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Connectivity Study in Northwest Spain: Barriers, Impedances, and Corridors

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Abstract: Functional connectivity between habitats is a fundamental quality for species dispersal and genetic exchange throughout their distribution range. Brown bear populations in Northwest Spain comprise around 200 individuals separated into two sub-populations that are very difficult to connect. We analysed the fragmentation and connectivity for the Ancares-Courel Site of Community Importance (SCI) and its surroundings, including the distribution area for this species within Asturias and in the northwest of Castile and León. The work analysed the territory's connectivity by using Geographic Information Systems (GIS). The distance-cost method was used to calculate the least-cost paths with Patch Matrix. The Conefor Sensinode software calculated the Integral Connectivity Index and the Connectivity Probability. Locating the least-cost paths made it possible to define areas of favourable connectivity and to identify critical areas, while the results obtained from the connectivity indices led to the discovery of habitat patches that are fundamental for maintaining connectivity within and between different spaces. Three routes turned out to be the main ones connecting the northern (Ancares) and southern (Courel) areas of the SCI. Finally, this work shows the importance of conserving natural habitats and the biology, migration, and genetic exchange of sensitive species.

Keywords: connectivity; Natura 2000 Network; brown bear; fragmentation

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1. Introduction

Over recent decades there have been breakthroughs in many fields affecting human population development. This means great progress for humanity in terms of demographic changes, urban development, and growth in economic sectors such as industry, agriculture, and tourism [1,2], as well as a burgeoning of the infrastructure network connecting cities thousands of miles apart in only a few hours [3,4]. However, this growth has taken place over a short time and has not been planned from an ecological point of view. It has involved land-use change, habitat fragmentation and degradation, and damage to wildlife. These factors, alongside others, have resulted in the loss of biodiversity [5]. In particular, land use change has been identified as the main problem in biodiversity change [6,7], as it leads to the modification and loss of habitats.

In the European Union, the Natura 2000 Network comprises 27,661 sites covering 117 million hectares, making up 17% of the surface area of the European Union (EU) [8]. Specifically, 27% of the territory of Spain is within the Natura 2000 Network. One of the main objectives of this protection and conservation tool for natural areas is to maintain ecological connectivity between these areas. Article 10 of the Habitats Directive encourages Member States to improve the ecological coherence of the Natura 2000 network by managing the elements of the landscape that are of major importance for wild fauna and flora [9]. It refers to those elements that by their continuous, linear structure (such as rivers and 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.

In Germany, Italy, and Spain spatial connectivity has been found to be better across internal borders, while functional connectivity is better across international borders [10]. Several studies have been conducted to analyse fragmentation and/or connectivity between natural areas, taking different species as their reference. Debinski and Holt [11] conducted a literature survey and canvassed the ecological community to identify experimental studies of terrestrial habitat fragmentation. Crooks et al. [12] used developed high-resolution habitat suitability models to conduct comparative analyses and to identify global hotspots of fragmentation and connectivity for the world's terrestrial carnivores. There are also more specific research works on the species studied: Coulon et al. [13] have shown the importance of landscape composition for gene flow and structure in roe deer populations (Toulouse, France), and Mazaris et al. [14] examined how the current Natura 2000 network will perform with regard to the conservation of four birds of prey. One more recent study evaluated the effectiveness of wildlife crossings to provide genetic connectivity for two bear species [15].

We have analysed and characterized the fragmentation and connectivity for the Ancares–Courel Site of Community Importance (SCI), Cruzul-Agüeira SCI, in the northwest of Asturias and Castile and León (Natura 2000 Network), which is a potential expansion area for the brown bear. We have analysed connectivity between habitats, employing benchmarks that best define the permeability and displacement cost of bears in the area. Our goal was to establish, assess, and locate the impedances due to transport infrastructure, rivers, urban features, land use, and other barriers which are limiting dispersal corridors.

We have been working on the development of this methodology since 2012 through a project carried out in Galicia. First, we studied connectivity and fragmentation in three protected areas in northern Galicia. In this case, we selected as "type species" those that belonged to the mustelid family. After developing this methodology, we tested the model through "animal truth" That is, we checked with different field work if the model could be used as a pattern for these animals. The result was positive. Next, we continued working on this topic with other wild animals. At present, we are testing the model for the bear and for this reason we are publishing the model. Once this is published, we will continue with the results of the first project (the mustelid family) along with the data that we are presently collecting with respect to the bear.

After several years studying this model and making corrections after all the checks, we have created this model based on the expert criteria and knowledge along with the experiences of other similar studies, mainly those found in [16–19].

2. Materials and Methods

2.1. Study Area

The study was conducted in the O Courel and Ancares mountains (provinces of Lugo, Ourense, Asturias and León, Northwest Spain), covering roughly 684,169.50 ha (Figure 1). This area has an average altitude of 939 m and is located at the western end of the Cantabrian Mountains. The territory is part of the Natura 2000 Network included in the Ancares-Courel SCI. This study area is bounded in the north by the line between sub-basins of the main tributaries of the Miño, Sil, and Navia rivers.

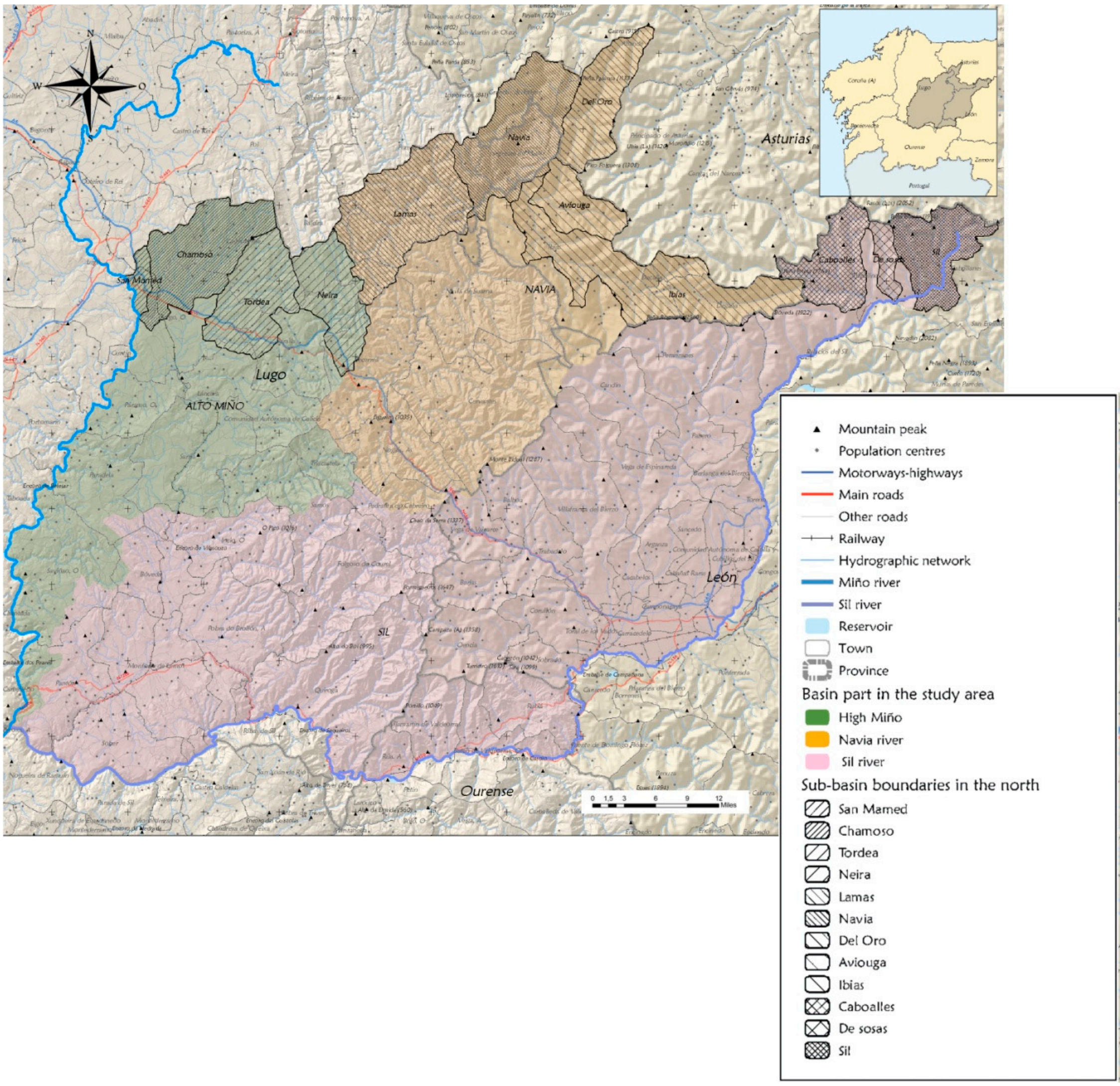

Figure 1. Study area.

