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Implementation of multispecies ecological networks at the regional scale: analysis and multi-temporal assessment

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7 **Implementation of multispecies ecological networks at the** 8 **regional scale: analysis and multi-temporal assessment**

9 **Abstract**

10 Today, major landscape changes affect ecological connectivity exerting adverse effects on ecosystems. Connectivity
11 is a critical element of landscape structure and supports ecosystem functionality. Landscape connectivity can be
12 efficiently increased in landscape ecology by building ecological networks (EN) through models mimicking the
13 interaction between animal and vegetal species and their environment. ENs are important in sustainable landscape
14 planning, where they need to be studied both by applying landscape metrics and by performing multi-temporal
15 analyses. This paper presents theoretical and practical evidence of an analysis of a multispecies ecological network
16 in Calabria (Italy) and its changes over three decades. Landscape connectivity was modeled basing on 66 focal
17 faunal species' requirements. Human disturbance (HD) was defined and assessed according to distance from
18 different disturbance sources. This allowed for the definition of overall habitat quality (oHQ). Landscape permeability
19 to the animal movement was focused as the main concept to measure landscape fragmentation. Landscape graph
20 theory was applied to perform a spatial comparison of the ENs robustness. Many binary and probabilistic indices
21 and landscape morphological spatial pattern analysis (MSPA) were used in this perspective. We obtained a set of
22 ecological networks, including nodes, patches (i.e., habitat patches), linkages, and corridors, all intertwined in one
23 giant component. The multi-temporal analysis showed many indices' stationary values, while MSPA yielded an
24 increase of habitat quality and habitat patches in core areas. This methodological approach allowed for assessing
25 the regional EN's robustness in the time-span considered, thus providing a reliable tool for landscape planners and
26 communities.

27 **KEYWORDS:** Habitat patches; Landscape connectivity; landscape graphs model; multi-temporal assessment;
28 landscape fragmentation; morphological spatial pattern analysis (MSPA).

29

30

31 **1 Introduction**

32 Worldwide, land use/land cover changes are widespread and progressively changed the urban-rural landscape
33 arrangements, with a dramatic acceleration in the 20th century (Kienast et al., 2019), and significant adverse effects
34 on ecosystem functionalities (Defries et al., 2004; S. Di Fazio et al., 2011; Modica et al., 2012; Vitousek, 1997).
35 While certain land use/land cover modifications lead to landscape fragmentation (LF) - i.e., the process of
36 subdivision of large habitats into smaller and more isolated patches (Battisti, 2003; De Montis et al., 2018; European
37 Environment Agency (EEA), 2011; Fichera et al., 2015), other actions are conversely increasing landscape
38 homogeneity (Farina, 1998; Forman, 1995). These dynamics are generating complex transitional landscapes, in
39 which natural components interact with urban and rural ones in a continuous urban-rural-natural gradient (Vizzari
40 et al., 2018; Vizzari & Sigura, 2015). Among land use/land cover changes trajectories, land abandonment and soil
41 degradation represent two opposite phenomena that are progressively reducing landscape quality (Modica et al.,
42 2012; Modica et al., 2017; Statuto et al., 2018). They both descend from intense progressive urbanization and
43 population migration from rural to urban areas mainly occurred over the 20th century. A critical and common
44 phenomenon in Italy - and some other southern European regions- is the so-called 'sprinkling' contributing to land
45 take processes and LF (Romano et al., 2017; Saganeiti et al., 2018).

46 The loss of habitats, with consequent threats to biodiversity (Fahrig, 2003), is a major effect of the phenomena
47 described above. In the last century, in Italy, as in most European countries, an ever-increasing depletion of natural
48 resources and biodiversity loss, caused by unbalanced forms of land anthropization, has been paralleled by
49 progressive growth in the number and surface of natural protected areas, as a matter of compensation (Di Fazio &
50 Modica, 2018). The European Landscape Convention (CoE, 2000) has compelled the European governments to
51 change their cultural vision and policies to integrate heritage and nature conservation in spatial planning and
52 attribute primary importance to landscape (OECD, 2007). Methodological approaches to the definition of planning
53 tools, either structural/general or specific and action-oriented, have been greatly influenced by this change of
54 perspective. On the one hand, ecological approaches have gained significant consideration in view of sustainable
55 landscape planning, which can be effectively pursued by taking into account the ecological network (EN) (Opdam

56 et al., 2006). On the other hand, ENs, when set into the framework of spatial planning, need to be conceived in a
57 different, more functional and usable way. It has been observed that the use of landscape ecological-based
58 methodologies for the definition of an EN can reduce some shortcomings arising in a species centered approach.
59 Since their focus is not on individuals but habitats, landscape ecology-based methodologies typically overcome the
60 lack of information about the various animal and vegetal species' needs. This allows for spatial landscape metrics,
61 based instead on data readily available (land use, land cover), and enables a multitemporal landscape analysis to
62 detect habitat changes, in both quantity and quality (Fernandes, 2000; Botequilha Leitão & Ahern 2002).

63 In landscape planning, time is a variable as important as space. Since the landscape is a living entity (Steiner,
64 2008), it cannot be appropriately studied only by considering its present state as a static configuration. It must be
65 seen from a historical perspective to investigate its ongoing change dynamics (Di Fazio & Modica, 2018).

66 The debate about the ENs' reliability in conservation and landscape planning is still open. Several researchers
67 recently endorsed them as a useful framework for informing decision-makers in sustainable landscape planning
68 (Babí Almenar et al., 2019; De Montis et al., 2016; Ersoy et al., 2019; Foltête, 2019; Tarabon et al., 2020).
69 Nevertheless, spatial ENs implementation still deserves a finer focus. In this respect, there is a research gap in the
70 studies concerning the mapping resolution grain most suitable to assess and design the landscape connectivity (LC)
71 patterns at different scales (state, region, province) (Beier et al., 2011), the number of faunal species to be
72 considered and the temporal analysis of the related habitat requirements.

73 To deal with the design of ecological corridors, some researches (e.g., Belote et al., 2016; Brodie et al., 2015)
74 proposed the exclusive use of protected areas' boundaries, but this approach has been criticized, considering that
75 in this way potential suitable patches could be excluded in the EN design (Beier et al., 2011).

76 Several studies modeled ENs taking into consideration one (Ehlers Smith et al., 2019; Hofman et al., 2018; S. Liu
77 et al., 2018) or few focal species (Babí Almenar et al., 2019; Ersoy et al., 2019; C. Liu et al., 2018; Préau et al.,
78 2020). The recent work of Tarabon et al. (2020) implemented the design of landscape connectivity modeling the
79 requirements of twenty faunal species in Toulouse's conurbation (France).

80 In this research, we respond to the following questions, i.e. how to: i) construct ENs based on the habitat
81 requirements (i.e., autecological needs) of numerous faunal species at the regional scale; ii) account for the
82 dynamics occurring on a landscape and, therefore, on the EN design, in the framework of a sustainable landscape
83 planning; iii) assess the robustness of an EN.

84 Our main contribution is to provide a methodological framework for integrating multiple data-sources into a
85 consistent EN. Its novelty relies on the combination of: i) multispecies LC analysis at a regional scale, ii) multi-
86 temporal assessment, and iii) robustness assessment.

87 In the region of Calabria (Italy), concerning three different years (1990, 2012, and 2018), it was defined an EN
88 based on the choice of 66 representatives (i.e., focal or umbrella) faunal species, to cover the resource requirements
89 of most wildlife species in the region. Moreover, we focused on the change of LC over time, developing a multi-
90 temporal assessment that accounts for landscape evolution trends. In this respect, our primary objectives are to
91 analyze ENs robustness and LF's role by interpreting the spatial change patterns of physical constituents (i.e., the
92 different land uses) and qualitative constituents (distribution of habitats and landscape permeability).

93 Therefore, our research is the first that proposes the implementation of a multispecies EN at a regional scale based
94 on the requirements of dozens of focal species and considering a diachronic assessment over nearly thirty years.
95 Beyond the inclusion of integral natural reserves and Sites of Community Interest (SCIs) belonging to the so-called
96 Natura 2000 European network (Council of Europe, 1992), we considered those areas with high suitability to the
97 animal movement and acting as either habitat patches or corridors.

98 The paper is organized as follows. Section 2 presents a state of the art summary on landscape connectivity and
99 multi-species EN. Section 3 illustrates the study area. Section 4 shows the input data (sub-section 4.1), explains
100 step-by-step the rationale of the methodology adopted (sub-section 4.2), and describes the assessment and the
101 diachronic comparison of the ENs (sub-section 4.3). In Section 5, we present the results that are discussed and
102 interpreted in Section 6. In Section 7, we summarize the main messages of our work, presenting our conclusions
103 and opening to future research directions.

104 **2 Landscape connectivity, ecological networks and multi-species ecology** 105 **studies: a state of the art summary**

106 LC, the counterpart of LF, is a critical element of landscape structure and can be defined as the degree to which
107 each component facilitates or impedes faunal species' movements among existing habitats or resource patches
108 (Taylor et al., 1993). The role of LC for maintaining the landscape and ecosystem functioning is widely recognized
109 (Chetkiewicz et al., 2006; Fahrig, 2003; Gaston et al., 2008). LC is species-specific, as different species have
110 different habitat requirements and depend on scale and time (Kool et al., 2013; Rudnick et al., 2012). Moreover,
111 connectivity analysis depends on the adopted spatial scale (Urban and Keitt, 2001). A multi-scale approach allows

112 considering a network of habitat patches at a large-scale while, at a finer scale, the analysis focuses on individual
113 habitat patches (Wildemeersch et al., 2019).

114 While in the case of LC fine-grained resolution, analyses concern site-specific interventions (i.e., linkage designs),
115 coarse grained-resolution analyses (i.e., connectivity maps) constitute key-elements in decision support tools able
116 to assess and design LC pattern of nations, regions or provinces (Beier et al., 2011). Moreover, According to Beier
117 et al. (2011), this last type of LC analysis has rarely been developed in scientific literature.

118 The negative effects of habitat loss and LF on biodiversity and animal population persistence have been widely
119 investigated by scholars that highlighted the positive effects of managing LC in reducing these impacts (Heller &
120 Zavaleta, 2009). While LF hinders animal populations' ability to move and respond to external perturbations (Liu et
121 al., 2018; Sawyer et al., 2011), LC increase is associated with situations where species range expands (Keeley et
122 al., 2018). Additionally, LC improvement policies and actions are widely recommended as favorable issues for
123 climate change adaption (Heller & Zavaleta, 2009). For instance, wildlife corridors play a significant role in improving
124 species persistence and resilience to even severe climate changes (Keeley et al., 2018).

125 LC measurement methods are directed to i) assess structural connectivity through the spatial pattern of habitat
126 patches or ii) gauge functional connectivity along with different species behavioral responses to physiographic
127 conditions (Holyoak, 2008; Theobald, 2006). In this respect, many algorithms, tools and software packages are
128 nowadays available and easily accessible to researchers and practitioners, as they are based on free and open-
129 source software (Dickson et al., 2018; Foltête et al., 2012; Kool et al., 2013; McRae et al., 2013; McRae et al.,
130 2008; Saura & Torné, 2009; Theobald et al., 2006).

131 Moreover, the inclusion of LC assessment in landscape planning and conservation programmes has been widely
132 recommended (Botequilha Leitão & Ahern, 2002; De Montis et al., 2016), also in multi-actor planning processes
133 considering different alternatives (Opdam et al., 2006). The EN provides analysts and practitioners with a compelling
134 concept for modeling LC evolution in landscape ecology. An EN includes nodes, which stand for the habitat patches
135 and links for the corridors representing functional (i.e., bidirectional) connections between the patches (Fall et al.,
136 2007; Urban & Keitt, 2001). Since LC reflects the interaction between species and their environment, an EN's
137 modeling is currently an essential issue for landscape planning and management (Gurrutxaga et al., 2010; Opdam
138 & Wascher, 2004).

139 The concept of EN is increasingly accepted as an operational tool for i) improving the quality of natural ecosystems,
140 ii) protecting biodiversity and iii) maintaining and improving LC (Damschen, 2013; De Montis et al., 2016; Forman,
141 1995; Gilbert-Norton et al., 2010; Jongman, 1995; Opdam et al., 2006). Besides, a key-role of ENs and LC is
142 recognized in landscape planning and management policies and strategies (De Montis et al., 2016, 2019; Fichera
143 et al., 2015; Keeley et al., 2018; Opdam et al., 2006; Termorshuizen et al., 2007; Xu et al., 2019).

144 Several studies have recently examined EN theory and practice (Battisti, 2013; Bennet, 1998; Boitani et al., 2007;
145 Fahrig, 2013; Foltête, 2019; Gippoliti & Battisti, 2017; Opdam et al., 2006; Vimal et al., 2012). The assessment
146 through field observations of the actual functional connectivity is not an easy task. Thus, many scholars -mainly
147 involved in landscape studies at the regional scale- have proposed several methods to estimate potential functional
148 connectivity (Adriaensen et al., 2003; Boitani et al., 2015; Calabrese & Fagan, 2006; Cook, 2002; Drielsma et al.,
149 2007; McRae et al., 2008; Moilanen & Hanski, 2001; Tischendorf & Fahring, 1975; Urban & Keitt, 2001). To analyze
150 the environmental interactions of structural and functional properties of ENs, the ecological network analysis (ENA)
151 has been proposed by scholars (Fath et al., 2007).

