	1	2	1.38
243	1	2	1	1	1	1	1	1	2	1	2	1	0	3	2	2	2	2	2	1	0	3	1	1	1	1	1	1	1	1	1	2	1.34
242	1	1	1	1	1	1	1	1	0	0	2	0	0	2	1	0	0	0	0	0	0	2	1	1	1	1	1	1	1	1	1	1	0.78
241	1	1	1	1	1	1	1	1	0	0	1	0	0	2	0	0	1	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0.72
231	1	1	2	1	1	1		1		1	0	1	0		0			0	0	0		1	1		2	1	1	1	1		1	1	0.83
223	1	1	1	1	1	1	1	1	0	0	1	0	0	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	2	2	0.88
222	1	1	1	1		1	1			0	3	0		1	1		1	2	2	1	0	1	1	1	1	1	1	2	1	2	1	1	1.11
221	1	1	1	1	1	1	1	1	0	0	1	0	0	1	0		1	0	0	0	0	1	1	1	1	1	1	2	1	1	1	1	0.74
212	1	1	1	1	1	1		1		0	0	0		2	2		1	0	0	0	0	1	1	1	1	1	1	1	1	2	1	1	0.86
211	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0.66
143	0	0	0	0	0	0		0	0	0	0	0	0		0			0	0		0		0	0	0	0	0	0	0	0	0	0	0.00
142	1	1	1	1	1	1	1	1	1	0	0	0	1	3	2		0	1	1	0	2	2	1	1	1	1	1	1	1	1	1	1	1.00
141	1	1	1	1		1		1		0	1	0					0	1	1				1	1	1	1	1	1		1	2	1	0.90
133	1	0	0	0	0	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1	1	1	0	1	1	1	1	1	0.50
132	0	0	0	0		0				0	0	0		1	1			0	0	0	0		1		1	1	0	1	1	1	2	0	0.43
131	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0		0	0	0	0		0	1	1	1	0	1	1	1	1	0	0.40
124	1	1	1	1					0		0	0	0			0		0	0						1	1	1	1	1	1	1	1	0.63
123	0	0	0	0			0	0	0	0	0	0	0	2	1			0	0	0	0		1	1	1	1	1	1	1	1	1	1	0.48
122	1	1	1	1	1	1	1	1		0	0	0		2	0		0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0.76
121	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0			0	0	0	0	1	1	0	1	1	1	1	1	1	1	0	0.37

Figure 11 – A screenshot of a part of the elaboration table of global habitat suitability values.

Results

In order to avoid biases coming from the edge effect, the connectivity analysis implemented in Linkage Mapper is extended beyond the limits of the study area.

The results generated by the implementation of this methodology to identify the ecological corridors are a composite raster map of linkage maps, where each cell represents the minimum value of all individual normalized corridor layers, and a shapefile representing the normalized least-cost corridors (Figure 12). The GIS-tool[33] returns a map where CWD[34] values are included in the range between 0 and 260,746 km, and a shapefile where twenty-four linear corridors are identified. In the attribute table of the shapefile of the linear corridors, a field contains a ratio of CWD to Euclidean distance that can be used as a quality metric to assess the corridors (McRae *et al.*, 2011).

Since the linear corridors are identified starting from a resistance map, a different situation can occur by assessing them through the ratio of CWD to Euclidean distance. For instance, a corridor which has a short length could show a high cost-weighted ratio (e.g. due to the presence of several urbanised areas and the high value of obstacles in the initial resistance map). In contrast, a corridor which has an extended length could show low cost-weighted ratio (e.g. due to the presence of low resistance values in the initial resistance map).

The spatial boundaries of the ecological corridors are defined by classifying the raster map of the normalized cumulated CWD values in ten deciles and selecting the first decile as a threshold value which is equal to 2.4 km and identifies an area of 245 km^2, around 14% of the total study area.

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33 The implementation of this methodology requires a powerful computer which spends many hours in calculations due to the several necessary iterations.

34 CWD values indicates the cumulative weighted distance between two core areas in terms of length units (km).

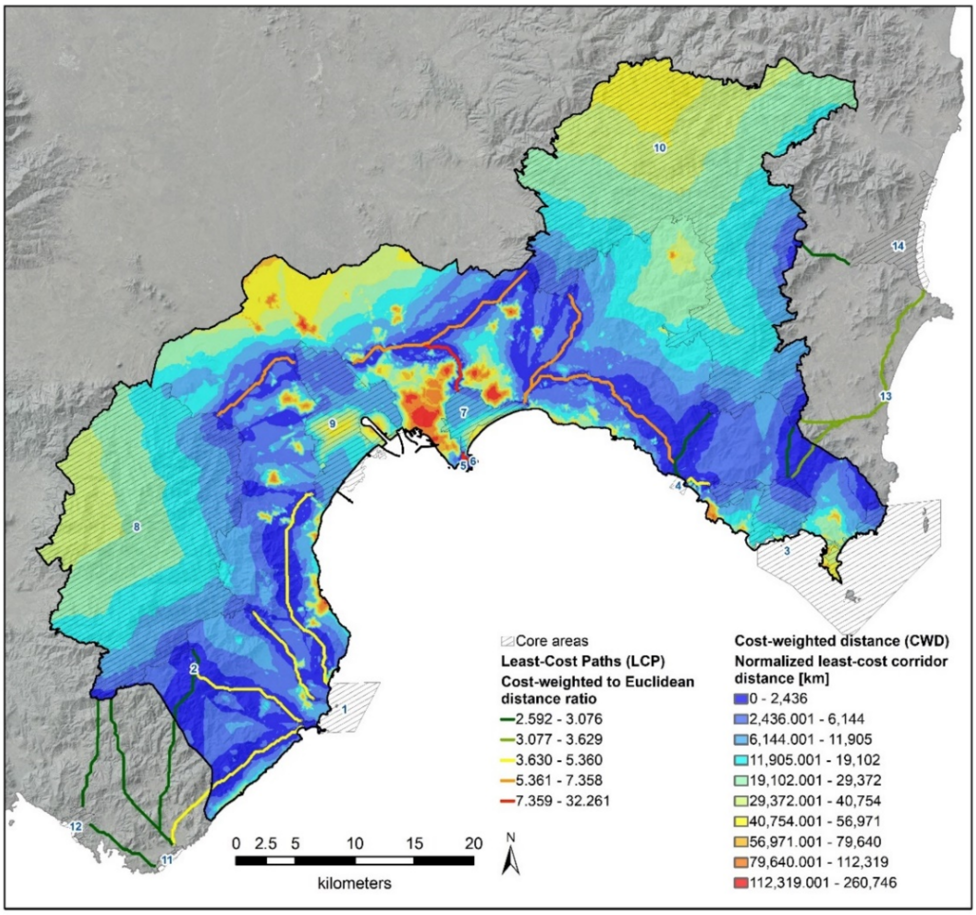

Figure 12 – The set of potential ecological corridors related to the metropolitan area of Cagliari.

In terms of land covers, referred to the first CLC class, the ecological corridors show the following proportions:

- 0.71%, Artificial surfaces (1.75 km^2);
- 36.24%, Agricultural areas (88.78 km^2);
- 61.07%, Forest and semi-natural areas (149.62 km^2);
- 0.75%, Wetlands (1.83 km^2);
- 1.22%, Water bodies (3.00 km^2).

Discussion

Spatial planning and landscape ecology are facing a crucial challenge: restoring and maintaining functional connections in ecological networks. Habitat patches can be even located outside of protected areas and they can have a significant connective role in building spatial networks of sites endowed with environmental values.

The methodological approach implemented in this case study aims at prioritising key patches outside protected areas with reference to their potential connectivity. Species are assumed to perceive the movement across the surface as a cost represented by the resistance opposed by the landscape to movements. This cost is an intrinsic value of the energy spent to move, the mortality risk, the negative impact on future reproductive potential.

The methodology based on LCP algorithm returns LCP paths representing the less expensive way that is likely to be chosen by species to move across a surface in order to shift from a patch to another, that can be considered as ecological corridors.

Since an ecological corridor is a spatial connection, to identify its physical structure, spatial data modelling and planning methods have to be involved, aiming to prioritise spatial elements to maximize the supply of ecosystem services from biodiversity by granting the most effective flow of species.

In this study, the identification of a set of potential ecological corridors, by implementing a GIS-tool, is based on two input layers: a layer of sites to be connected, and a layer concerning habitat suitability and ecological integrity issues combined in a global resistance map.

The results show that the use of Linkage Mapper can be effective to identify sets of ecological corridors. Sets of potential ecological corridors in the metropolitan area of Cagliari are selected by connecting the Natura 2000 sites with the purpose to prioritise functional land patches identifying the most suitable territorial areas to constitute connective elements on the basis of their accessibility, that is, on their negative attitude, towards contributing to landscape fragmentation. Several species, with different behaviours, can benefit from improved connectivity entailed by the definition of this set of ecological corridors and their identification as worth protecting natural areas.

Although the effectiveness of LCP analysis can be affected by the quality of input data, expert opinions can help to build a resistance values map as well as other methods. LCP analyses can be based on individual interpretations, but the approach is useful for land use managers and planners to spatially identify environmental priorities, in particular, the landscape in the set of potential corridors.

The metropolitan government could be aware of the presence of important ecological corridors in its boundaries and their strategic role in policies concerning environmental protection and conservation of natural heritage, by implementing methodologies based on LCP analyses.

Conservation strategies implemented into spatial plans of protected areas are species-specific and site-specific, but these measures should be extended outside their boundaries in order to address issues concerning biodiversity conservation in specific sectors. For instance, the results show the highest percentage of ecological corridors involving forest and semi-natural areas, but also a high percentage of agricultural areas is included in ecological corridors as defined. As stated by Bakker *et al.* (2015), ecological corridors are often constituted by habitat patches between protected areas that can be used by species to move from a site to another and natural vegetations or extensively-used agricultural areas compose the most part of ecological corridors.

Landscape connectivity can be preserved and improved at the metropolitan scale, by integrating this concept into land use management practices.

The third case study: multispecies ecological corridors in Sardinia

The Sardinian PPR, in its Technical Rules[35], reveals the intention to implement ecological corridors in a regional ecological network including the Natura 2000 sites and other protected areas, and their integration within the management plans. Nevertheless, it delegates the implementation to other planning instruments.

Despite the presence of several protected areas in Sardinia, no ecological corridor has been defined in Sardinia, and explicit rules for identifying ecological corridors have not been provided by the PPR yet.

Furthermore, the PPR states that provincial planning regulations have to identify and manage ecological corridors, in order to build a network of connections between protected areas, biotopes and natural areas. Thus, the concept of ecological corridors assumes a strategic implication in wide areas. These features make Sardinia suitable to this implementation since a regional scheme of ecological corridors can address the management of elements at lower scales.

In this case study, a similar methodology implemented in the Metropolitan City of Cagliari is applied in order to obtain a regional scheme of potential ecological corridors which can be integrated at lower scale into a wide planning area addressing the framework action, even at municipal scale.

Study area

Sardinia island is one of the two largest Italian islands located in the Mediterranean basin. The surface amount to around 24,090 km². The length from North to South is 270 km and the width from East to West is 145 km.

35 As previously discussed at page 23 of this thesis.

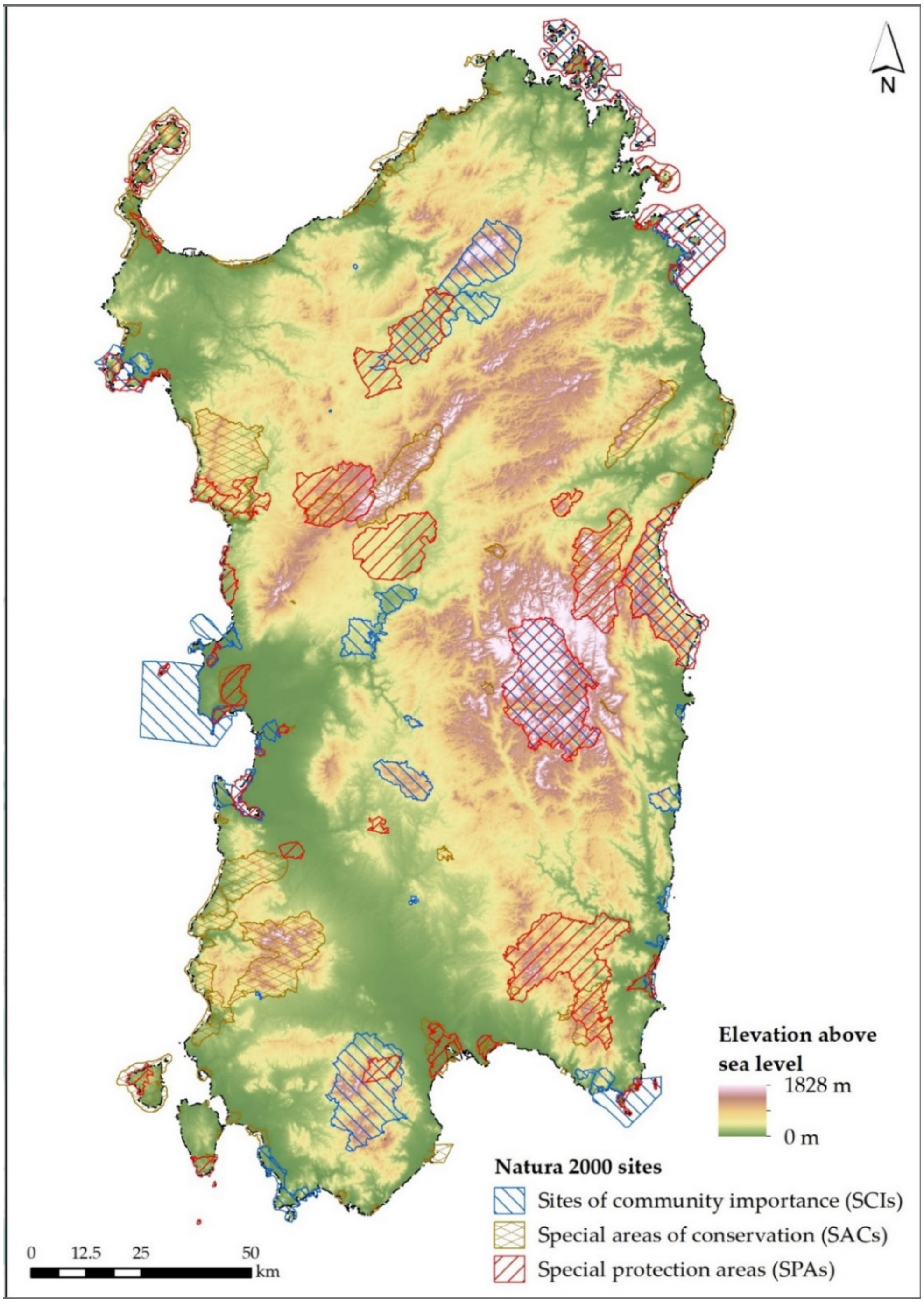

Figure 13 – Sardinia: the study area.