The area of the Ancares belongs to the Eurosiberiana Region, the Atlantic-European Province, the Orocantabrica Subprovince, and the Laciano-Ancarense Sector. It presents an ocean mountain climate [20,21], with average annual rainfall of 2042 mm and an average temperature of 8 °C, while the average minimum temperature varies between −2 °C and 4 °C in the winter. The northern area (Navia) is slightly less rainy (1800 mm per year) and has the almost the same average temperature (9 °C). The Eurosiberiana biogeographic region borders the Mediterranean in the lower areas of the León slope. The very rugged relief is characterized as highly irregular and broken by the strong engagement of their valleys.

2.2. Fragmentation of the Habitat

The fragmentation analysis inside the protected areas used Environmental Units from cartographic material from the Territorial Biodiversity Information System [22]. These units refer to portions of the territory that have homogenous geological and ecological features, and, in addition, show the same response in the face of actions stemming from human processes and constitute the basic support element for planning and managing a natural space. The cartographic data corresponding to the units is a polygonal vector map for each natural space and its periphery area, with a minimum size of 0.5 ha in a shape format at a scale of 1:5000. All the 74 Environmental Units were regrouped according to their affinity, giving rise to 18 more generic units (Table A1 from Appendix A). Afterwards, the vector data were converted into raster format for which a pixel size of 10 × 10 m was defined.

Fragstats 3.3 software was used to carry out the fragmentation analysis [23]. The study was carried out on three different levels: (1) for each patch or tile, (2) for each class of habitat, and (3) for the global landscape of the study area being considered. In the first case, the different existing patches were defined as relatively homogenous areas in terms of their habitat and in the fact that they differed from those around them, as described by Freemark et al. [24]. At the second level of analysis, all the patches containing the same habitat type formed a single "class". The resulting spatial metrics describe the structure of the patches for each habitat class [25]. Finally, a "landscape"-level study was carried out, for which parameters were calculated that referred to the mosaic structure of the habitats forming the area being considered in the study. The set of parameters or metrics calculated in the three levels of analysis is summarized in Table A4.

2.3. Connectivity

2.3.1. Mapping Data and Data Pre-treatment

The connectivity analysis used cartographic data regarding land use and coverage from the Land Use Information System of Spain "*Sistema de Información sobre Ocupación del Suelo de España*" [25]. This data is in vector format at a scale of 1:25,000 and provides information about the percentage of each different land cover type making up each patch. The cartography concerning coverage and land use was transformed in the following way. Firstly, missing value errors were detected in some patches. Unless corrected, these errors led to "gaps", places with "no data" for usage or to places where different types of land coverage overlapped. The chosen solution was to put a value in those patches for land use from the Galician Territorial Information System [26]. Secondly, regrouping was performed on land uses in order to facilitate the connectivity analysis and to be able to unify homogenous uses (Table A2 from Appendix A).

For the connectivity analysis, cartographic data was used (Table A3 from Appendix A) referring to hydrography, the communications network, land use and the network of natural spaces for three different Spanish Autonomous Community regions (Galicia, Castile and León, and Asturias). The data was in vector format and converted to raster, and a pixel size of 10 × 10 m was defined, except in the case of the digital model of the territory, for which it was 25 × 25 m.

In order to carry out the connectivity analysis between the natural spaces, this study included leafy deciduous masses as they include species of community interest such as Galician–Portuguese oak woods of *Quercus robur* and *Quercus pirenaica*, chestnut woods (*Castanea sativa*), and priority habitats from the Habitat Directive (92/42/EEC) such as alluvial woodlands of *Alnus glutinosa* and *Fraxinus excelsior*, found in the Galician Natura 2000 Network. Furthermore, these masses play a fundamental role in the biology of the brown bear and that of a wide range of bird and other land mammal species [27].

The whole functional connectivity analysis was carried out using a Geographic Information System and ArcGis software (Ver. 9.3, Esri, Madrid, Spain).

2.3.2. Selection of the Reference Species

The choice of species type took into account that it had to be one with strict habitat requirements that included leafy woodland. The daily movement and dispersal distance also had to be compatible with the scale used in this work. For these reasons the brown bear (*Ursus arctos*) was chosen as it also ensured that the connectivity study included various mammal species such as those of Mustelidae and birds that are also linked to habitats of this type.

The bear is included in the Berne Convention on the Conservation of European Wildlife and Natural Habitats in Annex II of Directive 92/43/EEC [9], in Annex II of Law 42/2007 (catalogued as a species of community interest whose conservation requires special designated areas), and in Annex

V as a species of community interest requiring strict protection [28]. In Royal Decree 139/2011 [29], the brown bear is included in the maximum risk category as "in danger of extinction", in accordance with the Galician Catalogue of Threatened Species [30].

2.3.3. Choice of Sources

The sources are the areas containing the ideal habitats and possessing suitable features for the development of the chosen reference specie whose connectivity was to be studied. The brown bear's habitat requirements are an abundance of leafy deciduous woodlands combined with a specific diversity of other types, especially small areas with other uses such as mountain meadows, wetlands, thickets of berry bushes, and pinewoods. Artificial coverage is the least favourable. Deciduous woodland near river water courses and cool overgrown stream beds are favourable [27], especially for feeding, sheltering, and breeding.

With these requirements in mind, patches have been identified with impedance equal to or lower than 5 with a continuous area of over 25 ha and located within the limits of the protected spaces.

An impedance lower than 5 corresponds to patches in which the land use called "leafy deciduous" has a percentage of between 54% and 100% and is combined with other low-impedance uses such as mountain scrubland, pinewoods, and also meadows, peat bogs, and mountain wetlands. The variety of uses was, therefore, reflected positively in the impedance.

2.3.4. Assigning Impedances (Resistance to Movement)

Impedance is defined as the resistance that a particular patch puts up against the displacement of a type of species [31]. The resistance value for each raster cell is calculated according to the resistance values of each land cover type. For the species chosen the impedance of each pixel has been calculated according to the coverage of land use and its closeness to rivers, communication routes and population centres. The impedance of each pixel in the landscape matrix was calculated as:

$$I_{TOTAL} = (I_{USES} \times F_{RIVERS} \times F_{ROUTES} \times F_{CENTRES}) + I_{BARRIERS} \quad (1)$$

where each component was calculated in the following way:

(1) Impedance according to land use coverage (I_{USES})

A value between 1 and 100 was assigned to each patch with different land use coverage, according to the resistance it produces to movement of the reference species (from lower to higher resistance). The more the land use approaches that of the habitat types used for feeding or shelter, the less resistance it offers to species movement (Table 1.a). The impedance value (I) for each patch is obtained from the following formulas:

If the value of the main use takes up 60% or more of the patch surface:

$$I = (I_{max} + V_2)/2 \quad (2)$$

where

I_{max} = impedance value of the main use (Table 1).

V_2 is the area weighed average of the impedances of the uses present on the patch corrected with a factor that considers diversity. The greater the number of different coverages the larger the ecotone effect, and thus the chances the animal may have to cross are greater and the impedance value may be smaller.

V_2= average uses x diversity factor.

The diversity factor is a number smaller than 1 that is calculated with the formula:

$$Diversity\ Factor = 1 - (\frac{n-1}{30}) \quad (3)$$

where n is the number of different uses appearing on each patch. The number of potential different uses according to SIOSE land use categories is 30, with exceptions made for those considered impossible to cross (e.g., buildings).

If the value for the main use takes up less than 60% of the patch surface:

$$I = V2 \quad (4)$$

The result is a map in raster format, where each pixel has an impedance value somewhere between 1 and 100 depending on land use.

Table 1. Impedances.

(a) Land Use	Code	Impedance
Crops and meadows	S1	30
Forest woodland. Leafy evergreen varieties	S2	1
Forest woodland. Leafy deciduous varieties	S3	1
Forest woodland-conifers	S4	10
Scrubland	S5	10
Land with no vegetation	S6	40
Artificial covers	S7	100
Marshylands	S8	5
Beat bogs	S9	5
Continental waters	S10	70

(b) Distance to the Route	Impedance Increment Factor			
	Motorways–Highways	Main Roads	Other Roads	Railway
25	1.40	1.32	1.2	1.32
50	1.36	1.24	1.1	1.24
75	1.32	1.16		1.16
100	1.28	1.08		1.08
125	1.24			
150	1.20			
175	1.16			
200	1.12			
225	1.08			
250	1.04			

Note: (**a**) Impedance of the distinct land uses; (**b**) Impedance increment factor according to route type and the distance from it.

