

# Proposal of new Natura 2000 network boundaries in Spain based on the value of importance for biodiversity and connectivity analysis for its improvement

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## ABSTRACT

The aim of the Natura 2000 Network is to ensure the conservation of habitats and species in their natural areas of distribution. Connectivity is an essential part of this conservation. For this purpose, a value map of importance for biodiversity (V.I.B) was generated proposing 4 levels of protection and overlapped with the Natura 2000 network. New boundaries for the zoning are proposed adding 1.600.000 ha. Two connectivity indices (MSPA and PC) are calculated in the 4 different scenarios. With these indices it is possible to know the number of existing nuclei and connectors in each of the scenarios. New boundaries cover more areas of interest for biodiversity as well as zones of great importance in relation to connectivity. We propose a uniform method that can be extrapolated to any European territory.

## 1. Introduction

Biological diversity means the “variability among living organisms of all kinds, including terrestrial and aquatic (marine and inland water) organisms, and the ecological complexes of which they are part; it includes diversity within species, between species and of ecosystems” (Council of the European Communities, 1992). This is the definition that was adopted by the 150 nations that signed the Convention on Biological Diversity at the United Nations Conference on Environment and Development (UNCED). According to the Rio Convention, the objective of biodiversity conservation is “the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including appropriate access to such resources and the appropriate transfer of relevant technologies, considering all rights over those resources and technologies” (Council of the European Communities, 1992).

Europe is home to a unique natural diversity, with areas of high

biodiversity globally recognized and protected under various protection figures. In addition, many of its species are threatened in Europe (European Environment Agency, 2005). Protected areas are essential for biodiversity conservation (Dudley, 2008). In this sense, proposals have been developed to combat the loss of biodiversity since the middle of the 20th century at national, European and international level (Velázquez, 2008). Systematic conservation planning is necessary to ensure the long-term maintenance of biodiversity (Groves et al, 2009).

One of the largest internationally coordinated actions of vital importance for biodiversity conservation is the Natura 2000 Network of protected areas in the European Union (EU). The main objective of this approach is to guarantee the persistence of the most valuable species and habitats in a long term perspective. These species and habitats are covered by the Birds Directive (Council of the European Communities, 2009), and the Habitats Directive (Council of the European Communities, 1992).

Therefore, the Natura 2000 Network is based on the Birds Directive

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(2009/147/EC), which declares the Special Protection Areas for Birds (SPAs), and the Habitats Directive 92/43/EEC, which will define the Special Conservation Areas (SCAs) and thus allows protecting habitats, flora and fauna of community interest. Important are the sites of community interest (SCIs), which will be understood as SACs when the appropriate management measures are applied to them, either through a Natural Resources Management Plan or a Master Plan for Use and Management. The member states are responsible for selecting the areas of community interest that will form part of the Network, as well as applying a conservation measure to them. Currently, the Natura 2000 Network contains more than 27,000 sites covering 18% of the land in the European Union (European Commission, 2016). The Habitats Directive already raises the importance of conserving or, where appropriate, improving the connectivity of the Natura 2000 Network. In Spain, there are 118 areas listed in Annex I and 263 species listed in Annex II to the Habitats Directive. On the other hand, there are 125 species listed in Annex I of the Birds Directive. All these species are present throughout the land and marine waters of Spain (Ministerio para la Transición Ecológica, 2019). The Natura 2000 Network in Spain currently comprises 1467 sites of Community importance (SCIs), which are included in the lists of SCIs approved by the European Commission, and 644 Special Protection Areas for Birds (SPAs) which cover a total surface of approximately 210,000 km<sup>2</sup>. Out of the total extension of the Natura 2000 Network in Spain, more than 137,000 km<sup>2</sup> represent the land area, which corresponds to about 27% of the Spanish territory, and about 72,500 km<sup>2</sup> to the sea surface (Ministerio para la Transición Ecológica, 2019).

To achieve the conservation objectives of the Natura 2000 Network, a good selection of important sites for biodiversity is necessary. This can be achieved by using values of importance for biodiversity (V.I.B.), through which the different conservation criteria such as habitats, protected species or land uses, are related. Based on this V.I.B., the best areas for the extension of the Natura 2000 Network will be selected, which would improve connectivity between these areas.

Many connectivity studies have been carried out in recent years, as a crucial part of biodiversity conservation planning (Hodgson et al., 2016; Olds et al., 2011). The systematic evaluation of conservation to improve connectivity should be highlighted in this regard (Correa et al., 2016; Begier et al., 2010; Bottrill and Pressey, 2012; Velázquez et al., 2017; Tian et al., 2017), and the fact that there is no legislation that establishes a better way to preserve natural areas as well as the lack of parameters and methods to select other new areas. Connectivity plays a transcendental role in the interactions between species and landscapes and is therefore a fundamental element in the structure of the landscape. The 21st century prototype of connectivity conservation is being pursued (Crooks and Sanjayan, 2006; Worboys et al., 2010) through hundreds of habitat network initiatives around the world (Bennett and Mulongoy, 2006). The Natura 2000 Network is created to provide connectivity to the natural spaces that compose it.

Ecological connectivity can be defined as the ability of a territory to facilitate to a greater or lesser extent the movements of species and ecological flows between habitat tesserae (Taylor et al., 1993). Connectivity makes genetic variability among different populations possible, as well as increasing not only the capacity to recover from any type of disturbance, but it will also enhance the guarantees of survival of populations against possible local extinctions (Saura et al., 2011). Ecological connectivity is currently affected and reduced by several processes, basically anthropogenic alterations such as changes in land use (agriculture, urbanization, construction of road infrastructures, etc.) (Gurrutxaga and Lozano, 2010). This type of alterations in the territory reduce the continuous surface of vegetation, and increase isolated areas, and therefore disconnected. This is known as habitat fragmentation (Forman, 1995). Such isolated zones that arise due to fragmentation may be like each other or have very different characteristics because of their new sizes, shapes, boundaries, etc. (Forman, 1995). For this reason, the existence of connectivity between the different natural spaces is

important (Ministerio para la Transición Ecológica, 2019). Ecological connectivity requires continuity and coherence of the landscape; in this sense, ecological corridors acquire high importance, since they act as connectors of significant regions for the conservation of biodiversity that decrease the negative effects derived from habitats fragmentation (García and Abad, 2014). Corridors work by linking two or more areas with similar environmental characteristics. In this way, they secure the conservation of ecological diversity and biological evolutionary processes through the migration and dispersal of species (Bennett and Mulongoy, 2006). In addition, the intensity of ecological flows is greater than in the rest of the territory (Simberloff, 1992).