The surface elevation shows a range from 0 to 1,828 meters above the sea level.

Currently, the population amount to around 1.6 million[36]. The regional organization is structured in five authorities as follows: the Metropolitan City of Cagliari, the Provinces of Sassari, Nuoro, Oristano and Southern Sardinia. 377 municipalities are included in the region of Sardinia. Cagliari is the capital of the region.

The Natura 2000 sites in Sardinia includes 31 SPAs, 34 SCIs, 53 SACs, 3 overlapping of SPAs&SCIs and 3 SPAs&SACs (Figure 13)[37].

Many other protected areas are identified in Sardinia, but the implementation of this case study regards only the Natura 2000 Network within the region of Sardinia.

Methodology

The applied methodology is similar to that applied in the second case study presented above, which explain that approaches based on LCP are useful to prioritise patches to define ecological corridors between the Natura 2000 sites, as shown in other studies based on LCP algorithms (Adriaensen *et al.*, 2003; Beier *et al.*, 2009; Beier *et al.*, 2011; Sawyer *et al.*, 2011; Zeller *et al.*, 2012; EEA, 2014; Lee *et al.*, 2014; Liquete *et al.*, 2015; Rayfield *et al.*, 2016; Lechner *et al.*, 2017; Pietsch, 2017).

In order to implement even this case study, by using the GIS-tool Linkage Mapper, based on LCP algorithm (Adriaensen *et al.*, 2003), a source layer con-

36 Data based on ISTAT (*Istituto nazionale di statistica* [National Institute of Statistics]) http://demo.istat.it/ (accessed 31 January 2019).

37 Statistics derived from Natura 2000 data available at: https://www.eea.europa.eu/data-and-maps/data/natura-9 (accessed 31 January 2019).

taining the spatial aggregation of the Natura 2000 sites within Sardinia and a resistance layer (Forman, 1955; EEA, 2014; Graves *et al.*, 2014; Lechner *et al.*, 2017) are used as input in the model.

In this implementation, the methodology is applied according to the following steps.

1) The source layer is built by aggregating all Natura 2000 sites within Sardinia without including marine sites.
2) Potential habitat suitability values[38] are determined (Figure 14) on the basis of the monitoring system (AGRISTUDIO *et al.*, 2011).
3) According to LaRue and Nielsen (2008, as cited in Zeller *et al.*, 2012) and other studies (Forman, 1955; EEA, 2014; Graves *et al.*, 2014; Lechner *et al.*, 2017) resistance values are computed as the inverse value of habitat suitability values.
4) The resistance map is built by taking into account both areal and linear elements. Indeed, after mapping the resistance of the areal elements, the resistance values are increased by summing values of the street network, decreased on the basis of the presence of the hydrological network[39].
5) The resistance map is rescaled in the [1÷100] interval (Figure 15), where 100 represents the highest resistance and 1 the lowest (McRae *et al.*, 2011).
6) The set of potential ecological corridors in Sardinia is defined through the GIS-tool Linkage Mapper (McRae *et al.*, 2011).

38 See point (1) on page 72 of this thesis.

39 The meaning is that crossing a road could increase mortality risks; the proximity of a river can provide a shelter without necessarily having to be crossed, anyway, it is worth mentioning, though, that for few species hydrological networks can even work as barriers.

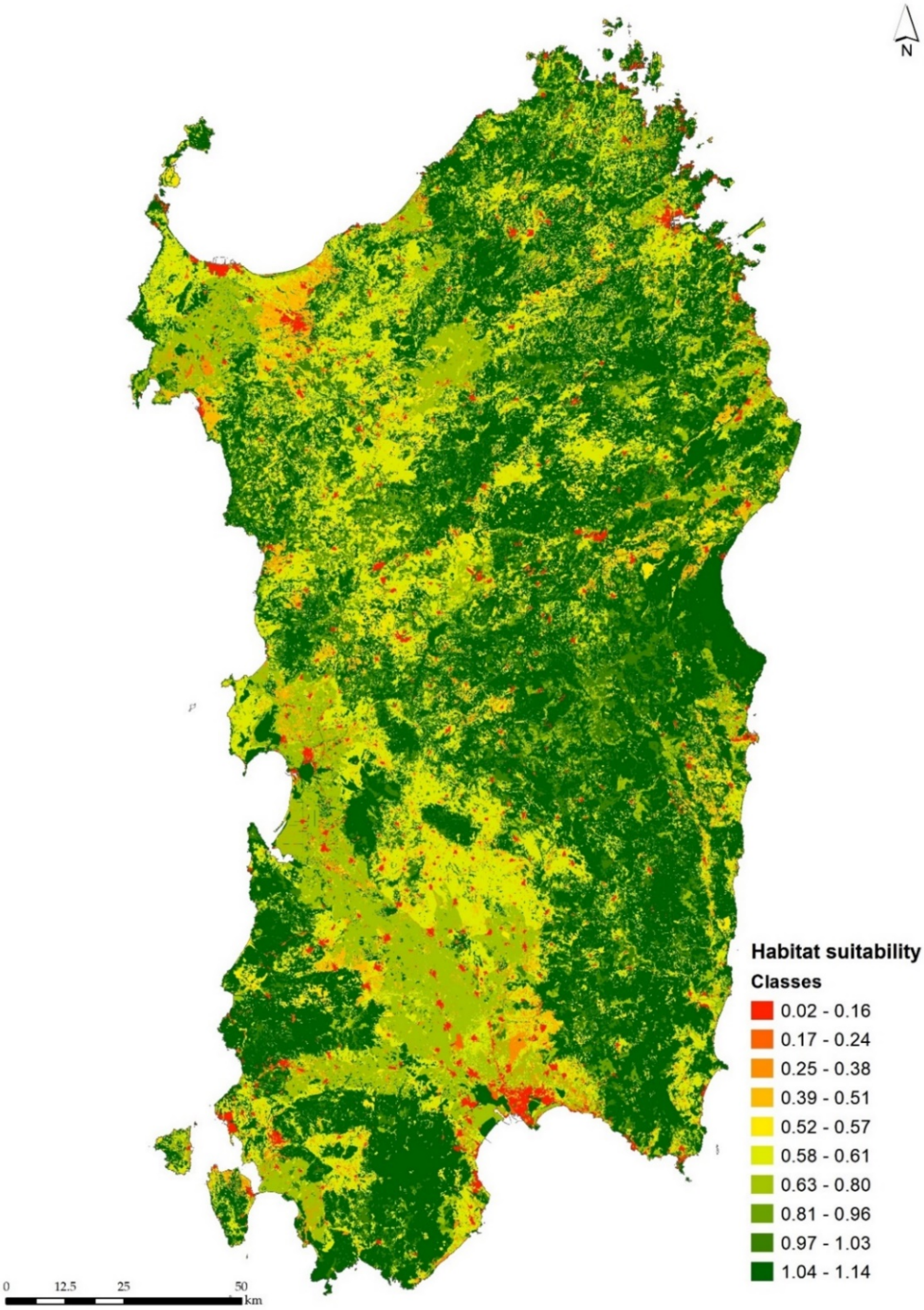

Figure 14 – The habitat suitability map in Sardinia.

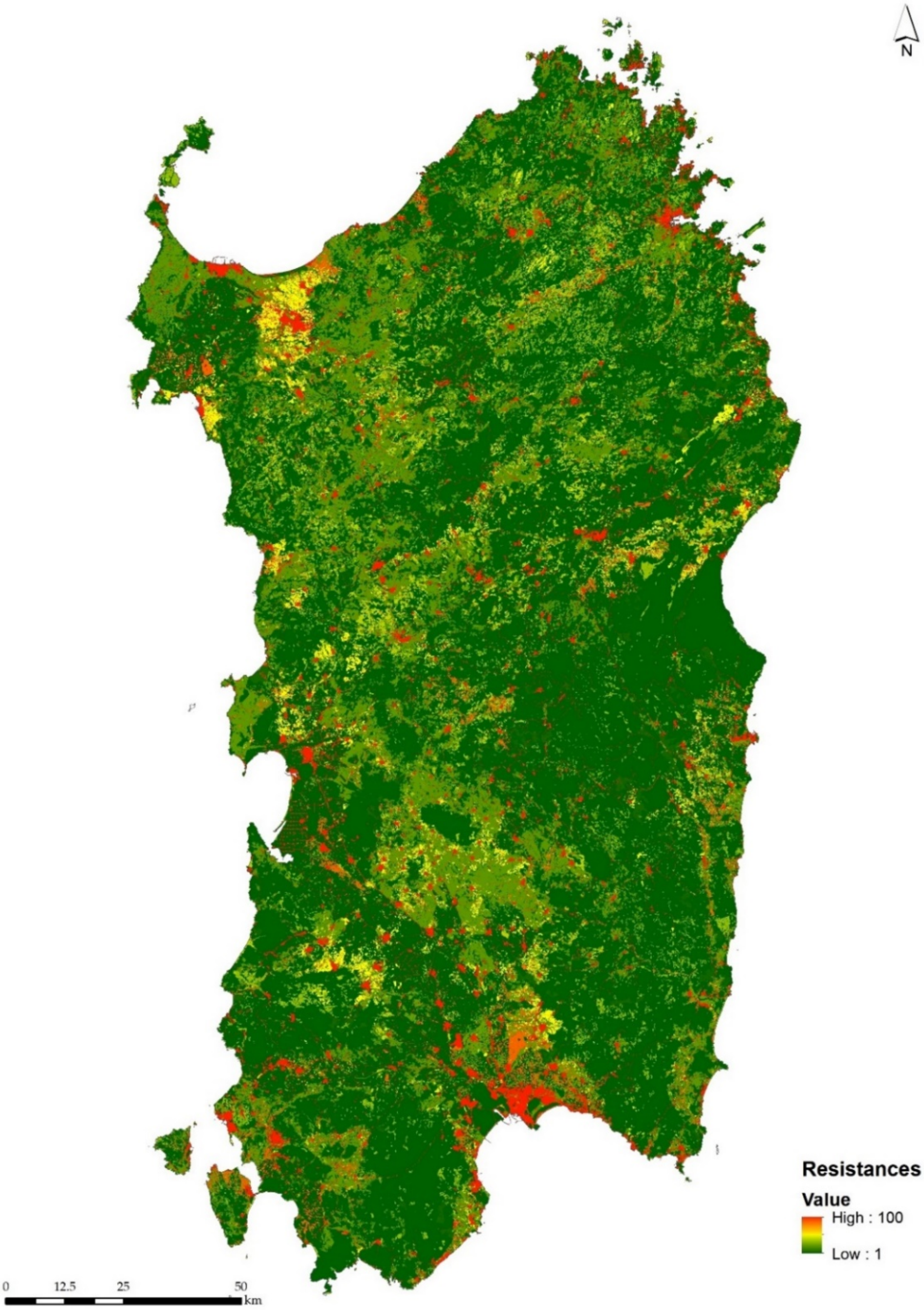

Figure 15 – The resistance map in Sardinia.

Results

The results of this implementation in Linkage Mapper are shown in Figure 16 and consists of a raster map of CWD[40] containing values ranging from 0 to 656,074 km and a linear shapefile containing 170 links as normalized least-cost corridors.

The raster map of normalized corridors is reclassified in ten deciles, in order to identify two-dimensional ecological corridors, rather than only linear elements.

All patches whose values are included in the first decile are assumed to be part of the set of the regional ecological corridors. Around 2% of the Sardinian regional area belongs to this set.

Mainly, the set of ecological corridors consists of agricultural areas (21.6%) and forest and semi-natural areas (77.6%).

Discussion

Since this methodology is a regional extension of a methodology already applied at the local scale, its implementation can be even exported in other regional situations in the European Union, in order to define a set of ecological corridors between nodes of isolated protected areas, as the Natura 2000 Network which is currently disconnected, and, by doing so, to make it more coherent under the provisions of the Habitats Directive.

In terms of results, the set shown in Figure 16 should not be conceived as the compulsory final spatial structure of Sardinian ecological corridors, but rather as a decision-making tool to help planners drafting a regional and normative spatial plan.

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40 CWD values indicates the cumulative weighted distance between two core areas in terms of length units (km).

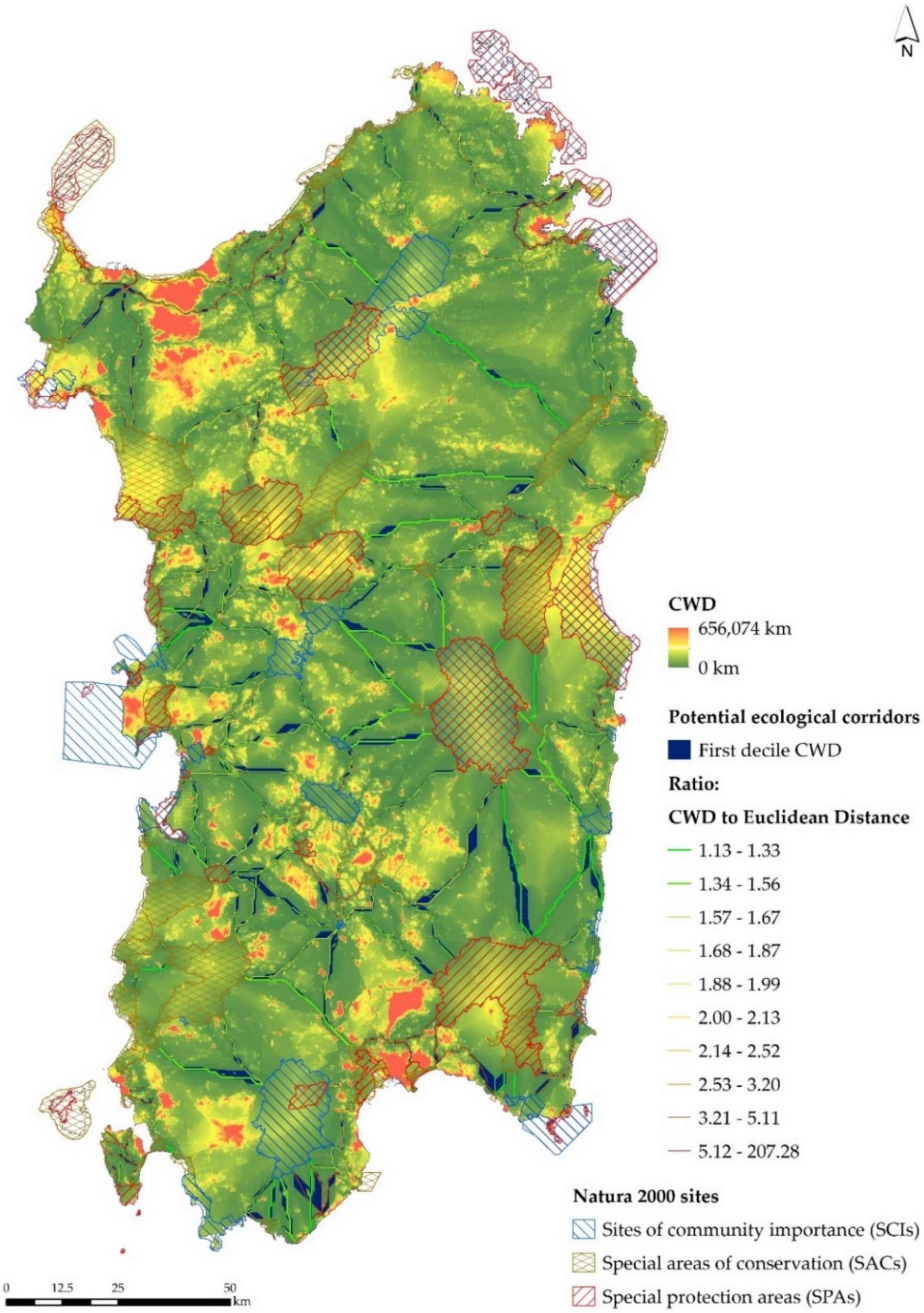

Figure 16 – The ecological corridors in Sardinia.