(2) Impedance Correction Factor Based on Closeness of Rivers (F_{RIVERS})

Riversides have been taken into account for the reference species, particularly those with good plant coverage or dense riverside woodland that favour connectivity. Therefore, the impedance must be corrected and decreased to take them into account. A correction factor was calculated for each pixel, that is, if it was within a certain distance from a river, the impedance value was decreased (favouring connectivity). A distance for an affected area of 100 m has been considered for this study and, if present, the impedance value was reduced by 20%.

(3) Impedance Correction Factor Based on Closeness to Communication Routes (F_{ROUTES})

Communication routes cause great resistance to the movement of organisms as they can lead to a greater death rate [32]. The areas around communication routes are also unfavourable for the chosen species to pass through or stay in, and they are generally avoided. Therefore, a correction is applied so that the impedance is increased along strips of land affected by them. In such a strip, the impedance is corrected by means of a factor that takes into account the type of route and the distance from it.

Thus, if it is nearby, the impedance is increased and connectivity is negatively affected, and the more important the communication route, the greater the increase (Table 1)).

(4) Impedance Correction Factor Based on Closeness to Population Centers ($F_{CENTERS}$)

Likewise, areas near population centres do not favour the movement of the species, so a correction is needed to increase impedance close to such centres. An impedance correction factor is calculated for each pixel that takes into account the distance from the population centre in such a way that the nearer it is, the higher the value. As well as the distance, the population size also affects the value of each pixel. A layer of population centres has been generated which shows the number of inhabitants in each one [33]. By using the "kernel density estimation" tool in ArcGIS, a layer was generated in which the impedance correction factors for each pixel were increased as the population centres were approached. In the field for population the number of inhabitants of each centre was chosen and in the field for "Search radius" a value of 2500 m was selected, as this is considered to be the maximum distance for any effect. The maximum impedance value was assigned to centres with over 1500 inhabitants, where the value was increased by 40%. For all the other centres the increase in impedance depended on the number of inhabitants. In areas where several centres were grouped together, the increase in total impedance for the area was greater than if they had been encountered individually.

(5) Barrier Impedance ($I_{BARRIERS}$)

The elements that represent impassable barriers for the chosen species had very high impedance values (1000). This is the case for communication routes that are fenced off, wide rivers, reservoirs, or water masses that cannot be crossed except in exceptional cases.

2.3.5. Distance Cost and Route Cost

From the impedance calculations and the resulting sources, the cost distances were calculated by using the Cost Distance tool in ArcGis. The cost value for each cell represents the minimum accumulated cost distance or displacement effort through the resistances matrix to the nearest source, taking into account the distance to it and the horizontal cost factors. Consequently, each cell of this map shows the functional distance to the nearest source, or the accumulated displacement cost between the source-points, taking into account the landscape matrix impedances and the distance existing between them. The grids included in the sources have cost 0. The cost is measured in cell equivalents [16,34]. That is, a value of cost "*n*" indicates the displacement cost through *n* cells with impedance 1, which would be the equivalent to the displacement cost through one cell with value "*n*". The cost distance multiplied by the width of the cell provides the effective distance in meters and kilometres [34].

2.3.6. Least Cost Paths

We have used a least-cost path analysis to obtain the effective distances between sources. This analysis makes it possible to identify the routes with least resistance between sources depending on the impedance values assigned to the distinct land uses and their layout [35]. It allows the least-cost distances (LCD) to be obtained, which are the cost-distance values, or the accumulated resistance of the least-cost path (LCP) between each pair of sources. The least-cost path between two sources runs through those parts of the landscape matrix for which the Pathmatrix program for Arcview 3.2 calculated the minimum accumulated resistance [36].

2.3.7. Connectivity Indices

Connectivity indices based on habitat availability were calculated using Conefor Sensinode 2.2 software to identify landscape elements that are critical for connectivity [35].

(1) Integral Index of Connectivity (IIC)

To calculate the relative importance value in the connectivity of each element as a habitat link, the Integral Index of Connectivity (IIC) was used [37]. The index is based on the combined use of Geographic Information Systems (GIS), graph structures, and habitat availability indices.

(2) Probability of Connectivity (PC)

The PC index was calculated [35]. This represents the probability of two points located randomly in the landscape being situated in habitat areas that are connected to each other. The PC index increases as connectivity improves and ranges between the limits of 0 and 1. The source patches were taken as the reference in order to calculate the indices.

(3) Relative Importance of Patches

In order to demonstrate the relative importance of the connectivity function of types of land cover in the source patches as habitat elements that are available for a specific wildlife species, a 500-m displacement distance was defined and attributed to any species capable of such dispersal and home ground range. The relative importance was calculated for each patch (Delta of the Integral Connectivity Index: dIIC or Delta of the Connectivity Probability: dPC, depending on which index was used). The individual importance of a patch was obtained by calculating the connectivity index for the whole landscape and observing the difference in the index's value when it was recalculated for a landscape from which one patch had disappeared [35,38].

At the same time, with a view to calculating the importance of each patch three different assumptions were made for analysis, depending on the dispersal distances (500 m, 5 km, 10 km, and 50 km) that had been defined for the brown bear, both for males and females with cubs. In this case the relative importance value was calculated for each patch: (1) "intra-patch connectivity" which represents the connectivity within one patch; (2) "flux-patch connectivity" which measures the amount of dispersal flux received by the other patches making up the landscape; and (3) "connector-patch connectivity" which is the patch's contribution to connectivity between other habitat patches as a connector element [38,39].

3. Results and Discussion

3.1. Fragmentation

3.1.1. Landscape Level

The density values (6.84 patches/km^2) and average patch size (14.62 ha) indicate a landscape mosaic of patches that are relatively large but above all very variable in size (Table 2). Most patches (49.4%) contain less than 1 ha, 27.6% between 1 and 5 ha, 13.7% from 5 to 20 ha, and 9.3% cover large areas (>20 ha). The indices that refer to their shape (shape index and fractal dimension index) point to the existence of irregularly shaped patches, which is positive because it indicates that the landscape has a certain "naturalness" [40]. The fractal dimension values approach 1, which suggests that there are few elongated patches and a scarce influence on the landscape of negative longitudinal elements such as roads (as in the study by Mateo-Sanchez et al. [41] on the same species in Cantabria), or positive ones such as mountain stream courses or riverside woodlands. This result may have been affected by the way the Fragstat program does its analysis, causing thin longitudinal elements to be interrupted and not taken as a single patch.

Table 2. Values for landscape level parameters, calculated using Fragstat for the protected space being studied and its surroundings. SCI: Site of Community Importance.

Parameter	Acronym	Ancares–Courel SCIs and Their Surroundings
Area (ha)	TA	108,420.42
Number of patches	NP	7417.00
Patch density per km^2	PD	6.84
Proximity index	PROX_MN	3756.92
Nearest neighbour distance mean	ENN_MN	113.08
Juxtaposition index	IJI	55.65
Patch richness	PR	11.00
Shannon's Diversity Index	SHDI	1.38

The value for habitat richness (Table 2) appears high bearing in mind that it represents the number of habitats present in the area being studied, and even more so if the regrouping of environmental units is considered, where a total of 18 different such units were distinguished (Table A1 from Appendix A). In order to gain a more accurate idea of habitat diversity the Shannon diversity Index (SHDI) can be analysed, which has a value of 1.38. This is a mid-to-high value when it is considered that the maximum index that could have been reached with the classes of habitat present would be 2.4. These results indicate that in this area the landscape is dominated by the presence of scrubland (47.48%), leafy deciduous trees (24.37%), and rural mosaic with hedgerows (17.14%), which together come to almost 90% of the surface area. The index for interspersion and juxtaposition (IJI) allows the nearness between patches to be known. This study obtained a medium value, which indicates that there is nearness of some coverage types and that the landscape is moderately mixed.

The richness of habitats (PR: the number of habitats present in the studied area) is 11, a high number bearing in mind that according to our regrouping of environmental units a total of 18 different such units are distinguished. The indices obtained for diversity and dominance (Table 2) indicate a landscape with a richness of environmental units that are fairly evenly spread out.

Regarding the density of patch richness, the area and its surroundings show maximum values (max. 7) where the richness density is greater and the landscape has more of a mosaic layout. It can be seen that the areas near water courses show high richness density due to these being areas where there are leafy deciduous trees forming a ramification system over the predominant class: mountain scrubland.