152 The analysis and implementation of ENs are often based on graph theory, a branch of mathematics that deals with
153 connectivity. In graph theory, each graph is a mathematical structure composed of points and lines that represent
154 complex and interconnected ecosystems in landscape studies. Nevertheless, it is also a spatial graph, where each
155 node (point element) represents a habitat patch with its position in space. One node is linked to another through a
156 link (line element) that generally indicates dispersal potential and has length, direction, and orientation (Dale &
157 Fortin, 2010; Urban et al., 2009). This is a universal spatially explicit model suitable for conservation planning issues
158 (Galpern et al., 2011) and provides powerful tools to analyze network connectivity in terrestrial and marine
159 landscapes (Appolloni et al., 2018).

160 Animal movement analysis refers to the dispersal capacity and implies assessing each patch's avoidance and
161 attractive effects (Croft et al., 2008). Several authors develop single or two-species ecological corridors (Brodie et
162 al., 2015; Hofman et al., 2018; Tarabon et al., 2019). In implementing multi-species LC (Brodie et al., 2015; C. Liu
163 et al., 2018; Ersoy et al., 2019; Strimas-Mackey & Brodie, 2018, Tarabon et al., 2020), one of the most common
164 approaches is to consider focal species with a wide-range dispersal capacity, so that the resulting spatial
165 arrangement allows to support also smaller size species with low dispersal capacity (Baguette et al., 2013).

166 A crucial aspect of animal movements' analysis is the permeability of the surrounding landscape patches to the
167 species dispersal. Thus, in graph-based approaches, the Euclidean distance is replaced by the least-cost distance.

168 This allows highlighting the least resistance connection between two suitable habitat patches based on landscape
169 characteristics (Etherington, 2016; Fall et al., 2007; LaRue & Nielsen, 2008; Sawyer et al., 2011). Geographic
170 Information Systems (GIS) and GIS-based tools play a crucial role in processing spatial analyses and designing the
171 EN's components (Gurrutxaga et al., 2010; Landguth et al., 2012; Marulli & Mallarach, 2005; Theobald et al., 2006).

172 **3 Materials and Methods**

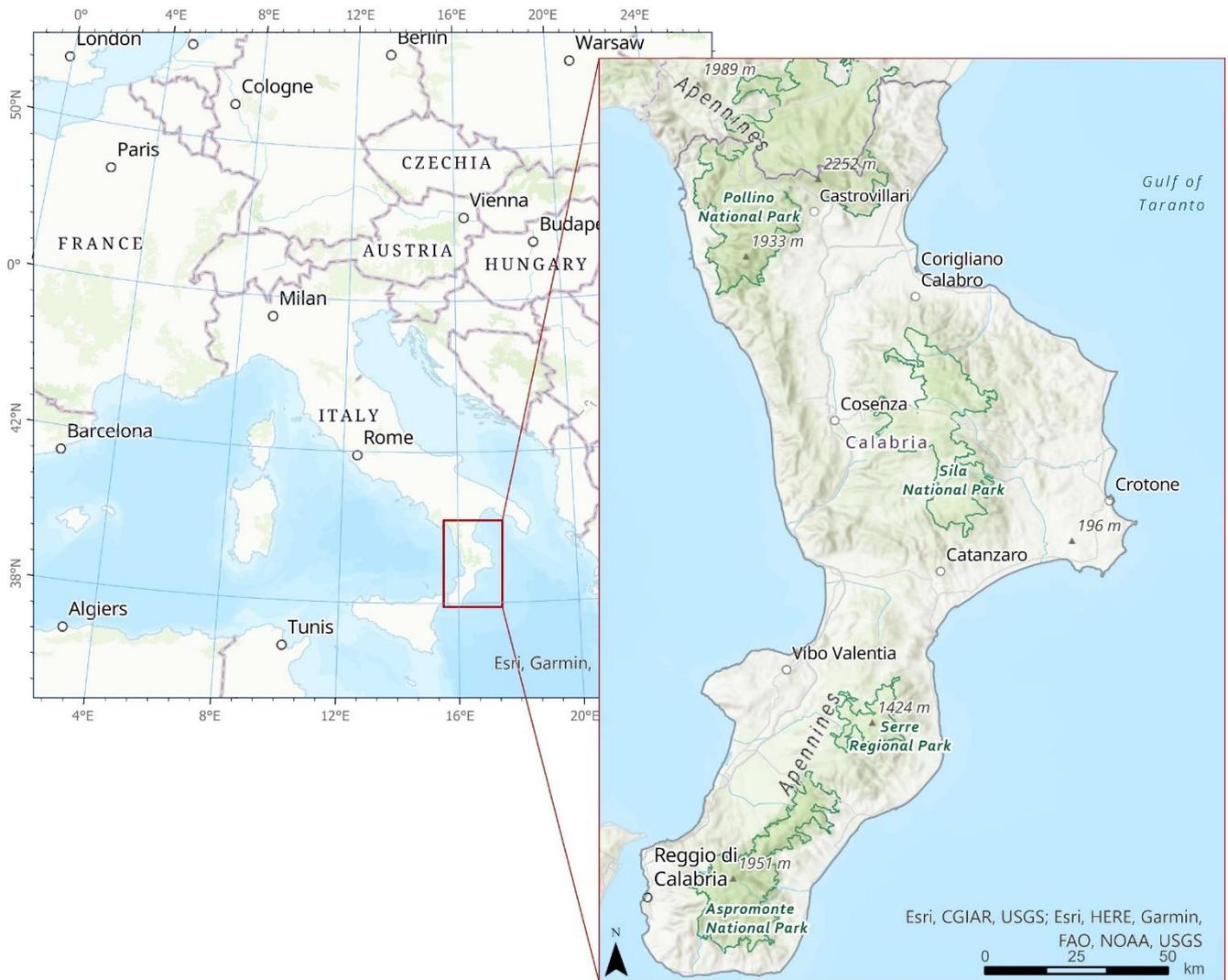
173 **3.1 Selection of a case study in Italy**

174 We applied our method to the implementation of the EN of Calabria, the most southern region of peninsular Italy.
175 This region extends for about 15,600 km², is comprised between the Ionian Sea and the Tyrrhenian Sea, and shows
176 a remarkably long coastline (738 km). The region's shape is slightly elongated, almost 250 km from North to South,
177 and a width between 31 and 111 km (Figure 1).

178 Three national and one regional park cover a considerable extension of the region (a surface area equal to about
179 360,301 ha corresponding to 24% of the regional territory) and preserve critical habitat patches for flora and fauna
180 species. From North to South, the first protected area is the Pollino National Park, which partly covers the Basilicata
181 region. Founded as Regional Park in 1986 and upgraded to a national park in 1993, it extends for a surface of about
182 192,565 ha. Secondly, we find the Sila National Park, which was first established in 1968 as National Park of Calabria
183 and restructured in 1997, and extends for a total surface of about 73,695 ha. Then, the Natural Regional Park of
184 Serre, established in 1990, extends for 17,687 ha (www.parcodelleserre.it – last access 17/05/2020), and finally,
185 the Aspromonte National Park, established in 1994, shows a total surface of 64,153 ha.

186 According to CORINE land cover (CLC) data (Table S3, supplementary material), urbanized areas occupied 2.59%
187 of the territory of the Calabria region in 1990, a value increased to 3.58% in 2012, and that remained almost the
188 same in 2018 (3.59%).

189 Because of its geographic position, Calabria has a typically Mediterranean climate at the center of the Mediterranean
190 Basin. It is influenced by the Apennines mountains (Pellicone et al., 2018) stretching from North to South in the
191 center of the region so that the Ionian side of it is mainly affected by winds from Africa and has a higher temperature
192 and lesser precipitations than the Tyrrhenian one, where western winds prevail (Caloiero et al., 2011).

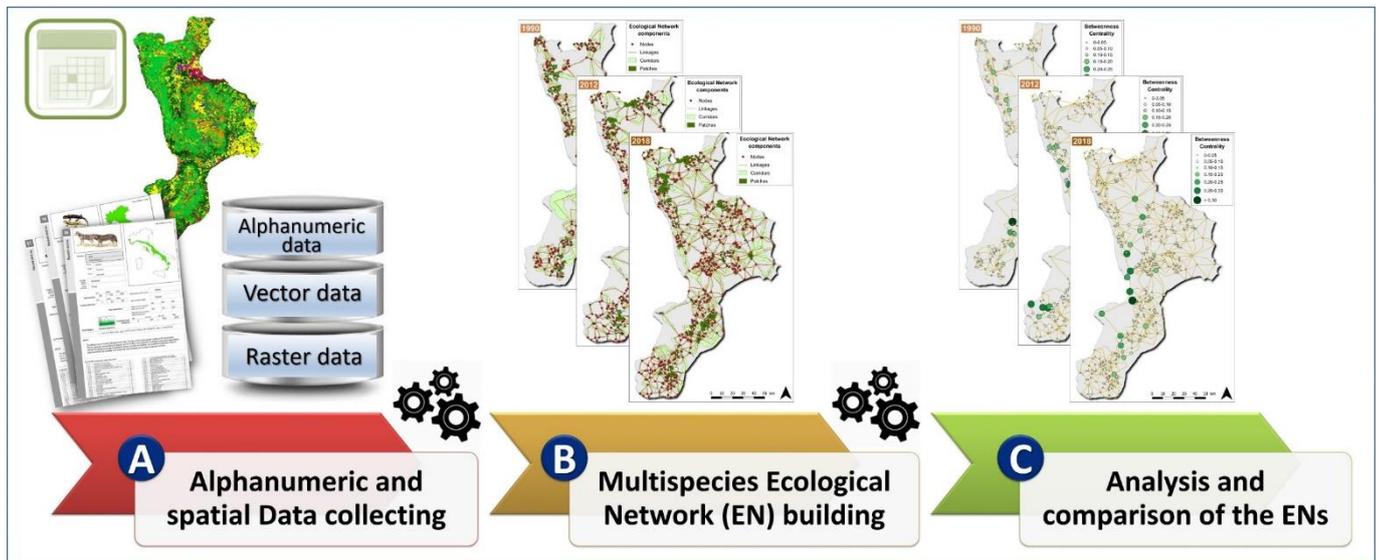


193

194 **Figure 1.** The geographical location of the study area, the Calabria region (Southern Italy).

195 **3.2 Methodology for building and assessing multispecies and multitemporal ecological**
 196 **networks (ENs)**

197 We structure the method in three major phases, as described in Figure 2. In Phase A, data are gathered and
 198 organized. Data reliability is relevant for describing the ecological characteristics (i.e. the foraging needs of the focal
 199 species) of the region of Calabria. In Phase B, spatial input data are processed in four steps to obtain ecological
 200 networks spanning through the entire region, and for years 1990, 2012, and 2018. In Phase C, these ecological
 201 networks (ENs) are analyzed to monitor their robustness in time. Each phase is detailed in the following subsections.



202

203 **Figure 2.** The workflow of the methodology including three phases: (a) collection of alphanumeric and spatial data; (b)
 204 building of the multispecies ecological networks (ENs); (c) ENs robustness analysis and comparison.

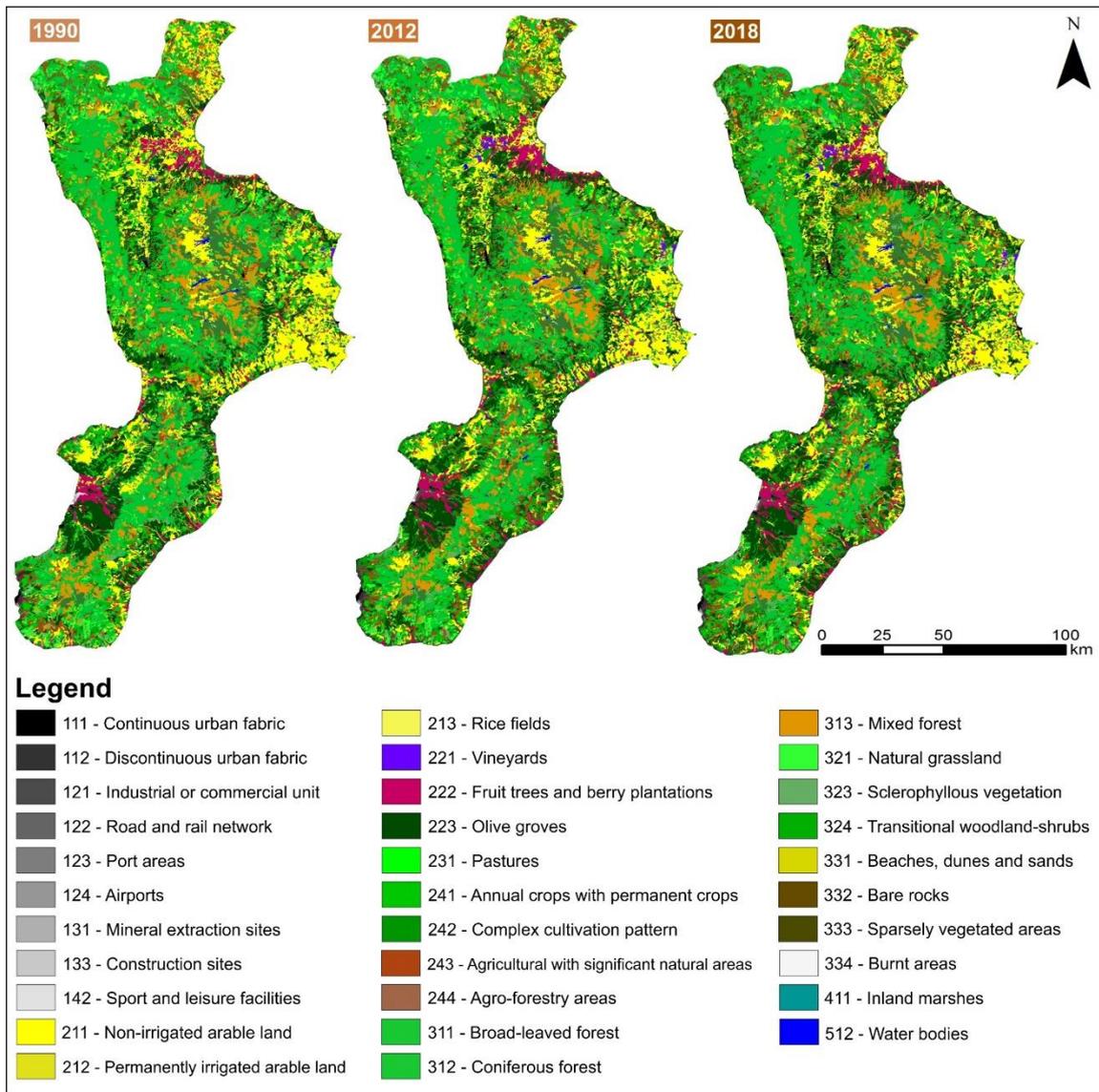
205 **3.2.1 Base data**

206 In Phase A, the spatial datasets reported in Table 1 were collected, organized, and analyzed. We used the CORINE
 207 land cover (CLC) inventory provided by the European Union with the Copernicus programme (see Table 1 and Fig.
 208 3). The minimum mapping unit is 25 ha for areal phenomena while, for linear phenomena, minimum width of 100
 209 m is established (<https://land.copernicus.eu/pan-european/corine-land-cover>, last access 15 September 2020). All
 210 spatial data were converted on a raster data model with 20 m x 20 m spatial resolution and projected in the WGS84
 211 UTM zone 33N (EPSG code 32633) coordinate reference system (CRS).

