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Conservation planning of vertebrate diversity in a Mediterranean agricultural-dominant landscape

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Abstract

To improve effectiveness of protected areas, selection of priority areas should include consideration of three main components, namely special conservation elements, focal species and representation. We present a three-track approach related to these components for vertebrate conservation planning in Castilla-La Mancha, central Spain. As special conservation elements, we identified Priority Areas for Conservation of species using five criteria: species richness, geographic rarity, species vulnerability, a Combined Index of these three criteria, and a Standardised Biodiversity Index (SBI) that integrate the three criteria and four studied taxa. The Natura 2000 Network was used to include conservation areas for focal species. We evaluated the representation of every landscape type in the existing conservation areas. To delineate the spatial configuration for vertebrate conservation, we combined the identified Priority Areas for Conservation, existing conservation areas and connectivity areas by cost–distance analysis. The Combined Index was the most efficient criterion analyzed to identify Priority Areas for Conservation. The Natura 2000 Network showed a high percentage of coincidence with identified Priority Areas for Conservation, whereas the natural protected areas network had a low percentage of coincidence. Six agricultural landscapes were inadequately represented in the current conservation network. According to our multi-track approach, ~29% of study area was required to capture 100% of vertebrate species and all landscape types. Our results show that the existing conservation areas are insufficient to guarantee the conservation of biodiversity in the study region. Additional areas with outstanding features of diversity, connectivity areas and establishment of targets for off-reserve conservation are of fundamental importance for strengthening biodiversity conservation.

Keywords: agroecosystem; Combined Index of biodiversity; gap analysis; landscape representation; least-cost path analysis; Natura 2000 Network.

1. Introduction

Establishing protected areas is an important tool for biodiversity conservation, and constitutes the cornerstone on which local, regional and global strategies are built (Funk and Fa, 2010; Margules and Pressey, 2000; Soulé, 1991). However, the effectiveness of protected areas in representing biodiversity has been frequently questioned (Andelman and Willig, 2003; Gaston et al., 2006; Scott et al., 2001), and it is accepted that existing conservation areas usually provide inadequate coverage to biodiversity (Rodrigues et al., 2004; Wiersma and Nudds, 2009). The major cause is that economic and development interests are often opposed to conservation goals, but also because of the array of different reasons that motivate the establishment of protected areas. Thus, selection of critical areas for biodiversity conservation needs to set prior targets and precise prescriptions (Margules and Pressey, 2000; Myers et al., 2000; Pimm et al., 2001; Soulé and Sanjayan, 1998; Underwood et al., 2008). However, how to set such prior targets continues to be a widely debated issue in the scientific literature (Araújo and Williams, 2001; Bartolino et al., 2011; Cayuela et al., 2011; Estrada et al., 2011; Minteer and Miller 2011; Nelson and Boots, 2008).

For conservation planning to be relevant, approaches that integrate consideration of special conservation elements (i.e. critical areas for species at risk, hotspots of diversity and rarity), focal species (i.e. target species for conservation), and representation are suggested (Noss et al., 1999). However, to date, few applications integrate multiple components into regional conservation plans (Beazley et al., 2005; Burgess et al., 2006; Cowling et al., 2003; Hoctor et al., 2000; Noss et al., 2002). We propose an analytical approach that considers all these three components to achieve a more complete procedure to select conservation areas, and provide a case study within the European Union (EU) nature conservation context.

Conservation goals of the EU have motivated the development of the Natura 2000 Network in the last decade. This framework will include the sites of Community importance determined by the Habitats Directive (92/43/EEC) and the areas established by the Birds Directive (79/409/EEC). Natura 2000 Network promotes the maintenance of biodiversity by means of protecting the distribution areas of focal species of wild fauna and flora (the so called “species of Community interest”) and of the ecosystems that are their habitat. It also provides protection to natural habitats per se of Community interest because they (1) are in danger of disappearance; (2) have a small natural distribution area; and/or (3) present outstanding examples of typical characteristics of European biogeographical regions. However, in many parts of Europe, besides “natural and semi-natural habitats”, there are agricultural landscapes that are over several centuries old (Groppali, 1993; Williamson, 1986). Over the last few decades, agricultural changes have had accelerating adverse effects on wildlife (Benton et al., 2004; Voříšek et al., 2010), and actually many species that occur in these agricultural landscapes such as steppe birds and raptors are not well protected (Seoane et al., 2006). Accordingly, effective conservation planning should consider every type of landscape.