The values for the indices referring to isolation between patches of the same habitat are a measure of structural connectivity. In the mountain landscape of the Ancares-O Courel SCI, certain classes of habitat such as continental waters and the traditional rural mosaic become developed in the favourable land areas: low-altitude valleys and lower lands. Because of the mountainous character of the SCI, these valleys are dispersed, which conditions their ability to gain high average values for the distance to the nearest patch. This, rather than being due to landscape fragmentation caused by humans, can be explained through natural causes stemming from the lie of the land of such areas, which is something other studies have identified [42]. Regarding the results for the proximity index, very high values were obtained for the area being studied. This is due to the existence of continuous patches and a large surface area of mid and high mountain scrubland. However, the proximity values are conditioned by the shape of the space and by the fact that we are analysing the landscape in physical space and its nearest setting. Thus, when calculating the proximity index for each patch, the tools seeks patches of the same class within a 10,000 m radius and takes into account their number and surface area. So, at the extremities we are always going to have lower proximity indices because there are no patches in a large part of the circle.

Moreover, it can be seen that the proximity indices are high for scrubland, which indicates scarce isolation of these patches and, consequently, a good situation for this class of plant formation as it is hardly fragmented. Conversely, conifers have low proximity indices. This is due to the fact that those patches appear as dispersed, dotted around the large surface area of scrubland. The only exception would be the large mass of conifers located to the south west of O Courel. For the patches corresponding to leafy deciduous trees, the results obtained for the proximity index were quite high.

3.1.2. Class Level

The analysis at class level provides more useful information about the distribution and the state, in terms of fragmentation, of each class of habitat, or of each of the environmental units the study area was divided into. It can be seen that the richness of patches, which refers to the number of classes of habitat present in the space, is 11. In the SCI being studied we have obtained a diversity index that is not very high due mainly to the way in which the surface area is shared out among the environmental units. According to the results, the dominant environmental unit is scrubland (47.48%), followed by leafy deciduous trees (24.37%) and the rural mosaic of fields surrounded by hedgerows (17.14%). Below is an analysis of the results with the classes of vegetation that possess greater conservation value: (1) leafy deciduous trees, and (2) leafy evergreens.

Leafy deciduous trees are the second class of environmental unit that takes up a large percentage of surface area (Percentage of landscape: PLAND = 23.94%), after scrubland (Table 3). The leafy patches cover an average area of 9.71 ha and their surfaces areas are within the range of 0.01–2474.1 ha. In the SCI being analyzed and its surroundings, 67.6% of the leafy patches are of less than 1 ha, and 15.9% are of between 1 and 5 ha. There are 47 patches of over 100 ha in the heart of the Ancares–Courel SCIs and the surroundings. According to the theory of island biogeography, species biodiversity on an island, which can also be understood to be a patch of habitat surrounded by unfavourable habitat, depends on the size of the patch and its distance from others with the same habitat [43]. What that means is that patch size shows a clear correlation with the diversity of species it can shelter. The existence of large leafy patches is important for the maintenance of certain "inland" species native to leafy deciduous woodland such as pteridophytes and vertebrates such as forest birds and small carnivores with strict habitat requirements such as martins and polecats.

Table 3. Values for class level parameters calculated for the different types of environmental unit present in the protected space being studied and its surroundings.

Space	Land Use	CA (ha)	PLAND (%)	NP	AREA _MN (ha)	GYRA _MN	SHAPE _MN	FRAC _MN	PROX _MN	IJI
Ancares–Courel	Leafy deciduous	25957.81	23.94	2673	9.71	81.68	2.01	1.12	4129.64	56.30
Surroundings	Conifers	7124.16	6.57	314	22.69	166.85	2.06	1.12	1324.76	53.13
	Eucalyptus and other leafy plantations	2.79	0.00	3	0.93	42.38	1.45	1.09	0.00	55.96
	Acacias and other invasive species	13.84	0.01	5	2.77	90.78	2.12	1.14	26.36	53.83
	Rural mosaic of fields surrounded by hedgerows	18436.21	17.00	2347	7.86	96.95	2.16	1.14	1035.20	56.94
	Rural mosaic of fields without hedgerows	1199.65	1.11	164	7.31	113.14	1.85	1.11	67.22	58.34
	Scrubland	51961.15	47.93	1081	48.07	191.55	2.37	1.13	12824.18	60.11
	Peat bogs	77.16	0.07	44	1.75	57.80	2.04	1.14	6.08	61.01
	Leafy evergreens	418.78	0.39	44	9.52	135.41	1.99	1.12	39.91	62.58
	Artificial cover	1109.36	1.02	574	1.93	54.82	1.56	1.09	33.63	48.37
	Continental waters	2119.51	1.95	168	12.62	450.09	8.98	1.29	508.97	51.18

Note: CA = Area; PLAND =; NP = Number of patches; AREA_MN = Patch area mean; GYRA_MN = Radius of gyration mean; SHAPE_MN = Shape index mean; FRAC_MN = Fractal dimension index mean; PROX_MN = Proximity index mean; IJI = Interspersion & Juxtaposition Index, FRAC_MIN: fractal dimension.

As for the shape of the patches, the values for the compactness index GYRATE (Radius of gyration) indicate a large area of patches in the studied area (Table 3). The fractal dimension (FRAC_MIN) reaches low values (Table 3). This is due to the fact that the woodland types existing do not only develop because of the floors of stream beds, in a narrow strip on both sides of the water course, but also extend from the riverside area towards the hillsides. It can be seen that the greater indices of fractal dimension (1.29) have been obtained for the "continental waters" class. This class is made up of rivers and reservoirs, that is, longitudinal polygons that provide high indices of fractal dimension. Comparing the leafy deciduous patches with other classes of forest vegetation—conifers and leafy evergreens—it can be seen that they all have similar fractal dimension indices.

The SHAPE index has proved to be high in value in the studied area (SHAPE = 2.01), which indicates the leafy patches have complex shapes, a sign of a very natural landscape with little influence from fragmentation processes caused by humans.

The value obtained for the proximity index is very high (Table 3), which points to there being many large patches close to each other and that isolation is generally quite scarce. Comparing the proximity indices for leafy deciduous woodland with those for other classes of forest environmental units, it can be seen that the index for the deciduous ones greatly exceeds the others, even reaching four times that for conifers despite these also having a high index value. The juxtaposition index has medium-high values (Table 3), which is a sign of an interspersed habitat with a certain amount of juxtaposition.

At the same time, the leafy evergreens class of environmental unit is not present so much in the studied area (PLAND = 0.39%) There are 44 patches that come to a sum total of 418.78 ha. They are patches of considerable size as they have a surface area of at least 1 ha. In the studied SCI and its surroundings, 45.5% of the patches are within the 1–5 ha interval and 40.9% within the 5–20 ha interval. The GYRATE area variable was found to be high in comparison with the other classes analysed (Table 3), which indicates a high degree of compactness of the leafy evergreen habitats in the area being studied. The SHAPE index (1.99) has an intermediate value among the values obtained for all the other vegetation coverage types, just like the value obtained for fractal dimension. The average proximity index obtained for the leafy evergreen patches (39.91) has an intermediate value in relation to all the other habitats, which indicates an average continuity for these patches in the area studied.

3.2. Connectivity

3.2.1. Sources

A map was drawn up (Figure 2) with a total of 245 sources including the habitat patches for which the connectivity was calculated. This value is high because the area studied is rich in habitats that meet the characteristics needed to become sources. To make it easier to study the connectivity of these sources in the landscape, reference points from within them were chosen. A 3000-m-wide square mesh was superimposed on the source patch layer. The nodes coinciding with the source patches were selected as reference points. In source patches that are of interest or isolated, where there is no intersection point between the sources and the mesh, a point has been placed randomly within the source patch. In areas of high source patch density, a single reference point was selected. In this way a mesh made up of 50 reference points located on the source patches was finally used for the connectivity analysis (points-source).