The identification of ecological corridors should be included within regional landscape plans, as well as their management should be legally established. A tool to integrate them into drafting landscape plans is the SEA procedure, in accordance with European Directive 2001/42/EC.

In this way, land parcels, located outside the Natura 2000 sites and included into the ecological corridors, related to habitats of community interest, can benefit of the same rules of that located inside the Natura 2000 sites. The lack of rules related to habitats of community interest can make possible that anthropic activities (e.g. new industrial and residential developments, or agriculture) can impact with land parcels that can be protected in a framework of ecological corridors.

Since ecological networks provide several ecosystem services, maintaining or enhancing them into a framework of ecological corridors is a prolific advantage. Sustainable uses of ecological corridors can be promoted by enhancing touristic or recreational purposes, in accordance with cultural services category, and even improving agricultural sectors which can have a role in provisioning services category (e.g. by providing food), and in the supporting services category (e.g. wrong agricultural practices can cause negative effects on species and habitats located either in the Natura 2000 sites or outside).

Land use and management influence the system properties, processes and components that are the basis of service provision. Land use or management changing can modify services supply, not only for specific services but for a complete bundle of services provided by (eco)systems (de Groot *et al.*, 2010).

For this purpose, multidisciplinary planning measures should be enlisted to protect the environment from land-taking due to anthropization processes.

The Sardinian Public Administrations, addressing local authorities as Provinces and Municipalities, can play a central role to implement and extend best practices under the provision of the Italian Government and the European Union.

The Belgian case study: connectivity in Flanders

This case study involves the Flemish Region (Belgium) where, besides the Natura 2000 network, even a regional level ecological network is legally established. Various overlapped areas exist between these ecological networks.

Although the regional ecological network conceives spaces of ecological connections, they are not officially implemented yet.

This condition makes the Flemish Region as a case to study a further implementation of methodologies of Sardinian cases.

This case study, however, is not implemented in any GIS-tool; it illustrates a conceptual way to select from the ecological networks patches which need to be connected, and a way to design landscape resistance involving experts' judgments.

As results of this implementation in a least-cost-based, ecological corridors should be understood as spatial elements that support the connectivity of habitats and their protection, by respecting the concept of area of connectivity conservation defined as «[a] recognised, large and/or significant spatially defined geographical space of one or more tenures that is actively, effectively and equitably governed and managed to ensure that viable populations of species are able to survive, evolve, move and interconnect within and between systems of protected areas and other effective area-based conservation areas. The vision and purpose of an Area of Connectivity Conservation is to connect protected areas and other effective area-based conservation areas and to maintain or restore ecosystem function and ecological and evolutionary processes of species and ecosystems across (and between) landscapes, freshwater-scapes or seascapes for biodiversity conservation in areas that may also be used and occupied for a variety of human purposes, so that people and other species are able to survive and to adapt to environmental change, especially climate change» (Worboys *et al.*, 2016).

Study area

The study area consists of Flanders, a region located in the north side of Belgium (Figure 17).

The Flemish Region adjoins: in the northern and north-eastern side, the Netherlands; in the north-western side, the Atlantic Ocean; on the eastern side, France.

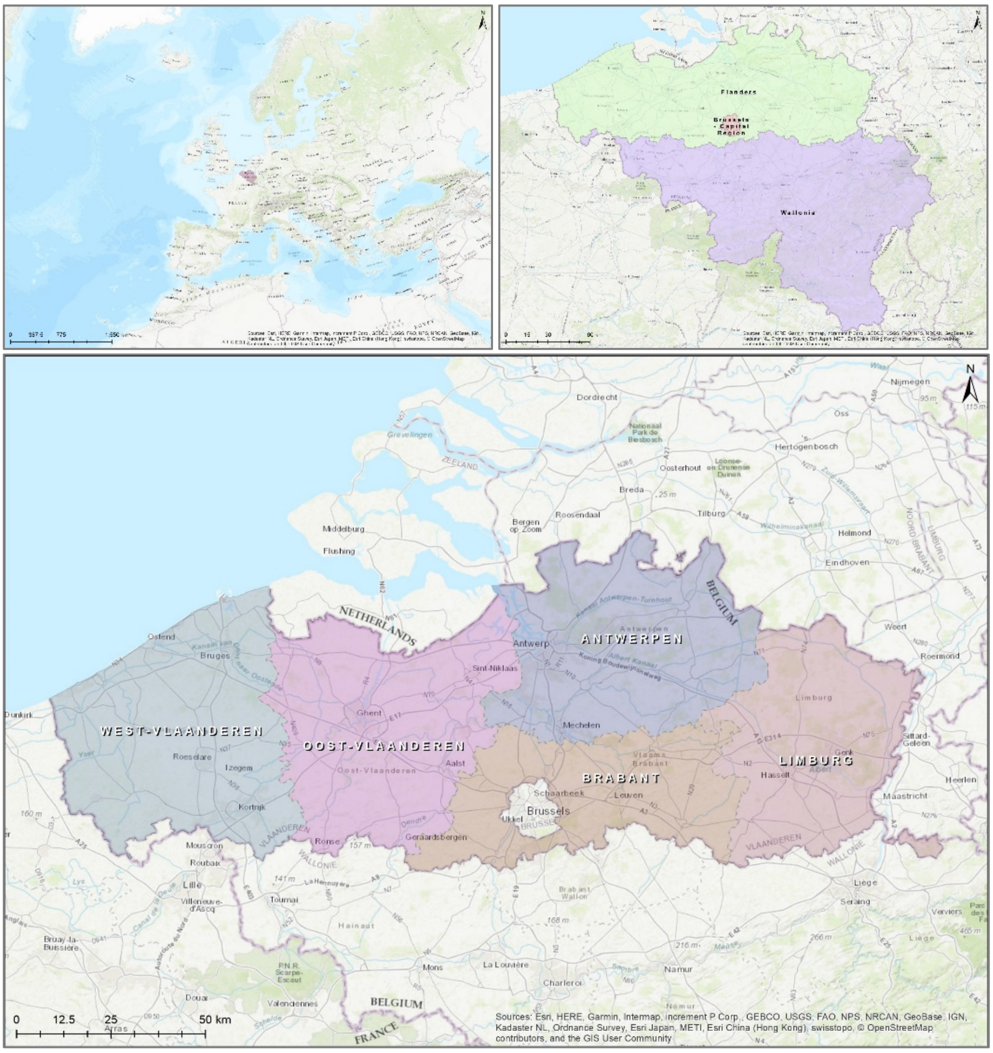

Figure 17 – The case study of the Flemish Region: on the top left, the localisation of Belgium in Europe; on the top right, the localisation of Flanders in Belgium; below, the Flanders.

The Region has an area of approximately 13,600 km^2. Investigating land covers and land uses, the dominant land covers are related to grassland and crops, covering each one around 27% of the region; 10% is forest vegetation; around 15% is settlement; 3% consists of water; and the rest, around 16%, is another kind of vegetation. The dominant land use is related to agriculture, concerning 46% of the region; uses related to nature conservation are 7%; recreational uses are 2%; related to urbanization are 27%; and related to water are 1%; the remnant 17% is related to various land uses.

Ecological networks in Flanders

The Natura 2000 Network

In Flanders, the nodes of the Natura 2000 Network (Figure 18) are the sites as established by the Habitats Directive (SCIs), and by the Birds Directive (SPAs). In particular, 62 sites (24 SCIs and 38 SPAs) are included into the boundaries of the Flemish Region; 5 marine sites, in the north of Flanders, are part of the Natura 2000 Network; 3 SPAs are included in the boundaries of the Brussel Capital Region, which is autonomous, but spatially located into the Flemish Region.

Investigating on standard data forms[41] of all Natura 2000 sites within the Flemish region, 67 species are included in the Natura 2000 Network: 27 (1 amphibian; 8 fish; 6 invertebrates; 8 mammals; 4 plants) are mentioned in the Annex II[42] of Habitats Directive and 40 birds are mentioned in the Annex 1[43] of the Birds Directive.

41 Last update can be downloaded from: https://www.eea.europa.eu/data-and-maps/data/natura-9 (accessed 31 January 2019).

42 The annex II of the Habitat Directive reports animal and plant species of community interest whose conservation requires the designation of SACs.

43 Article 4 of the Birds Directive says: «The species mentioned in Annex I shall be the subject of special conservation measures concerning their habitat in order to ensure their survival and reproduction in their area of distribution».

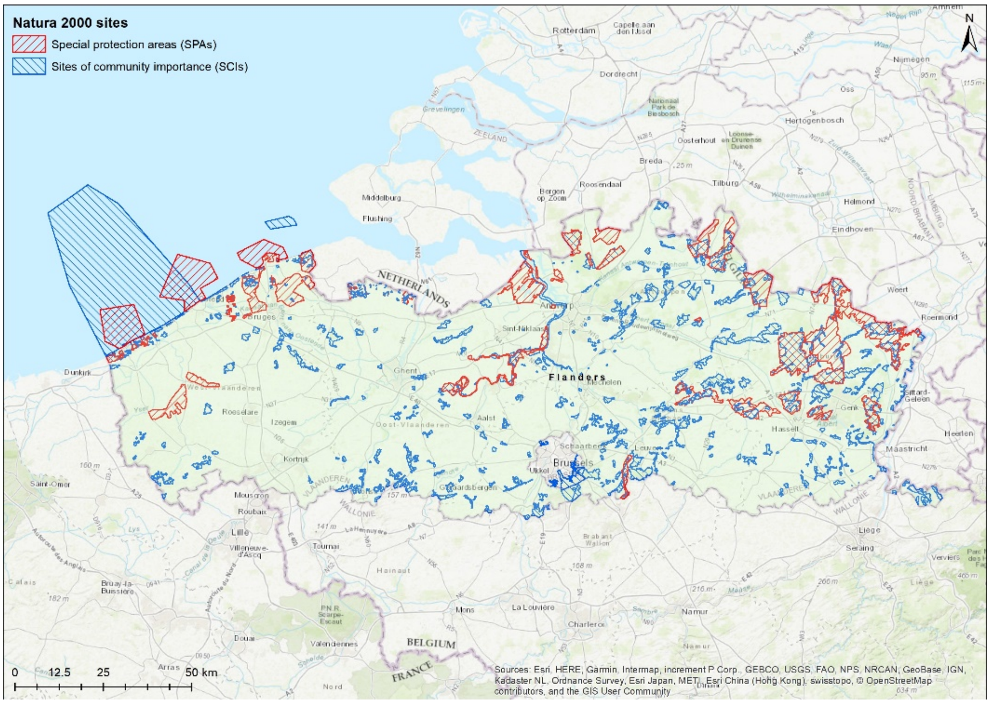

Figure 18 – The Natura 2000 Network in Flanders.

The Flemish Ecological Network

The Flemish Government, in order to preserve and develop environmental issues, established a Flemish Ecological Network (*Vlaams Ecologisch Netwerk*, VEN)[44], as a structure of areas where nature conservation policy is the main objective to be developed in the network and in its "Integral Intervention and Support Network" (*Integraal Verwevings- en Ondersteunend Netwerk*, IVON), that is its surrounding support (Figure 19). In this way, in Flanders, nature should be extra-protected, and users and owners can directly participate to improve the environment. In fact, this kind of ecological network is the integration of, on the one hand, the areas of the VEN, as per the decision of the Flemish Government,

44 The Flemish Ecological Network was established through the "*Decreet betreffende het natuurbehoud en het natuurlijk milieu* [Decree concerning nature conservation and the natural environment]" of 21/10/1997, officially stated on 10/01/1998 and entered in force on 20/01/1998. This decree is also quoted as the "*Natuurdecreet* [Nature Decree]". In particular, the network is mentioned in the Chapter V, Section 1, Article 17.

and, on the other hand, the areas of the VEN and the nature interleaving areas, that are delineated in the regional spatial implementation plans.

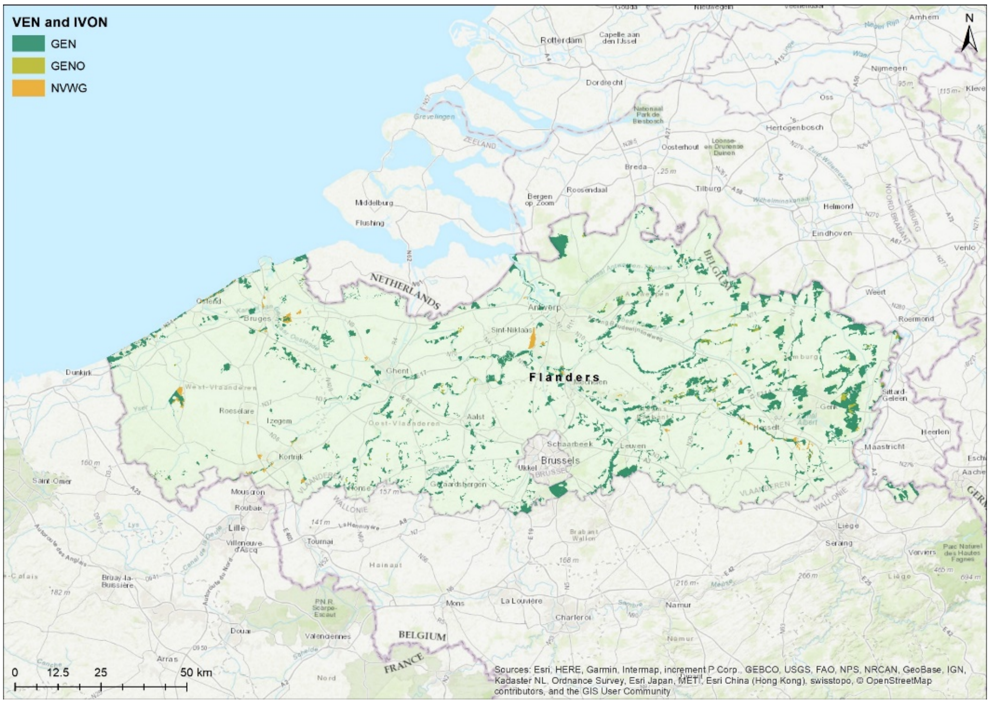

Figure 19 – The ecological network in Flanders.