These reasons show the need to conserve and restore protected natural spaces by improving the connectivity of the territory, given that it is a fundamental element for the survival of species (De la Fuente et al., 2018). Ecological connectivity is the most effective if it ensures preservation of zonal-specific communities that favour aboriginal species. At the same time, one should take into account that corridors may accelerate dissemination of invasive species as well which could become critical in highly transformed areas. Hence, measures to monitor and control, if possible, alterations in species composition of corridors are needed in some cases. Though the importance of ecological connectivity for animal migration is well-known, a planner should not ignore multifunctionality of corridors both in desirable and undesirable senses. On the one hand, high connectivity of zonal-specific communities in most cases ensures control over runoff formation, erosion, natural hazards (mudflows, landslides, extensive floods, etc.), and local climate. On the other hand, continuity of uniform land cover may result in rapid undesirable expansion of natural and/or anthropogenic disturbances. For example, in some xerophytic forest communities, management activity is aimed at artificial fragmentation of forest cover to prevent expansion of fire events. The challenge for connectivity studies is how to harmonize the needs to enhance natural ecological flows and to avoid detrimental effects resulting from disturbances. The objectives of the Natura 2000 Network can only be achieved through the optimal location of the areas to be protected; in fact, the establishment of nature reserves is a fundamental pillar of regional conservation strategies (Myers et al., 2000; Maiorano et al., 2007; Kingsland, 2002), since the establishment of biological reserves in habitats is a tool for combating biodiversity loss (Batisse, 1982; Chazdon et al., 2009). The provision of information as well as criteria to identify conservation priorities is the main objective of the ecological assessment (Roberts et al., 2003). Therefore, in order to select protected sites, it is absolutely necessary to define specific criteria for the conservation of biological diversity (Geneletti and Van Duren, 2008). In this sense, the optimal selection of sites to be protected is the foundation on which the decision-making process for nature conservation should be based (Hernando et al., 2010; Teeffelen and Atte, 2008). Some methods have been applied at the national and international levels to identify protected areas that act as nature reserves where the representation of diversity is maximized (Pressey et al., 1996; Margules and Pressey, 2000; Xu et al., 2017; Cantú et al., 2014; Gaston et al., 2006). For all these reasons, Member States must acquire clear criteria whereby it is possible to identify and define protected areas at the European level in order to improve conservation and nature protection (Förster and Kleinschmidt, 2006).

The purpose of this work is to determine whether the areas included in the Natura 2000 Network proposed by the Autonomous Communities (Andalucía and Castilla y León) have been correctly assigned and delimited considering their environmental values. The proposal of these new Natura 2000 network boundaries will allow us to evaluate the current ecological connectivity capacity of the habitats of the study area.

## 2. Material and methods

### 2.1. Study area

The study area focuses on the two largest regions/autonomous

communities in Spain: Andalucía, which has a total area of 87.599 km<sup>2</sup> and Castilla y León, which has a total area of 94.224 km<sup>2</sup> (Fig. 1).

Natura 2000 Network in Andalucía covers a total extension of 2.67 million hectares. Of this total, 2,59 million hectares are terrestrial and only 0,07 million are marine areas. In this way, are distinguished 63 Special Protection Areas (SPA), 190 Sites of Community Interest (SCI) and 163 Special Conservation Areas (SCA).

The Natura 2000 Network in Castilla y León is made up of 70 SPAs, with a total surface area of 1.997.977 ha, and 120 SCAs, with a surface area of 1.890.600 ha, representing 21,20% and 20,06% of the region respectively, taking into account the overlap between different areas, the total surface area of the Network in Castile and Leon is 2.461.759 ha, occupying 26,13% of Castilla y León (Fig. 2).

## 2.2. Methodology

The proposed methodology for the analysis of biodiversity in Andalucía and Castilla y León, as well as for the assessment of connectivity of Natura 2000 areas, presents four different phases (Velázquez et al., 2017; Rincón et al., 2019):

- **First phase (Cartographic database):** The aim of this phase is to carry out an inventory, where relevant information for the analysis of the biological diversity of the protected zones will be collected. The selection criteria to be considered will also be established at this stage.
- **Second phase (Analysis and assessment of important areas for biodiversity conservation):** A multi-criteria analysis is carried out to obtain a map of the Value of Importance for Biodiversity (V.I.B.) in Andalucía and Castilla y León. Once the V.I.B. in the study area has been calculated, a map will display the different values of importance for biodiversity.
- **Third phase (Study of the layout of the Natura 2000 network and zoning proposal in Andalucía and Castilla y León):** Generation of scenarios for a proposal of zoning for Natura 2000 conservation. In this way, a new zoning proposal is obtained for 4 different scenarios, which has considered the V.I.B., the different land uses (CORINE Land Cover 2012 by Copernicus) and the areas currently included in the Natura 2000 Network.
- **Fourth phase (Analysis of connectivity at different levels of biodiversity importance):** Connectivity analysis for the different zoning scenarios of Natura 2000 sites in Andalucía and Castilla y

León is obtained. On the one hand, structural connectivity Morphological Spatial Pattern Analysis (MSPA) (Attorre et al., 2007) will be analysed, it measures the number of connecting elements present as cores or ecological corridors in the study area. On the other hand, the second index that we applied is the Probability of Connectivity (PC) (Attorre et al., 2007). This index measures the importance of each of the connecting elements previously analysed by means of structural connectivity.

The following figure (Fig. 3) shows an outline of the phases to be followed in the methodology.

### 2.2.1. Phase I. Cartographic database

The factors selected for this work are the percentage of amphibians, birds, mammals, fish, reptiles and total fauna; species included in N.C.E. S.; species included in Habitats Directive and Birds Directive; percentage of protected habitats and Shannon Biodiversity index (Shannon and Weaver, 1949).

Cartographic information for each factor has been taken from reliable databases of the following public administration websites. These sources are:

- **Habitats Directive Protected areas.**
- **Habitats Directive Protected species.**
- **Birds Directive Protected Species.**
- **Corine Land Cover (CLC) 2012.**
- **National Biodiversity Inventory (NBI):** NBI consists in a grid of 10 × 10 km. In each cell of the grid, the different species of mammals, reptiles, fish, birds and amphibians are counted. These data are very relevant to determine the species richness in the study area, according to the existence of species in the grid.
- **National Catalogue of Endangered Species (NCES):** NCES includes the taxa or populations of the threatened biodiversity. In the catalogue there are categories that the species are confronted with: critically endangered, endangered species and vulnerable species.

At this stage, the evaluation and selection of the main criteria to identify the most suitable location for the areas that require protection under Natura 2000, according to their biodiversity value, was also addressed. From the information collected, the indicators whereby it is possible to evaluate the biodiversity of a site have been used to define the criteria (Rincón et al., 2019).