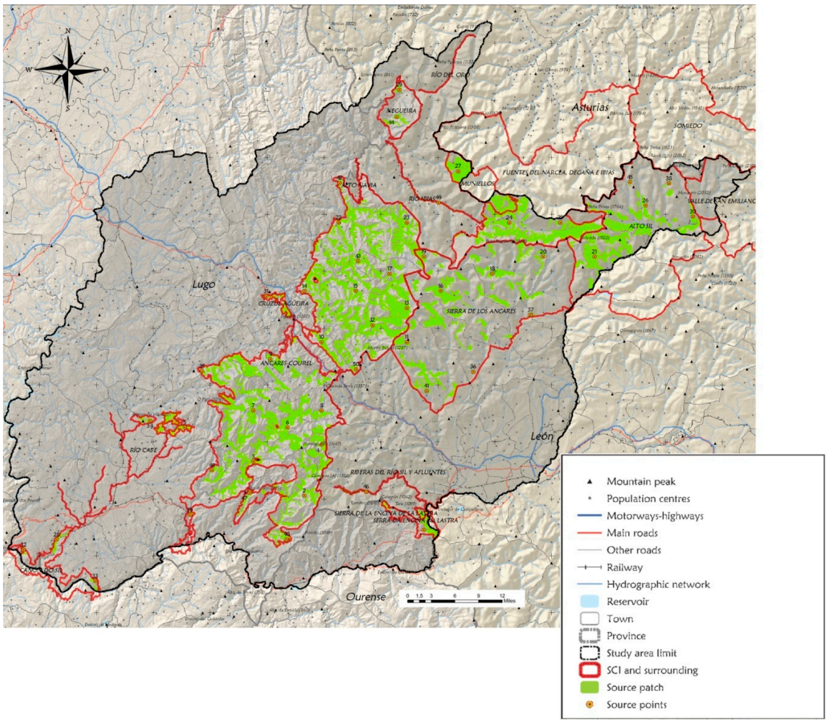

Figure 2. Location of the selected sources.

3.2.2. Cost Distances

A high level of connectivity (low cost distance) was seen in the strip that crosses longitudinally through the area of study from south to north (Figure 3). It corresponds to the areas included within the SCIs of Sil canyon (south area), River Cabe (north area), Cruzul–Agüeira, Ancares–Courel, Banks of the River Sil and tributaries, Sierra de la Encina de la Lastra, Serra da Enciña da Lastra, River Íbias, Alto Navia, Muniellos, Fuentes del Narcea, and Degaña eIbias. The areas belonging to the SCIs Sierra de los Ancares, Negueira, Oro River, Alto Sil, and Somiedo are, in general terms, areas with high connectivity although some areas and specific points can be found where connectivity is low. This is due to the presence of reservoirs and mining areas.

The SCI with the worst connectivity in the area is the Valle de San Emiliano. The reason for this is that it is located at the very end of the study area and has high impedance levels [44], in addition to being separated from the rest by a communications route. This is the line on which the population centres of Vilasante, Toiriz, and Ribas Altas are to be found.

Two large areas have been detected where connectivity has low levels: firstly, the strip following the river Miño to the northwest and, secondly, the area around Ponferrada to the southwest.

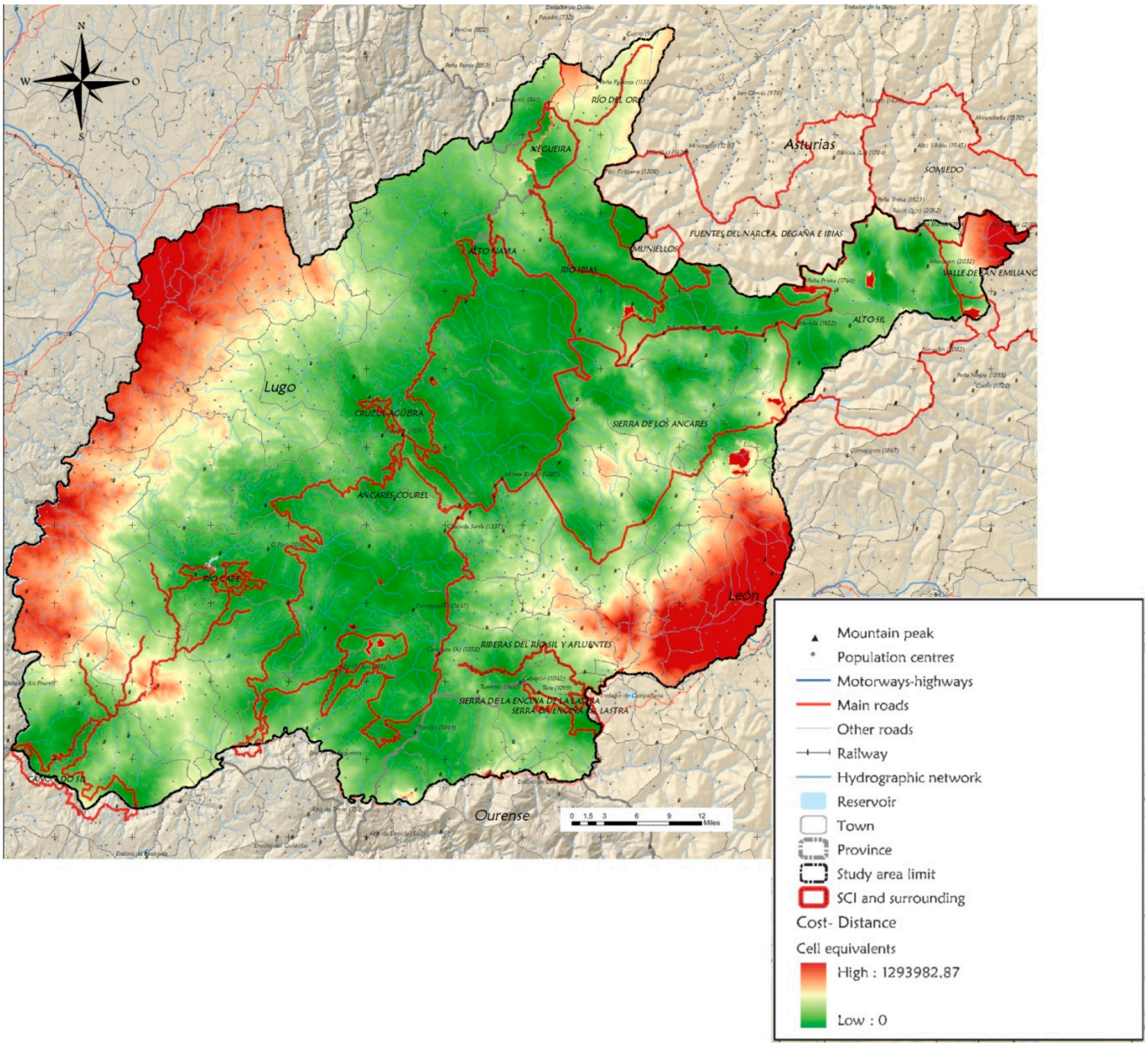

Figure 3. Distances in the study area.

3.2.3. Effective Distances between Sources

The greatest average cost distance for the least-cost paths between sources was obtained in the Sil Canyon SCI (Table 4), which indicates a worse habitat connectivity situation for the species in this space. In the River Sil Banks and Tributaries, Ancares-Courel, Cruzul-Agüeira, and Sierra de los Ancares SCIs, these distances turned out to be practically half those for the Sil Canyon, which indicates a better connectivity situation. These distances are a more realistic measurement for assessing functional connectivity than Euclidean distances for species with strict habitat requirements. They provide a measurement for isolation for each patch and the inverse of this is a measurement of connectivity [44].

Within the Ancares-Courel SCI, the range of values for accumulated cost of the least-cost paths was between 99.51 and 3699.56 km (Table 4). The minimum effective distance is 99.51 km, which means a theoretical species with a dispersal capability of ≥99.51 km through ideal habitat would be able to spread between both source-points. It should be borne in mind that suitable patches of habitat exist outside the protected spaces. These have not been identified as such in these analyses, which are aimed at assessing the Natura Network's connectivity, and thus when source-points were chosen for the connectivity study not all the source patches existing in the area were taken into account.

Table 4. Least cost distances between sources located in the distinct protected spaces: average, least and maximum cost in km of cost.

Origin Space	Number Paths that Leave the SCI	Average Value (km)	Minimum Value (km)	Maximum Value (km)
Alto Sil	90	2498.62	334.38	5404.21
Ancares–Courel	641	1445.04	99.51	3699.56
Sil Canyon	57	3027.02	309.89	5395.85
Cruzul-Agüeira	19	1482.87	553.51	2838.01
Fuentes del Narcea, Degaña E Ibias	51	1852.29	214.82	4339.63
Muniellos	23	1966.34	286.04	4064.79
Negueira	27	2386.44	891.39	4411.72
Banks of the river Sil and tributaries	4	1400.54	872.58	2177.99
River Cabe	62	1775.87	210.37	3683.38
Serra da Enciña da Lastra	49	2294.5	678.49	4116.23
Sierra de los Ancares	202	1672.39	144.02	4451.08

3.2.4. Least Cost Paths

A total of 1225 least-cost paths were generated that link the 50 selected source-points (Figure 4). Overall, 69.96% of the length of these paths runs within the Natura 2000 Network spaces. Inside the Ancares-Courel SCI there are a total of 1112 least-cost paths which run either partly or wholly within that area. It was found that 46.43% of the length of those paths was located within the park. By locating these paths, the areas that favour connectivity can be defined and critical areas identified.