In particular, the structure of the Flemish Ecological Network consists of two parts, as above mentioned: VEN and IVON. VEN, in turn, consists of great units' nature (*Grote Eenheden Natuur*, GEN) and great units' nature in development (*Grote Eenheden Natuur in Ontwikkeling*, GENO), which could be understood as core areas of the network. IVON, in turn, consists of nature interrelation areas (*Natuurverwevingsgebieden*, NVWG) and nature connection areas (*Natuurverbindingsgebieden*, NVBG), which could be understood as connective elements. Despite the spatial definition of NVWG, NVBG has not been identified yet[45].

45 The dataset of VEN and IVON, released at 21/06/2016, is available at: https://www.milieu-info.be/dms/d/d/workspace/SpacesStore/35e9923f-f86e-45e6-8d7e-105025fc9e07/ps_ven.zip (accessed 31 January 2019). Metadata reports that the file is suitable for use on a medium scale, maximum scale 1:25,000 and has not a legal value; the file is updated on the basis of new regional spatial implementation plans or their abolition thereof by the Council of State.

VEN and IVON are among important legal instruments of environmental policy that are shared with spatial planning policy[46].

Furthermore, species or subspecies of organisms, which need protection measures, are listed in Annexes III and IV of the Nature Decree.

The Annex III is related to animal and plant species of community interest mentioned in Annex IV of the Habitats Directive, which occur in Flanders.

In turn, the Annex IV is related to bird species, which occur in Flanders, mentioned in Appendix I of the Birds Directive.

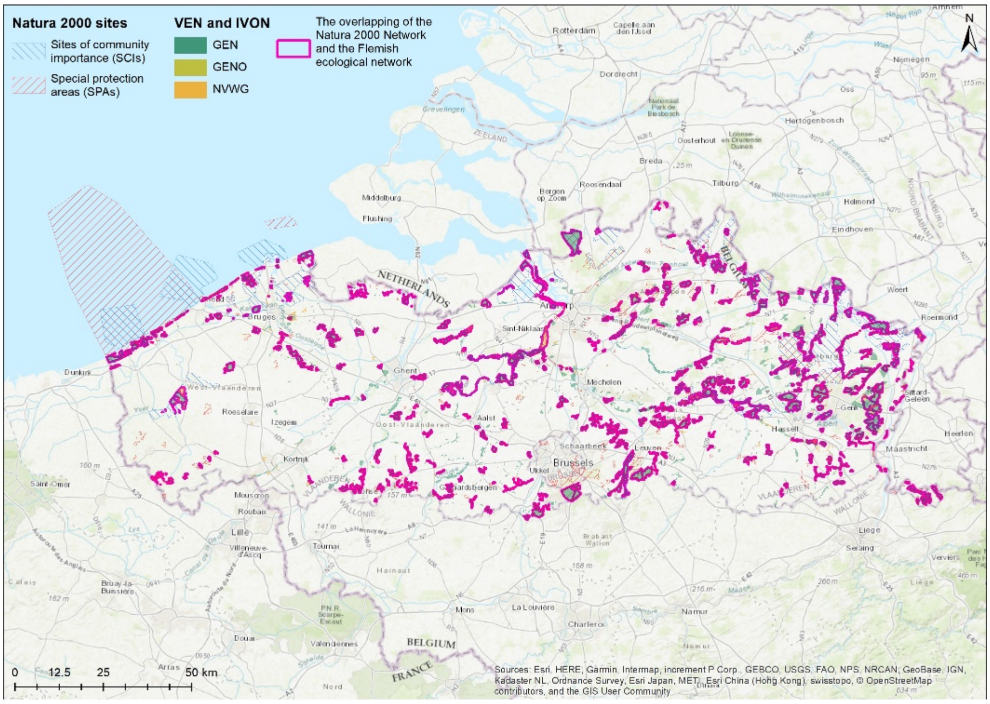

Figure 20 – The Natura 2000 Network and the ecological network of Flanders.

46 More information can be found at: https://www.natuurenbos.be/beleid-wetgeving/beschermde-gebieden/ven-ivon/inleiding (accessed 31 January 2019).

Materials

The biological valuation map of Flanders

In 2016, Flanders is analysed into a biological valuation map (*Biologische Waarderingskaart en Natura 2000 Habitatkaart – Toestand* 2016, BWK) (Figure 21 and Table 3). It is a database[47] where the evaluation of the Flemish territory is based on the presence of important fauna elements, vegetation and soil cover, (De Knijf *et al.*, 2010) and habitat types by the Habitats Directive. It is the second version, more detailed, in terms of content and accuracy, then the previous version.

Table 3– Description of the codes of the EVAL attribute field of the biological valuation map of Flanders.

Eval	Description
m	*Biologisch minder waardevol* [Biologically less valuable]
mw	*Complex van biologisch minder waardevolle en waardevolle elementen* [Complex of biologically less valuable and valuable elements]
mwz	*Complex van biologisch minder waardevolle, waardevolle en zeer waardevolle elementen* [Complex of biologically less valuable, valuable and very valuable elements]
mz	*Complex van biologisch minder waardevolle en zeer waardevolle elementen* [Complex of biologically less valuable and very valuable elements]
w	*Biologisch waardevol* [Biologically valuable]
wz	*Complex van biologisch waardevolle en zeer waardevolle elementen* [Complex of biologically valuable and very valuable elements]
z	*Biologisch zeer waardevol* [Biologically very valuable]

47 The database can be downloaded at: http://www.geopunt.be/download?container=bwk2\2016&title=Biologische%20waarderingskaart%20-%20Natura%202000%20Habitatkaart (accessed 31 January 2019).

The metadata explain that this map is used for further development of the Natura 2000 policy and is also the basis for the preparation of the regional and area-specific conservation objectives.

As specified in Vriens (2011), a qualitative valuation, both in individual and complex shape of biotopes is implemented in the database in terms of their biological value, and this represents the legend of the valuation map.

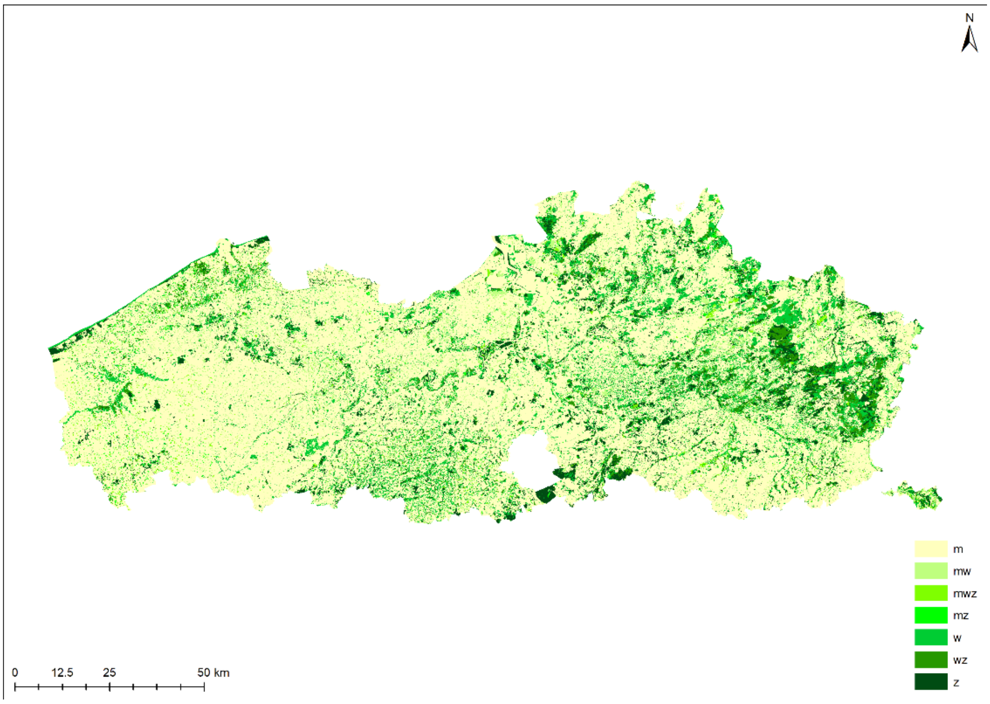

Figure 21 – The biological valuation map of Flanders.

The ECOPLAN Project

ECOPLAN (IWT-SBO) @2014 is a consortium consisting of the research group Ecosystem Management (University of Antwerp), the Aquatic Ecology research group (University of Gent), the Department of Earth and Environmental Sciences (KULeuven), Earth Observation group (VITO), the Spatial Environmental Aspects group (VITO) and the Institute for Nature and Forest Research (*Instituut voor Natuur- en Bosonderzoek*, INBO).

The ECOPLAN project was financed by the Flemish Agency for Innovation through Science and Technology, during 4 years from 2013 to 2016.

The main objective of ECOPLAN was to develop spatially explicit information and tools for the assessment of ecosystem services, in order to improve land use efficiency and environmental quality. Open source final products were released for identifying, quantifying, valuing, validating and monitoring ecosystem services. These products can be used by administrations and consultants in project development, cost-benefit analysis, environmental impact reporting and all concerning planning processes.

Maps concerning demand or production of ecosystem services can be consulted using the ECOPLAN monitor[48] which lists ecosystem services maps for Flanders on the basis of existing spatial data and data processing.

Land use and land cover of Flanders

In order to analyse land uses and land covers, land use maps (Figure 22) and land cover maps (Figure 23) are downloaded from the database of the ECOPLAN project. The land cover and land use maps of Flanders were designed on the basis of a number of the most recent and detailed GIS datasets in Flanders from various Flemish Institutions, with a resolution of 5 m per pixel.

The land cover map shows detailed soil coverages on 3 levels, 64 classes on the third level are aggregated in 27 classes on the second level, which is, in turn, aggregated in 10 classes on the first level).

The land use map describes current land uses within Flanders on 31 classes aggregated to 6 basic classes. This map does not completely cover the area of Flanders because land use is not always well documented on the scale of Flanders. In particular, several uses of forests are often unclear.

48 The ECOPLAN monitor can be consulted at: http://www.ecosysteemdiensten.be/cms/nl/node/12 (accessed 31 January 2019).

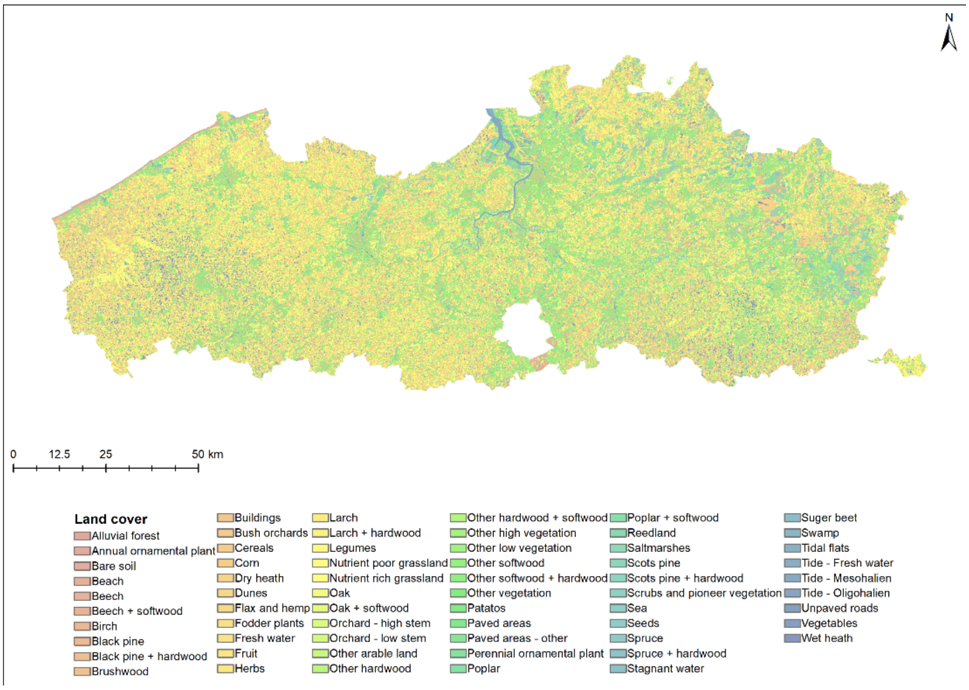

Figure 22 – The land cover map of Flanders.

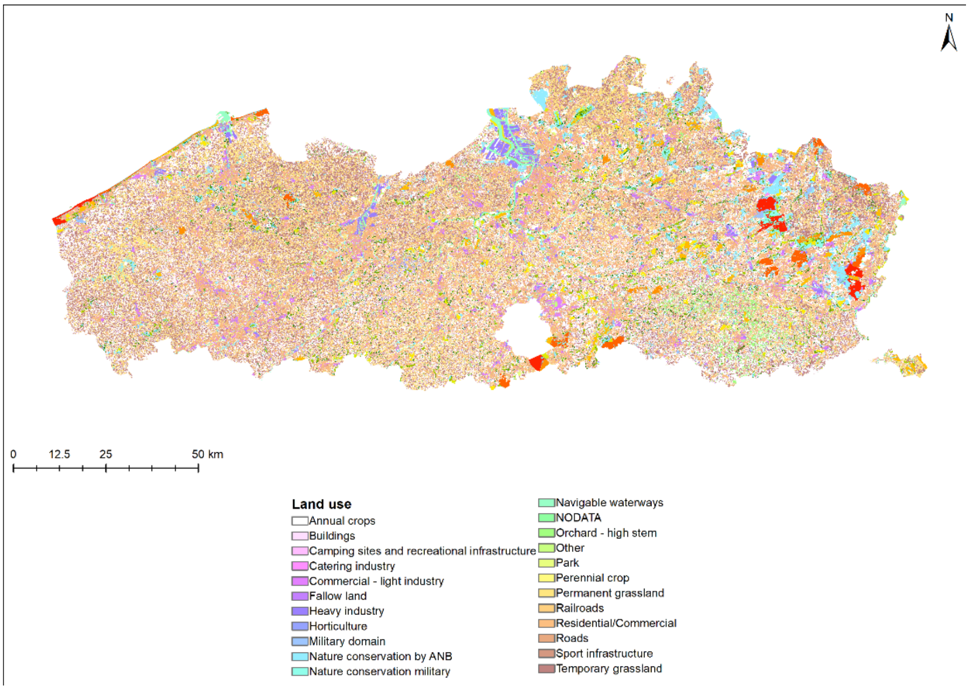

Figure 23 – The land use map of Flanders.