212 **Table 1.** Description of the spatial datasets adopted by reference year and data source.

Data description	Reference years	Data source
Land cover - CORINE Land Cover (CLC) at the third level of detail	1990, 2012 and 2018	Copernicus Programme of the European Union (https://land.copernicus.eu/pan-european/corine-land-cover , last access 15 September 2020)
Boundaries of the urban built-up areas to integrate the CLC data	1995	Cartographic Centre of the Calabria region (CCR)
	2012 and 2018	Urban Atlas - Copernicus Programme of the European Union (https://land.copernicus.eu/local/urban-atlas , last access 15 September 2020)
Road and railroad networks data to integrate the CLC data	1995	Cartographic Centre of the Calabria region (CCR)
	2014	Tom Tom railroad database
	2018	OpenStreetMap data (©OpenStreetMap contributors)
Digital Terrain Model (DTM) with a geometric resolution of 5 m x 5 m.	2008	Cartographic centre of the Calabria region (CCR) (ftp://geoportale.regione.calabria.it/DTM5X5 - last access 15 September 2020)

213



214

215 **Figure 3.** CORINE Land Cover (CLC) data for the years 1990, 2012 and 2012. The legend reports the III hierarchical level
 216 classes of the CORINE land cover project.

217

218 The assessment of the habitat-quality (HQ) is based on processing the autecological information of 66 terrestrial
 219 faunal focal species (Table S1, supplementary material). In Figure 4, we report on two exemplary cards drawn from
 220 the work of Boitani et al. (2003, 2007). Eleven focal species are included in the International Union for Conservation
 221 of Nature (IUCN) red lists of threatened species (IUCN, 2020).

04 Record card no.



Species: Grey Wolf
Canis lupus (L.)

Family: Canidae
Order: Carnivora
Class: Mammalia

circadian activity pattern: Nocturnal
social structure: Group

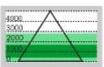


Area of diffusion in Italy

Patch size (ha): Min 80, Mean 170, Max 240
Feeding radius (km): Min 1, Mean 15, Max 38

Relationship with the patch: Interior
High suitability habitat: Spread

Water dependence:
Distance from temporary water sources (km): Min, Mean, Max
Distance from permanent water sources (km): Min, Mean, Max

Relationship with altitude (m):  Min 0, Min opt 300, Max opt 1600, Max 2500

IUCN Category: Red List Least Concern (LC)
Legislation references: L157, art.2; Bern Conv., app.2; CITES, all A; CITES, all B; Habitat Dir., app. 2; Checklist (M)

NOTES
The diffusion area runs along the Appennines ridge, this way confirming the species' preference for forest areas. Wolves, given their strong dispersal capacity, seem to be able to find adaptation to situations presenting fragmentation, although the species is strongly threatened by habitat reduction and isolation. Wolf presence is markedly related to areas presenting high suitability, while areas with lower suitability can be used as dispersal corridors.

Suitability score of the CORINE Land Cover (CLC) classes

1.1.1	Continuous urban fabric	0	2.4.3	Land principally occupied by agriculture, with significant areas of natural vegetation	25
1.1.2	Discontinuous urban fabric	0	2.4.4	Agro-forestry areas	75
1.2.1	Industrial or commercial units	0	3.1.1	Broad-leaved forest	100
1.2.2	Road and rail networks and associated land	0	3.1.2	Coniferous forest	100
1.2.3	Port areas	0	3.1.3	Mixed forest	100
1.2.4	Airports	0	3.2.1	Natural grasslands	75
1.3.1	Mineral extraction sites	0	3.2.2	Moors and heathland	75
1.3.2	Dump sites	0	3.2.3	Sclerophyllous vegetation	50
1.3.3	Construction sites	0	3.2.4	Temperate woodland-shrubs	75
1.4.1	Green urban areas	0	3.3.1	Beaches, dunes, sands	0
1.4.2	Sport and leisure facilities	0	3.3.2	Bare rocks	0
2.1.1	Non-irrigated arable land	0	3.3.3	Sparsely vegetated areas	25
2.1.2	Permanently irrigated land	0	3.3.4	Burnt areas	50
2.1.3	Rice fields	0	3.3.5	Glaciers and perpetual snow	0
2.2.1	Vineyards	0	4.1.1	Inland marshes	0
2.2.2	Fruit trees and berry plantations	50	4.1.2	Peat bogs	0
2.2.3	Olive groves	0	4.2	Maritime woodlands	0
2.3.1	Pastures	75	5.1.1	Water courses	0
2.4.1	Annual crops associated with permanent crops	0	5.1.2	Water bodies	0
2.4.2	Complex cultivation patterns	0	5.2	Marine waters	0

14 Record card no.



Species: Fire salamander
Salamandra salamandra (L.)

Family: Salamandridae
Order: Caudata
Class: Amphibia

circadian activity pattern: Nocturnal
social structure: Intermediate

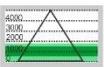


Area of diffusion in Italy

Patch size (ha): Min 0.0005, Mean 0.001, Max 0.01
Feeding radius (km): Min 0.005, Mean 0.01, Max 0.1

Relationship with the patch: Interior
High suitability habitat: Spread

Water dependence:
Distance from temporary water sources (km): Min, Mean, Max
Distance from permanent water sources (km): Min 0, Mean 0.005, Max 0.02

Relationship with altitude (m):  Min 0, Min opt 600, Max opt 1300, Max 2500

IUCN Category: Red List Least Concern (LC)
Legislation references: Bern Convention app.3

NOTES
The species is strongly (but not absolutely) dependent on permanent water sources and shows marked preference for areas with natural cover, specially forests. The species area shows little fragmentation, thanks to the kind of distribution of the areas presenting medium and low suitability, continuous along the whole arc of the Appennines mountains. Species conservation depends on the continuity of naturally vegetated areas of hill and foothill regions. Important threats are observed in the coastal areas, as a result of habitats isolation and reduction.

Suitability score of the CORINE Land Cover (CLC) classes

1.1.1	Continuous urban fabric	0	2.4.3	Land principally occupied by agriculture, with significant areas of natural vegetation	25
1.1.2	Discontinuous urban fabric	0	2.4.4	Agro-forestry areas	25
1.2.1	Industrial or commercial units	0	3.1.1	Broad-leaved forest	100
1.2.2	Road and rail networks and associated land	0	3.1.2	Coniferous forest	100
1.2.3	Port areas	0	3.1.3	Mixed forest	100
1.2.4	Airports	0	3.2.1	Natural grasslands	100
1.3.1	Mineral extraction sites	0	3.2.2	Moors and heathland	50
1.3.2	Dump sites	0	3.2.3	Sclerophyllous vegetation	25
1.3.3	Construction sites	0	3.2.4	Temperate woodland-shrubs	75
1.4.1	Green urban areas	0	3.3.1	Beaches, dunes, sands	0
1.4.2	Sport and leisure facilities	0	3.3.2	Bare rocks	0
2.1.1	Non-irrigated arable land	0	3.3.3	Sparsely vegetated areas	25
2.1.2	Permanently irrigated land	0	3.3.4	Burnt areas	0
2.1.3	Rice fields	0	3.3.5	Glaciers and perpetual snow	0
2.2.1	Vineyards	0	4.1.1	Inland marshes	25
2.2.2	Fruit trees and berry plantations	25	4.1.2	Peat bogs	25
2.2.3	Olive groves	0	4.2	Maritime woodlands	0
2.3.1	Pastures	0	5.1.1	Water courses	75
2.4.1	Annual crops associated with permanent crops	25	5.1.2	Water bodies	75
2.4.2	Complex cultivation patterns	25	5.2	Marine waters	0

222

223
224

Figure 4. Two examples of the organized cards containing the autecological information of the considered 66 terrestrial faunal focal species and each of the CORINE Land Cover (CLC) classes' suitability score.

225

3.2.2 Building the multispecies ecological Network (EN)

226

In Phase B, we built the multispecies ENs for the years 1990, 2012 and 2018, following the workflow illustrated in

227

Figure 5 and the approach proposed by Fichera et al. (2015). We used the Functional Connectivity (FunConn) model

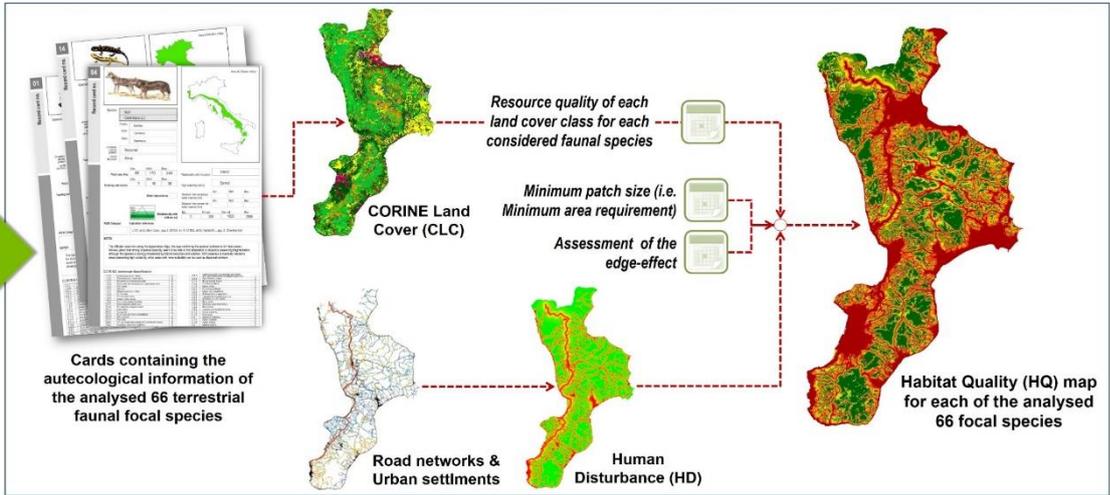
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v1 (Theobald et al., 2006, 2011), a toolbox working on ArcGIS® environment that allows to identify the movement

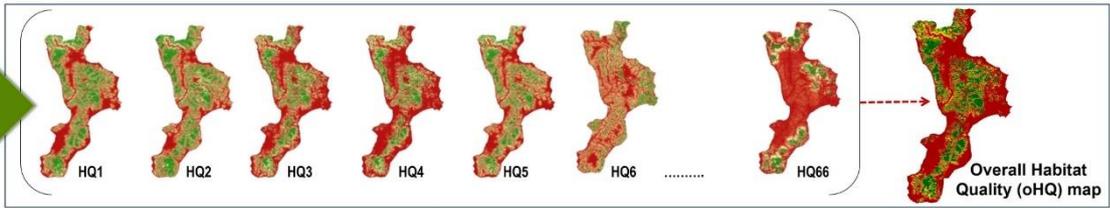
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patterns and the LC for each single faunal species.