Among the sources selected for the study area, the main passing area of the least-cost paths is the territory belonging to the Ancares-Courel SCI. There are three main paths linking the SCI's northern area (Ancares) with the southern one (Courel). The first route, located in the northwest, is in the area north of the population centre of Doncos. The other two are located in the southeast area —one near Pedrafita do Cebreiro and the other between the centres of Pedrafita do Cebreiro and Noceda. The Cruzul-Agüeira SCI also acts as a path linking both areas.

The least-cost paths are distributed over the area of study to form a network of routes, particularly across the Ancares-Courel SCI and the area to the southwest of it. This network crosses the A-6 Highway (a piece of infrastructure forming a major barrier within the territory) at 10 different points spaced practically uniformly along the road between the Cruzul-Agüeira SCI and the population centre of Villamartín de la Abadía. This is of great interest for the purposes of checking the real degree of connectivity, that is, the use by bears or other types of wildlife of these corridors, in order to evaluate their true importance in terms of connectivity [45].

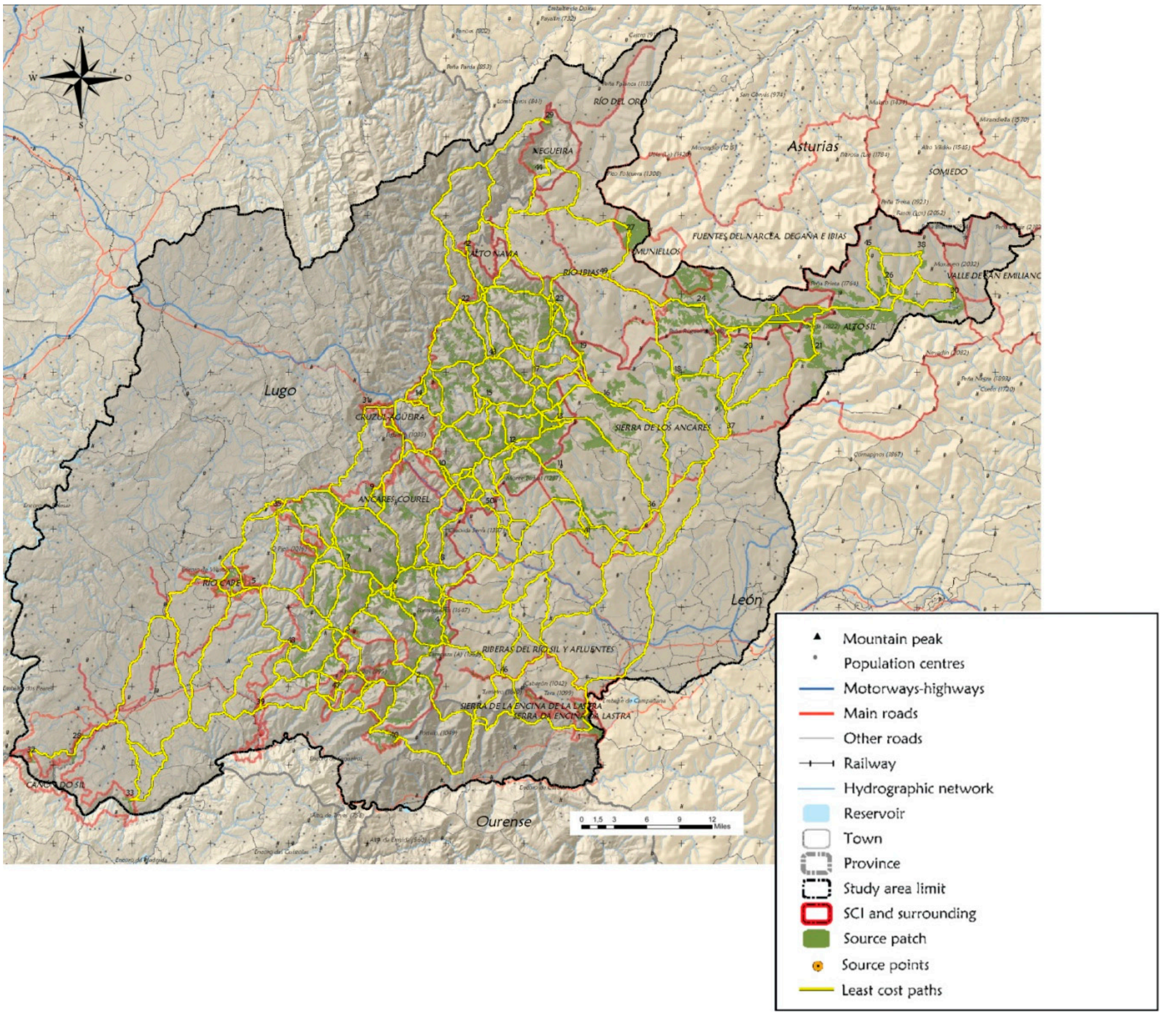

Figure 4. Cost paths obtained using Path Matrix.

3.2.5. Connectivity for Distinct Dispersal Distances

For the dispersal distance of 500 m, a total of 113 combinations of patch pairs that are connected to each other have been obtained, i.e., 9.22% of the cases, whereas over 90% of the combinations have no connection. Bearing in mind that these results are for a dispersal of 500 m, it can be said that there is a high number of connections.

Patches 23 (Ancares-Coures, Galicia), 24, 25 (Fuentes de Narcea, Asturias), and 26 (Alto Sil, Castile and León) have the greatest dA (% of the sum of the total areas in the landscape, corresponding to each parch), and therefore also have the greatest dPC and dIIC importance (Figure 5; Figure 6). That is, those patches can be identified as the most critical ones for maintaining connectivity. Also worth noting is that they are followed by patches 9, 22, and 35 located in Ancares-Courel (Galicia), and patches 21 (Alto Sil) and 36 (Sierra de losAncares) in Castile and León. All these patches are of great importance in maintaining connectivity between the 50 source patches, and particularly between and within the protected areas in the various autonomous communities [46].

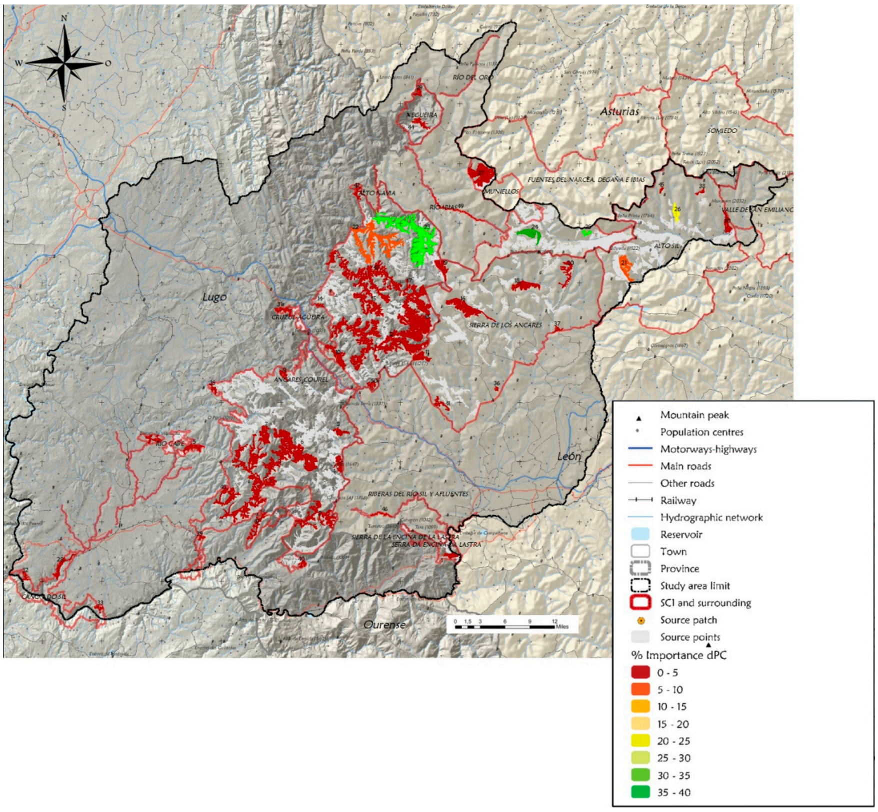

Figure 5. dPC importance (%) for a dispersal distance of 500 m.