In this study, we used a three-track approach to vertebrate conservation planning that integrated special elements, focal species and landscape representation. We defined two conservation targets: (1) inclusion of all species in a regional conservation network; and (2) representation at least of 15% of every landscape type in that conservation network. We applied this approach to a case study in central Spain, namely the Castilla-La Mancha region, as an illustrative example to strengthen the persistence of existing vertebrate species and their habitats. We identified areas of high conservation value (Rey Benayas and de la Montaña, 2003) as special conservation elements. The identification of these areas is based on several biodiversity indices and they fulfil one of the major objectives for the establishment of conservation areas, i.e., to maximise the number of species conserved with the minimum land required (Cabeza and Moilanen, 2001). We used the EU Natura 2000 Network as surrogate of focal species because the selection of conservation areas for species of Community interest in this Network is based on criteria that consider their global ecological value. To address the issue of landscape representation, we evaluated existing conservation areas and ensured that every important landscape for the maintenance of biodiversity in the studied humanised area was represented in such areas. Landscape in this context refers to the different land-use types that individually or in an assemblage form any natural, semi-natural or agricultural habitat.

Our analyses are illustrative, not exhaustive. They provide an example of planning for conservation of biodiversity that can be used by researchers, managers and politicians to streamline conservation efforts anywhere in the world as long as the raw data are available. A similar approach can be used elsewhere using different species groups, criteria, threats or scales.

2. Material and methods

2.1. Study area

Castilla-La Mancha is an autonomous region located in central Spain (Fig. 1). It is 79 222 km^2 in extent. We selected an autonomous region in the country as case study because regional governments are the administration authorities responsible for conservation planning in Spain and, consequently, the results of this study can be readily managed and eventually implemented. It is surrounded on all sides by mountains; two additional mountain systems together with the vast southern Spanish plateau complete the relevant geomorphologic units. Altitude range is around 2000 m (ranging from 306 to 2273 m), although 80% of the territory is at altitudes below 1000 m. Climate is continental Mediterranean, with dry, hot summers and cold winters. Mean annual T is 15.4 ºC and mean annual precipitation is approximately 400 mm yr^{-1}, with 50-80 days of rainfall each year (García-Pedraza and Reija-Garrido 1994). There is a variety of climatic areas, mostly related to altitude differences. This causes considerable variation of vegetation composition and structure. The area is mostly devoted to agricultural activities.

2.2. Criteria for identifying Priority Areas for Conservation

We used five criteria (i.e. five diversity indices) to identify priority areas for conservation (PACs) for vertebrate species: species richness, rarity, vulnerability, a Combined Index of these three criteria, and a Standardised Biodiversity Index (SBI) (Rey Benayas and de la Montaña, 2003). The sources of the species distribution data (19 amphibians, 26 reptiles, 203 breeding birds and 64 mammals) were national atlases (Ministerio de Medio Ambiente, 2002, 2003, 2007). These atlases provided information on species distribution based on their presence in 10 × 10 km cells, with a total of 906 cells in the study region, all of which had information on species distribution.

Rarity of a species *i* was defined by its geographical range measured as the inverse of the number of cells in which it was present ($1/n_i$). For a cell *r*, the rarity index was $\sum_{i=1}^{S} (1/n_{ri})/s_r$, where s_r was the number of species found in the cell.

Species vulnerability was quantified using the categories defined by the World Conservation Union (IUCN 2001). Vulnerability is a surrogate concept of rarity plus

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rates of habitat loss and other threats. The following species categories were considered, (we show in parenthesis the number of vertebrate species classified in each category for the study area): critically endangered (3), endangered (11), vulnerable (49), near threatened (50), and least concern (199). We assigned every category a score related to its degree of vulnerability: 5 for critically endangered species, 4 for endangered species, 3 for vulnerable species, 2 for near threatened species, and 1 for species of least concern. We acknowledge the subjectivity of these scores; they merely represent a rank and have a relative value, and any other choice would have been equally subjective. For a cell, the vulnerability index was $\sum_{i=1}^{S} V_{ri}/s_r$, where V_{ri} was the vulnerability score of the species *i* present in the cell.

We used the Combined Index of species richness, rarity and vulnerability defined by Rey Benayas and de la Montaña (2003): $\sum_{i=1}^{S} (1/n_{ri})V_{ri}$. In this index, species richness is implicit in $\sum_{i=1}^{S}$.

We also used the SBI, a standardized index that measured species richness, rarity and vulnerability of all four taxa together in every cell. We standardized by dividing the combined index of biodiversity of each taxonomic group in every cell by its mean across all cells, and then added up the four standardized combined indices. The Standardized Biodiversity Index formula is $\sum_{j=1}^{4} 1/m_j \sum_{i=1}^{jS} (1/n_{ji})V_{ji}$, where m_j refers to the mean combined index of biodiversity of the taxonomic group *j* across cells.