### 2.2.2. Phase II. Analysis and assessment of important areas for biodiversity conservation

The main objective of the second phase is to carry out an analysis and to process of the information. This is carrying out and processing information through a multi – criteria analysis and based on the results we will obtain a map of the Value of Importance for Biodiversity (V.I.B.). Therefore, multi-criteria analysis aims to establish a V.I.B. that functions as a valid criterion and can be considered for decision making in biodiversity conservation.

To achieve this goal, each criterion (Table 1) was first evaluated by a group of 5 experts (academic experts in connectivity, biodiversity management experts, members of the public administration and others stakeholders) establishing a weight ranging from (1–5). It is understood that value 1 is the least important for biodiversity, with 5 being the most important. The experts were selected according to their experience in research, biodiversity management and conservation and organizations for the preservation of biodiversity (Rincón et al., 2019).

Multicriteria analysis is used through Multi-Attribute Utility Theory (Attorre et al., 2007). The scores for each criterion are summed (Lott, 1926). This method is considered one of the best designed systems in the world (Eraslan, 2013). The scoring method has three characteristics: the use of rating factors, the factors are graded on a numerical scale and the weights reflect the importance of each factor (Milkovich et al., 2014).



Fig. 1. Study area. Regions of Andalucía and Castilla y León in Spain.

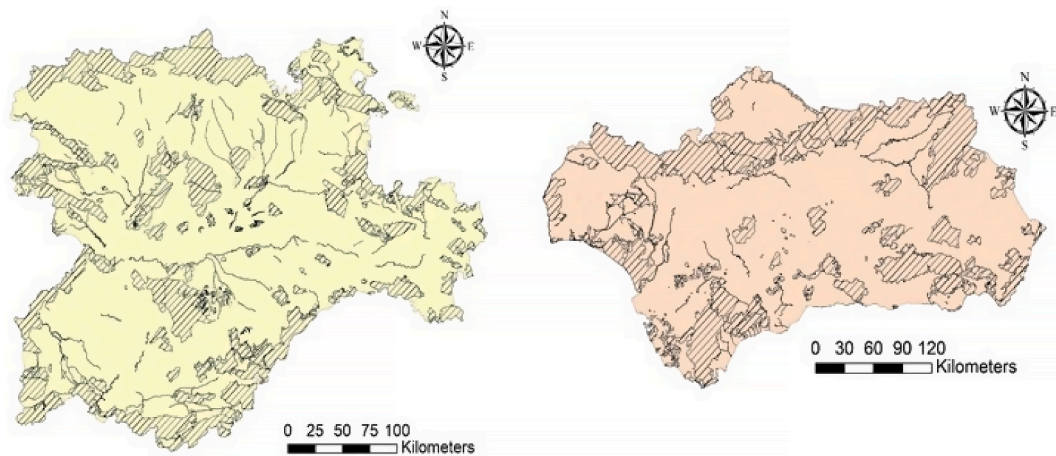


Fig. 2. Natura 2000 Network distribution in Castilla y León and Andalucía.

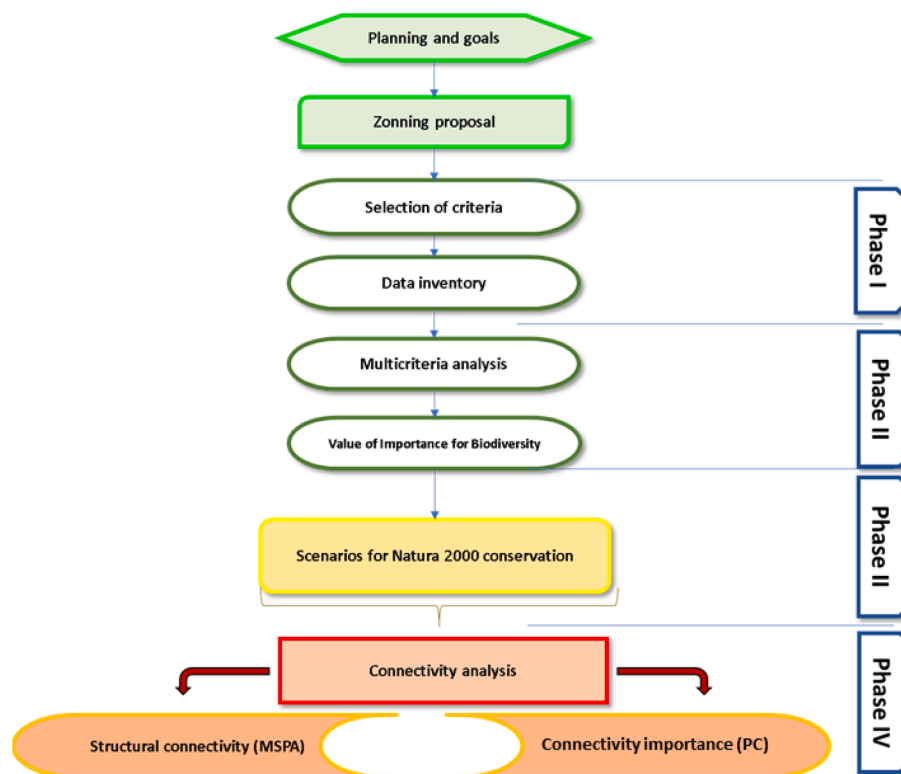


Fig. 3. Methodology for the analysis of connectivity of Natura 2000 areas.

Table 1

Pixel 1 Structural connectivity data in Andalucía.

Activity	Structural connectivity (MSPA): Pixel 1									
	Natura 2000 Network		Level 1		Level 2		Level 3		Level 4	
	Study area (%)	Andalucía (%)	Study area (%)	Andalucía (%)	Study area (%)	Andalucía (%)	Study area (%)	Andalucía (%)	Study area (%)	Andalucía (%)
<b>Cores</b>	97.67	15.72	97.37	30.99	97.04	19.51	97.09	18.57	97.38	17.62
<b>Islets</b>	0.13	0.02	0.10	0.03	0.10	0.02	0.10	0.02	0.11	0.02
<b>Perforations</b>	0.05	0.01	0.09	0.03	0.18	0.04	0.27	0.05	0.30	0.05
<b>Edges</b>	1.87	0.30	2.16	0.69	2.46	0.49	2.31	0.44	1.98	0.36
<b>Loops</b>	0	0	0.01	0	0.01	0	0.01	0	0.01	0
<b>Bridges</b>	0.09	0.01	0.09	0.03	0.07	0.01	0.07	0.01	0.08	0.01
<b>Branches</b>	0.18	0.03	0.18	0.06	0.14	0.03	0.15	0.03	0.15	0.03



From these scores, a parts per unit of the total is calculated. This method is used to evaluate various solutions taking into account selected criteria. The following equation is used for this purpose:

$$VIB : p_1u_1(x_{i1}) + p_2u_2(x_{i2}) + \dots + p_nu_n(x_{in})$$

Where:

$p_n$  = weights

$u_n$  = Subjective utilities

$x_{in}$  = Actions under analysis

The table in appendix A.1 shows the description and the different weights obtained for each criterion.