Step 1
Habitat Quality (HQ) assessment for each focal faunal species



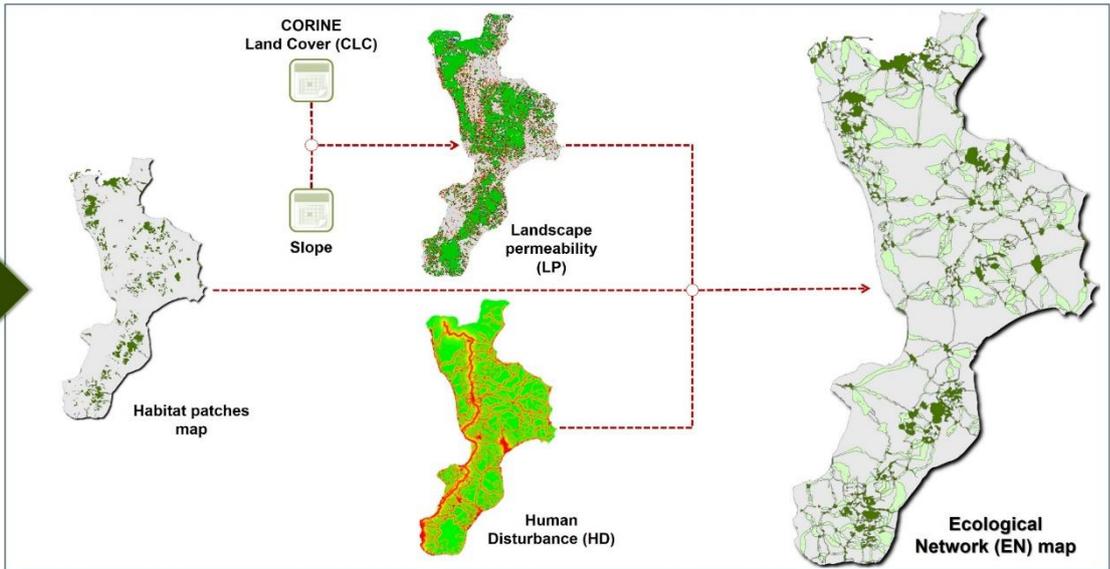
Step 2
Overall Habitat quality (oHQ) calculation



Step 3
Identification of Functional Patches (FPs)



Step 4
Ecological Network (EN) building



230

231 **Figure 5.** Methodologic workflow for building the multispecies ecological network (EN).

232

233 FunConn is a toolbox based on graph theory combined with the least-cost path analysis and permits to obtain a
234 spatial and a topological EN model. FunConn was chosen for its reliability and flexibility, which lead to a much more
235 informed identification of the most suitable habitats for a given species (Evangelista et al., 2012). Moreover, in this
236 framework, the habits of the focal species and land use pattern are keys to the construction of ENs. Two specific
237 datasets affect the spatial configuration and robustness of the obtained EN: i) Landscape permeability (LP), and ii)
238 Human disturbance (HD). HD is calculated by processing spatial data on human settlements' surface and road and
239 railway systems. As Figure 5 illustrates, the method develops in four steps (Theobald, 2006; Theobald et al., 2006),
240 as detailed in the following subsections.

241 3.2.2.1 STEP 1. ASSESSMENT OF THE HABITAT-QUALITY (HQ) FOR EACH FOCAL FAUNAL SPECIES

242 Step 1 consists of mapping in raster format the habitat-quality (HQ_i) for the focal species i at the periods considered
243 (1990, 2012, and 2018). HQ_i ranges from zero (no habitat) to 100 (optimal habitat) and depends on the quality
244 and availability of foraging resources. The HQ_i is first modeled by considering each focal faunal species' habitat
245 preferences taking into account the following parameters: resource quality of each land cover class, minimum patch
246 size (MPS), and patch structure.

247 The resource quality is obtained by reclassifying, for each species, the land cover maps into five classes of suitability
248 score (0, unsuitable; 25, low; 50, medium; 75, high; 100, very high), according to the species' preferences for each
249 land cover class (Figures 4 and 5). To avoid surfaces too small to guarantee species survival, we also considered
250 the MPS parameter, representing the smallest surface area enough granting good functioning biological behavior
251 to individuals belonging to the same species. It can be estimated by considering the relationships between the mass
252 of the animal and the home range size or minimum foraging radius (MFR), i.e., a measure of how far target species
253 move seeking out forage (Girvetz & Greco, 2007; Jetz et al., 2004).

254 In this application, we used MPS values provided by Boitani et al. (2003, 2007). The patch structure accounts for
255 the so-called 'edge-effect' on the animal movements and consists of modeling the animal preference for the edges
256 or core areas of the same quality and depends on the influence of functional patch structure (Theobald et al.,
257 2006). The assessment is based on the evaluation of the distance from the patch edge. A species is defined as
258 edge negative when a core area is more attractive than its edge, and edge positive, otherwise. If core areas and
259 edges are equally attractive, the species is said to be edge neutral (Theobald et al., 2006).

260 The resulting map is then corrected, taking into account the typology and distance from the HD sources, describing
 261 the disturbance of some land cover classes (e.g., built-up areas, major roads, and railways).

262 Species like large carnivores are persisting outside protected areas (Chapron et al., 2014; Forrest et al., 2011) and
 263 capable of tolerating moderate levels of HD (Smith et al., 2019; Kimmig et al., 2020), being able to survive in
 264 human-dominated landscapes worldwide (Athreya et al., 2013; Carter et al., 2012; Chapron et al., 2014). Thus, we
 265 modeled HD sources' effect through a coefficient of reduction (HD_{coeff}) of the HQ value at a pixel level. HD_{coeff} values
 266 were implemented according to the different typology of disturbances and the distance in seven classes of HD
 267 (Table 2). The HD_{coeff} assumes values ranging from 0 (e.g., the maximum disturbance that makes a given pixel
 268 unsuitable) to 1 (e.g., no disturbance, therefore no effect on the HQ of a given pixel).

269 **Table 2.** Values of the human disturbance coefficient (HD_{coeff}) are defined according to the different classes of distance from
 270 the HD sources and to classes of HD (HD_i , $i = 1, 2, \dots, 7$) by built-up area extension (BAE) and infrastructure type. HD1: BAE >
 271 2500 ha and motorways. HD2: 1000 ha < BAE < 2500 ha and highways. HD3: 500 ha < BAE < 1000 ha, provincial roads, and
 272 railways. HD4: 100 ha < BAE < 500 ha, and municipal roads. HD5: 50 ha < BAE < 100 ha. HD6: 10 ha < BAE < 50 ha. HD7: BAE <
 273 10 ha.

Classes of distance [m]	Human Disturbance coefficient (HD_{coeff})						
	<i>HD1</i>	<i>HD2</i>	<i>HD3</i>	<i>HD4</i>	<i>HD5</i>	<i>HD6</i>	<i>HD7</i>
< 50	0	0	0.10	0.15	0.50	0.75	0.85
50-100	0	0.10	0.15	0.25	0.75	0.85	0.90
100-200	0.05	0.15	0.50	0.65	0.80	0.90	0.95
200-300	0.05	0.20	0.65	0.75	0.85	0.95	0.95
300-400	0.05	0.35	0.75	0.85	0.90	0.95	1
400-500	0.10	0.50	0.80	0.90	0.95	1	1
500-750	0.10	0.65	0.90	0.95	1	1	1
750-1000	0.25	0.80	0.95	1	1	1	1
1000-1500	0.40	0.85	1	1	1	1	1
1500-2000	0.50	0.90	1	1	1	1	1
2000-3000	0.60	0.95	1	1	1	1	1
3000-4000	0.75	0.95	1	1	1	1	1
4000-5000	0.85	1	1	1	1	1	1
> 5000	0.9	1	1	1	1	1	1

274 3.2.2.2 STEP 2. MAPPING THE OVERALL HABITAT-QUALITY (OHQ).

275 In Step 2 of our methodology, we mapped the overall habitat-quality (oHQ) through a combination of all HQ_i
 276 according to the weighted mean aggregation rule obeying to the following Equation 1:

$$oHQ = \frac{\sum_{i=1}^{66} HQ_i \cdot w_i}{\sum_{i=1}^{66} w_i} \quad (1)$$

277 Where w_i is a weight that accounts for the ecological importance of the focal faunal species i . For species included
278 in the IUCN Red List, $w_i = 3$, while for those included in a Site of Community Interest (SCI), $w_i = 2$. For all other
279 target species, $w_i = 1$. The complete list of weight values is reported in table S1 of the supplementary material.

280 3.2.2.3 STEP 3. DEFINING THE HABITAT PATCHES

281 In Step 3, we defined the habitat patches considering the minimum foraging requirements of each focal species
282 and the possibility of animal movement among different patches (Girvetz & Greco 2007). Key information is provided
283 by the oHQ map and the two main organism-specific parameters: the minimum foraging radius (in meters) and the
284 MPS (in ha). Besides, we inserted the boundaries of integral natural reserves, and the SCIs, these last, only for
285 2012 and 2018 ENs, having them been designated and instituted in Italy since 1997, therefore not present in 1990.

286 All areas with an oHQ value above the threshold equal to 75 (very high suitability) were grouped according to a
287 smoothing moving windows. Moving (or sliding) windows is a low-pass spatial filter used to smooth borders among
288 different raster classes. In our case, we used the most common kernel of 3 x 3 pixels. The resulting surface
289 represents the permeability (i.e., the inverse of resistance to the animal movement) across the analyzed landscape.
290 While high-quality areas have high permeability (low resistance), cells grouped in low-quality areas have low
291 permeability (high resistance) (Theobald et al., 2006; Zeller et al., 2012). According to the foraging radius, patches
292 have grown outward from the core of the most suitable areas across the resistance surface to animal movement.
293 As a result, we obtained an integrated network of habitat patches. In defining the three multi-species ENs (Fichera
294 et al., 2015), the minimum foraging radius and the MPS were fixed at 500 m and, respectively, 10 ha, following the
295 weighted mean aggregation of values of each faunal species (Table S2, supplementary materials).

296 3.2.2.4 STEP 4. CONNECTING THE HABITAT PATCHES

297 In Step 4, the method implies the completion of the EN through the identification of the ecological linkages - i.e.,
298 corridors- between the habitat patches. The analysis is based on LC's operationalization via the concept of
299 permeability, implemented as a continuous gradient based on landscape permeability (LP). According to percolation
300 theory (Sapoval & Rosso, 1995; Williams & Snyder, 2005) and directional and least-cost connectivity analysis
301 (Theobald, 2006; Theobald et al., 2006), it is possible to obtain the LP map, which also combines information on
302 land cover, HD, and slope. Step 4 includes the final generation of the ENs, where habitat (i.e., functional) patches
303 (the nodes) are meant as source regions. At the same time, corridors with the least resistance to animal movement

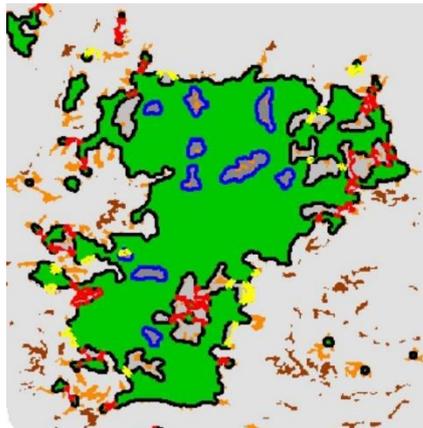
304 are adopted as edges. The spatial EN representation implies that each link is drawn as a segment with extreme
 305 points located on patch boundaries.

306 3.2.3 Analysis and diachronic comparison of the ecological networks (ENs)

307 In Phase C, we analyzed EN's spatial configuration by diachronically monitoring its characteristics through the three-
 308 time periods considered (1990, 2012, and 2018).

309 To investigate the fragmentation dynamics, we analyzed LF by using the FOSS software Guidos toolbox (Graphical
 310 User Interface for the Description of image Objects and their Shapes) (GTB) v2.9 (Vogt & Riitters, 2017). We apply
 311 the morphological spatial pattern analysis (MSPA) (Soille & Vogt, 2009; Vogt et al., 2007a; 2007b) that allows
 312 describing LF through the morphology of its different constituents: core, islet, perforated, core opening, edge, loop,
 313 bridge and branch (Table 3). We analyzed two different foreground elements: i) areas with $oHQ > 75$ (i.e., areas
 314 presenting high suitability for the focal species and affected by low HD); and ii) habitat patches (i.e., the core areas
 315 of an EN). To this end, we reclassified the input data as binary data (i.e., background, value 1, and foreground
 316 value 2) and calculated LF as a function of spatial entropy (Shannon, 1948; Vogt & Riitters, 2017).

317 **Table 3.** The eight Morphological Spatial Pattern Analysis (MSPA) into which the foreground components of a landscape are
 318 subdivided (after Soille & Vogt, 2009; Vogt et al., 2007a). The provided ideogram showing how the MSPA can be spatially
 319 configured in a landscape.

Morphological class	Description	Graphical description
<i>Branch</i>	Connecting surfaces not belonging to any of the other classes. They emanate at one end from edge, loop, perforation, or bridge.	
<i>Edge</i>	Outer boundaries of core surfaces (i.e., transition zones between core areas of habitat patches and oHQ).	
<i>Islet</i>	Disjoint and too small surfaces to constitute a core area.	
<i>Core</i>	Interior area of the landscape, allowing a broad movement of faunal species.	
<i>Bridge</i>	Connecting surfaces of two different core areas. Movement outside a core area that connects to a different core area.	
<i>Loop</i>	Connecting surfaces emanating from the same area. Animal movement outside a core area returns to the same core area.	
<i>Core Opening</i>	Surfaces inside core areas and surrounded by perforation pixels.	
<i>Perforation</i>	Interior holes in a core area that constitute transition zones between core and non-core surfaces (dilation of the non-core areas). Movement in inner boundary adjacent to gaps in the core area.	

321 The analysis includes the calculation of two indices: foreground connectivity, which describes the adjacency pattern
 322 between pixels, and the edge width, that corresponds to a thickness threshold, under which it is not possible to
 323 discriminate core from non-core areas (Vogt & Riitters, 2017). As for the first index, MSPA was conducted using an
 324 8-connectivity pattern: for each central pixel of a 3x3 pixel moving window, we included in the analysis the 8
 325 surrounding pixels with a border and/or a corner in common. As for the second index, we set an edge width
 326 threshold at 10 pixels, corresponding (with 20 m x 20 m pixel resolution) to a circle with a 200 m radius. We
 327 performed a comparative EN robustness dynamic analysis using the free software Conefor v2.6 (Saura & Torné,
 328 2009).