Methodology

This case study concerns a further development of methodologies of Sardinian cases (Figure 24). Although it is not processed in the GIS-tool Linkage Mapper, it presents a conceptual scheme to understand what kind of landscape elements needs to be connected and how the landscape can offer resistances (Figure 24, even based on literature data by involving expert knowledge. In particular, some variations are introduced to improve the identification of connective landscape elements in a scheme directly implementable in GIS.

The main purpose is the prioritization of functional land patches by identifying the most suitable elements on the basis of their biological value, assuming its value as friction to be used by species. By doing so, this spatial structure can decrease the negative attitude towards contributing to landscape fragmentation.

Since Linkage Mapper requires two inputs, as previously described, this methodology regards both the layer of core areas and the frictions layer.

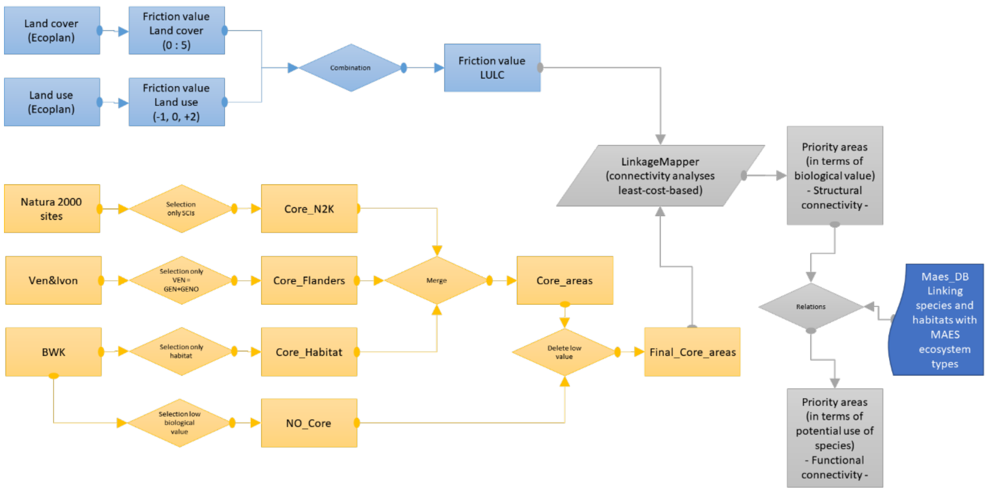

Figure 24 – The scheme of the implementation of the case study in Flanders.

The frictions layer

The frictions layer concerning the opposition of the landscape to species movement is built in three steps.

1) On the basis of land covers, experts are required to score each type of cover in a range from 0 to 5, thinking on the landscape resistance, which represents the opposition to species movement from a source point to a destination point. The lowest value represents the lowest resistance and vice versa. The first classification concerning resistances of land covers is determined in this way (in Figure 24: Friction value Land cover).
2) On the basis of land uses, the friction is increased or decreased, from –1 to +2. A second classification concerning resistances of land covers and their land uses is determined (in Figure 24: Friction value Land use).
3) The frictions layer (in Figure 24: Friction Value LULC) is created by using geoprocessing and map-algebra to combine all values.

The layer of core areas

The purpose to build a layer of core areas by following the steps shown above is that large parts of protected areas do not have high biological values. Even within the Natura 2000 sites could exist barriers. These barriers can be excluded by selecting the low biological value from the biological valuation map of Flanders.

1) From the Natura 2000 sites, only SCIs are selected to identify core areas, since, at this large scale, birds should not have migration issues and they can be not sensitive to fragmentation (in Figure 24: Core_N2K).
2) From the Flemish Ecological Network, only parts of VEN=GEN+GENO are selected to identify core areas, since IVON zones have not been officially implemented yet (in Figure 24: Core_Flanders).
3) From the biological valuation map (BWK), only parts of classed as habitat are selected to identify core areas (in Figure 24: Core_Habitat).
4) The first layer of core areas is built by merging all previously described core areas (in Figure 24: Core_areas).

5) From the biological valuation map (BWK), parts classed with low ecological values are selected, since the low biological value can have ecological resistance (in Figure 24: NO_Core).
6) All patches contained in the NO_Core map are deleted from the Core_areas map, to obtain a map of core areas with high ecological values (in Figure 24: Final_Core_Areas).

Results and discussion

The scheme presented in Figure 24 represents a conceptual way to identify core areas in the ecological network within Flanders[49] and define resistances based on land use and land cover. Further, the methodology consists of an implementation of connectivity analysis (i.e. by using Linkage Mapper) to obtain a first set of links which represents structural connectivity. Then, by relating species on MAES database to land use and land cover within connective elements, functional connectivity can be studied for interesting species.

Particular efforts coming from data in this methodology can regard the combination of land covers and land uses since a land cover can have several uses (e.g. forests can have particular uses as nature conservation, recreation, military domain, etc.). The combination of land covers and land uses of Flanders generates a classification consisting of 1,144 new classes (Figure 25).

Further results can be implemented in spatial and management planning to support decision-making processes.

49 The Ecological Network of Flanders covers 932.91 km^2 of which 638.67 km^2 (68.5%) are totally contained into the Natura 2000 Network.

Description			Land use	0	1		2								3			4							5	6				
				NoData	Nature conservation		Agriculture								Recreation			Urban							Water	Other				
				NODATA	Nature conservation by ANB	Nature conservation military	Annual crops	Perennial crop	Temporary grassland	Permanent grassland	Orchard - high stem	Horticulture	Buildings	Fallow land	Sport infrastructure	Park	Camping sites and recreational	Residential/Commercial	Catering industry	Heavy industry	Commercial - light industry	Roads	Railroads	Other	Navigable waterways	Military domain				
Land cover			COD	0	1101	1301	2101	2102	2201	2202	2302	2501	2601	2701	3101	3102	3103	4101	4102	4201	4202	4301	4302	4304	5101	6201	SUM (Area)	COUNT	Total	Total
1	Other vegetation	Scrubs and pioneer vegetation	1101	54340350	19721125	1757675	2475625	4675	4107000	4545725	115925	71100	218075	302000	1006725	1025	1575	11269425	23475	12601625	2865450	225	25	2781925	769575	347800	119328125	23	2097.86	15.39%
		Brushwood	1201	64673550	33434875	4586575	253225	2575	577350	1478525	43650	64000	101900	92775	2250075	20600	5025	6566400	56225	2391425	2296025	325	100	1188700	422800	802250	121308950	23		
		Bush orchards	1301	8486425	359050	1450	13400725	3875	16097050	6216525	476925	19872700	1401975	570550	73275	18425	5675	3695675	6775	53575	269075	50	0	115800	0	13350	71138925	21		
		Orchard - low stem	1302	12867000	780175	24900	6432850	875	6103875	2279400	66888550	274050	818250	897800	25575	19075	2900	2819575	1575	16325	275325	75	0	55250	0	2350	100585750	21		
		Orchard - high stem	1303	1024350	475	0	346300	0	362075	159100	1202250	5525	60125	29975	8475	22175	0	363050	1075	0	21325	0	0	850	0	0	3607125	15		
		Other high vegetation	1401	118688375	6584500	399250	0	0	0	0	0	0	6758875	411300	14722750	25344600	5814700	288388700	2306425	5533325	27999275	5275	75	4632600	50525	2404375	510044925	17		
		Other low vegetation	1402	182746425	5127800	1160500	0	0	0	0	0	0	21261050	1128050	15474925	15309550	3294400	719718775	2878450	18401450	51444175	7050	100	9004725	140600	4072000	1051170025	17		
		Other vegetation	1403	30558625	931250	181825	0	0	0	0	0	0	3349725	705425	1953450	1536375	505850	68690250	509875	2715025	7282400	2150	0	1287000	19350	450975	120679550	16		
2	Forest	Birch	2101	1445900	472550	19900	17675	0	69175	75250	0	350	12950	1375	76600	150	575	360850	2000	15575	68700	0	0	14650	0	2100	2656325	18	1326.73	9.74%
		Beech	2102	12190625	29540725	96625	35525	0	141050	185075	2625	3800	21300	6350	353350	1321725	1300	1808175	17700	1425	207175	50	0	323900	0	214700	46473200	20		
		Beech + softwood	2103	301675	1124575	25	0	0	75	1000	0	0	0	0	11700	20100	0	46625	0	0	425	0	0	1175	0	0	1507375	10		
		Oak	2104	72911500	47393300	3100800	301150	425	1359450	1729650	31950	44800	159675	59500	1597800	1943825	48550	9252550	94650	272700	1455325	575	0	640650	10850	2030750	144440425	22		
		Oak + softwood	2105	3683650	4051775	186750	2375	0	15075	12125	175	75	375	1225	191800	184425	14750	598800	2800	2475	65200	0	0	47125	0	52450	9113425	19		
		Poplar	2106	135492500	37183750	44750	492175	1450	1449900	6538900	118000	111000	244800	173100	1211450	1325225	295650	6351850	66075	658500	1322200	375	0	333125	12475	98350	193525600	22		
		Poplar + softwood	2107	615625	177825	0	275	75	2750	6500	0	0	150	325	13600	6125	14525	20400	0	0	875	0	0	750	0	0	859800	14		
		Other hardwood	2108	143122125	75589825	5775525	863475	1125	2502500	4201125	106275	259600	420875	187300	5293350	11155250	589275	22104975	297100	1820900	5603425	650	0	1221825	31900	2219950	283368350	22		
		Other hardwood + softwood	2109	20988600	10856950	1847075	13500	25	60150	103725	300	132125	20875	2200	907425	1436125	156350	3303525	53000	163200	654475	25	0	111850	0	417175	41228675	21		
		Larch	2201	9053375	7342950	197975	5900	0	28250	27850	800	50	3950	2900	283000	157100	12575	976400	825	6450	79425	0	0	43175	0	28175	18251125	19		
		Larch + hardwood	2202	2670925	2158900	1650	1775	0	10525	6925	0	300	500	0	125500	79400	2975	155775	0	9050	12550	0	0	7600	0	9850	5254200	16		
		Spruce	2203	15489450	3885175	159500	14325	0	91725	129025	1175	58200	19600	4025	515850	237350	79625	1543175	5800	8850	138975	550	0	36350	0	21150	22439875	20		
		Spruce + hardwood	2204	2411775	539225	0	1150	0	8650	13975	0	6425	1250	450	124450	86950	13800	263825	0	4850	9825	0	0	2325	0	300	3489225	16		
		Black pine	2205	27877400	60608600	2051875	15100	0	89725	77000	1050	3000	15100	2650	1148050	119675	50225	2911950	55000	312675	469625	425	0	134275	0	299250	96242650	20		
		Black pine + hardwood	2206	1425700	2453100	83475	475	0	7525	5800	0	0	900	0	41625	25825	450	353450	525	7225	38100	0	0	9925	0	14400	4468500	16		
		Scots pine	2207	152711300	133733575	13456425	123925	25	658425	647400	2850	41350	215150	15225	6426200	581750	298675	23928000	785475	3582650	3343700	775	0	1185625	4825	3537450	345280775	22		
		Scots pine + hardwood	2208	17959575	15450125	3160900	2800	0	30400	43400	425	750	23025	1475	636150	275425	40225	3141650	24450	309050	755050	50	0	336900	25	513325	42705175	21		
		Other softwood	2209	25557575	15672900	350775	235175	25	468300	504700	14850	99050	73675	23100	1263175	176675	33075	4800925	65425	109125	343150	375	0	116475	100	96300	50004925	22		
		Other softwood + hardwood	2210	6932400	5281025	101425	2875	0	13725	35525	0	6100	6800	425	537750	605600	41775	1626950	10900	22550	109275	0	0	22025	0	61825	15418950	18		
3	Grassland	Nutrient poor grassland	3101	108208150	26886500	4383575	214096625	215275	194918275	58097900	1189575	1700650	3527075	3318725	37049700	51875	16475	31984850	549900	2709350	11247450	2525	0	2352850	1007300	2754750	706269350	22	3735.97	27.41%
		Nutrient rich grassland	3201	552559625	118835300	3543275	111640050	109375	365520550	1538394950	4044700	3810925	56907225	8327850	10141600	1842550	309050	214079350	695375	8551800	21372025	4775	0	4805775	58325	4145775	3029700225	22		
4	Heath	Dry heath	4101	8470325	32078375	32120225	14375	0	92650	93675	1375	2375	300	2025	220625	175	325	722550	450	351600	1757650	50	0	174025	0	13993125	90096275	20	100.31	0.74%
		Wet heath	4201	309600	4021900	4330200	5750	0	550	10925	0	0	0	0	625	0	0	16100	0	1800	200	0	0	3725	0	1516175	10217550	12		
5	Bare soil	Bare soil	5101	151600	22401350	12650	2475	0	0	8000	0	0	0	0	127275	5875	1350	104200	0	2125	7200	0	0	166900	1750	5450	22998200	14	119.75	0.88%
		Dunes	5201	1979425	3357475	73500	150	0	300	550	0	0	0	0	34375	0	1675	211550	26175	108725	63275	0	0	1875	1200	137825	5998075	15		
		Beach	5301	3143725	468275	0	0	0	0	0	0	0	0	0	7200	0	175	4125	25	0	25	0	0	50	33525	25	3657150	10		
		Unpaved roads	5401	668975	383100	39300	193700	1550	392550	646600	10850	5875	22575	10225	34300	4425	5125	1651950	5150	2821850	475225	36100700	33920950	9575825	100	121275	87092175	23		
6	Agriculture	Patatos	6101	753600	4075	0	0	0	0	0	0	0	39150	7700	1300	600	1200	170000	800	2075	12575	0	0	4350	0	775	998200	13	3666.96	26.91%
		Corn	6102	130356500	10746175	1192475	443873000	136325	1001118425	254228575	7559425	8719350	7068200	10723375	2047250	73275	82225	46342075	159125	2888675	5984475	1875	0	1616375	27475	473750	1935418400	22		
		Cereals	6103	55992150	6438850	486525	483207875	537050	329608125	51452650	4636350	1818225	2983250	10634900	997225	19150	16800	15572075	95425	945900	2347700	250	0	549450	575	1207675	969548175	22		
		Seeds	6104	84850	725	0	583550	0	604600	97175	31450	48775	9350	14175	2125	400	0	47575	0	0	3975	0	0	25	0	0	1528750	14		
		Legumes	6105	2687800	85700	50	32606575	44725	20903350	4290100	331725	284100	288150	433150	525	1275	1475	461350	150	8325	129975	25	0	7875	0	69550	62635950	21		
		Sugar beet	6106	8226850	1029350	143250	92913875	87400	75277750	7092100	1933575	380725	740200	1522650	248375	6875	850	3125325	25875	164175	512975	125	0	68325	100	338550	193292275	22		
		Vegetables	6107	17579800	696125	775	121735475	185800	80179200	18371600	41422325	2589350	1895900	1073175	41150	5100	6725	5540125	22950	103975	546300	50	0	88075	0	19075	292103050	21		
		Herbs	6108	752350	474175	500	11216075	0	2931475	697600	64700	40600	604550	11550	73950	100	0	2211025	3025	81100	350000	125	0	28125	0	850	19541875	19		
		Fruit	6109	31600	47575	0	1292725	0	168475	29000	1950	0	149725	175	300	50	0	260575	25	1175	40675	25	0	4675	0	0	2028725	16		
		Flax and hemp	6110	8223650	990925	56650	32722325	29600	38323150	24667000	375475	250600	615100	807850	157600	8975	8175	2554875	1025	72775	292150	0	0	64375	0	173700	110395975	20		
		Fodder plants	6111	3595175	320000	2150	11378650	36300	26354950	7602575	63425	226500	223125	351100	32550	5925	1150	1705450	1625	79250	99175	0	0	37850	0	33750	52150675	20		
		Other arable land	6112	4728550	990575	16875	3482475	1227650	4719350	3310250	3120875	184300	243050	341000	169725	17450	4075	709700	375	21275	114375	0	0	14325	75	27950	23444275	21		
		Annual ornamental plant	6201	727425	10900	0	533125	300	475575	188700	37800	568500	47275	15425	25	0	0	451975	0	0	2000	0	0	3650	0	0	3062675	14		
		Perennial ornamental plant	6202	305950	200	0	62075	0	114425	14775	12075	51850	54100	8400	6225	0	500	209350	0	125	26025	0	0	575	0	0	866650	15		
7	Swamp	Swamp	7101	1868850	3372175	369075	10550	0	56775	252975	175	375	50	400	9625	0	175	46250	0	0	4850	0	0	4025	0	3900	6000225	16	116.21	0.85%
		Reedland	7201	9726475	7678450	12250	604925	0	785775	1326975	9575	7050	23550	85225	93825	125	150	329600	6350	753100	63650	25	0	142550	731950	3725	22385300	21		
		Alluvial forest	7301	50466375	30952225	1443125	104200	225	275975	1296050	17575	15725	31350	50025	481400	250	1175	1490300	17000	90300	162425	0	0	108350	1075	818950	87824075	21		
8	Tidal flats and saltmarches	Tidal flats	8101	337550	2238825	0	0	0	0	29950	0	0	0	0	1225	0	25	8225	0	28175	20750	0	0	8725	3472025	0	6145475	10	8.49	0.06%
		Saltmarshes	8201	61675	1541400	0	3400	0	42225	499150	0	0	3675	6875	275	0	0	14275	0	3550	0	0	0	73400	94225	0	2344125	12		
9	Urban	Buildings	9101	29232675	172950	92700	1560875	1250	2751050	4645650	171875	177575	50719075	59125	4108700	443725	364775	430525100	4266450	41931750	108037675	1700	25725	4227425	3175	2070225	685591225	23	2067.65	15.17%
		Paved areas	9201	15313175	2378750	1550475	406125	925	650800	1122175	161075	116475	1312775	32275	3824500	2350575	635900	16001700	583175	10061450	11212075	711838100	239250	19238700	698675	2895625	802624750	23		
		Paved areas - other	9202	70017900	1166375	840900	15975	0	14900	14975	1675	0	32568825	592100	6672325	3162750	1109050	292380200	3564500	58142275	93237450	12700	125	12444875	367025	3111275	579438175	21		
10	Water	Stagnant water	10101	55239775	15754725	1473200	1220575	3225	2039200	6124225	78625	84250	1602225	77300	2378100	3146575	3492175	7997500	227525	1297675	1953650	175	0	440575	17675	235475	104884425	22	388.38	2.85%
		Tide - Mesohalien	10201	1171875	463725	0	0	0	0	4325	0	0	0	0	25	50	200	3825	0	21900	100	0	0	2600	21854325	1025	23523975	12		
		Tide - Oligohalien	10202	156300	650	0	0	0	0	0	0	0	0	0	0	50	1600	1375	225	30875	28975	0	0	11725	5781700	3700	6017175	11		
		Tide - Fresh water	10203	1740050	49325	0	325	0	3400	1775	0	0	0	0	400	10925	1425	8200	350	7950	5050	0	0	2250	9767950	1750	11601125	15		
		Fresh water	10204	83402300	25348175	665525	4662525	5800	8185800	18882775	275750	207625	799750	435825	889175	3223500	742500	5389025	58925	1384400	945650	275	0	626200	82873975	311100	239316575	22		
		Sea	10301	2909775	32125	0	0	0	0	0	0	0	0	0	0	0	25	0	0	10200	0	0	0	875	79450	0	3032450	6		
			SUM (Area)	2357409200	841873600	91596850	1595188775	2637925	2190764350	2032519925	133961750	42346125	197690500	43562100	126127675	76393150	18131000	2267393425	17577575	181699675	368188250	747982500	34186350	80557925	128336675	52187375	13628312675		13628.31	100.00%
			COUNT	63	63	48	53	28	53	56	42	44	53	51	61	55	54	62	49	56	61	34	8	63	34	53		**1144**		
				17.30%	6.18%	0.67%	11.70%	0.02%	16.08%	14.91%	0.98%	0.31%	1.45%	0.32%	0.93%	0.56%	0.13%	16.64%	0.13%	1.33%	2.70%	5.49%	0.25%	0.59%	0.94%	0.38%				