Next, all diversity indices for the taxa across cells were ranked from highest to lowest values. To quantitatively define PACs, we considered the pool of cells within the upper ranked values for the various criteria that included all species. This was done by selecting cells one by one, starting with the cell with highest diversity indices and in decreasing order of their diversity indices value until all species were included in; that is, for each new selected cell we listed the new species that were added until all species were included in the selected set of cells. We also determined the number of cells necessary to capture all threatened species.

2.3. Existing conservation areas in the region

There are 30 main natural protected areas (two national parks, six natural parks and 22 natural reserves) in the region that have a protection level according to IUCN categories II, IV and V (IUCN, 2008), which represent 3.5% of the study region (Fig. 1). The Natura 2000 Network will cover 22.9% of the study region once completed. The current natural protected areas in the study region have been proposed as sites of Community importance and, therefore, they will be included in the Natura 2000 Network. We performed a gap analysis by looking at those identified PACs that did not overlap with conservation areas (i.e. the Natura 2000 Network and the current natural protected areas). We did not use a particular threshold to deem such overlap (i.e. PACs and existing conservation areas did overlap or not), but looked also at those PAC cells with <10% of overlap with existing conservation areas). The statistical significance of the coincidence between the identified PACs and the conservation areas was based on χ^2 tests.

We used the CORINE Land Cover 2000 (European Environment Agency, 2002) to evaluate the representation of all landscapes in the existing conservation areas network, regardless of their anthropogenic origin and maintenance. To simplify the analysis, the initial 85 categories of land use were reclassified into 28 broader categories that are a representative and simple hierarchical classification of landscapes in the study area (Fig. 2). The resulting land-use map was overlapped with the Natura 2000 Network. As starting criterion, we deemed a landscape as under-represented if less than 15% of its total area was included in the Natura 2000 Network. We chose this threshold arbitrarily because there are no standard guidelines that refer to the percentage area of each landscape that should be included in a conservation plan, and because the commonly used 10 or 12% is considered insufficient to achieve conservation goals (Margules and Pressey, 2000; Soulé and Sanjayan, 1998). However, 15% for a rare landscape -and thus relevant from a conservation perspective- could be a territory too reduced to be conserved, and a dominant landscape in the study area could be determined as under-represented only for a proportion's problem which is far from ecological reasons. Consequently, the starting 15% threshold was flexibly used to fine-tuning landscape representation (see Results).

Non-metric multidimensional scaling (NMDS) was used to examine the relationships between land-use types and the different criteria or diversity indices used to identify PACs. To achieve this, we first computed the resemblance matrix between cells based on diversity indices scores using the Bray-Curtis dissimilarity distance. The results were plotted in a NMDS ordination diagram. We then fitted the area values of land-use types in each of the assessed 906 cells onto the first two axes of the NMDS. Squared correlation coefficients (R^2) and empirical p-values (p) were calculated for these linear fittings. Ordination was performed with package 'vegan' (Oksanen et al., 2011) in the R environment (R Development Core Team, 2011).

2.4. Selecting areas for conservation planning

To include unprotected areas that were detected by gap analysis, we combined the identified PACs according to the SBI with the Natura 2000 Network. These represent special conservation elements and focal species because they provide areas with high biodiversity value and habitats for species of Community interest. In general, focal species include those that (1) are of disproportional functional importance in an ecosystem, (2) have large area requirements, (3) have specialized habitat needs and/or are habitat quality indicators, (4) are special or vulnerable populations, and/or (5) have charismatic appeal that will provide a flagship function for conservation initiatives (Millar et al., 1998-1999; Noss, 1991). The criteria underpinning the EU Natura 2000 Network as surrogate of focal species are related to (1) size and density of the local species populations in relation to the population present in the country, (2) degree of conservation of relevant habitat elements for the species persistence and restoration possibilities, (3) degree of isolation of the species in the site in relation to their natural distribution area, and (4) global assessment of the site for the conservation of particular species.

However, the identified PACs together with the Natura 2000 Network may still inadequately represent all important landscapes for biodiversity preservation in the region. Thus, we selected additional areas of under-represented landscapes, and gave priority to patches that improved connectivity between the largest areas delineated by merged PACs and the Natura 2000 Network, in order to provide supplementary habitats for focal species and opportunities for dispersal.