Taking into account the obtained weights, they are applied to the different values of each criterion that each 10x10 km grid has. By doing the summation, the V.I.B. for each grid is obtained and thus the V.I.B. map can be created, achieving one of the objectives of this work: the creation of a map showing the areas with the most important biodiversity values, according to the Natura 2000 framework.

The generated map of Value of Importance for Biodiversity (V.I.B.) is obtained by means of the resulted values from phase II. This step was achieved by interpolation of V.I.B. for the 10 × 10 km grid of the National Biodiversity Inventory.

Each grid is assigned a value (V.I.B.). In order to perform the interpolation, the centroid of each grid is calculated and the V.I.B. value is assigned to it. Once the values in points are available, the interpolation is done. An important feature of the method is that it has a low range of error compared to other methods. Specifically, this range of error is  $R^2 = 7,1688$ . In addition, this method uses statistical models that give us the possibility of obtaining prediction models, standard errors of prediction, probabilities (Rincón et al., 2019).

Once the interpolation method has been set up, a map of value of importance for biodiversity (V.I.B.) is generated, this one is linked to the map of the Natura 2000 Network sites in Andalucía and Castilla y León.

### 2.3. Phase III. Study of the layout of the Natura 2000 network and zoning proposal in Andalucía and Castilla y León

Within this third phase, the main objective is to obtain the different scenarios (different zoning levels to calculate connectivity) in the study area. For this purpose, a combination of the V.I.B. and the land uses (CORINE) is carried out for the zoning we were selecting among 4 levels (level 1, level 2, level 3 and level 4) being level 1 the most restrictive. Land use in each zone was expected to be well-adapted to landscape conditions, need for nature protection and enhancing connectivity.

The areas that obtained higher values of V.I.B. were combined with the current land uses (CLC 2012) to define the new zoning of the Natura 2000 Network.

Urban-industrial covers were eliminated in this process because they are not important for biodiversity conservation.

In each of the land use zones, it was possible to classify the distribution of the V.I.B. according to the V.I.B. quartiles. If the V.I.B. value belonged to the first quartile (i.e. 25% of the highest values) the highest level on protection was recommended for a polygon. The value within the lower quartile required the least strict protection measures or no such measures. A classification of these polygons into 4 levels of protection was made according to both the ideal land uses for such conservation and the criteria for biodiversity conservation.

Protection levels were then identified (Table A2), they were grouped depending on the type of protection and the given level by various land use classifications. Considering the level of protection, the zones can be grouped according to the characteristics of importance for biodiversity in the study area (Rincón et al., 2019).

In this way, a new zoning proposal was obtained for 4 different scenarios, which has considered the value of importance for biodiversity

(V.I.B.), the different types of land uses, (CLC 2012), and the zones currently included in the Natura 2000 Network.

#### 2.3.1. Phase IV. Analysis of connectivity at different levels of biodiversity importance

After executing the previous phases, we are about to execute the connectivity analysis (structural connectivity analysis).

The maps and values derived from the previous phase serve as input for connectivity analysis which has been developed through the Guidos software (Vogt, 2016; Vogt and Riitters, 2017), analyzing connectivity among the different scenarios generated from the Value of Importance for Biodiversity (V.I.B.).

The Morphological Spatial Pattern Analysis (MSPA) is based on a mathematical analysis of morphological patterns and can classify the main core habitats, connectors and isolated areas of a given territory (Hernando et al., 2010). Thanks to this categorization, spatial patterns at pixel level can be shown on a map, making very sensitive variations over time (Saura and Pascual-Hortal, 2007). In this case, we will carry out the analysis with three different pixel sizes, so that comparative results can be obtained between the different edge sizes (Pixel 1, Pixel 2 and Pixel 3 in MSPA program). The preparation of these maps have been introduced in the program Guidos, which is responsible for development of connectivity in the study areas. To this end, the maps of differing levels of biodiversity are introduced in ".tiff" format.

As mentioned above, there are 4 different levels of maps and therefore, 15 maps will be produced, one for the analysis of the Natura 2000 Network, and another for the connectivity of each of the levels in 3 different pixels. Pixel 1, where the cores predominate over the connectors, and as the number of pixels increases, the surface of the cores decreases and the size of the ecological corridors increases. In this way, we have pixel 2, which is an intermediate level, and pixel 3, which obtains the highest corridor surface area values.

A reclassification of the map value is then established:

- **Foreground:** The value in the foreground indicates the areas protected or to be protected at the different levels.
- **Background:** The study areas that are outside the foreground.

When running the analysis of each pixel input to the program, included as an area of interest, each pixel is assigned to an MSPA class. In this way, the input foreground image will have an identical surface to the output image with class assignment (Vogt, 2016).

The MSPA classes defined are as follows (Saura and Rubio, 2010):

- **Core:** Represents the inner surface of habitats that is not altered by the edge effect.
- **Islet:** These are habitats that are isolated and, due to their limited size, cannot form a core.
- **Bridge:** These are connectors that establish a relationship between one core and another. They are recognized as effective corridors.
- **Branch:** Linear connector of pixels that joins a bridge, loop, perforation or edge at each end.
- **Loop:** Narrow surface of pixels connecting a single core within a hole.
- **Perforation:** Perimeter surrounding an area of background within a core.
- **Edge:** Perimeter of pixels that includes each core unit.

Analysis of the connectivity importance (PC):

The PC (Probability of Connectivity) index makes it possible to assess functional connectivity based on habitat availability, dispersal probabilities and graph structures (Soille and Vogt, 2009). As shown by Saura and Rubio (2010) the dPC importance values for each landscape element can be divided into three fractions that quantify the different ways in which that landscape can contribute to habitat connectivity and availability:

$$dPC = dPC_{intra} + dPC_{flux} + dPC_{connector}$$

where dPC is the amount of area connected (intrapatch connectivity), dPC<sub>intra</sub> is Available habitat area provided by patch, dPC<sub>flux</sub> is the potential amount of dispersal flow expected to exit or reach a habitat patch, dPC<sub>connector</sub> is the extent to which a particular landscape element acts as a connecting or stepping stone between other forest habitat areas (by cores and bridges) (Saura et al., 2011).