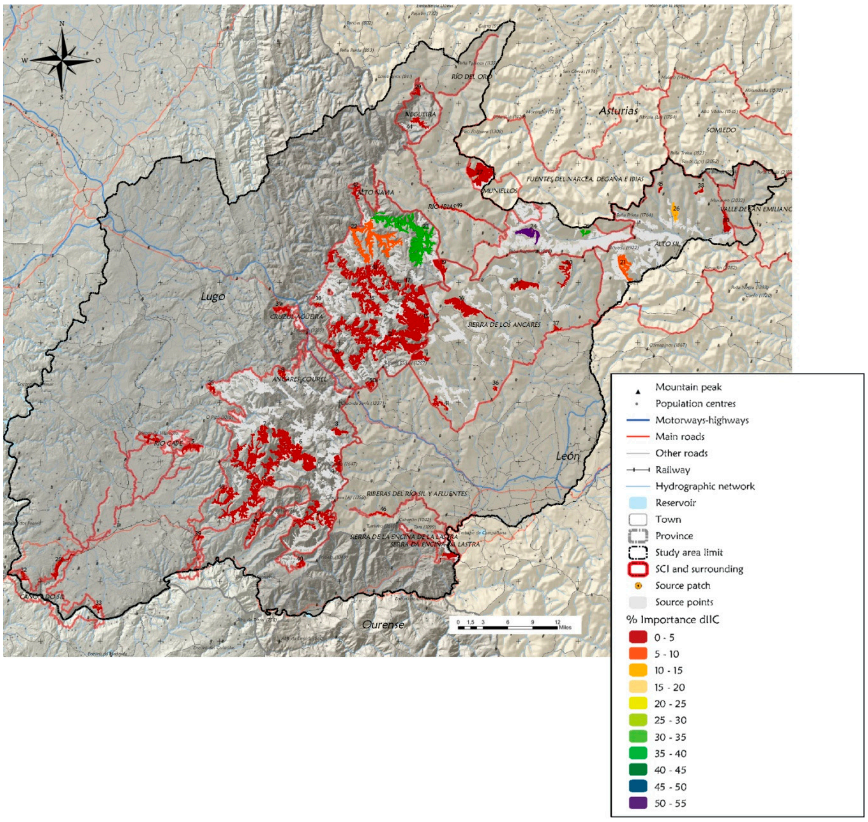

Figure 6. dIIC importance (%) for a dispersal distance of 500 m.

3.2.6. Influence of Connectivity in Decision Making

Assessing scenarios by means of a diagnosis of landscape connectivity is a highly relevant tool for decision making. This is because of its capacity to analyse the implications of possible future plans for conservation and sustainable development for the ecological integrity of the land. Taking measures to prevent and correct the negative impacts of fragmentation processes on habitats and wildlife populations requires comprehensive territorial strategies and instruments for regulation. A holistic approach to policy therefore plays a more important role in matters of land planning, urban planning, public works (roads, rail, and water), farming, forestry, and nature conservation. Likewise, procedures for assessing environmental impact and habitat fragmentation should guarantee integration of ecological land connectivity criteria. It should be pointed out that linear transport infrastructures are a particularly relevant factor in the degree of permeability that a landscape offers biological flows [47]. That is why, when it comes to planning their routes, ecological connectivity criteria must be taken into account so there is minimum impact. In short, routes should be those that are ideal in that they imply no major problems to connectivity.

The identification and characterization of the intersections between the landscape matrix and the artificial network of current infrastructures and future ones are fundamental when it comes to carrying out the landscape's connectivity diagnosis.

From the standpoint of connectivity, the diagnosis has important implications for the design of ecological conservation networks and the creation of green infrastructures or corridors. The definition of priorities for the protection, restoration and connection of areas of ecological interest on the basis of this type of criteria are considered fundamental [48–50].

At the same time, it is worth mentioning the reference from the Directive 92/43/EEC from the European Council regarding the conservation of natural habitats and wild flora and fauna [9], or the Habitats Directive on the need to improve ecological coherence of the Natura 2000 Network by means of management of landscape elements that are fundamental in order to guarantee migration, geographic distribution and genetic exchange of wild species. Given this need for instruments for managing natural spaces and the context of the European normative, it can be seen that there is a need in Galicia to increase scientific knowledge on habitat connectivity. Specifically, there appears to be an urgent need to investigate lesser studied aspects of spatial ecology of species: dispersal patterns, capacity for displacement in more or less hostile habitats, and so on.

Analysis of the landscape pattern and its relationship with functional connectivity requires methodological studies carried out from different levels of approach (ecosystems, biotopes, species sets, and specific species) and spatial scales of analysis [51]. These vary according to mobility and the living domain of the organisms or the size of the ecological processes being studied. It seems advisable to continue research along these lines.

As for the network of protected spaces in Galicia, it is worth pointing out that the network has meant an improvement in ecological connectivity, increasing the coherence of existing conservation networks and their possible enlargement. In this sense, there are some considerations to be made. Firstly, the design of coherent ecological networks must take into account the requirements for permeability of the landscape for the set of species that is negatively affected by the fragmentation of their habitats. Secondly, traditional uses as well as newly implemented ones are important in order to keep the landscape permeable to biological flows and to favour a mitigation of the edge effect of the matrix on natural spaces and the landscape elements that are of interest in terms of connectivity. Thus, policies for rural development, farming and livestock, forestry management, infrastructures, energy, and mining, play an important role when maintaining and restoring connectivity. Thirdly, coordination with other instruments for sector planning and the development of networks of natural spaces and interconnected habitats require models for assessment, design, and tracking. Putting into practice the management of these coherent networks implies active participation from the various agents and institutions involved. Fourthly, in terms of protected space management, there appears to be some difficulty when trying to take into consideration species whose capacity for dispersal is excessively limited, but also at the other extreme (when there is great capacity for dispersal). For this reason, it is more effective to take into account species with intermediate capacities for dispersal, for which the connectivity of their habitats can be analysed by GIS. Fifthly, as the economic resources available for land conservation and planning are limited, one suggestion is to prioritize the maintenance or setting up of ecological corridors between sensitive habitat patches, as well as the conservation or improvement of the quantity and quality of those that are fundamental for certain species with specific handicaps.

Generally, specialized species are used, closely linked to specific habitats for which the connectivity is of interest. Another criterion is that they have a capacity for dispersion appropriate to the scale of the work. For example, to evaluate connectivity between wetlands, birds could be used as Anatidae. However, their large displacement capacity makes them less sensitive to fragmentation, and only an analysis on a very broad scale would make sense. However, if an amphibian was chosen as a reference species, its displacement capacity will be very limited, in addition to requiring microhabitats, so a study with great level of detail would be necessary. This is not possible to address in an analysis with GIS based on land use mapping. On a landscape scale similar to that used in this study, it is common to use large and medium-sized mammals with a forestry vocation as a reference species [51]. These species move by land, have vital domains and dispersal capacities that make them sensitive to fragmentation [48], and in this way the connectivity of their habitats can be analysed, as is addressed in this study, with GIS and land use mapping. Analysing the connectivity from the point of view of these carnivores, we ensure the connectivity of various species of manifers such as mustelids as well as passerines and other birds which are less limited in their movements but closely linked to these types of forests. Some examples are the parties included in Annex II of the Berne Convention (Council Decision 82/72/EEC of 3 December 1981, concerning the conclusion of the Convention on the conservation of wildlife and the natural habitats of Europe).

4. Conclusions

This study has analysed and characterized part of the Galician Network of Protected Spaces from the standpoint of fragmentation and connectivity.

The proximity index can be considered as a measure of structural connectivity. In and around the Ancares–Courel SCI the proximity indices are generally very high, due to the existence of continuous patches of large areas of mid- and high-mountain scrubland. This indicates scarce isolation of these patches and, consequently, a good situation for plant formation in terms of its fragmentation. Conversely, low proximity indices were obtained for conifers. This is due to the fact that those patches appear to be scattered over the large area taken up by the scrubland. The results obtained for the patches of leafy deciduous trees showed that their proximity index had quite high values.

With the map of the cost distance for each cell, the areas with low cost values showing maximum connectivity can be outlined. Likewise, the key areas for connectivity can be more easily identified. These are where it would be more suitable to strengthen the landscape's connectivity to favour dispersal and displacement of organisms, particularly the brown bear. Measures that could be put in place include the conservation and recovery of pockets of leafy deciduous trees that are a priority for conservation as they are located in potential corridors for dispersal of the species. Likewise, it is important to conserve riverside woodlands and scrubland areas, above all those with berry thickets, copses between traditional crops, and continuous natural vegetation in stream beds. In short, locating least-cost paths makes it possible to define the areas that favour connectivity and identify critical areas.

Finally, connectivity indices enable identification of those habitat patches that are fundamental in order to maintain connectivity within one space or between spaces, depending on the species being studied (with its respective dispersal distances for males and females with young). They also make it possible to evaluate the importance of each patch and its contribution to the territory's connectivity.