We selected connectivity areas by conducting cost–distance analysis between target areas that contained under-represented landscapes. The least–cost path represents the least amount of resistance for species movement between habitats and is a function of width, distance, habitat suitability and obstacles (Beazley et al., 2005). We created cost–surface maps by combining habitat suitability and recently built or planned infrastructures for the next few years (highways and roads, high-speed railway lines, gas pipelines, one airport, one theme park, wind farms and water reservoirs and pipelines; Rey Benayas et al., 2006), in order to avoid future impacts. We also considered zones of high wildlife mortality (“black spots”) identified by environmental organisations (unpublished data). In particular, black spots for birds (n=7 cells, total area=587 000 ha) are areas in which there are a high number of electrocutions and collisions with power lines, mainly of raptors and steppe birds, that in some cases are endangered like the Spanish imperial eagle (*Aquila adalberti*) or the great bustard (*Otis tarda*). Other wildlife black spots refer to areas with high number of road kills (n=38, total longitude=477 km), corresponding to seven species of amphibians, 15 of reptiles, 12 of mammals and 36 of birds.

To create the cost-surface map each habitat was assigned with a value of suitability; those under-represented habitats were assigned with 0 resistance value and urban habitat with a maximum resistance value of 100. As all under-represented habitats are agroecosystems and the objective is to select connectivity areas including these habitats, the most suitable habitats for the presence or dispersion of species typical of agroecosystems were assigned with lower resistance values (e.g. 10 for grassland), while the dense forest habitats were assigned with higher resistance values (e.g. 70 for deciduous broad-leaved). Recently built and planned infrastructures and "black spots" were assigned with the highest resistance value. Cost–distance analyses were completed in ArcView 3.2 (ESRI, 1999). We first used the nearest features extension (Jenness, 2007) to select the largest (>10 000 ha) and nearest target areas. Secondly, we used the pathmatrix extension (Ray, 2005) to find least–cost paths across cost–surface grids, and then manually selected connectivity areas to achieve at least 15% representation of each under-represented landscape. Finally, we overlaid the selected connectivity areas with identified PACs and Natura 2000 Network to create a synthesis layer.

3. Results

3.1. Distribution and evaluation of Priority Areas for Conservation

For the four taxa, the mean percentage of cells that was necessary to retain all species was 2.6% for the Combined Index, 4.4% for rarity, 20.1% for richness and 34.9% for vulnerability. For threatened species, it was 2.4%, 4.4%, 20% and 26.7%, respectively (Table 1). The Combined Index of biodiversity was the most efficient criterion to identify areas for protection of reptiles, breeding birds and mammals in Castilla-La Mancha, since it required the lowest number of cells to retain 100% of all species and of all threatened species. The rarity index was the most efficient criterion for all species and threatened species of amphibians.

One hundred and twenty-five cells (13.8% of the total) highlighted by the SBI were necessary to retain 100% of species of all taxa (Fig. 3). There was an aggregation of PACs at the southern and northern peripheral mountains, whereas they were sparsely distributed in the central part of the region.

3.2. Coincidence of Priority Areas for Conservation and existing conservation areas

There was a low percentage of PACs identified by the Combined Index of biodiversity of the different taxa that did not coincide with the Natura 2000 Network (<22%, mean of 11.3% across taxa). In contrast, there was a high percentage of PACs that did not coincide with the network of 30 natural protected areas (>58%, mean of 68.1% across taxa) (Table 2). The gaps between PACs according to the Combined Index of biodiversity and both conservation networks followed the order amphibians > breeding birds > mammals > reptiles. Percentages for the SBI were close to the reported means, with 8% of gaps for the Natura 2000 Network (χ^2 = 55.20, p <0.000 for coincidence of cells) and 76% of gaps for the natural protected area network (χ^2 = 10.38, p <0.015 for coincidence of cells). Additionally, there were 10.4% and 9.6% of cells identified as PACs according to the SBI with <10% of their area included in the Natura 2000 and natural protected areas networks, respectively.

3.3. Landscape representation in the Natura 2000 Network

We found that eight out of the 28 classes were inadequately represented by the Natura 2000 Network (<15% of their area included on it, Table 3). Two of these classes were urban land and irrigated land, which are of little importance for the maintenance of biodiversity in the study region; thus, we did not consider urban and irrigated land in further analysis. The other under-represented landscape types were all agricultural habitats. Vineyard (4%), olive grove (6.5%) and rain-fed cropland (10.3%) are traditional Mediterranean farm systems that extend over large areas. However, their individual patches are frequently of little area and are found in combination with other types of natural vegetation. Mosaics of farms (7%), farm with *dehesa* (13.7%), and mosaics of natural vegetation (14.9%) were also inadequately represented. These six under-represented landscapes were 41 550 km^2 in extent, i.e. 52.3% of the study region. Lagoons were the best landscape represented in the Natura 2000 Network (~75% of their total area).

The delineation and addition of PACs to the Natura 2000 Network significantly improved landscape representation, with a mean increase of ~77% of under-represented landscape types (Table 3). There was also a high increase in the representation of important habitats for biodiversity conservation in the humanised *dehesa* landscapes, grasslands and wetlands (~46%, ~41% and ~36%, respectively).