329 In this perspective, we calculate several network analysis metrics, both binary (B) and probabilistic (P), as detailed
 330 in Table 4.

331 **Table 4.** Network analysis metrics, by type (B, binary; P, probabilistic), description and ecological meaning, mathematical
 332 expression, and references.

Index	Type	Description and ecological meaning	Formula	References
Number of Patches (NP)	B	A patch is a habitat surface functionally defined by quality, size, and proximity. Topologically, a patch is modeled as a node located in the centroid of the polygon representing its boundary.	//	
Number of Links (NL)	B	A link stands as a connection (or corridor) between two patches. It is key to understanding the potential movement of faunal species. Since a more connected landscape has more links, this index is very useful in a comparative and/or diachronic analysis between landscapes.	//	(Fall et al., 2007; Urban & Keitt, 2001)
Number of Components (NC)	B	A component includes a set of nodes (patches) connected pairwise by at least one path. Disconnected (isolated) nodes constitute a component. The higher NC, the lower the connectivity. An NC value higher than 1 signals the rise of the insularization phenomenon.	//	(Urban & Keitt, 2001)
Harary index (H)	B	Half of the sum of reciprocals of topological distances between all pairs of nodes in a connected graph. The higher H, the higher LC.	$H = \frac{1}{2} \sum_{i=1}^n \sum_{j=1, i \neq j}^n \frac{1}{nl_{ij}}$	(Harary, 1969; Jordán et al., 2003; Pascual-Hortal & Saura, 2006; Ricotta et al., 2000)
Landscape Coincidence Probability (LCP)	B	The probability that two points randomly located within the landscape belong to the same component. The higher LCP, the higher LC.	$LCP = \sum_{i=1}^{nc} \left(\frac{a_i}{A_L} \right)^2$	(Pascual-Hortal & Saura, 2006)
Integral Index of Connectivity (IIC)	B	Habitat availability on a binary connection model. It equals to 1 in the hypothetical condition that the landscape equals to a habitat patch. Values range between 0 and 1: the higher IIC, the higher LC.	$IIC = \frac{\sum_{i=1}^n \sum_{j=1}^n \frac{a_i \cdot a_j}{1 + nl_{ij}}}{A_L^2}$	(Pascual-Hortal & Saura, 2006, 2008)
Flux (F)	P	The probability that animal species disperse throughout the patches.	$F = \sum_{i=1}^n \sum_{j=1, i \neq j}^n p_{ij}$	(Saura & Pascual-Hortal, 2007)
Probability of Connectivity (PC)	P	The probability that two points randomly placed within the landscape falls into habitat areas interconnected	$PC = \frac{\sum_{i=1}^n \sum_{j=1}^n a_i a_j p_{ij}^*}{A_L^2}$	(Saura & Pascual-Hortal, 2007)

Index	Type	Description and ecological meaning	Formula	References
		(i.e., reachable from each other). Values range between 0 and 1.		
Betweenness Centrality (BC_k)	P	For any patch k , BC is the ratio between the number of shortest paths connecting two patches i and j ($i, j \neq k$) and passing through that patch k and the total number of shortest path linking i and j in the network. BC_k gives a measure of how much a generic patch k serves as a stepping-stone for animal movements between pairs of proximal patches.	$BC_k = \sum_i \sum_j \frac{g_{ij}(k)}{g_{ij}}$	(Bodin & Saura, 2010; Estrada & Bodin, 2008; Freeman, 1977)
Betweenness Centrality-IIC (BC_k^{IIC})		This metric is derived from BC_k and also considers the surface area associated with each patch i and j and passing to the patch k ($i, j \neq k$). The index allows focusing on the role of larger patches.	$BC_k^{IIC} = \sum_i \sum_j a_i a_j \frac{1}{1 + d_{ij}}$	(Bodin & Saura, 2010)

- 333 n_C , total number of habitat components.
334 a_i and a_j , sum of node attribute (i.e., patch area) for nodes (patches) i and j .
335 A_L , whole analyzed landscape area (i.e., comprising non-habitat areas).
336 n , total number of nodes in the landscape.
337 n_{ij} , number of links in the shortest paths between patches i and j .
338 p_{ij} , probability of direct dispersal between patches i and j .
339 p_{ij}^* , maximum probability for all links (paths) between patches i and j .
340 $g_{ij}(k)$, all separate shortest paths between patches i and j , and passing through the generic patch k .
341 d_{ij} , distance between patches i and j
342

343 Betweenness Centrality (BC_k) metrics have an essential role, and these measures are provided at the node level
344 (Saura & Torné, 2009). BC was introduced by Freeman (1977) to measure the inter-centrality of a node i as the
345 share of shortest paths connecting a pair of nodes and passing through that node i and the total number of shortest
346 paths connecting those nodes in the whole network. So, BC is a significant signal for a patch's bridging role, i.e.,
347 for identifying stepping-stones: the higher the BC_k , the higher the patch's importance as a stepping-stone for animal
348 movement. We analyzed the classical BC_k and its generalization, the BC_k^{IIC} , introduced by Bodin & Saura (2010), that
349 takes into account the area of those patches bridged by that node and giving more importance to those nodes that
350 bridge larger (i.e., more important) patches.

351 4 Results

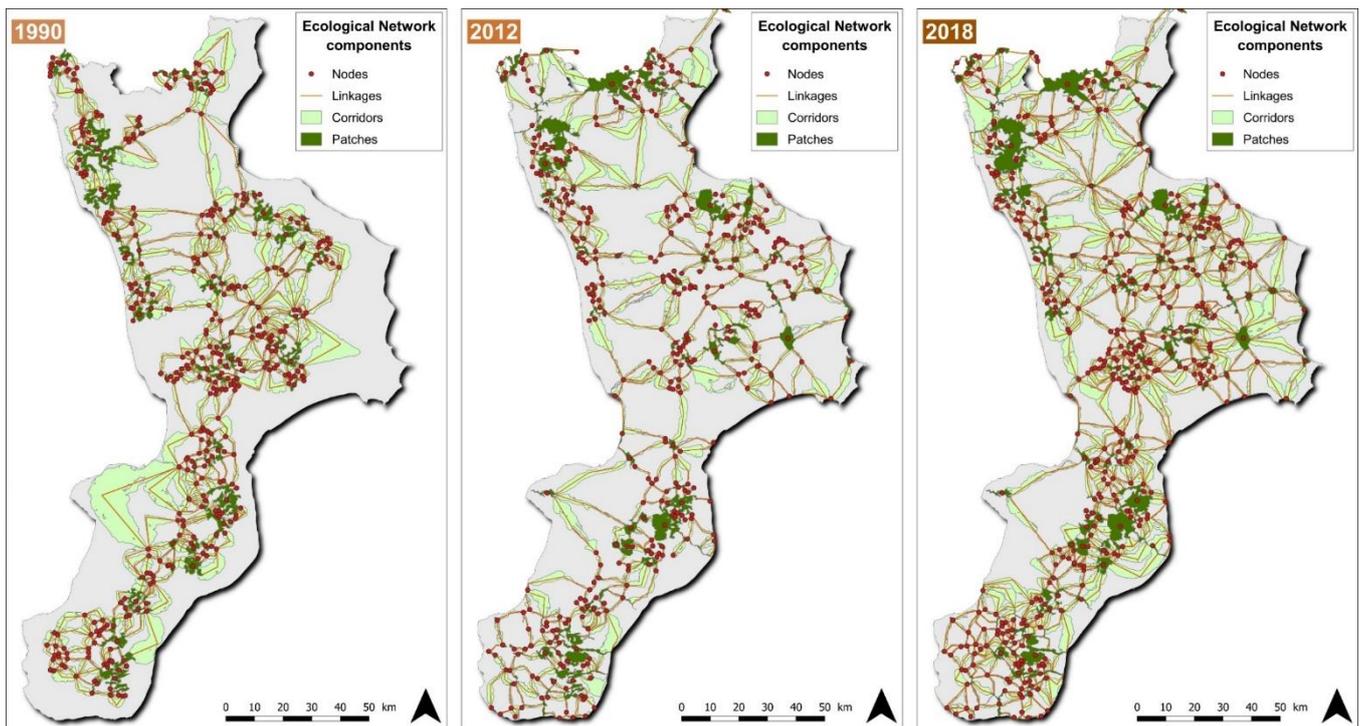
352 4.1 Land cover dynamics in the time period 1990-2018

353 From 1990 to 2012, we found a remarkable increase in urban settlements (+15,600 ha, +37.59%), while from
354 2012 to 2018, these surfaces are nearly the same. Most new urban areas occupied past agricultural areas that
355 decreased by 30,000 ha (-3.82%). On the other hand, the surface occupied by forestry formations (CLC 311, 312
356 and 313) has slightly shrunk from 1990 to 2012 (-18,700 ha, -3.2%) while, in 2018, a little increase can be noticed
357 (+0.4%) (Table S3, supplementary material).

358 **4.2 Spatial configuration and indicators of ecological networks (ENs)**

359 We obtained three types of results: i) the spatial configuration of the three ENs, ii) EN robustness analysis metrics,
360 and iii) fragmentation dynamic analysis concerning oHQ and LPs. The surface covered by ENs accounted for 503,808
361 ha in 1990 (32.14% of the study area), 424,421 ha in 2012 (27.07%), reaching the largest surface in 2018 (610,285
362 ha, 38.93%) (Table S4, supplementary material). Referring to the CLC classes falling in the ENs, most parts of
363 habitat patches are forestry areas, with the highest values in 1990 (98.32%), while in 2012 and 2018, they account
364 for more than 80%. On the other hand, agricultural areas cover significant parts of corridors with the highest value
365 in 2018 (47.66%), 46.36% in 2012, and 42.65% in 1990.

366 Figure 6 illustrates the dynamic spatial analysis of the ENs in 1990, 2012, and 2018. Maps include the ecosystem
367 and topological representations of the ENs: patches and corridors are modeled through nodes and edges. Over
368 time, a strengthening of ENs is evident with an increasing number of nodes and linkages from 1990 to 2012. This
369 first visual appreciation is confirmed by the quantitative results of the network analysis reported in Table 5.



370
371 **Figure 6.** Spatial configuration dynamic analysis of the Ecological network (ENs) obtained for 1990 (left), 2012 (center), and
372 2018 (right). The EN components (corridors, in light green, and patches, in dark green) are reported together with the
373 topological components (nodes, red dots, and linkages, orange lines) in each map.

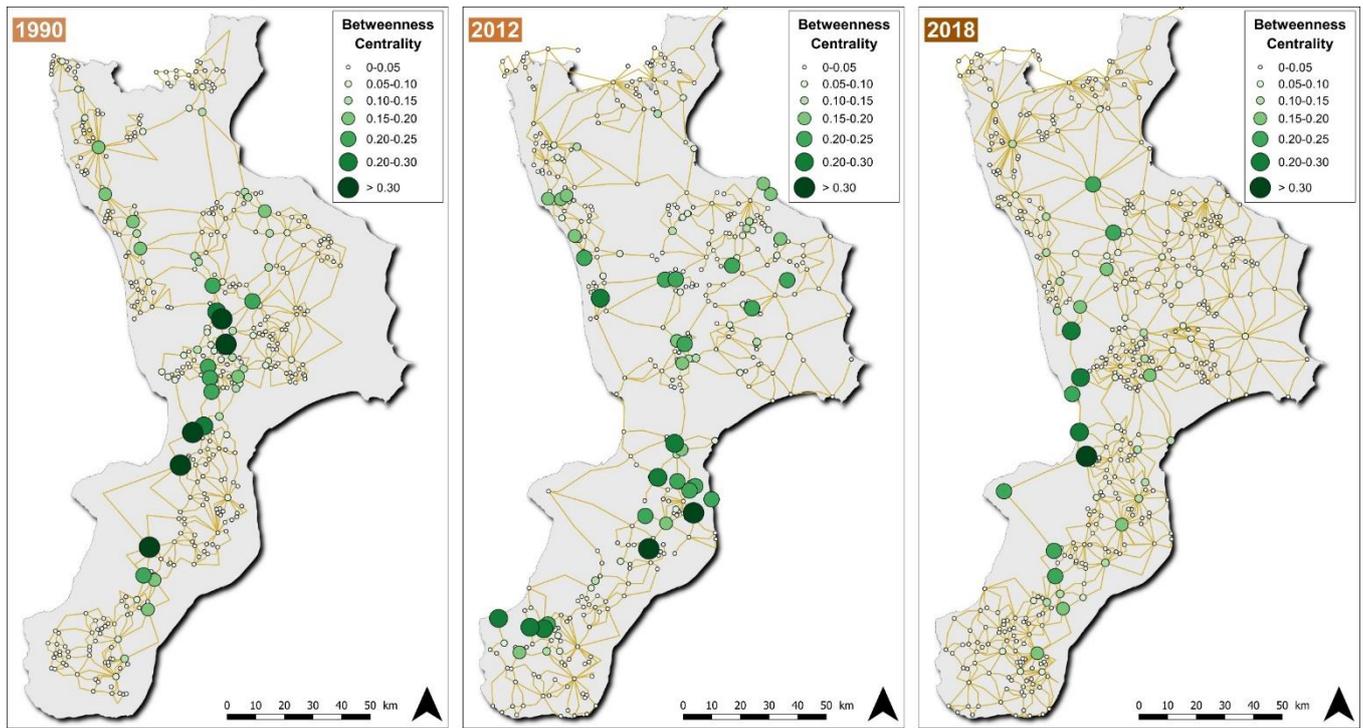
374
375 **Table 5.** Diachronic analysis of EN spatial configuration using overall indexes - i.e., at the ecological network (EN) level – and
376 node-level indexes (years 1990, 2012, 2018).