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Appendix A

Table A1. Regrouping of SITEB (Sistema de Información Territorial da Biodiversidade) Environmental Units.

(a) SITEB Classification	Regrouping	Code
Coastal shoreline lagoons Offshore deep seawaters Near shore seawaters	Sea waters and coastal lagoons	1
Large reservoirs Flowing waters Still waters Small reservoirs	Continental waters	2
Small, seminatural wetlands with heavy use	Wetlands	3
Pinewoods Forestry plantations of allochthonous *Gymnospermae* Natural conifer woods	Conifers	4
Beaches Fossilized dune systems Active coastal dunes Consolidated dunes	Beaches and dunes	5
High peat bogs Low peat bogs Peat bogs with cover	Peat bogs	6
Waste tips and landfill Recreational routes and paths Overland communication routes Ports, airports and railways (not communication routes) Population centres		
Power supply lines Water supply and management infrastructures Farm, forestry and fish farming buildings Industrial or commercial buildings Abandoned buildings, farms and outbuildings Mines Sports, recreation or non-residential areas Temporarily disturbed areas	Artificial coverage	7
Forestry plantations of allochthonous *Gymnospermae* Eucalyptus woods	Plantations of eucalyptus and other leafy varieties	8

Table A1. *Cont.*

(a) SITEB Classification	Regrouping	Code
Gallery formation dominated by invasive species Formations of invasive species	Acacias and other invasive species	9
Forestry plantations of autochthonous species Birch woods Deciduous oak woods Beech woods Cork and deciduous oak woods Rain forest Seminatural sweet chestnut woods Large areas of ancient forest Large areas with ancient forest complexes Ravine woods	Leafy deciduous trees	10
Holm oak woods Holly woods	Leafy evergreens	11
Rocky eulittoral morphologies Slopes and raised coastal deposits Coastal cliffs	Rocky coastal morphologies	12
Mountain area rural mosaic Small enclosed rural plot mosaic Rural mosaic of fields surrounded by tree rows Rural mosaic of fields surrounded by bush rows	Rural Mosaic of fields surrounded by hedgerows	13
Rural mosaic of unaligned fields Rural mosaic of trained vines, crop fields and meadows Rural mosaic of vine terraces	Rural mosaic of fields without hedgerows	14
Large-scale continental wet grasslands Medium-scale wet grasslands	Wet grasslands	15
Large areas of irrigated intensive farmland Large areas of unirrigated farmland	Large areas of intensive farmland	16
Scrubland and limestone rocks Scrubland and mountain rocks Scrubland and serpentinic rocks Scrubland and siliceous rocks Scrubland and ultramafic rocks Wet continental scrubland Large areas of scrubland with harmless legumes Large areas of sub-sclerophyll scrubland Large areas of heath	Scrubland	17
Wet intradune depressions Estuaries Mudflats Large areas of shore reed beds	Coastal wet area	18

Table A2. Regrouping of SIOSE (Sistema de Información sobre Ocupación del Suelo de España) land cover.

(a) Description According to SIOSE	Regrouping	Code
Crops. Woody crops. Fruit trees. Citrus trees Crops. Woody crops. Fruit trees. Non-citrus trees Crops. Woody crops. Vineyards Crops. Woody crops. Olive groves Crops. Woody crops. Others Crops. Pasture and meadowland Pasture Crops. Herbaceous crops. Herbaceous crops other than rice Crops. Herbaceous crops. Rice	Crops and Pasture	S01
Forestry woodland. Leafy varieties. Evergreens	Forestry woodland. Leafy varieties. Evergreens	S02
Forestry woodland. Leafy varieties. Deciduous varieties	Forestry woodland. Leafy varieties. Deciduous varieties	S03
Forestry woodland. Conifers	Forestry woodland. Conifers	S04
Scrubland	Scrubland	S05
Land with no vegetation. Boulders. Rocky outcrops and boulders Land with no vegetation. Bare land Land with no vegetation. Burnt areas Land with no vegetation. watercourse Land with no vegetation. Glaciers and permanent snow Land with no vegetation. Boulders. Scree Land with no vegetation. Boulders. Quaternary lava outflows	Land with no vegetation	S06
Artificial cover. Artificial green area and urban treeland Artificial cover. Way, parking area or pedestrian area with no vegetation Artificial cover. Other buildings Artificial cover. Unbuilt-on land Artificial cover. Extraction area or tip Artificial cover. Building	Artificial cover	S07
Wet cover. Continental wetlands. Marshy areas	Marshy areas	S08
Wet cover. Continental wetlands. Peat bogs	Peat bogs	S09
Artificial cover. Artificial layer of water Water cover. Continental waters. Water courses Water cover. Continental waters. Layers of water. Lakes and Pools. Water cover. Continental waters. Layers of water. Reservoirs	Continental waters	S10
Water cover. Sea waters. Coastal lagoons Water cover. Sea waters. Estuaries Water cover. Sea waters. Seas and oceans	Sea waters and coastal lagoons	S11
Wet cover. Continental wetlands. Continental salt flats Wet cover. Marine wetlands. Mud flats Wet cover. Marine wetlands. Salt flats	Salt flats and mud flats	S12
Land with no vegetation. Boulders. Marine cliffs	Marine cliffs	S13
Land with no vegetation. Beaches, dunes and sands	Beaches, dunes and sands	S14

Table A3. Cartographic material from the various autonomous community regions used.

Entry Information	Proportional Scale
Land Belonging to Galicia	
Information on cover and land uses from SIOSE	01:25.0
Information on land uses drawn up by SITGA (Sistema de Información Territorial de Galicia)	01:25.0
Information on communication routes drawn up by SITGA	
Motorway and highway	01:25.0
Provincial roads	01:25.0
Main and complementary road network	01:25.0
Trunk roads	01:25.0
National network	01:25.0
Secondary network	01:25.0
Railway	01:25.0
Hydrographic network	01:25.0
Natural spaces	
SCI	01:05.0
ZEPVN (Zonas de Especial Protección de los Valores Naturales)	01:25.0
Digital Land Model (DLM)	01:25.0
Land Belonging to León And Asturias	
Information on cover and land uses from SIOSE	01:25.0
Digital Land Model (DLM)	04:20.0
Information on Communication Routes	04:20.0
Administrative boundaries	04:20.0
Hydrography	
Water basins to one sea	Generated from the 100×100-cell DLM
River or riverbed	04:20.0
Reservoir	04:20.0
Protected spaces	04:20.0

Table A4. Parameters related to fragmentation that were analysed with their English nomenclature, abbreviation, measurement units, and analysis level from which they result.

Parameter		Acronym	Unit	Calculation Level		
Total surface area	Area	AREA/CA/TA	ha	P	C	L
Patch perimeter	Patch perimeter	PERIM	m	P		
Area	Radius of gyration	GYRATE	m	P	C	L
Perimeter-area ratio	Perimeter-area ratio	PARA	-	P	C	L
Shape index	Shape index	SHAPE	-	P	C	L
Fractal dimension index	Fractal dimension index	FRAC	-	P	C	L
Proximity index	Proximity index	PROX	-	P		
Surface proportion of the class	Percentage of landscape	PLAND	%		C	
Number of patches	Number of patches	NP	-		C	L
Patch density	Patch density	DP	patches/km^2		C	L
Patch area mean	Patch area mean	AREA_MN	ha		C	L

Table A4. *Cont.*

Parameter		Acronym	Unit	Calculation Level	
Patch area standard deviation	Patch area standard deviation	AREA_SD	ha	C	L
Total edge	Total edge	TE	m	C	L
Edge density	Edge density	ED	m/ha		L
Area mean	Radius of gyration mean	GYRATE_MN	m	C	L
Perimeter-area ratio mean	Perimeter-area ratio mean	PARA_MN	-	C	L
Shape index mean	Shape index mean	SHAPE_MN	-	C	L
Fractal dimension index mean	Fractal dimension index mean	FRAC_MN	-	C	L
Proximity index mean	Proximity index mean	PROX_MN	-	C	L
Euclidean Nearest Neighbor Distance mean	Euclidean Nearest Neighbour Distance mean	ENN_MN	m	C	L
Interspersion & Juxtaposition Index	Interspersion and juxtaposition index	IJI	%	C	L
Patch Richness (PR)	Patch richness	PR	-		L
Shannon's Diversity Index	Shannon's Diversity Index	SHDI	-		L
Simpson's Evenness Index	Simpson's Evenness Index	SIEI	-		L

Note: P: parameter calculated at patch level; C: parameter calculated at Environmental Unit level; L: Parameter calculated at protected space level.

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