3.4. Association between landscape types and diversity indices

Non metric multidimensional scaling (NMDS) allowed us to visually inspect similarities and dissimilarities in diversity indices in all 10x10 km cells (Fig. 4). All diversity indices for reptiles were found in the upper part of the ordination, whereas all diversity indices for amphibians appeared on the lower right part of the plot. Diversity indices for mammals and birds were scattered along the first NMDS axis, attaining both negative and positive values. Selected PACs, based on the largest SBI values, were clustered mostly on the right side of the ordination diagram. These sites were characterised by holding a high number of species of amphibians and/or reptiles, many of which were rare and threatened, as well as relatively large numbers of rare birds and mammals.

A total of 19 landscape types showed a significant relationship with the NMDS ordination axes (Table 4, Fig. 4). Correlations were weak ($R^2 < 0.15$) in all cases. All diversity indices for amphibians, as well as mammal and bird rarity, the Combined Index for mammals, and the SBI, were related to a variety of landscape types, including forest ecosystems such as dense evergreen shrubland, acicular conifer forest, mosaic of natural vegetation, deciduous broad-leaved forest, broad-leaved plantation, and riparian forest, and agroecosystems such as *dehesa*, grassland, low vegetation, and farm with *dehesa*. These indices were also related to the amount of lagoon and wetland as well as urban types. All diversity indices for reptiles were associated to forest ecosystems (dense shrubland, acicular conifer), agroecosystems (*dehesa*, grassland, low vegetation, farm with *dehesa*, mosaic of farms, vineyard) and water bodies (lagoon, wetland). The remaining diversity indices were not influenced by the amount of lagoons and wetlands, but they were related to different forest ecosystems, agroecosystems and urban cover.

3.5. Selection of connectivity areas for the design of a vertebrate conservation system

The identified PACs according to the SBI, the Natura 2000 Network and connectivity areas delineated the spatial extent of the proposed vertebrate conservation planning, which also includes habitat patches required to reach the target of 15% of landscape representation (Fig. 5a). It included special elements for conservation, habitats for focal species, and landscape types relevant for biodiversity conservation. Altogether, they represented ~29% of the Castilla-La Mancha territory.

Based on the location of the least-cost paths, we delineated connectivity areas of under-represented agroecosystems (Fig. 5b). After combining the identified PACs and Natura 2000 Network with selected connectivity areas, the new extent of mosaic of farms was 15.4% (34 688 ha added), vineyard was 15.8% (15 258 ha added), and olive grove was 15.9% (8460 ha added). Mosaic of natural vegetation and farm with *dehesa* were landscape types that were under-represented in the Natura 2000 Network; however, it was not necessary to select additional patches for this landscape type because the existing patches in combination with PACs extend over an area of ~39% and ~64%, respectively (Table 3). Although rain-fed cropland area included in Natura 2000 Network is <15% of total area of this habitat, this habitat was not considered as foreground to establish connectivity areas because the total area occupied by it in the study area is large (Table 3) and hence it is not essential to increase its surface to guarantee its conservation. All landscape types with < 10 000 ha included in the Natura 2000 Network (Table 3) have a representation percentage ranging between 25% and 77%; thus, we did not deem necessary to include any of these habitats as priority habitats to augment their area within the proposed conservation network.

4. Discussion

4.1. Identification of priority areas for conservation planning

An index to measure diversity, such as the Combined Index of species richness, geographic rarity and level of threat for species present in a given area, has theoretically a notable intrinsic value. Our results confirm the value of the Combined Index. We showed that it was the most effective measure of diversity by retaining all species and all threatened species of vertebrates within the lowest number of 10 x 10 km cells. These results fit with our previous studies that used cells of 50 × 50 km (Rey Benayas and de la Montaña, 2003) and cells of 20 × 20 km (Rey Benayas et al., 2006). Consistency across different scales of analysis significantly increases the robustness of this criterion. Thus, the Combined Index is a useful tool for determining special conservation elements. Undoubtedly, identification of PACs is dependent on the quality of species distribution data (especially for rare species), including location precision and sampling bias (Lomolino, 2004).

Species richness is assumed to be an indicator of conservation value and is typically considered to optimise conservation targets (Fleishman et al., 2006; Meir et al., 2004; Prendergast et al., 1999). Our current and previous results have shown that both the Combined Index and the rarity criterion are more effective than the richness criterion. This fact has been reported in other works (Haeupler and Vogel, 1999; Margules et al., 1988). Consequently, selecting sites that contain the highest number of species is not the most efficient way to maximally represent biodiversity (Pimm and Lawton, 1998; Reid, 1998).