Overall Indices at EN level	1990	2012	2018
Number of habitat patches (nodes) (NP)	391	393	451
Number of Links (NL)	781	638	1078
Number of Components (NC)	1	1	1
Harary index (H)	9701.4	8947.9	14,503.1
Landscape Coincidence Probability (LCP)	0.39	0.32	0.47
Integral Index of Connectivity (IIC)	0.04	0.03	0.06
Flux (F)	1562	1316	2156
Probability of Connectivity (PC)	0.39	0.32	0.47
<i>Betweenness Centrality (BC) metrics at the node level</i>			
mean BC_k (median)	0.029 (0.005)	0.033 (0.004)	0.021 (0.002)
mean BC_k^{IIC} (median)	1.89 (0.408)	2.143 (0.363)	1.39 (0.182)

377

378 All values slightly decrease from 1990 to 2012, except the number of habitat nodes (NP), increasing from 391 to
379 393, and the number of components (NC), 1 for all the three ENs (Table 5). The number of links (NL) evidences
380 the different rearrangements of the ENs, with a slight decrease from 1990 to 2012 (from 638 to 781) and a relevant
381 increase toward the highest value reached in 2018. The Harary index (H) shows the same dynamics: it highlights
382 the highest complexity in 2018 after a slight deceleration.

383 As NC stays equal to 1, LC metrics such as Landscape Coincidence Probability (LCP), Probability of Connectivity
384 (PC), and Integral Index of Connectivity (IIC) show very similar and stabile trends. The Flux (F) index, the measure
385 of dispersal probability, confirms what is reported for the other metrics: it first decreases, then increases, reaching
386 the value of 2156. As for BC, in Figure 7, we mapped the BC_k of each node, differentiating the size and color of the
387 symbol dots according to their different BC values.

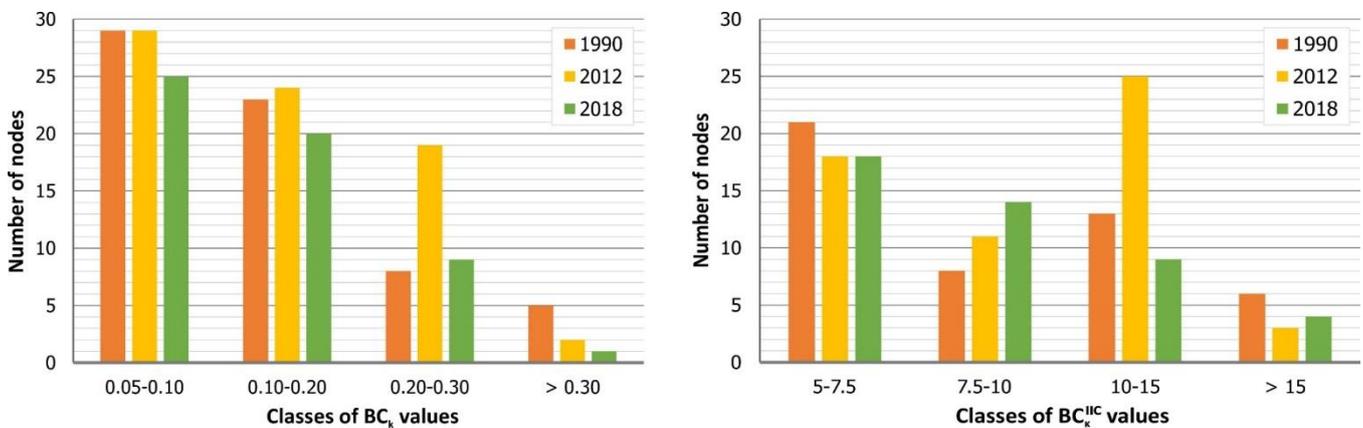


388

389 **Figure 7.** Maps of the betweenness centrality (BC_k) for the ENs in 1990 (left), 2012 (center), and 2018 (right).

390

391 In Figure 8, we reported the graphs showing the BC_k and the BC_k^{LIC} values of the best patches (i.e., those with the
 392 highest values). As for BC_k^{LIC} , the highest value is 21.36 in 1990, 19.41 in 2012, and 16.82 in 2018. In graphs of
 393 Figure 8, we reported the highest BC_k and BC_k^{LIC} values grouped into four classes. As for BC_k , most significant
 394 differences in the connectivity concern the 2012 EN, with 19 nodes (4.8% of the total) with high values of BC_k
 395 (class 0.20-0.30), while in 1990 and 2018, they are equal to 8 and, respectively, 9. The same insights can be found
 396 analyzing BC_k^{LIC} , with 6 nodes in 1990 falling in the class with the highest connectivity (>15), 3 in 2012, and 4 in
 397 2018. The analysis of the BC_k^{LIC} at the node level shows good LC over time.

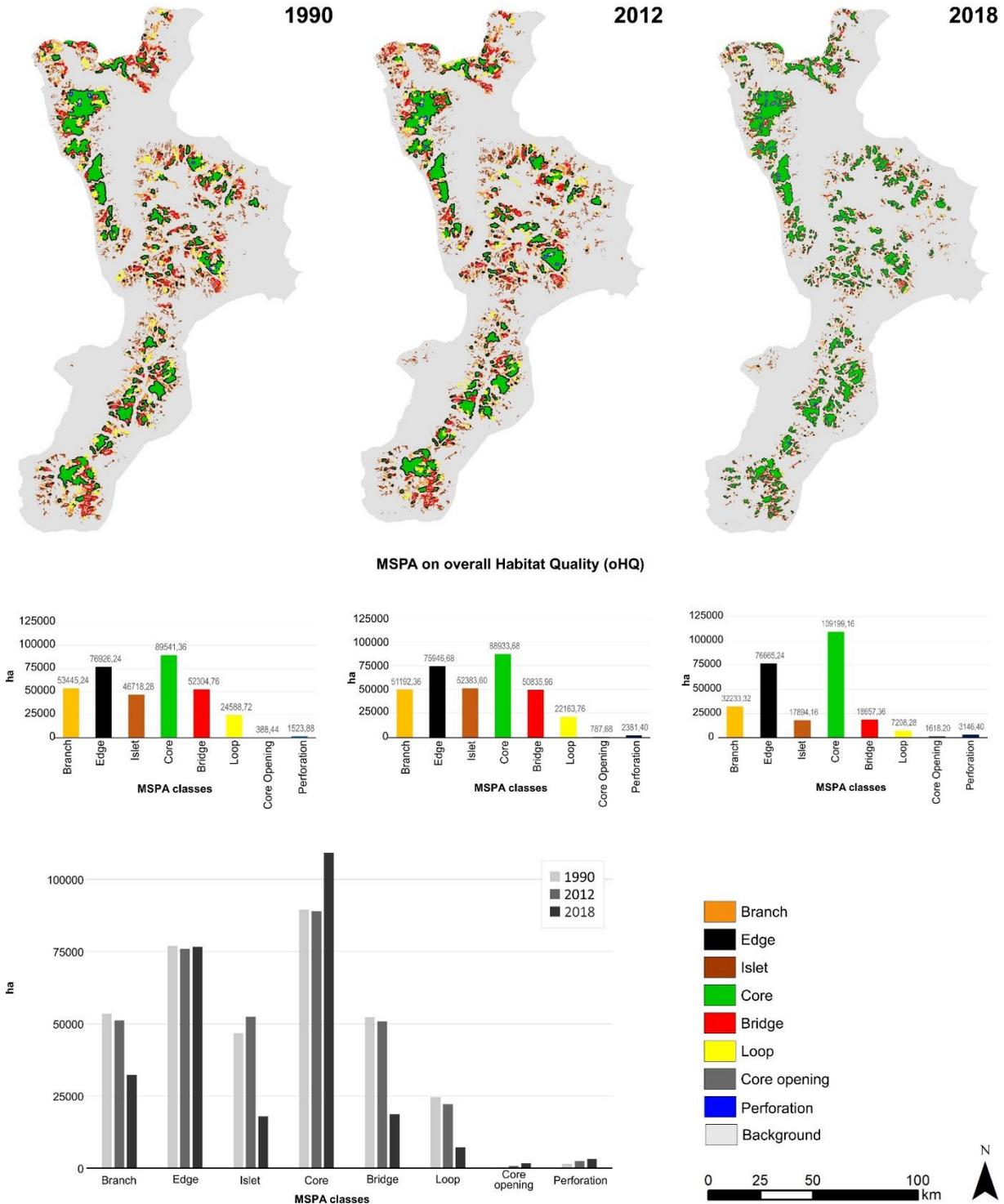


398

399 **Figure 8.** Graphs showing the number of nodes with the highest BC_k and BC_k^{LIC} values grouped into four classes and according
 400 to the three analyzed ecological networks (ENs).

401 **4.3 Landscape fragmentation (LF) analysis**

402 In Figure 9, we reported the Morphological spatial pattern analysis (MSPA) results by mapping the pattern of the
 403 fragmentation classes in each time period of the areas with oHQ higher than 75. As for oHQ, the core class passed
 404 from 89,541 ha in 1990 to 88,934 ha in 2012 and 109,199 in 2018. The edge class maintains the same surface,
 405 about 76,000 ha, in all years.

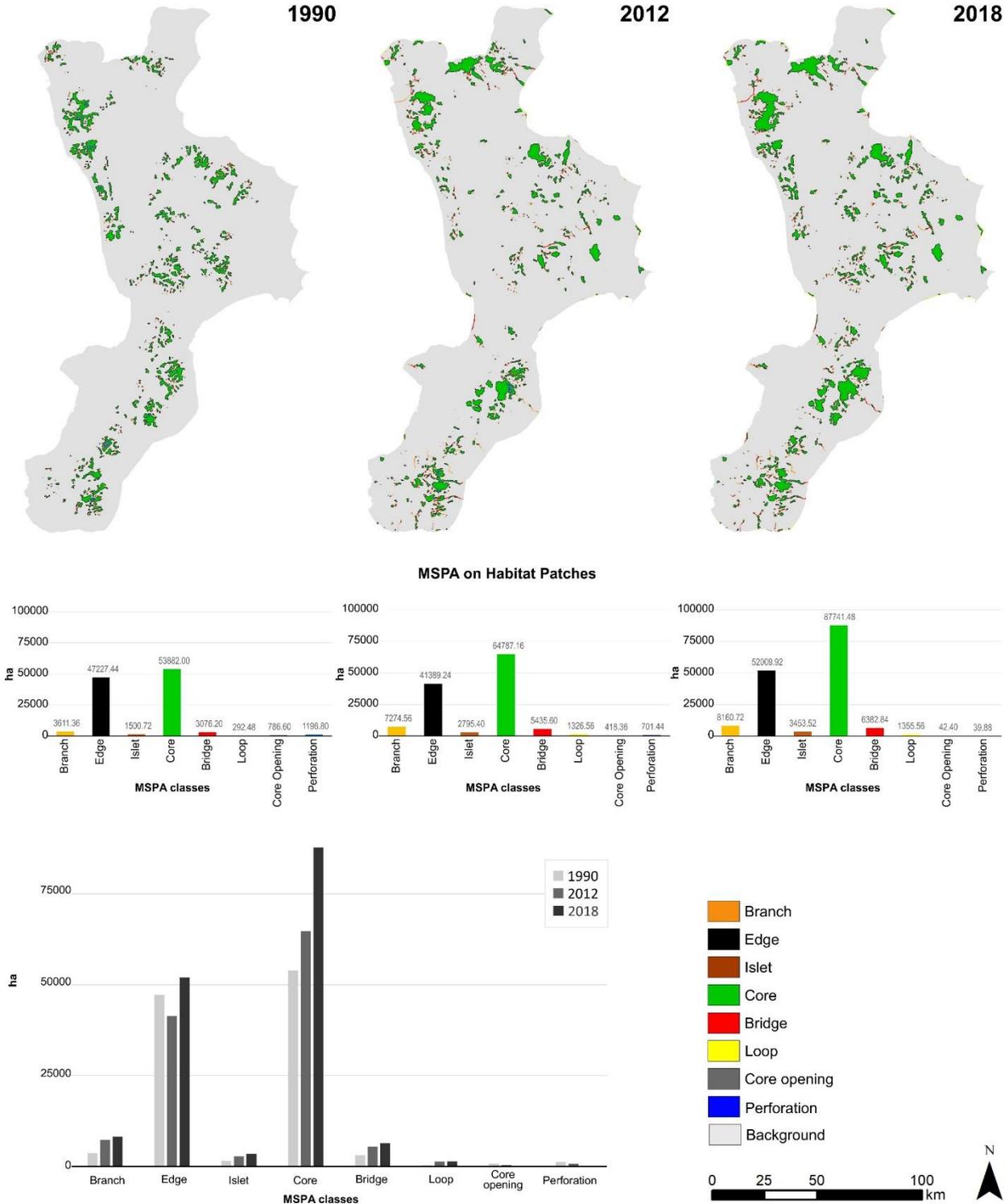


406

407 **Figure 9.** Morphological spatial pattern analysis (MSPA) of the areas with the overall Habitat Quality (oHQ) higher than 75 for
 408 the ENs in 1990 (top left), 2012 (top center), and 2018 (top right).