Velázquez et al. (2017) recommends the application of this index for the analysis of connectivity due to its capacity to reflect habitat loss and landscape fragmentation.

From the previously performed MSPA analysis, a network composed of cores and bridges can be extracted, without considering the rest of the analysis classes (Vogt, 2016). In order to analyze the importance of connectivity, the significance of cores and links is studied using the dPC index (Percentage variation in Probability of Connectivity). This index measures the percentage reduction in connectivity that would occur due to the loss of a given core or link (Saura and Rubio, 2010).

This analysis has been carried out for the 5 scenarios (actual proposed scenarios “levels 1–4”) mentioned above with 3 different edge sizes (Pixel 1, 2 and 3) for each scenario.

### 3. Results and discussion

#### 3.1. Natura 2000 network layout

Once the interpolation method has been implemented, a value map of importance for biodiversity (V.I.B.) is generated, which is linked to the map of the areas of the Natura 2000 Network in Andalucía and Castilla y León (Fig. 4) (Rincón et al., 2019).

These maps show the degree of correspondence between the values of importance for biodiversity in Andalucía and Castilla y León and the boundaries of Natura 2000 Network. In this way, it is possible to verify the disposition of the territories according to pre-established criteria of great importance for conservation (Rincón et al., 2019).

The maps analysis indicates that not all regions with a high biodiversity value are currently included in the Natura 2000 Network and therefore, through this work, it has been possible to develop a clear and concise methodology for a correct zoning of the Natura 2000 Network in relation to the conservation of natural areas with a significant biodiversity value. According to Velázquez et al. (2019) there is a relationship between areas with higher species richness and areas with good connectivity.

There are limitations to applying this methodology, the most important of which is the state of the data, which can vary from state to state, making unification more complicated. In addition, it should be borne in mind that each country has its own data, possibly with different grid sizes, and some data may be out of date.

#### 3.2. Proposals for zoning of the Natura 2000 network

The relevance of this study is its application for an adequate management and conservation of the Natura 2000 Network in the member states of the European Union, guaranteeing the natural resources of each area. This facilitates planning for conservation or restoration measures for protected natural areas. For this purpose, we will propose a uniform and simple method, so that it can be extrapolated to any European territory.

Following the application of the methodology explained in phase III, 4 levels of protection have been established (Figs. 5 and 6), ranging from 1 to 4, so that level 1 denotes the most exclusive zones, made up of the spaces with the highest V.I.B., while level 4 has the greatest non-realistic number of the potential areas for biodiversity conservation comprising almost the whole province. Each one of the protection levels is overlapped with the areas of the Natura 2000 Network and are presented as zoning proposal (Rincón et al., 2019).

Based on the available data, new boundaries have been proposed adding 1.600.000 ha under Natura 2000 network. In this way, the areas included in the SCIs and SPAs have a certain V.I.B., and this can be seen on the conclusions section (Rincón et al., 2019).

This zoning has been done starting from the V.I.B. map generated in the previous phases. Thus, it is quite consistent that the Natura 2000 Network does not cover all the proposed areas and that have a high biodiversity interest value. On the other hand, it is possible to observe zones that do not have a great V.I.B., and that are included in the Natura 2000 Network (Rincón et al., 2019). As indicated in the methodology, each of the proposals has been based on biodiversity criteria which makes possible a clear vision of the territories of greatest importance in terms of conservation and protection of the environment.

#### 3.3. Structural connectivity analysis (MSPA)

Below are the maps and values obtained using the Guidos software for the Natura 2000 Network and the different levels of protection according to the value for biodiversity.

In this way, the maps represent the distribution of the elements present in the MSPA analysis. This will make it possible to analyze the greater or lesser connectivity depending on the patches and linking elements and compare them with the entire territory of Andalucía and Castilla y León.

It is important to know that as the number of pixels increases, there is a notable increase in the surface of the edges and, as a result, the surface of all the cores is reduced while the percentage of surface occupied by the connectors (links, bridges, and ramifications) has increased considerably (Hernando et al., 2010).

The amount of perforations is insignificant, and with respect to the connecting elements, they are limited and the ones that stand out the most are the bridges and the ramifications. At the level 1, the result is quite like the current scenario. There is a clear abundance of elements that are identified as cores. In addition, the surface area of isolated sites