4.2. Existing conservation areas and priority areas for conservation

It is useful to identify areas with outstanding features of biodiversity to rank priorities for optimising resource investment in conservation (Zafra et al., 2010). In our study, the Natura 2000 Network considerably improved the guarantees for conservation of all taxonomic groups as gaps related to PACs decreased significantly with respect to the natural protected areas network. This was predictable because there was a six-fold increase in the amount of protected area. However, our gap analysis showed that the Natura 2000 Network is still insufficient to guarantee the protection of all species in Castilla-La Mancha. One hundred and twenty-five PACs defined by the SBI of all taxa would be necessary to achieve the target protection level, but 14 of these PACs were not included within the Natura 2000 Network (Dimitrakopoulos et al., 2004 and Maiorano et al., 2007 reported other assessments of Natura 2000 Network).

Gaps between PACs defined by the Combined Index for amphibians and the existing natural protected areas are more numerous than for other taxa, as we have found at a smaller scale analysis (Rey Benayas and de la Montaña, 2003). Ecological requirements of amphibians contribute to this fact, since they need adequate environmental moisture and specific habitats for reproduction that are scarce in Mediterranean climate regions (Green, 2003; Kiesecker et al., 2001; Semlitsch, 2000). Amphibian populations are frequently concentrated in small and isolated wetlands without protection. The relationships between diversity indices for amphibians and amount of lagoon and wetland, as well as *dehesa*, grassland and farm with *dehesa*, which are habitats with small seasonal wetlands of natural origin or man-made for cattle use, support this hypothesis.

The Natura 2000 Network in Castilla-La Mancha satisfactorily represents forests, shrublands, grasslands and wetlands at the landscape scale. However, *dehesa* is the only adequately represented agroecosystem. Traditional farm of rain-fed cropland, olive grove and vineyard, and areas of mosaic of farms, mosaic of natural vegetation and farm with *dehesa* are all under-represented, as is their biodiversity. These landscape types form agroecosystems with high landscape heterogeneity and habitat diversity that can be critical for wildlife conservation (Benton et al., 2003; Bennett et al., 2006; Farina, 1997; Tucker, 1997). Traditional landscapes of farmland and extensively managed mosaics are characteristic of Mediterranean regions. Agricultural changes in Europe in the last few decades, namely intensification and abandonment, have caused loss of biodiversity in most agroecosystems (Benton et al., 2003; Donald et al., 2006; Kleijn et al., 2006), which is particularly well documented for farmland birds (BirdLife International, 2004; European Bird Census Council, 2010). Our results are consistent with the importance of these agroecosystems, as vulnerability of birds, mammals and reptiles are related to three of the agroecosystems that are dominant in the study area (rain-fed cropland, mosaic of farms and vineyard).

4.3. Proposal for conservation planning

Our assessment shows that approximately 29% of the Castilla-La Mancha land is required to protect special conservation elements, focal species and all landscape types. This agrees with other studies that estimate that the proportion of a region required to capture important elements of biodiversity is between 33 and 75% (see Soulé and Sanjayan, 1998 for a review).

Our proposal achieved two conservation targets, namely inclusion of all vertebrate species and representation of all landscape types. The combination of the identified PACs in this study, the Natura 2000 Network and the proposed connectivity areas results in a spatial configuration that achieves the first objective of nature reserves, i.e. to represent the biodiversity of each region (Margules and Pressey, 2000). However, representation of biodiversity does not guarantee the persistence of viable population (the second objective of reserves) or the protection of ecological processes that maintain biodiversity (Salomon et al., 2006). Targets for off-reserve conservation are particularly important, and conservation on private land is also essential (Jackson and Gaston, 2008; Soares-Filho et al., 2006), especially in fragmented and humanised landscapes (Peres et al., 2010) where reserves are likely to be small and isolated.

Currently, many species depend on large areas of traditional agriculture (Billeter et al., 2008). Therefore, our proposed conservation planning considers the inclusion of additional areas of under-represented agroecosystems that improve connectivity into protected area networks for strengthening biodiversity conservation. Furthermore, to protect farmland wildlife adequately, it is necessary to improve agri-environment schemes (Kleijn and Sutherland, 2003; Kleijn et al., 2006), which are considered the most important policy instrument for protecting biodiversity in agricultural landscapes (European Environment Agency, 2004). This should avoid unsustainable intensive farming that is damaging biodiversity conservation and rural economies.