Figure 25 – The combination of land cover and land use of Flanders.

Discussion of the case studies

The case studies analysed in this chapter show different ways to define and identify a set of ecological corridors at different scale by focalising through multispecies concepts.

The general scheme to implement a connectivity analysis is synthesized in a flow-chart in Figure 26, and some characteristics of each case are resumed in Table 4.

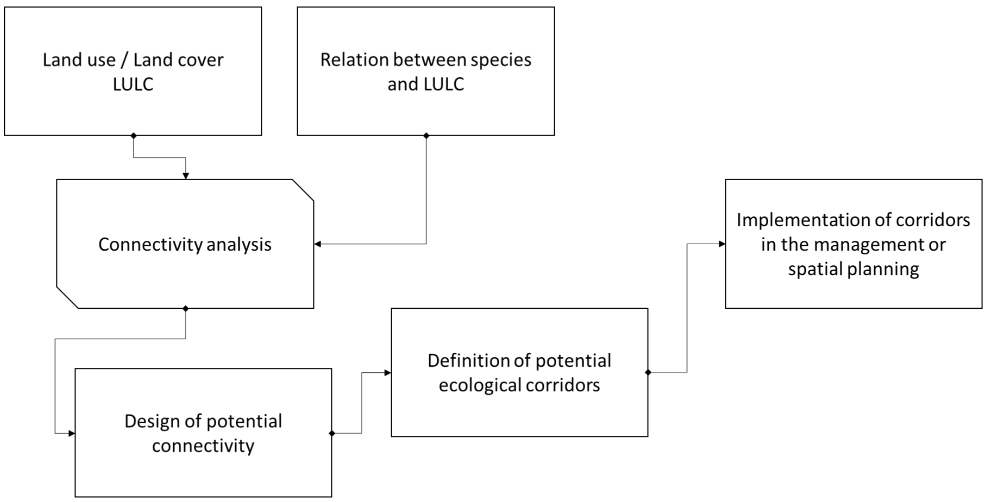

Figure 26 – The general methodology applied in case studies.

Connectivity maps and linkage designs are useful to support decision-making, management plans, and, in general, spatial planning. These results should be integrated by public administrations, transportation agencies, and land management agencies into their land use and planning efforts.

Since this theme concerns multidisciplinary issues, professionals, experts, researchers and other important figures, by working in a team, can provide specific handbooks to the integration of connectivity maps in land use, zoning, transportation, and other plans.

Table 4 – The comparison of case studies.

Context	***Metropolitan City of Cagliari***	***Metropolitan City of Cagliari***	***Sardinia***	***Flanders***
Scale	Local Metropolitan	Local Metropolitan	Regional	Regional
Species	One species: *Euleptes Europaea*	Multispecies	Multispecies	Multispecies (without birds)
Purposes of methodologies	Finding patches outside protected areas which can be used from a particular species	Defining a local structure of landscape connective elements to improve the coherence of ecological networks	Defining a global structure of landscape connective elements to improve the coherence of regional ecological networks	Prioritising all patches with high permeability and high biological values and determine landscape resistance values involving experts
Results	Habitat suitability map	A set of metropolitan ecological corridors	A set of regional ecological corridors	A model of instructions to implement a GIS tool to obtain a set of areas to be connected and a set of resistance values
Further utility	By implementing a methodology such this for each species, a global map can show where global criticalities are present in the study area	This kind of information can be adopted in the decision-making processes of metropolitan planning	This structure can be used to address regional landscape plans and it can be improved by other local structure of ecological corridors	This methodology can be applied by using LCP to obtain connectivity maps and linkage designs useful to support decision-making or guide management of landscape

Approaches based only on functional connectivity, that are based on species behaviours, are species- and context-specific issues. They require more complex phenomena often difficult to sample, experiment on, and described synthetically; furthermore, connectivity needs of all species and processes can be difficult to meet within any one implementation (Bélisle, 2005).

Furthermore, decision-makers need tools to quickly conceive connectivity issue without being complex, difficult to use or time-consuming.

The methodologies presented in these case studies show simple methods to implement even a multispecies approach to obtain outcomes useful and integrable in spatial planning. The outputs provide a basis from which start to prioritise land patches for their connective importance as the first step towards more accurate connectivity assessment. Expert knowledge, specific quantitative and distribution data of species to design ecological corridors could show more representative results, but these conditions could increase time or resources that are not often available, delaying decisions that have not been taken yet.

Section 5 – Proposals to integrate ecological corridors into spatial planning

A system of environmental connections, complementary to the consolidated structure of protected areas, requires an *ad hoc* plan which can harness both natural and cultural aspects linked to the ecological network, by relating the urban environmental system with coordination elements of planning, generating continuous multidisciplinary and multi-sectoral feedback from local levels to regional levels and vice versa.

Designing an ecological network project, without defining any plan, undermines not only its realistic feasibility (both in terms of constraints and management) but even its integration into spatial planning processes (APAT, 2003).

For this reason, in this chapter, a structure of a new plan to manage ecological corridors in spatial planning is proposed. The proposal is presented in a schematic form and then different levels of planning and functions are discussed in terms of coordination in a framework to implement ecological networks.

Important tools, as the ecosystem approach and the SEA (discussed in next paragraph), can help to address the plan to themes of protection and enhancement of the environment. Furthermore, results and considerations coming from the case studies discussed in previous chapters can be implemented in this plan.

Important issues to integrate ecological corridors into spatial planning

Spatial relationships between the natural and the anthropic system require that spatial planning develops governance strategies, overcoming traditional approaches, in order to implement environmental requalification and improve actions, ranging from regional to local scales.

In 2014, the UNI[50] publishes a reference practice[51] "Guidelines for sustainable development of urban and peri-urban green areas – Planning, design, realization and maintenance" which introduces "Plans for the Restoration of Ecological Continuity". The UNI states that this kind of plans should become a compulsory work in the drafting of the Metropolitan Strategic Plans, Municipal and Rural. This plan integrated into metropolitan plans should have priority as it can provide a clearer overview of the existing ecological system and its possible future implementation scenarios, also with respect to the construction of a local ecological network.

In the next paragraphs, Table 6 shows the structure of an operative proposal for the implementation of plans related to the ecological corridors in spatial planning. It is applicable to different levels of scale. The contents of Table 6 are intended to illustrate the concept of ecological corridor management and to address the analytical path that can lead to the definition of a plan concerning ecological corridors into spatial planning.

50 The UNI (*Ente nazionale italiano di unificazione* [Italian national unification body]) is a private non-profit association that operates on regulatory activities in many sectors.

51 The UNI reference practices are documents that introduce technical prescriptions, elaborated on the basis of sharing processes restricted only to authors, under the operative management of UNI. Reference practices are available for a period of 5 years, maximum time from their publication within which they can be transformed into a normative document or must be cancelled.

Since different planning levels can have different governance tools, different functions and purposes of the ecological network can be defined. Table 7 highlights goals and addresses that a similar plan could assume in its implementation, providing some recommendations for each level.

Ecosystem approaches

In the second meeting of the Conference of the Parties (COP) of the Convention on Biological Diversity (CBD), held in Jakarta from the 6th to the 17th of November 1995, a scheme of an ecosystem approach was presented with the aim to build a framework for action under the Convention. In the fifth meeting of the COP, held in Nairobi in 2000, the ecosystem approach was resumed in twelve principles[52] (Table 5). These principles provide a useful source of inspiration for enhancing ecological network concepts. Furthermore, these principles can address any approach to integrate ecological network concepts, in particular, the implementation of ecological corridors, in new plans.

The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. The application of this approach can help to reach a balance of conservation, sustainable use, and the fair and equitable sharing of benefits arising out of the utilization of genetic resources. The rationale of this approach is to understand that ecosystems should be managed for their intrinsic values and for tangible or intangible benefits for humans. Ecosystem functioning and resilience depend on a system of dynamic relationship within species, among species and between species and their biotic environment, as well as the physical and chemical interactions within the environment. Humans, with their cultural diversity, are an integral component of the ecosystems. The ecosystem approach requires adaptive management to address the complex and dynamic nature of ecosystems

52 Further specifications can be found at https://www.cbd.int/doc/publications/ea-text-en.pdf (accessed 31 January 2019).

and the lack of knowledge or understanding of their functioning. The implementation of the ecosystem approach does not consist in a single best way since it can depend on local, provincial, national, regional or global conditions. In the ecosystem approach, other past knowledge should be conceived to integrate complex situations (Secretariat of the Convention on Biological Diversity, 2004b).

Table 5 – The twelve complementary principles of the ecosystem approach.

Principle	**Description**
1	The objectives of management of land, water and living resources are a matter of societal choice.
2	Management should be decentralized to the lowest appropriate level.
3	Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.
4	Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management programme should: (a) Reduce those market distortions that adversely affect biological diversity; (b) Align incentives to promote biodiversity conservation and sustainable use; (c) Internalize costs and benefits in the given ecosystem to the extent feasible.
5	Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.
6	Ecosystems must be managed within the limits of their functioning.
7	The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.
8	Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term.
9	Management must recognize that change is inevitable.
10	The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.
11	The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices.
12	The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

This implies that human activities influence issues related to ecological networks, and, in turn, they are influenced. For this purpose, an ecosystem approach can help to draft a new plan concerning the management of ecological corridors which takes into account the appropriate level in planning dimensions, impacts coming from the implementation of human activities and a framework to address negative impacts towards the enhancement of positive effects.

The Strategic Environmental Assessment

In the Extraordinary meeting of the Parties to the Espoo Convention, held in Kyiv on May 2003, during the Ministerial "Environment for Europe" Conference, the Protocol on the SEA was adopted. The protocol ensures that the individual parts integrate the environmental assessment into their plans and programs at the earliest stage, thus helping to lay the foundations for sustainable development.

The Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment (SEA Directive) transposes the Protocol in the EU legislation, since the CBD requires Parties to integrate as far as possible and as appropriate the conservation and sustainable use of biological diversity into relevant sectoral or cross-sectoral plans and programmes.

The main objective of the SEA Directive is «to provide for a high level of protection of the environment and to contribute to the integration of environmental considerations into the preparation and adoption of plans and programmes with a view to promoting sustainable development, by ensuring that an environmental assessment is carried out of certain plans and programmes which are likely to have significant effects on the environment» (Article 1, SEA Directive).

In accordance with Article 3, paragraph 2, the SEA is a compulsory process for plans (or programmes) which influence agriculture, forestry, fisheries, energy, industry, transport, waste management, water management, telecommunications, tourism, town and country planning or land use and which set the framework for future development consent of projects listed in the Environmental Impact Assessment Directive[53]; or, an assessment is required under the Habitats Directive.

The SEA procedure consists of steps, as follows: an environmental report is prepared (the likely significant effects on the environment and alternatives of the proposed plan or programme are identified); Public and Environmental Authorities are informed and consulted on the draft plan or programme; the environmental report is finally prepared. In case plans and programmes are likely to have significant effects on the environment in another Member State, the Member State in whose territory the plan or programme is being prepared must consult the other Member State(s)[54].

Thus, the SEA is a focal process to integrate environmental considerations into the preparation and adoption of certain plans and programmes which are likely to have significant effects on the environment.

This assessment involves a systematic identification and evaluation of environmental impacts by considering even social, environmental and economic effects of plans or programmes.

The SEA can address the preparation of the contents of the new plan proposed in the next paragraphs, at its earliest stage, by ensuring its sustainable implementation. The process, that follows the plan during its preparation, guides the plan towards environmental sustainability objectives, by analysing the survey area subdivided into characteristic environmental aspects.

53 See Annexes I and II to Directive 85/337/EEC that is more specific for impacts of projects.

54 In this case, the SEA Directive pursues the approach of the SEA Protocol.

In this way, all interferences, that can occur between the human dimension and the environmental dimension, can be analysed and taken into account both in the plan and in the environmental report.

In the environmental report, connectivity analysis (as shown in the case studies) should have an important position (i.e. an appropriate analytical sheet concerning flora, fauna and biodiversity).

Furthermore, the ecosystem services provided by the ecological network should be highlighted through appropriate methodologies, so that the SEA can be a guide for the management of any elements of green infrastructure – and its delivered ecosystem services – that can be delineated in the study area.

The proposal for a new planning instrument: The Ecological Connectivity Management Plan

The integration of ecological networks in the dimension of spatial planning, in particular, the integration of connective elements of landscape and their management, requires a new kind of plan.

A new structure of plan to implement and manage ecological corridors are proposed and shown in Table 6 (from 1 to 3), by taking into account suggestions coming from the reference practice of UNI (2014), by implementing principles of the ecosystem approach, by having the continuous support of the SEA during the preparation of the plan. In this plan, all activities and results of case studies previously discussed can be used to implement the ecological corridors framework.

In the integration of ecological networks in the dimension of spatial planning, each planning level can have a different role, according to the level of definition of the ecological network, as shown in Table 7. Further, the Guidelines, that are suggested to attach in the proposed plan, can show methodologies to design the ecological corridors, as discussed in the case studies (i.e. the flow-chart in Figure 26).

At the regional level, a global ecological network structure can be defined, including any node of the protected area which has strategic functions (parks, the Natura 2000 sites, etc.) and a primary scheme of connective elements. The main role of the regional level planning is to define guidelines for the protection and enhancement of natural and environmental resources to be implemented in lower levels.

At the intermediate level, aspects related to the ecological network scheme can be deepened, even to define substructures. This planning level (e.g. large, provincial or metropolitan area), in the middle between regional and local, incorporates guidelines of regional spatial planning instruments, by coordinating tools of the municipal planning level in prescriptive terms by addressing planning standards aimed at improving the environment.

At the municipal level, various micro-scale elements of an ecological network can be taken into account in relation to transformations, from regional to urban, and assessed from the point of view of the sustainability of the effects on the environmental system. Planning rules are translated into urban planning norms whose purpose is to provide a plan for improving spatial endowments in terms of urban and (eco-)environmental quality standards. In municipal plans, the morphology of anthropized spaces, new or existing, can be declined by natural elements of the ecological network.

The schematic structure of planning levels, proposed above, reminds to the concept of scale «Think global, act local [think globally, act locally] [55]», according to the philosophy proposed by McHarg (1969, 2007), which means that ecological considerations can be integrated into different planning levels.

55 Sentence of clear meaning, but of doubtful paternity. It is often attributed to Patrick Geddes (1915), *Cities in Evolution*, London, Williams.

Table 6 – (Part 1/3) – The structure of the Ecological Connectivity Management Plans proposed in this thesis.

Level	Title	Contents
1	**The definition of the ecological network**	The ecological network is an interconnected system of protected areas which aims to safeguard biodiversity through the creation or strengthening of a system of connections between areas and isolated natural elements, to avoid the landscape fragmentation and its negative effects on biodiversity. The simplest structure of an ecological network must include at least: - Core areas, where the conservation of biodiversity assumes primary objectives. - Corridors, where connections have to be ensured by maintaining physical linkages between core areas. They can be: linear corridors (such as a hedgerow, forest strip or river); or, stepping stones, that is, an array of small patches of habitat that individuals use during movement for shelter, feeding and resting; or, other various shapes of interlinked landscape matrices that allow individuals to survive during movement between habitat patches.
1.1	*The level scale of the ecological network*	The reference scale of the ecological network depends on the level of planning it is aimed at. The plan can be integrated and updated, at each level of scale, taking into account that the plan is based on the following criteria: - identification of the elements constituting the ecological network on the basis of an ecosystem approach and of the natural characteristic of the territory; - analysis of the context of the elements of the ecological network (in terms of possible pressures or threats); - analysis of the links between the areas identifying the connections to be restored and/or to be created; - periodic updating of the evolutionary trends of the ecological network; - analysis of possible interferences of the ecological network with spatial planning forecasts (compared to the reference scale).
1.2	*Purposes and objectives*	In this plan, the ecological network is the main tools for achieving the containment of soil consumption, as a multifunctional network, able to integrate environmental, landscape-related and tourism-recreational criteria. The ecological network aims to maintain and increase biodiversity: - by protecting the biodiversity through the creation of new naturalised areas to enrich the natural and economic capital; - by safeguarding, enhancing and increasing the residual natural or semi-natural areas, in favour of a greater permeability of the territory to improve ecological connections between main core areas; - by supporting the presence of natural or semi-natural spaces, already existing or coming from new creation, useful for native species and equipped with particular ecological functionality; - by strengthening the function as an ecological corridor that waterways can have, recognizing that waterbodies and their river play a triple role: hydraulic defence, naturalistic quality and quality landscaping; - by promoting ecological and landscape restorations into the ecological network through the provision of suitable mitigations and compensatory measures; - by promoting the enhancement of ecological networks also through the experimentation of measures of regulatory intervention and incentives, coordinating objectives coming from planning visions of different institutional levels or sector; - by coordinating urban designs and infrastructures, since harmonize the spatial distribution and the morphological quality of settlements to builds functional elements of the ecological network.

Table 6 – (Part 2/3) – The structure of the Ecological Connectivity Management Plans proposed in this thesis.

Level	Title	Contents
2	**General rules**	Spatial planning and policies can contribute to the implementation of the ecological network take into account the set of objectives above mentioned and, as far as their competence, to pursuing them. All public administrations, during the update of their planning instruments, will have to conceive the spatial structure of the ecological network, defining the measures of the interference of their plan predictions with the functions and objectives of the ecological network. In the case, public administrations can improve the state of the ecological network by identifying further functional areas, in particular of ecological connection.
2.1	*Environmental compensation*	If negative effects on the ecological network are identified in a plan, any environmental compensation measures must also be defined in order to increase the environmental and landscape compatibility of the interventions.
2.2	*Urban equalization*	The good management of the elements of the ecological network can also be achieved through the instrument of urban equalization, safeguarding areas of particular value for its naturalistic characteristics.
3	**Specific rules for the elements of the ecological network**	Sustainable uses of areas have to be regulated in order to exploit opportunities within the landscape mosaic for safeguarding natural resources with the maintenance of most ecosystem services into ecological corridors.
3.1	*Core areas*	In core areas, the quality of the habitats, as well as preserved, must be improved and, where possible, increased. The public administrations undertake to identify possible interference deriving from the planning and to define measures to compensate for any negative effects.
3.2	*Ecological corridors*	The ecological corridors can have a shape with a prevalent linear dimension or can be constituted by small patches, like stepping stones. In areas identified as ecological corridors, new settlements should be kept to a minimum, due to their high interference with ecological continuity. If the design is strictly necessary, it should be preceded by an assessment of alternative locations so that do not interfere with corridor functions. If alternative locations are technically not feasible, and the structure is of modest impact, shielding measures must be provided and to ensure ecosystem continuity (e.g. overpasses or underpasses, expansion to other natural areas to recover lost corridor areas). In the ecological corridors, the elimination of arboreal or shrub formations, such as rows, hedges with prevalent linear development, riparian strips, groves, and large isolated trees must be limited to functional requirements. Any undeferrable activity must be adequately compensated with new naturalistic interventions of equivalent value within the same ecological corridor.
4	**Interference with buildings and infrastructures**	Specific criteria to improve relationships between infrastructure, built environment and natural environment must be defined. Interference between infrastructures and elements of the ecological network must be identified in order to restore ecological connections. In particular, to avoid further breakdowns within the ecological network, the following activities should be provided: - prevention measures in order to contain resulting impacts; - measures to mitigate any negative impacts; - environmental compensation measures for impacts that can not be mitigated; - control measures on *post-operam* effects.

Table 6 – (Part 3/3) – The structure of the Ecological Connectivity Management Plans proposed in this thesis.

Level	Title	Contents
5	**Interference with other sectors**	In order to deepen the knowledge within the ecological network, several sectors should be included, exploring possibilities of synergy with the other sectors, in order to involve different stakeholders, for the promotion of economic activities and land use compatible with the maintenance of ecological connectivity.
5.1	*Transport*	Roads, railways and waterways facilitate human movements, but this increased mobility has caused growing pressure on the landscape, which, in turn, generates fragmentation and negative effects on species and habitats. Best practices related to methodologies, indicators, technical design and procedures to avoid, mitigate and compensate for negative effects on nature should be collected in a handbook for practitioners.
5.2	*Agriculture and zootechnical activities*	Agriculture and zootechny can influence species and habitats. The practices used in an agricultural system influence the type and quality of ecosystem services that are provided. Food and wood are typical products of an agricultural system and have a significant influence on the natural environment. These activities can influence the storage or loss of carbon; the quality of the water to support the aquatic life, or to be drunk, etc. In areas within ecological corridors, agri-environmental schemes for sustainable agricultural activities should be implemented in this plan, involving stakeholders to promote: - the protection of wildlife, species in general and their numerous habitats; - land management for preserving traditional features; - protection of historical characteristics and natural resources; - conservation of historical activities linked to traditional farming and agriculture; - the possibility of knowing the countryside in its sustainable uses.
5.3	*Climate changes*	Climate changes can affect the quantity and the quality of habitats, biodiversity and the number of species if wildlife cannot have possibilities to respond to pressures. In order to help the natural environment adapting to climate change, schemes to reduce greenhouse gas emissions, flood management, etc., must be provided.
6	**Protection of water bodies and wetlands**	Particular attention must be paid to take care of water bodies and wetlands inside the ecological corridors. Next to waterbodies spontaneous vegetations must be maintained, where present. Any pollution must be identified and studied to determine their origin.
7	**Participation**	Participatory processes are ways that, in sustainable governance, can be defined as socio-ecological innovation. If implemented by involving local communities that benefit from the ecological corridor spaces, it is possible to implement landscape transformations that reflect, not only the interests of people but also maximize the objectives that guide an ecological corridor. The active participation of stakeholders in the space management phase, in the form of various types of associations, can contribute to the functioning of the area of the ecological corridor. For this purpose, the training of administrators and technicians responsible for planning and designing assumes a fundamental role to transmit and share the meanings of ecological functions and ecosystem services and the advantage in terms of environmental, economic, but also well-being deriving from the adoption of sustainable practices and methodologies.
8	**Annexes**	The most useful tool to understand and help the decision-making processes is the cartography. Various cartographic elements, tables and related studies have to be attached to this plan. Contents of the environmental report of SEA process can be attached.
9	**Guidelines to design the ecological network**	[Concepts and methodologies as discussed in this thesis can be useful to draft a handbook]

Table 7 – The scheme of the integration and the definition of ecological network concepts in spatial planning.

Level	Governance tool	The function of the ecological network	Purposes	Recommendations
- Region	- Regional landscape plans	The main structure of ecological networks for any sub-level	The planning tool provides a regional ecological network scheme given by an interconnected system of territorial units for the preservation and maintenance of biodiversity.	The specificities and ecological purposes, that must be implemented by the lower-level instruments, must be highlighted and translated into urban planning in the form of a long-term strategy
- Provinces. - Metropolitan cities. - Wide areas.	- Coordination plans. - Inter-municipal plans.	Definition of local areas and safeguard addresses	The planning tool incorporates the structure of the regional ecological network and specifically defines the addresses for municipal-level planning tools.	Scientific knowledge concerning the components of the ecological network, in particular of ecological corridors, need to be studied in depth.
- Municipalities. - Associations of municipalities.	- Regulatory plans. - Urban plans.	Specific localization of areas up to the involvement of the private properties	The planning tool provides the addresses and specifically defines the measures to be taken locally for the protection of biodiversity	Environmental protection standards must be defined through specific surveys, possibly binding territorial transformation measures, since at this level improvements in the quality of life can be realized in terms of ecological and environmental endowments from which to benefit from the so-called ecosystem services.

The role of spatial planner

In accordance with "The Charter of European Planning" (ECTP-CEU, 2013), the role of planners is more challenging now than at any time in the past. Indeed, it requires greater planning, synthesis, managerial and administrative skills, in order to support and guide planning processes that concern multidisciplinary approaches during all their phases. Furthermore, the role of the planner requires: to build scientific approaches; to achieve social dialogues and agreements, to recognise individual differences, as well as the political nature of decisions; and, to lead the implementation, management and monitoring, and *in itinere* revision of plans and programs.

Spatial planners support key policies, programs and projects, by analysing, processing, implementing and monitoring development strategies. Planners are engaged in various stages and scales of planning processes.

Spatial planning does not require only plans preparation. It implies great effort to balance all stakeholders (public or private) to solve conflicts in the demands of spaces and development programmes.

In a type of plans as proposed above, a planner with greater mediation and negotiation skills is warmly expected since the involvement of a wide range of stakeholders coming from different sectors and different visions.