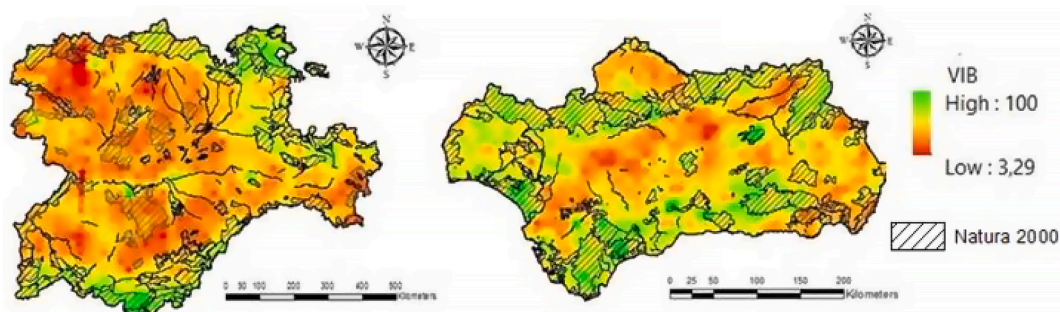
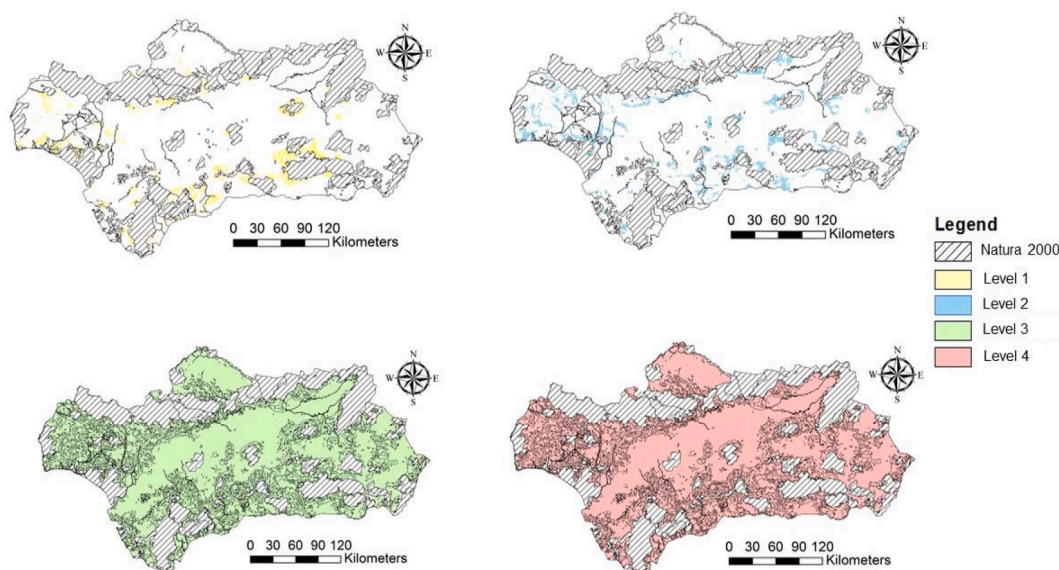
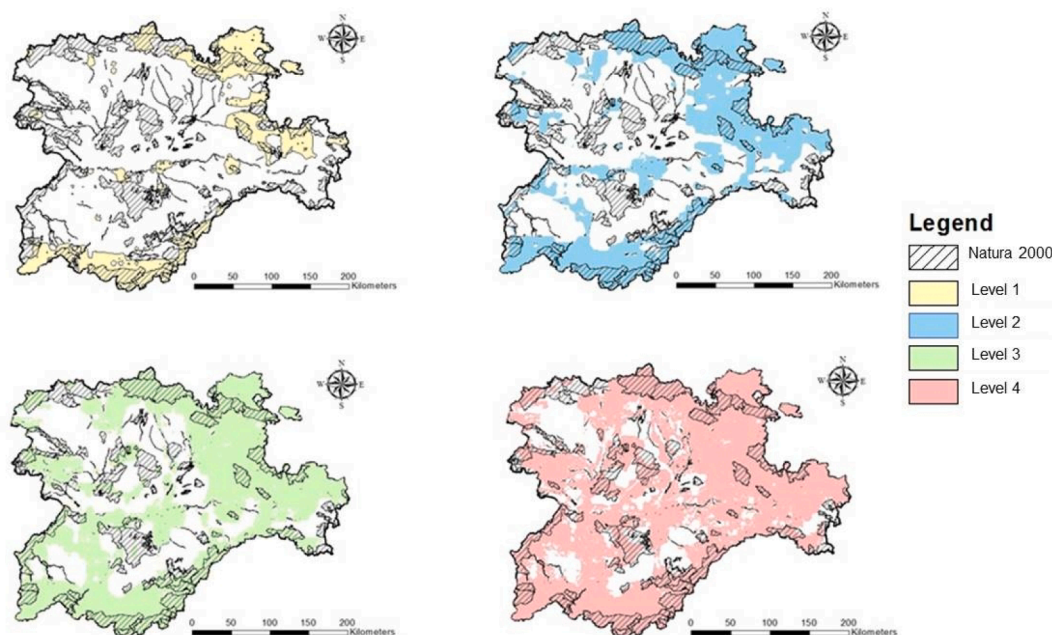


Fig. 4. Classification of Value of Importance for Biodiversity (V.I.B.). Hatched areas belong to Natura 2000 Network.



**Fig. 5.** Zoning proposal levels for biodiversity conservation in Andalucía. Level 1 areas are the most valuable biodiversity zones and Level 4 areas have the lowest value for conservation.



**Fig. 6.** Zoning proposal levels for biodiversity conservation in Castilla y León. Level 1 areas are the most valuable biodiversity zones and Level 4 areas have the lowest value for conservation.

is reduced compared to the previous scenario. This could be translated as a poor improvement in connectivity.

On the other hand, there has been an increase in bridges, which are the most important connections, since they are identified as the true ecological corridors. About level 2, it is again repeated that most of the territory studied is made up of areas identified as cores. This fact is quite coherent, given that all the different levels are related to each other. At this level, there is a minimal increase in cores. But it is important to mention that the number of perforations has increased the surface of the “background” inside a core which implies that the loss of habitat results in the loss of species dynamics (Thompson et al., 2017). In addition, the surface area of the isolated sites has been slightly increased, and the surface area of the connectors has been reduced. Thus, level 2 would be the most unfavorable scenario for biodiversity conservation and

connectivity.

In the level 3, the data obtained are very similar to level 2. In pixel 1 there is little increase in the cores, as well as the existing perforations in these cores.

Finally, in scenario 4, there is a small increase in the areas distinguished as cores, as well as islands and perforations. However, what acquires greater importance at this level is that there is an increase in linking bridges, which are considered as ecological corridors and therefore this scenario becomes very important. Therefore, level 4 is a scenario that has a great significance in relation to the conservation of species biodiversity as well as improved connectivity, given the large surface area of ecological corridors (bridges).

In general, we could say that, the new zoning favours the increase in the number of existing cores. It seems that, because of this, perforations



are also incremented. However, it should be noted that there is an enhancement of connectivity as the number of links, bridges and ramifications rises. Level 1 is considered the most favorable zoning, given that it is the one with the largest number of corridors and the largest area of cores. On the other side, there is a slight reduction in the surface area of isolated areas. For all these reasons, we could say that by means of this method an enhancement of the connectivity of the Natura 2000 Network can be provided.

Lastly, in the following table (Table 1), the MSPA data is shown, so that the improvement produced by the levels of importance of biodiversity compared to the Natura 2000 Network can be noted more accurately.

In appendix A all the tables related to the MSPA in Andalucía and Castilla y León can be found.

What has been analysed here is the percentage of area occupied by ecological cores and corridors, but the fact of having a greater number of cores or corridors does not mean that these have a greater or lesser importance. In other words, the number of ecological cores and corridors that exists in the study area has been analysed, however not their importance.

### 3.4. Analysis of connectivity importance (PC)

Maps shown at Fig. 7 were obtained based on the analysis of the connectivity importance conducted in the previous phase (Saura et al., 2011).

Firstly, the connectivity of the current Natura 2000 Network scenario has been analysed. It is important to know that as the number of pixels increases, there is a notable increase in the surface of the edges, and as a result, the surface of all the cores is reduced while the percentage of surface occupied by the connectors (links, bridges, and ramifications) has increased considerably.

Red areas can be identified as cores, while ecological corridors (bridges) have a blue or greenish colouring (Saura et al., 2011) (Fig. 8). As shown in the resulting map, if the pixel 1 map is analysed, there are cores of a lower tonality. This means that they are cores of vital importance, given that in addition to acting as habitats where different

species can perform their functions, they act as connectivity function between the different cores.

On the other hand, the map shows evidence that level 1 is slightly better than the current Natura 2000 scenario. This is due to the presence of cores of vital importance, which in addition to acting as habitats where the various species can carry out their functions, provide a connectivity function between the distinct core areas, and also a larger number of ecological corridors, all of it makes possible the survival of the species.