Presence/absence data of species occurrence are frequently used in approaches at the regional scale (Bonn and Gaston, 2005; Lennon et al., 2001; Manley et al., 2004); the value of biodiversity measures based on such data has been questioned for some authors in conservation planning (Smith and Wilson, 1996; Stirling and Wilsey, 2001). Our approach provides useful information, but our results were scale dependent (Rouget, 2003) and they were also determined by the selection of the study area because in each region the species, habitats and their representation in the protected areas network may be different. The results obtained in this study were expected because Castilla-La Mancha is a predominantly agricultural region.

Future research should include other taxa as fish (Doadrio, 2002) or invertebrates, and apply specific species analysis (rare or threatened species), incorporating habitat suitability and population viability for optimal selection of core areas (e.g. Beazley et al., 2005). We suggest a similar approach to establish adequate ecological restoration and environmental impact mitigation, and to integrate social and economic considerations. Land protection is often driven by local opportunities and politics rather than by a priori assessment of ecological value. But, in order to progress towards the global target of reducing the current rate of biodiversity loss (Mooney and Mace, 2009; Perrings et al., 2010), we need strategies for managing whole landscapes including areas allocated to both production and conservation. In humanised landscapes, it is of fundamental importance to maintain traditional resources management (e.g. extensive cattle and rotation of farmland) that is the origin and future of biodiversity in these areas.

In conclusion, we found that: (1) the Combined Index is an effective and robust measure of biodiversity; (2) the Natura 2000 Network delivers benefits for biodiversity conservation in Castilla-La Mancha, but represents insufficiently the most traditional agricultural landscapes and hence it does not guarantee the protection of their threatened vertebrate species, especially birds; and (3) our three-track approach achieves representation of every landscape and vertebrate diversity in the study region and, despite its limitations, has the potential for application in other regions.

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Table 1: Number (and proportion in parenthesis) of cells (906 cells in total) that were required to retain all species and all threatened species of amphibians, reptiles, breeding birds, and mammals according to the different criteria used to identify Priority Areas for Conservation.

Table 2: Percentage of identified Priority Areas for Conservation according to (i) the Combined Index of each taxonomic group and (ii) the Standardized Biodiversity Index of all taxa (SBI) that are not included in the existing conservation area networks (i.e. gaps).

Table 3: Total area of each land-use type in Castilla-La Mancha; area and percentage included in Natura 2000 Network; and percentage increase of land-use type area if Priority Areas for Conservation (PACs) defined by the Standardized Biodiversity Index were added to Natura 2000 Network.

Table 4: Squared correlation coefficients (R^2) and empirical p-values (p) for linear fitting of landscape types onto the first two axes of the Non Metric Multidimensional Scaling. Significant values ($p < 0.05$) are in bold.

Table 1

	Amphibians		Reptiles		Breeding birds		Mammals	
	All species	Threatened species	All species	Threatened species	All species	Threatened species	All species	Threatened species
Richness	33 (3.6%)	33(3.6%)	12 (1.3%)	8 (0.9%)	487 (53.8%)	487 (53.8%)	197 (21.7%)	197 (21.7 %)
Rarity	19 (2.1%)	19 (2.1%)	57 (6.3%)	57 (6.3%)	66 (7.3%)	66 (7.3%)	19 (2.1%)	19 (2.1%)
Vulnerability	76 (8.4%)	76 (8.4%)	234 (25.8%)	196 (21.6%)	712 (78.6%)	375 (41.4%)	243 (26.8%)	243 (26.8%)
Combined Index	23 (2.5%)	23 (2.5%)	12 (1.3%)	7 (0.8%)	52 (5.7%)	52 (5.7%)	7 (0.8%)	7 (0.8%)

Table 2

	Amphibians	Reptiles	Breeding birds	Mammals	SBI
Natura 2000 Network	21.7	0	17.3	6.1	8*
Natural protected areas	82.6	58.3	69.2	62.3	76*

* indicates coincidence between identified PACs and conservation areas that are significant at $p < 0.05$.