In fact, there are some disparities in the perception of ecological networks between practice and research that are reflected in different approaches of planners and ecologists (Table 8). Both figures work on the same field but they have a background that focuses on different characteristics and leads them to interpret ecological networks in different ways. Planners (and landscape designers) are more focused on structural features and interpret an ecological network as a project to be implemented. On the contrary, ecologists focus on functional aspects of particular species and processes and interpret an ecological network as a way of thinking to inform decision-making (Battisti, 2013).

Table 8 – Planners and Ecologists: their approaches. Adapted from Battisti (2013).

	Planners	**Ecologists**
Main goal:	Design of an ecologically based plan with areas characterized by specific rules and planning measures	Conservation of biodiversity targets affected by fragmentation
Emphasis on:	Synthesis aimed to design a deterministic map of ecological network units; short-term analyses; ecosystems as “closed” systems	Complexity, dynamism, determinism/stochasticity of the ecological systems; long-term analyses; ecosystems as “open” systems
An ecological network mainly is:	A design	A paradigm
Ecological network units correspond to:	“Closed” units on the map with a specific regime of conservation/planning/law	Ecological and functional units referred to specific targets (e.g. species)
Approach:	Prevalently pattern oriented (emphasis on habitat types more perceivable: e.g. forests and rivers)	Target oriented (e.g. species oriented at determinate scales), pattern and process oriented

The spatial planner assumes the important role of mediator. Now and in the future, mediation and negotiation skills of planners will become increasingly important.

The role of participation

Long-term conservation strategies are effective when decision-making processes involve knowledge and opinions of local communities. If they are involved, they will be more likely to comply and commit themselves to policies (as cited in Andrade *et al.*, 2012: Mascia, 2003; Fu *et al.*, 2004; Pretty and Smith, 2004; Gelcich *et al.*, 2005).

Approaches based on the marginalisation of the local community in decision-making might fail. Andrade *et al.* (2012) categorise the level of local community compliance with protected areas policies, by developing qualitative criteria, as:

"high", "moderate," and "low". High levels could realise that locals accept policies, illegal activities rarely occur, and/or locals are satisfied with the management. Moderate levels could realise that most locals respect policies, there could be illegal activities, and/or locals are not completely satisfied with the management. Low levels could determine that policies are not respected, illegal activities are commonly made, and/or locals are dissatisfied with the management. Furthermore, they define the participation of the local community into protected areas management, as: "included", "partially included" or "excluded". Included participation has high results in the management and, also, in decision making. Partially participation should generate complaints in the local communities. Excluded participation is the worst condition because the management is addressed taking into account neither problems of local communities, nor their needs.

Thus, to ensure the long-term success of policies on a planning structure, which aim to implement also the management of connective elements in an ecological network, high levels of agreement and included participation are required to support policies starting from the bottom, by the local communities. Since to avoid disagreed top-down approaches, all community should be involved in such purposes.

A useful way to involve people, should be similar to the involvement proposed by the Dutch government[56]: landowners could get a grant for conservation or landscape management; if they are a landowner of patches involved by the nature or biodiversity issues, they can apply for a grant to help to maintain protected species of plants and animals on their property. These grants can be assigned for farmers and for private owners of woodland or other natural areas through agri-environment and landscape management schemes. The purpose of these schemes is to design a management plan proposed by landowners. In fact,

56 For instance, see: https://www.government.nl/topics/nature-and-biodiversity/question-and-answer/can-i-get-a-grant-for-conservation-or-landscape-management (accessed 31 January 2019).

farmers who want to maintain natural and landscape values on their property could associate together with other farmers in the area, and they must draw up the management plan. If the plan is approved, a grant is awarded to the group. The Netherlands Enterprise Agency (RVO.nl) manages the various grant schemes for conservation and landscape management.

A similar way of the grant could be implemented in each spatial government to share the environmental concept with landowners those properties are involved in a defined area, which is important for the connectivity of the ecological network. In particular, these grants can be the base to actively involve landowners in the proposal of the new plan, in case their lands are within connective landscape elements.

Section 6 – Conclusions

Ecological networks protect habitats and species, endangered from the effects of increasing urbanisation. Over the decades, policies have shifted toward the creation of ecological networks with a focus on the preservation of biodiversity.

In the European Union, the Natura 2000 Network is the main goal of the Habitats Directive, which aims to promote the integration of biodiversity conservation within planning policies by establishing a wide ecological network throughout the Member States.

The Natura 2000 Network needs to be not conceived as a system of strictly isolated nature reserves where human activities must be excluded. Since Natura 2000 involves in its protected areas privately owned lands, any approach related to these areas would be much more effective if focused on people motivated to work for nature rather than against it. Protected areas should be managed in a sustainable way, both from an ecological and economic point of view.

These concepts should even be extended to the connective elements, although they are not identified yet. In this way, the ecological network can reach its coherence (as promoted by Articles 3 and 10 of the Habitats Directive) in terms of connectivity issues.

Further, the CBD provides the main framework to enhance issues on biodiversity, although it does not explicitly mention ecological coherence in the concept of ecological networks, it states that the development of tools to implement the ecological connectivity is a focal theme to establish and manage complete ecological networks with their ecological corridors. Indeed, the CBD Programme of Work on Protected Areas (Secretariat of the Convention on Biological Diversity, 2004a), specifically emphasises the ecological connectivity, since one of the targets of this Programme of Work was to ensure the integration of protected areas and protected area systems into the wider land- and seascape, by 2015, even by applying an ecosystem approach and taking into account ecological connectivity and the concept of ecological networks.

The CBD defines an ecosystem as «a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit» and suggests ecosystem-based approaches to integrate the management of land, water and living resources, to promote conservation and sustainable uses. Scientific methodologies involve processes, functions and interactions between organisms and their environment. Humans are components of ecosystems and they gain benefits from them, in terms of available ecosystem services. The term "ecosystem" does not necessarily have to correspond to terms "biome" or "ecological zone" or other definitions. The term can refer to any functional unit operating at any scale. The scale of analysis and actions should be determined according to the problem to be addressed.

Ecological corridors, as spatial elements of ecosystems, support the connectivity of habitats and their protection, and, by doing so, even the delivery of ecosystem services. Ecological networks concepts allow developing ecological-based approaches that should be integrated into landscape planning and management. The typical design of an ecological network is referred on concepts such as "patches", "matrices" and "corridors", which represent the main spatial disaggregation of landscape structure elements (Forman, 1986).

Spatial planning and environmental assessments are essential instruments for addressing issues related to the integration of ecological networks issues in decision-making processes.

The main aim of this thesis is to propose an expeditious methodological approach to understand by what means ecological corridors could be defined and evaluated, so that they could be integrated into planning issue at different scales, starting from available data in the literature.

Since all spatial elements cannot be classified as ecological corridors, their spatial identification should satisfy two issues: protection of biodiversity functions and their long-term maintenance, as explained by Snäll *et al.* (2016).

The purpose of the proposed approaches is the prioritization of spatial elements, as ecological corridors, which can provide highly biologically valuable areas where species movement should be improved through an implementation of a framework of planning and management regulation.

The landscape connectivity depends on not only the species behaviour (functional connectivity) but also on their spatial distribution (structural connectivity).

The main assumption is that the landscape could be a multispecies habitat, supporting: firstly, the structural connectivity; secondly, functions of prioritized areas as connective elements.

In this thesis, potential ecological corridors for enhancing connectivity are supposed to be managed into a new kind of plan. Even though methodologies are perfectible, it represents a quite flexible way to bring together available data, expert knowledge and technical support to obtain straightforward information to start planning processes in ecological terms; it could be a strategic way, since it can suggest where planning strategies to preserve the landscape biological integrity should be implemented in favour of an improved connectivity.

Least cost methods are suggested to study a “best” solution, even when the best could be not very good. Anyway, these tools can describe linkages design for many species and they can be used to compare linkages design to alternative designs in order to satisfy cost or political constraints.

Better results of connectivity analyses mainly depend on more accurate data (distribution of species, estimates of dispersion distances and mapping of the landscape resistance to movement). Despite the accuracy of the input data, which could require a higher computational cost, there will always be uncertainty about results which, however, should be interpreted and treated as a basic hypothesis on which to work for further evaluations.

Several aspects of connectivity issues should have more weight to improve the effectiveness of the design and implementation. Researches on species persistence, behavioural ecology and community structure can reduce uncertainties coming from connectivity models. The evaluation and test of connectivity results are important steps to achieve conservation objectives under climate change issues that communities and ecosystems can have to face. However, all these topics will have a lower priority if human activities are not integrated into connectivity planning. Substantial lack of certainty in the mapping of connectivity and in the assessment of resilience to climate change are certainly existing and improvable issues, but it is equally clear that the integration of issues related to the planning of conservation of the human and natural landscape to improve the connectivity of habitats is essential for the conservation of biodiversity (Rudnick *et al.*, 2012).

Professionals can elaborate network-level and patch-level connectivity measures and maps to help communicate the meaning and implications of connectivity to other stakeholders in planning processes and better assess the importance of particular habitats in detailed plans (Bergsten, 2013).

Connectivity modelling approaches, with appropriate simplifications, enable researchers to make efficient use of existing information to assess connectivity and identify or prioritize areas to be managed and protected and then implement proper plans, such as suggested in this thesis, to integrate them into planning processes.

In a perspective of environmental continuousness, in order to increase the connectivity between natural areas, connective elements can also constitute a criticality, since by them even invasive alien species can go through. Instead, the identification of ecological corridors and their management represents, on the other hand, a strategic strength. In fact, the problem of invasive alien species exists regardless of ecological corridors. The identification and management allow overcoming various negative effects of the widespread artificialization of the territory, among which the diffusion of alien species, in planned and monitored areas as ecological corridors.

In particular, important findings of this thesis, that have implications for planning, are: the proposed approaches show that ecological corridors could be designed by doing little simplifications to design a multispecies corridor; the "Ecological Connectivity Management Plan" represents a proposal aiming at managing the spatially defined set of ecological corridors, by taking into account, in planning processes and supporting landscape connectivity, issues between protected areas. Even an assessment based on the delivery of ecosystem services provided by ecological corridors can be included in this plan; in spatial planning, it could be useful to understand ecological concepts in the wide spatial reference of ecological corridors, since the inclusion of a wider set of factors in decision-making should contribute to reaching more sustainable and effective results. Bastian (2013) (citing Costanza *et al.*, 2007; and Rey Benayas *et al.*, 2009) estimates that the 1% of change in biodiversity matches the 0.5% of change in the value of ecosystem services; and, an analysis of ecosystem restoration projects indicates that restoration produces the 44% of increased biodiversity and the 25% of increased provision of ecosystem services.

This important aspect can be studied into an environmental assessment procedure. The adoption of SEA procedures in spatial planning, to integrate ecological corridors concepts, during the drafting of the proposed plan, provides a reliable framework where the inclusion of environmental issues into decision-making contribute to building more sustainable and effective results.

In the SEA, the themes of the protection and enhancement of the environment influence all levels and related planning tools; a hierarchical system of objectives, aimed at integrating environmental issues into planning, lead the planning process towards goals of sustainable development. If policies continue to be addressed only within protected areas, that is to say normatively established, without considering boundary conditions of connective elements, the sustainable development of an ecological network could in long-term become vain.

In spatial planning approaches, at regional scale, similar issues to design the connectivity between the Natura 2000 sites could be useful to draft a conceptual plan for ecological planning by understanding the priority location of ecological corridors to achieve landscape connectivity, and then improve, by conservation measures, a better functionality, to be ruled at lower planning level.

Public administrations, during the preparation of own plans, should be aware of the presence of ecological issues in their administrative boundaries. They should improve their policies for sustainable planning processes, perhaps by studying these ecological issues in the SEA. These issues can address any local public administration to promote a regulatory framework of land use policies that provide sustainable environments for human beings, but by taking into consideration best practices in strategically planned ecological corridors.

Since land uses, ecosystem components and, also, biodiversity, in general, are identified by sets of laws and regulations, from international to local scale, in order to reach the objectives of an ecological network, when ecological networks have to be established, this process involves a legal and regulatory framework: instruments concerning nature conservation (e.g. protected areas, Natura 2000);

instruments concerning land use planning and the management of rural development and water resources. In particular, other constraints have to be taken into account, thinking about local planning in ecological networks (e.g. property rights, land use spatial planning). It means that to implement or modify this framework, communication and stakeholder engagement are required, in order to increase recognition and appreciation among the main stakeholders and reach the public consensus.

Different perceptions of nature, thus of ecological networks, exist. It depends on the actor interested by facts concerning this social perception of nature. On one side, there is the scientific world, which is itself divided into different visions of different scientific disciplines (e.g. naturalists, planners); on the other side, three levels of perception could be considered: authorities; associations (nature, agricultural, recreational, etc.); and local people. Each opinion should be taken into account to understand opportunities and threads of nature conservation programmes and ecological networks at the social scale.

In fact, it should be noted that areas designated for network connectivity are often private areas that are used by the owners for different purposes. It is, therefore, necessary that the participation of citizens is always present and that, for this purpose, the European Union promotes actions aimed at a direct involvement.

Furthermore, since the most part of ecological corridors can be dedicated to agriculture and forestry and farmers (Bakker *et al.*, 2015) and landowners are direct actors in managing agricultural land use, some recommendations should be formulated:

- agriculture and forestry (or related human activities in general) should become environmental friendly otherwise connective elements could not work in a proper way;

- the application of a regulatory environmental framework should be compulsory in most of the agricultural territory, in particular in areas identified as connective elements of the Natura 2000 sites;
- the integration of ecological connectivity concept should be compulsory in agrarian policies and in practical implementation on the countryside;
- any policy or action should be implemented in a bottom-up approach in order to be more effective;
- the landscape permeability should be conceived as an environmental benefit to be achieved in rural landscapes (without permeability, protected areas are still isolated and, progressively, they lose biodiversity and environmental quality);
- farmers should adopt softening farming practices, to well manage farmland landscapes, avoiding chemical fertilizers and pesticides and preferring organic farming and biological methods in order to not compromise the service of connectivity, perhaps they could have reductions in economic outcomes;
- producers involved in high-value farmland should be encouraged to have green- or eco-labels to certify that their products are of certified origin and have a low environmental impact;
- consumers and markets should be sensitized towards the procurement of products of certified origin, for example by verifying the existence of green- or eco-labels.

In conclusion, the completion of a network of only nodal elements, through the identification of the connective elements, could assume the function of a requalification process, but a schematic mapping methodology may not be sufficient. In fact, in the analysis of connectivity and ecological integrity of the territory, issues on the various aspects of environmental protection should be investigated, favouring the definition of guidelines for sustainable development within spatial plans.

An *ad hoc* plan, that manages the ecological corridors, would be able to coordinate, at different levels, spatial planning in those areas designed to have connective functions, involving actively local populations. Only in this way, the anthropic and the environmental dimensions can be enhanced together.

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