The maximum value of ecological corridors at pixel 1 of this level is approximately 0,48 in Andalucía and 0,49 in Castilla y León, while in the current Natura 2000 scenario, the most important ecological corridor is 0,045 in Andalucía and 0,0012 in Castilla y León, this implies a substantial improvement in the importance of connectivity in Castilla y León. We have already commented in this work on the importance of ecological corridors, and a crucial difference is shown in the various levels.

With respect to level 2, all the core areas acquire big significance, given that it is substantial to have ecosystems where the species perform their vital functions. But on the other hand, no core of those presented has a minimum importance for the improvement of connectivity.

In contrast, we see that the corridor with the greatest relevance has a connectivity importance value of 0,19 in Andalucía and 0,612 in Castilla y León, which is higher than the current Natura 2000 Network.

In short, level 2, considering not only corridors but also the core zones, is the most unfavourable level for biodiversity conservation and improved connectivity.

Level 3 is quite like level 1 with the difference that there is a larger surface area of important cores, but on the other hand, as the number of pixels increases, ecological corridors become more important than level 1.

Thus, the maximum connectivity value of ecological corridors at pixel 1, of this level is approximately 0,21 and 1,36, being barely higher than the current Natura 2000 scenario and level 2 being clearly lower than the maximum connectivity value of ecological corridors at level 1. However, at pixels 2 and 3, the ecological corridors obtain an approximate maximum value of 29 in Andalucía and near 3 in Castilla y León.

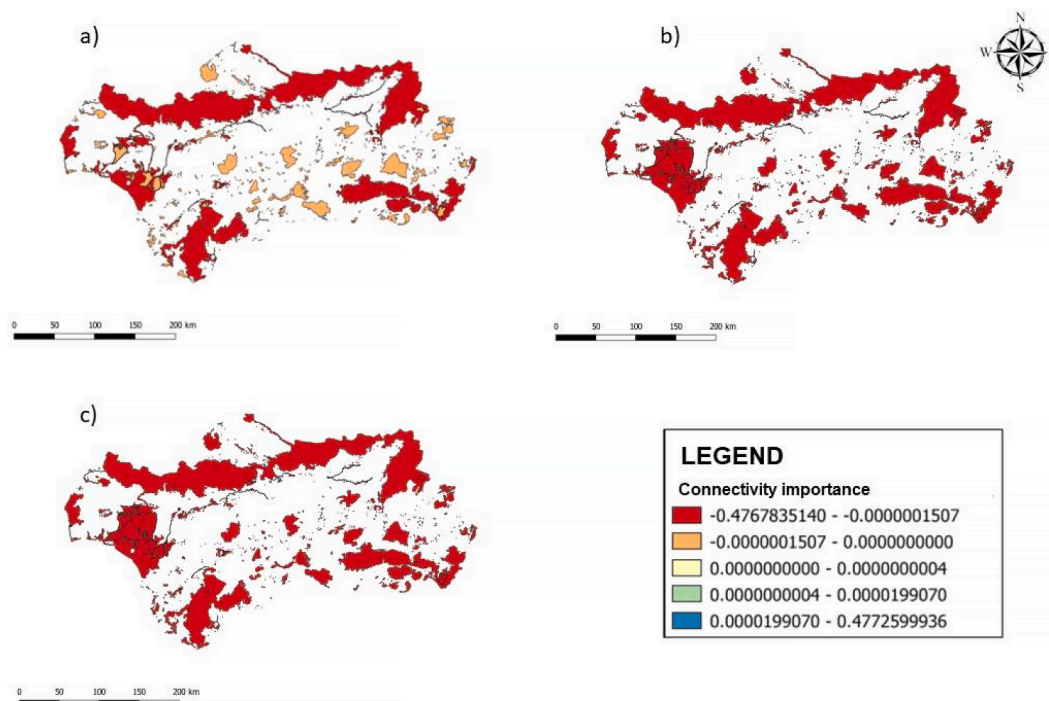
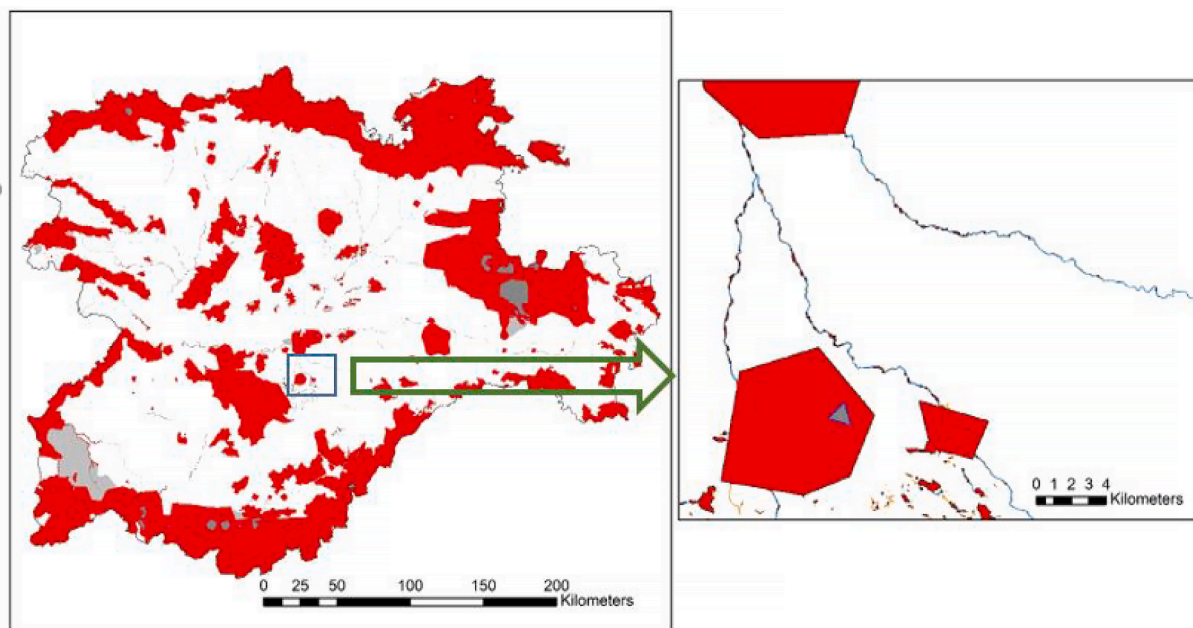


Fig. 7. Analysis of connectivity importance in Andalucía. Level 1. a) Pixel 1 b) Pixel 2 c) Pixel 3.





**Fig. 8.** Zoom to PC Index. Cores are red and bridges are blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Therefore, we could conclude that it is important to take level 3 into account for biodiversity conservation and improved connectivity.