409 The islet class denotes the highest fragmentation of oHQ in 2012, with a surface of 52,300 ha, while it was 46,700
 410 in 1990 and decreased significantly in 2018 (17,894 ha). The perforation class concerns limited oHQ largest areas
 411 (1523 ha in 1990, 2381 in 2012, and 3146 in 2018).

412 According to the MSPA of the habitat patches, EN shows a more robust configuration in 2012 and 2018 (Fig. 10).



413
 414 **Figure 10.** Morphological spatial pattern analysis (MSPA) of the Habitat Patches (HP) for the ENs in 1990 (top left), 2012 (top
 415 center), and 2018 (top right).

416

417 This is due also to the integration in the EN of SICs and integral reserves. The core class increased from 53,882 ha
418 in 1990 to 64,787 ha in 2012 and 87,741 in 2018. The edge class analysis confirms this insight: its surface decreased
419 from 1990 to 2018. As expected, the mean habitat patch surface increased from 282.6 ha in 1990 to 301.2 in 2012
420 and 353.1 in 2018. As for the bridge class, its surface covers a few thousand hectares (3076 in 1990, 5435 in 2012,
421 and 6382 in 2018). Nevertheless, particularly in 2012 and 2018, the bridge class concerns significant surfaces acting
422 as corridors while, in some cases, they allow the ENs to reach the coastal areas.

423 **5 Discussion**

424 In this section, we discuss the results concerning the research questions raised in the introduction. As for the first
425 research question (how to structure ENs based on the habitat requirements of focal faunal species), we have studied
426 ENs to implement the multispecies landscape corridors at the regional scale. In this respect, the definition of their
427 optimum width is still an open question, as there is no agreement on a clear methodological framework (Beier et
428 al., 2008; Sawyer et al., 2011). While previous studies have approached the issue by assessing the HQ by calculating
429 the interplay between land cover dynamics and human impact (Dong et al., 2020; Tang et al., 2020), we have built
430 a species-specific method. In our case, the study of HQ and LP is referred to the analysis of the autecological needs
431 of a remarkable number of focal faunal species, unlike other studies that have focused only on a few species (Babí
432 Almenar et al., 2019; Ehlers Smith et al., 2019; Ersoy et al., 2019; Hofman et al., 2018; C. Liu et al., 2018; S. Liu
433 et al., 2018). Thus, our results provide the analysts with a more comprehensive picture of LC from the perspective
434 of a tool aiding the design of multispecies ENs.

435 The second research question attains the dynamics occurring on a landscape and the adoption of LC as a tool to
436 support EN design. Evidence shows that the EN expands, as NP increases from 391 in 1990 to 451 in 2018, while
437 the increment slows from 1990 to 2012. These dynamics are confirmed by the trend of NL, which decreases from
438 781 (in 1990) to 638 (in 2012) and jumps up to 1078 (in 2018). This signals a consistent general rearrangement of
439 the components towards a more disjointed structure. Another relevant result is that the EN evolves, maintaining a
440 unique component (NC=1), which is a condition that an EN should have to preserve LC effectively. In this
441 configuration, no isolated patches are present, and two patches whatsoever can be reached through at least one
442 walkable path. In ENs spanning through large areas, this holds for species with enough moving capacity (e.g.,

443 carnivores, artiodactyls, etc.) and does not for too small species having much shorter dispersal distances. This
444 brings us to our third research question focusing on the assessment of EN robustness.

445 We have used landscape graphs suitable for computing connectivity metrics (Laita, Kotiaho, & Mönkkönen, 2011).
446 However, we have demonstrated how those metrics do not merely gauge topological features but offer information
447 on the robustness, a concept suitable to support EN planning and monitoring (Foltête et al., 2014; Rayfield et al.,
448 2011). Typically, BC is a key indicator of robustness. The nodes with higher BC values represent stepping-stones
449 for animal movements because they are interconnected with many pairs of nodes (Urban et al., 2009). The BC
450 analysis shows that the set of elements with BC_k value higher than 0.30 includes just four nodes in 1990, two in
451 2012, and one in 2018. This can be justified by the increasing number of network nodes and edges, a phenomenon
452 that makes the whole EN better interconnected and more robust in 2018, as a large pool of nodes show a moderate
453 value of BC, i.e., acting as stepping stones in compensating the loss of high BC values with a broad set of shortcuts.
454 Moreover, the BC_k^{HC} , assigning a higher value to those nodes linking larger habitat patches, highlights quite good
455 robustness of the 2012 EN, also compared to the 2018 EN. In fact, the mean value of BC_k^{HC} in 2012 is the highest
456 of the three ENs (2.143, st. dev. ± 3.819). By the way, BC values of nodes (mean and median) (Table 5) and their
457 distribution (Figure 7) confirm the major robustness of 2018 EN.

458 The MSPA analysis yields double-fold insights. On the one hand, it gives information on the past and the current
459 state of LC. On the other hand, it allows detecting priority areas requiring active interventions to strengthening the
460 EN. With reference to the results of the MSPA, two critical phenomena emerge: an increase of the total surface
461 area of the patches (from 53,882 ha in 1990 to 64,787 ha in 2012, and to 87,741 ha in 2018) and a decrease of
462 the core opening area. According to the same line, branch and bridge surface areas expand. This is an important
463 sign of improvement and consolidation. The larger number and extension of patches can be explained by the
464 increase of forestry areas from 1990 to 2018. The MSPA analysis on habitat patches confirms that integration of
465 the SCIs in 2012 and 2018 ENs is able to significantly improve the compactness and the spatial distribution of the
466 core areas. On the other hand, the increase of islet areas (Fahrig, 2003) from 1500 ha, in 1990, to 3453 ha in 2018
467 is a clear sign of an increase of LF in marginal areas. These figures suggest how a further strengthening of the
468 current EN (2018) would be advisable and focused on reducing LF in marginal areas, improving the quality and
469 distribution of forest and semi-natural habitats. Besides, the ENs spatial configuration highlights the need for an
470 increase of riparian corridors, falling in the 'bridge' class of MSPA analysis, allowing faunal species to reach the
471 coastal areas. On the opposite side, similar trends are also shown by the metrics used for studying the oHQ. The

472 analysis conducted on oHQ focus on the most critical (i.e. with oHQ greater than 75) areas, upon which the EN
473 should be built. Thus, this analysis is crucial to assess the vulnerability. The graphs with single year values of MSPA
474 classes show a slight worsening of the overall scenario from 1990 to 2012, driven by increased LF. The core areas
475 shrink from 89,541 ha to 88,934 ha, while the islet areas expand from 46,718 ha to 52,383 ha. On the other hand,
476 in 2018, a positive trend is signaled by the increase of core areas and the decrease of islet areas. However, the
477 increase in core areas is also accompanied by the rise in core opening areas, which expand from 388 ha in 1990 to
478 1618 ha in 2018, highlighting holes within the core areas. Also, these insights suggest the need for intervention of
479 amelioration of the habitat quality in these areas.

480 **6 Conclusions**

481 In this study, we started by analyzing the current land-use dynamics in the Calabria region and scrutinized LC
482 changes that occurred to multispecies ENs in the time shots 1990, 2012, and 2018. We clarified how the EN evolves
483 over time by changing elements, without losing its potential for biodiversity conservation (Opdam et al., 2006). In
484 a changing landscape, the dynamics of development and conservation can decrease one component of the EN that
485 may be compensated by improving another (Opdam et al., 2006).

486 This work contributes to multi-temporal analysis that widely showed its significant role in sustainable landscape
487 planning. The assessment of LC based on the requirements of a significant number of focal faunal species and the
488 assessment of the robustness of ENs provide a reliable tool for landscape planners. Moreover, several future
489 research directions are outlined: the analysis of intermediate years (2012 in this case), a deepening of the dynamics
490 of fragmentation and their effects on landscape connectivity, the impact of new built-areas and the effects of climate
491 change on biodiversity (Opdam & Wascher, 2004). In this respect, the implementation of a habitat quality
492 monitoring system attaining the whole region (not only the protected areas) would provide the analysts with much
493 more reliable outcomes. In our study, the CLC data present some limitations: relatively low (85%) thematic and
494 geometric (100 m) accuracy (<https://land.copernicus.eu/pan-european/corine-land-cover>, last access 05 July
495 2020). Thus, additional sources of information should be considered. As highlighted by Beier et al. (2011), building
496 an EN implies a variety of steps and the selection of several models, thresholds, and decision rules, for which there
497 is no clear best option. Accordingly, stakeholders' involvement since the first phases of the process can improve the
498 quality and acceptance of the outcomes (Modica et al., 2013; Xu et al., 2020). An effective EN design requires a
499 sufficient level of awareness of local communities and decision-makers (i.e., government agencies, policymakers)

500 on the importance of protecting and improving LC (Brodie et al., 2016). Another key issue attains the need to
501 deeply understand the impact of global changes, driven by human pressure, ecosystem functioning, and biodiversity
502 conservation (Requena-Mullor et al., 2018). LC can be classified as a supporting ecosystem service for the
503 biodiversity of plants and animals and, acting positively in reducing extinction rates, has a significant role in
504 maintaining the other ecosystem services (Haddad et al., 2015).

505 The preservation of LC requires specific financial actions, i.e., as in the case of preservation of faunal species in
506 national or regional parks. In this respect, the EN components (habitat patches and corridors) should be considered
507 a structural invariant in planning tools. In other words, the planning of new settlements and other land-use changes
508 leading to the HQ reduction should also be assessed, considering their impact on the robustness of the EN (De
509 Montis et al., 2019). Moreover, to have planning reliability, ecological corridors should be clearly delineated (Hilty
510 et al., 2020). It is also essential to highlight the replicability of the proposed method in other contexts, differing in
511 topography, land cover, and human pressure, and the possibility of integrating it with further information on
512 additional faunal species (birds, insects, etc.).

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Supplementary materials

Table S1. The 66 species selected as representative to build the three ecological networks (ENs). W_i is the multiplicative factor representing the different ecological importance of the species for the construction of the overall Habitat Quality (oHQ)

Card n°	Scientific name	Common name	w_i	Card n°	Scientific name	Common name	w_i
1	<i>Vulpes vulpes</i>	Red fox	1	34	<i>Capreolus capreolus</i>	Roe deer	2
2	<i>Martes foina</i>	Beech marten	1	35	<i>Bufo bufo</i>	Common toad	2
3	<i>Martes martes</i>	Pine marten	2	36	<i>Pseudepidalea viridis</i>	Green toad	2
4	<i>Canis lupus</i>	Wolf	3	37	<i>Mesotriton alpestris</i>	Alpine newt	2
5	<i>Lepus europaeus</i>	Brown hare	1	38	<i>Emys orbicularis</i>	European pond tortoise	3
6	<i>European hedgehog</i>	Common hedgehog	1	39	<i>Anguis fragilis</i>	Deaf adder	2
7	<i>Sciurus vulgaris</i>	Red squirrel	1	40	<i>Zamenis longissimus</i>	Aesculapian snake	1
8	<i>Salamandra salamandra</i>	Fire salamandra	2	41	<i>Neomys anomalus</i>	Miller's water shrew	1
9	<i>Hierophis viridiflavus</i>	Green whip snake	3	42	<i>Sorex samniticus</i>	Appennine shrew	1
10	<i>Elaphe situla</i>	Leopard snake	2	43	<i>Suncus etruscus</i>	Etruscan shrew	1
11	<i>Hemidactylus turcicus</i>	Mediterranean house gecko	1	44	<i>Talpa caeca</i>	Blind mole	1
12	<i>Podarcis sicula</i>	Ruin lizard	1	45	<i>Talpa romana</i>	Roman mole	1
13	<i>Podarcis muralis</i>	Wall lizard	1	46	<i>Lepus corsicanus</i>	Italian hare	3
14	<i>Lacerta viridis</i>	Green lizard	2	47	<i>Chionomys nivalis</i>	Snow vole	2
15	<i>Tarentola mauritanica</i>	Common gecko	1	48	<i>Myocastor coypus</i>	Coypu/Nutria	1
16	<i>Testudo hermanni</i>	Hermann's tortoise	3	49	<i>Mustela putorius</i>	European polecat	1
17	<i>Vipera aspis</i>	Asp viper	2	50	<i>Sus scrofa</i>	Wild boar	1
18	<i>Rana italic</i>	Italian frog	2	51	<i>Chalcides chalcides</i>	Three-toed skink	1
19	<i>Salamandrina terdigitata</i>	Spectacled salamander	2	52	<i>Natrix natrix</i>	Grass snake	1
20	<i>Dryomys nitedula</i>	Forest dormouse	2	53	<i>Crociodura leucodon</i>	Bicolored shrew	1
21	<i>Muscardinus avellanarius</i>	Hazel dormouse	3	54	<i>Crociodura suaveolens</i>	Lesser white-toothed shrew	1
22	<i>Felis silvestris</i>	European wildcat	3	55	<i>Neomys fodiens</i>	Eurasian water shrew	1
23	<i>Lutra lutra</i>	Eurasian otter	3	56	<i>Sorex minutus</i>	Pygmy shrew	1
24	<i>Bombina pachypus</i>	Appennine yellow-bellied toad	3	57	<i>Glis glis</i>	Edible dormouse	1
25	<i>Hyla intermedia</i>	Italian tree frog	2	58	<i>Myodes glareolus</i>	Bank vole	1
26	<i>Rana dalmatina</i>	Agile frog	1	59	<i>Apodemus flavicollis</i>	Yellow-necked mouse	1
27	<i>Triturus carnifex</i>	Italian crested newt	2	60	<i>Apodemus sylvaticus</i>	Wood mouse	1
28	<i>Lissotriton italicus</i>	Italian newt	1	61	<i>Mus domesticus</i>	West-European house mouse	1
29	<i>Coronella austriaca</i>	Smooth snake	1	62	<i>Rattus norvegicus</i>	Brown rat	1
30	<i>Elaphe quatuorlineata</i>	Four-lined snake	3	63	<i>Cervus elaphus</i>	Red deer	2
31	<i>Natrix tessellata</i>	Dice snake	2	64	<i>Mustela nivalis</i>	Least weasel	1
32	<i>Eliomys quercinus</i>	Garden dormouse	3	65	<i>Meles meles</i>	European badger	1
33	<i>Hystrix cristata</i>	Crested porcupine	2	66	<i>Rattus rattus</i>	Black rat	1

Table S2. Values of minimum foraging radius (MFR) [m] and minimum patch size (MPS) [ha] for each of 66 species selected. In the last row, the weighted values are reported.