Finally, level 4 is the most important for biodiversity conservation (not with the higher V.I.B.) and improved connectivity. This is due to the presence of core areas of essential significance, which in addition to acting as habitats where species can operate, exert a function of connectivity between the various cores and also a greater number of surface of ecological corridors, making possible the survival of species.

In this way it can be defined that the most important levels are 1,3 and 4, being proposed as a zoning that can optimise the conservation and connectivity of the species of the current Natura 2000 Network. From a planning perspective, they can be seen as bottlenecks and crucial areas for species movement and as fragile elements that are likely to be the first to be affected by landscape changes and management decisions (Saura et al., 2011). In Andalusia, the importance of the cores is lower at all levels than the current importance. With respect to the ecological corridors, in pixel 1 they acquire greater importance than the current importance, however, in pixels 2 and 3 this importance is less, as the size of the corridor is greater. The opposite occurs in Castilla y León, where, as the level and pixel size increases, the importance of both nuclei and ecological corridors increases. Comparing both cases, this methodology is better adapted for Castilla y León, although if we take into account that the areas with the highest value are those at level 1, the methodology works for both territories.

Connectivity is one of the most important aspects to take into account when assessing the conservation status of Natura 2000 habitats and sites (Hernando et al., 2017). Species richness in each habitat patch (local) and in the entire network (regional) declines as habitat is lost (Thompson et al., 2017).

Lastly, in the following tables (Tables 2 and 3), the importance of connectivity data is attached, so that the improvement produced by the levels of importance of biodiversity compared to the Natura 2000 Network can be noted more accurately.

The results obtained can be assimilated to those obtained by Saura et al. (2011), who used the PC-infinity index, in which an increase in bridge connectivity also increases the possibility of species moving from one core to another.

The limitations mentioned above must be taken into account (different grid sizes, outdated data, etc...). If the data is unified in all the

**Table 2**

Analysis of the connectivity importance data (PC) in Andalusia.

Connecting elements	Analysis of the connectivity importance data (PC): Pixel 1				
	Natura 2000 network	Level 1	Level 2	Level 3	Level 4
<b>Cores</b>	−0.052	−0.4768	−0.194	−0.1145	−0.41993
<b>Ecological corridors</b>	0.045	0.47726	0.194	0.207012	0.7045
Connecting elements	Analysis of the connectivity importance data (PC): Pixel 2				
	Natura 2000 network	Level 1	Level 2	Level 3	Level 4
<b>Cores</b>	−0.789	−0.2707	−2.774	−2.3093	−2.3093
<b>Ecological corridors</b>	29.9	0.4514	2.774	29.2491	29.2491
Connecting elements	Analysis of the connectivity importance data (PC): Pixel 3				
	Natura 2000 network	Level 1	Level 2	Level 3	Level 4
<b>Cores</b>	−4.602	−0.6305	−3.852	−6.294	−5.1046
<b>Ecological corridors</b>	29.96	0.4333	2.71	29.332	27.9397

**Table 3**

Analysis of the connectivity importance data (PC) in Castilla y León.

Connecting elements	Analysis of the connectivity importance data (PC): Pixel 1				
	Natura 2000 network	Level 1	Level 2	Level 3	Level 4
<b>Cores</b>	−0.0011	−0.0254	−0.0008	−1.3614	−0.4022
<b>Ecological corridors</b>	0.0012	0.0439	0.0612	1.3614	0.4934
Connecting elements	Analysis of the connectivity importance data (PC): Pixel 2				
	Natura 2000 network	Level 1	Level 2	Level 3	Level 4
<b>Cores</b>	−0.002	−0.0047	−0.0072	−2.6028	−4.0881
<b>Ecological corridors</b>	0.003	0.0033	0.0115	2.6026	4.0006
Connecting elements	Analysis of the connectivity importance data (PC): Pixel 3				
	Natura 2000 network	Level 1	Level 2	Level 3	Level 4
<b>Cores</b>	−0.0021	−0.0054	−0.0075	−2.8491	−29.7768
<b>Ecological corridors</b>	0.031	0.0044	0.0184	2.7955	29.8441

countries with Natura 2000 sites, the connectivity of all these sites at European level would be improved, achieving the objectives of the Natura 2000 Network.

#### 4. Conclusions

The member countries of the European Union have been disorganized in identifying conservation areas, due to the lack of clear guidelines for selecting protected areas. Despite this, attempts have been made to establish optimal selection criteria by developing different methodologies according to different approaches.

For this purpose, in this study, the conservation of biological diversity has been used as a point of view, so that the results obtained show areas of high value for the conservation of this diversity. Using the principle of spatial planning for conservation in designing the Natura 2000 network, can generate an optimum network for species conservation, as it was foreseen in the EU Directive (Niculae et al., 2016). This methodology allows the establishment of uniform and coherent criteria that can be easily considered by the member countries of the European Union, so that the process of evaluation and assignment of protected areas can be consolidated. It's important to maintain functional connectivity outside administrative boundaries in order to maintain Natura 2000 habitats and to avoid isolated cores (Estreguil et al., 2013).

It is possible to state that in this study the location of the protected sites is very similar to the results obtained from the evaluation of the biodiversity criteria. This means a zoning very close to the optimum has been achieved, despite the fact that areas have been identified that should be protected and yet they are not.

Likewise, the importance of the proposed new zoning lies in improving connectivity between protected spaces. The new zoning covers more areas of interest for biodiversity, as well as zones of great importance in relation to connectivity. In this manner, the most important ecological cores and corridors that allow the protection of biodiversity are catalogued.

In any case, the relevance of the implementation of this assessment lies in the appropriate land management by the European Union member countries, which supports sustainable development through the establishment of conservation areas that guarantee the necessary natural resources. It also facilitates compliance with European environmental policy.

#### CRedit authorship contribution statement

**Víctor Rincón:** Formal analysis, Methodology, Writing – original draft. **Javier Velázquez:** Conceptualization, Project administration, Investigation, Methodology, Formal analysis, Writing – original draft. **Javier Gutiérrez:** Formal analysis, Writing – review & editing. **Ana Hernando:** Data curation, Writing – review & editing. **Alexander Khoroshev:** Data curation, Writing – review & editing. **Inmaculada Gómez:** Data curation, Writing – review & editing. **Fernando Herráez:** Data curation, Writing – review & editing. **Beatriz Sánchez:** Data curation, Writing – review & editing. **Juan Pablo Luque:** Data curation. **Antonio García-abril:** Data curation, Writing – review & editing. **Tomás Santamaría:** Data curation, Writing – review & editing. **Daniel Sánchez-Mata:** Writing – original draft.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ecolind.2021.108024>.

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