Card n°	Scientific name	w_i	Minimum Foraging radius (MFR _i) [m]	Minimum Patch Size (MPS _i) [ha]	Card n°	Scientific name	w_i	Minimum Foraging radius (MFR _i) [m]	Minimum Patch Size (MPS _i) [ha]
1	<i>Vulpes vulpes</i>	1	2000	75	34	<i>Capreolus capreolus</i>	2	750	5
2	<i>Martes foina</i>	1	1000	90	35	<i>Bufo bufo</i>	2	100	0.005
3	<i>Martes martes</i>	2	1000	70	36	<i>Pseudepidalea viridis</i>	2	200	0.005
4	<i>Canis lupus</i>	3	2000	80	37	<i>Mesotriton alpestris</i>	2	50	0.1
5	<i>Lepus europaeus</i>	1	1000	3	38	<i>Emys orbicularis</i>	3	250	0.001
6	<i>European hedgehog</i>	1	200	5	39	<i>Anguis fragilis</i>	2	20	0.0001
7	<i>Sciurus vulgaris</i>	1	1000	2	40	<i>Zamenis longissimus</i>	1	50	0.05
8	<i>Salamandra salamandra</i>	2	5	0.0005	41	<i>Neomys anomalus</i>	1	300	0.01
9	<i>Hierophis viridiflavus</i>	3	100	0.05	42	<i>Sorex samniticus</i>	1	200	0.01
10	<i>Elaphe situla</i>	2	25	0.05	43	<i>Suncus etruscus</i>	1	200	0.01
11	<i>Hemidactylus turcicus</i>	1	5	0.0015	44	<i>Talpa caeca</i>	1	3	0.15
12	<i>Podarcis sicula</i>	1	25	0.0001	45	<i>Talpa romana</i>	1	3	0.15
13	<i>Podarcis muralis</i>	1	15	0.0001	46	<i>Lepus corsicanus</i>	3	1000	1
14	<i>Lacerta viridis</i>	2	5	0.002	47	<i>Chionomys nivalis</i>	2	20	1
15	<i>Tarentola mauritanica</i>	1	5	0.0005	48	<i>Myocastor coypus</i>	1	50	2
16	<i>Testudo hermanni</i>	3	100	0.001	49	<i>Mustela putorius</i>	1	150	8
17	<i>Vipera aspis</i>	2	15	0.005	50	<i>Sus scrofa</i>	1	3000	100
18	<i>Rana italic</i>	2	75	0.002	51	<i>Chalcides chalcides</i>	1	20	0.0001
19	<i>Salamandrina terdigitata</i>	2	5	0.001	52	<i>Natrix natrix</i>	1	50	0.05
20	<i>Dryomys nitedula</i>	2	1000	1	53	<i>Crocidura leucodon</i>	1	200	0.1
21	<i>Muscardinus avellanarius</i>	3	1000	1	54	<i>Crocidura suaveolens</i>	1	200	0.1
22	<i>Felis silvestris</i>	3	1000	70	55	<i>Neomys fodiens</i>	1	50	0.002
23	<i>Lutra lutra</i>	3	2000	10	56	<i>Sorex minutus</i>	1	200	0.053
24	<i>Bombina pachypus</i>	3	50	0.005	57	<i>Glis glis</i>	1	500	1
25	<i>Hyla intermedia</i>	2	100	0.005	58	<i>Myodes glareolus</i>	1	10	0.05
26	<i>Rana dalmatina</i>	1	50	0.002	59	<i>Apodemus flavicollis</i>	1	400	1
27	<i>Triturus carnifex</i>	2	50	1	60	<i>Apodemus sylvaticus</i>	1	300	0.2
28	<i>Lissotriton italicus</i>	1	50	1	61	<i>Mus domesticus</i>	1	50	1
29	<i>Coronella austriaca</i>	1	30	0.05	62	<i>Rattus norvegicus</i>	1	200	1
30	<i>Elaphe quatuorlineata</i>	3	50	0.05	63	<i>Cervus elaphus</i>	2	750	75
31	<i>Natrix tessellata</i>	2	50	0.05	64	<i>Mustela nivalis</i>	1	500	1
32	<i>Eliomys quercinus</i>	3	1000	1	65	<i>Meles meles</i>	1	1000	25
33	<i>Hystrix cristata</i>	2	5000	1	66	<i>Rattus rattus</i>	1	200	1

$$MFR = \frac{\sum_{i=1}^{66} MFR_i \cdot w_i}{\sum_{i=1}^{66} w_i} = 507.5 \text{ m}$$

$$MPS = \frac{\sum_{i=1}^{66} MPS_i \cdot w_i}{\sum_{i=1}^{66} w_i} = 10.4 \text{ ha}$$

Table S3. Distribution of the surface of the study area according to the Corine Land Cover (CLC) classes in the three years under investigation.

<i>CLC class</i>	Surface [ha]			Variations [%]		
	1990	2012	2018	1990-2012	2012-2018	1990-2018
<i>111</i>	2,958.96	4,117.72	4,132.64	<i>39.16%</i>	<i>0.36%</i>	<i>39.67%</i>
<i>112</i>	30,296.68	41,193.80	41,564.84	<i>35.97%</i>	<i>0.90%</i>	<i>37.19%</i>
<i>121</i>	3,991.60	6,695.96	6,771.28	<i>67.75%</i>	<i>1.12%</i>	<i>69.64%</i>
<i>122</i>	309.28	332.32	749.08	<i>7.45%</i>	<i>125.41%</i>	<i>142.20%</i>
<i>123</i>	741.80	943.80	771.68	<i>27.23%</i>	<i>-18.24%</i>	<i>4.03%</i>
<i>124</i>	614.32	686.52	686.48	<i>11.75%</i>	<i>-0.01%</i>	<i>11.75%</i>
<i>131</i>	967.44	1,193.88	1,049.64	<i>23.41%</i>	<i>-12.08%</i>	<i>8.50%</i>
<i>133</i>	987.48	611.36	112.08	<i>-38.09%</i>	<i>-81.67%</i>	<i>-88.65%</i>
<i>142</i>	730.60	1,458.48	1,441.72	<i>99.63%</i>	<i>-1.15%</i>	<i>97.33%</i>
<i>211</i>	228,842.20	214,714.28	214,174.88	<i>-6.17%</i>	<i>-0.25%</i>	<i>-6.41%</i>
<i>212</i>	1,047.68	748.16	825.40	<i>-28.59%</i>	<i>10.32%</i>	<i>-21.22%</i>
<i>213</i>	0.00	734.00	733.84	<i>--</i>	<i>-0.02%</i>	<i>--</i>
<i>221</i>	1,329.44	4,482.60	4,481.88	<i>237.18%</i>	<i>-0.02%</i>	<i>237.13%</i>
<i>222</i>	44,760.80	52,479.96	54,199.80	<i>17.25%</i>	<i>3.28%</i>	<i>21.09%</i>
<i>223</i>	194,290.80	191,520.08	194,991.76	<i>-1.43%</i>	<i>1.81%</i>	<i>0.36%</i>
<i>231</i>	7,315.08	9,348.60	10,796.92	<i>27.80%</i>	<i>15.49%</i>	<i>47.60%</i>
<i>241</i>	91,895.40	61,706.32	54,680.52	<i>-32.85%</i>	<i>-11.39%</i>	<i>-40.50%</i>
<i>242</i>	44,742.20	104,830.76	105,525.24	<i>134.30%</i>	<i>0.66%</i>	<i>135.85%</i>
<i>243</i>	90,875.64	105,694.84	105,695.92	<i>16.31%</i>	<i>0.00%</i>	<i>16.31%</i>
<i>244</i>	71,010.84	183.24	31.68	<i>-99.74%</i>	<i>-82.71%</i>	<i>-99.96%</i>
<i>311</i>	383,730.36	371,005.64	372,003.24	<i>-3.32%</i>	<i>0.27%</i>	<i>-3.06%</i>
<i>312</i>	95,882.12	80,726.92	80,876.88	<i>-15.81%</i>	<i>0.19%</i>	<i>-15.65%</i>
<i>313</i>	111,470.56	120,647.76	121,587.80	<i>8.23%</i>	<i>0.78%</i>	<i>9.08%</i>
<i>321</i>	57,222.16	50,003.36	18,340.00	<i>-12.62%</i>	<i>-63.32%</i>	<i>-67.95%</i>
<i>323</i>	25,709.68	34,062.12	35,683.00	<i>32.49%</i>	<i>4.76%</i>	<i>38.79%</i>
<i>324</i>	45,569.36	79,485.16	77,181.56	<i>74.43%</i>	<i>-2.90%</i>	<i>69.37%</i>
<i>331</i>	14,528.88	14,115.28	13,881.56	<i>-2.85%</i>	<i>-1.66%</i>	<i>-4.46%</i>
<i>332</i>	2,691.32	1,896.24	1,932.76	<i>-29.54%</i>	<i>1.93%</i>	<i>-28.19%</i>
<i>333</i>	10,093.04	8,123.40	38,962.96	<i>-19.51%</i>	<i>379.64%</i>	<i>286.04%</i>
<i>334</i>	574.72	699.00	574.72	<i>21.62%</i>	<i>-17.78%</i>	<i>0.00%</i>
<i>411</i>	58.00	40.00	39.96	<i>-31.03%</i>	<i>-0.10%</i>	<i>-31.10%</i>
<i>512</i>	2,538.16	3,295.04	3,294.88	<i>29.82%</i>	<i>0.00%</i>	<i>29.81%</i>
Total	1,567,776.6	1,567,776.6	1,567,776.6			

Table S4. Distribution of the surface of patches and corridors in the three designed ecological networks (ENs) according to the Corine Land Cover (CLC) classes.

CLC class	1990		2012		2018	
	<i>patches</i>	<i>corridors</i>	<i>patches</i>	<i>corridors</i>	<i>patches</i>	<i>corridors</i>
	<i>Surfaces [ha]</i>					
111	0.00	121.60	0.00	167.68	0.00	110.80
112	0.12	2,350.56	131.24	2,374.28	234.52	3,968.96
121	0.00	59.80	19.16	144.20	65.68	324.28
122	0.00	5.92	0.00	21.20	0.00	14.32
123	0.00	12.56	0.00	3.32	0.40	0.00
124	0.00	62.44	13.16	18.76	25.24	10.24
131	0.16	125.64	7.72	291.16	10.36	180.88
133	0.00	72.88	0.00	75.68	0.00	1.04
142	0.00	60.00	70.16	139.92	95.80	231.32
Subtotal	0.28	2,871.40	241.44	3,236.20	432.00	4,841.84
211	6.56	47,903.84	2,890.72	36,361.52	3,603.32	53,473.92
212	0.00	42.64	0.00	21.72	0.36	82.20
213	0.00	0.00	215.96	22.48	225.52	141.40
221	0.00	44.44	0.00	652.76	0.00	845.12
222	0.00	7,941.92	780.64	6,967.68	1,069.64	13,463.60
223	18.64	50,496.44	2,374.84	39,351.84	2,772.16	61,290.72
231	5.40	2,351.96	498.28	1,651.20	532.68	2,729.52
241	18.44	27,820.96	545.64	13,272.92	671.88	16,698.36
242	3.40	7,295.40	759.40	22,251.64	1,103.76	33,672.24
243	326.44	23,711.64	1,701.92	19,896.52	2,052.44	33,848.40
Subtotal	378.88	167,609.24	9,767.40	140,450.28	12,031.76	216,245.48
311	103,797.44	104,354.60	81,725.36	71,626.72	108,925.60	100,650.88
312	626.48	35,584.68	7,692.56	16,360.80	8,889.68	27,819.80
313	4,499.28	42,677.80	9,455.00	18,179.24	11,293.24	42,645.72
321	201.84	14,061.40	2,916.32	10,184.16	1,937.56	4,463.12
323	445.80	8,273.16	1,640.48	20,614.28	1,946.88	13,353.36
324	787.00	12,034.36	2,993.32	17,298.40	3,762.52	26,524.60
331	46.52	2,263.40	3,251.12	2,123.32	3,681.24	3,153.28
332	0.08	895.16	155.64	493.64	134.20	515.52
333	3.20	1,688.60	981.28	1,450.84	2,778.64	12,054.60
334	0.00	0.00	25.16	185.28	0.00	180.52
Subtotal	110,407.64	221,833.16	110,836.24	158,516.68	143,349.56	231,361.40
411	0.00	0.00	37.72	0.00	39.12	0.76
512	0.00	707.20	562.04	773.40	662.04	1,321.68
Total	110,786.80	393,021.00	121,444.84	302,976.56	156,514.48	453,771.16
% of the Calabria region	7.07%	25.07%	7.75%	19.33%	9.98%	28.94%
		32.14%		27.07%		38.93%