Table 3

Land-use type	Total area (ha)	Area in Natura (ha)	% in Natura	% in Natura-PACs	% increase
Lagoon	4285	3209	74.9	75.8	1.2
Rocky land	1564	1109	70.9	70.9	0
Cypress family conifer	19909	13804	69.3	71.5	3.2
Deciduous broad-leaved	47625	31413	66.0	69.5	5.3
Conifer and broad-leaved	181505	113592	62.6	65.8	5.1
Acicular conifer	566663	313943	55.4	56.2	1.4
Wetland	9149	5031	55.0	74.6	35.6
Low vegetation	16896	8917	52.8	58.7	11.2
Broad-leaved mix	119039	56520	47.5	53.5	12.6
Dense evergreen shrubland	452621	189285	41.8	44.9	7.4
Perennial broad-leaved	149908	61523	41.0	44.8	9.3
Dehesa	134912	52463	38.9	56.7	45.8
Broad-leaved plantation	6441	2450	38.0	42.2	11.1
Forest shrubland	819177	304910	37.2	44.7	20.2
Fruit tree	23098	8161	35.3	36.0	2
River	11362	3589	31.6	34.1	7.9
Sparse evergreen shrubland	435695	134901	31.0	39.1	26.1
Lake	33533	9171	27.3	29.9	9.5
Riparian forest	2978	756	25.4	27.5	8.3
Grassland	299532	72679	24.3	34.2	40.7
Mosaic of natural vegetation	292354	43497	14.9	20.7	38.9
Farm with *dehesa*	215155	29487	13.7	22.4	63.5
Rain-fed cropland	2288431	235351	10.3	14.1	36.9
Irrigated land	371555	30672	8.3	14.2	71.1
Mosaic of farms	796706	55565	7.0	11.7	67.1
Olive grove	193265	12566	6.5	11.1	70.8
Vineyard	369403	14695	4.0	11.3	182.5
Urban	77644	3037	3.9	5.8	48.7

Table 4

Land-use type	NMDS1	NMDS2	R^2	Pr(>r)
Urban	-0.810	-0.585	0.0085	**0.028**
Rain-fed cropland	-0.999	-0.037	0.1443	**0.001**
Irrigated land	-0.990	-0.136	0.0206	**0.001**
Vineyard	-0.835	0.549	0.0487	**0.001**
Fruit tree	-0.910	0.412	0.0001	0.953
Olive grove	0.578	0.815	0.0018	0.462
Mosaic of farms	-0.668	0.743	0.1200	**0.001**
Grassland	0.677	-0.735	0.0201	**0.001**
Mosaic of natural vegetation	-0.727	-0.686	0.0176	**0.001**
Dehesa	0.825	-0.565	0.0268	**0.001**
Farm with *dehesa*	0.780	-0.624	0.0091	**0.018**
Perennial broad-leaved forest	0.701	-0.712	0.0042	0.155
Deciduous broad-leaved forest	0.374	-0.927	0.0099	**0.012**
Broad-leave plantation	0.483	-0.875	0.0087	**0.025**
Broad-leaved mix forest	0.366	-0.930	0.0036	0.194
Riparian forest	-0.419	-0.907	0.0082	**0.027**
Acicular conifer forest	0.994	0.105	0.0234	**0.001**
Cypress family conifer forest	-0.891	0.452	0.0093	**0.010**
Conifer and broad-leaved	0.088	0.996	0.0011	0.631
Dense evergreen shrubland	0.943	-0.331	0.0494	**0.001**
Sparse evergreen shrubland	-0.020	-0.999	0.0003	0.889
Forest shrubland	0.999	-0.004	0.0151	**0.001**
Rocky land	0.994	0.107	0.0042	0.129
Low vegetation	0.999	0.021	0.0186	**0.004**
Wetland	0.869	-0.494	0.0082	**0.036**
River	0.520	-0.853	0.0006	0.755
Lagoon	0.876	-0.481	0.0101	**0.018**
Lake	0.189	0.981	0.0017	0.420

FIGURE LEGENDS

Figure 1. Map of Castilla-La Mancha in central Spain with the existing conservation areas: natural protected areas (two national parks, six natural parks and 22 natural reserves) and sites of Community importance established by the Natura 2000 Network.

Figure 2. There were 28 new categories in this land use classification reclassified from the initial 85 categories considered by CORINE Land Cover database in Castilla-La Mancha. Categories considered under-represented by existing conservation areas are showed in shades of grey (see Table 3).

Figure 3. Distribution of 125 identified Priority Areas for Conservation in 10 × 10 km cells that include 100% of vertebrate species in the region. Fourteen of these Priority Areas for Conservation (in black) are not currently included within existing conservation areas (Natura 2000 Network and current natural protected areas).

Figure 4. Non Metric Multidimensional Scaling (NMDS) of criteria or vertebrate diversity indices in Castilla-La Mancha, Spain. Next to each axis there is a list of landscape types showing, in decreasing order of importance according to the correlation coefficient (R^2) and for NMDS scores > 0.5, positive and negative relationships ($p < 0.05$) with the ordination axes (see Table 4 for details). Crosses indicate cells not designated as priority areas for conservation (PACs), whereas filled circles represent selected PACs.

Figure 5. (a) Spatial distribution of important vertebrate diversity areas for conservation planning in Castilla-La Mancha, including the identified Priority Areas for Conservation, existing conservation areas (Natura 2000 Network and current natural protected areas), and connectivity

areas delineated in this study. (b) Higher magnification of the boxed area in (a) that illustrates least-cost paths. This map shows the largest and nearest target areas selected after applying the nearest features extension of ArcView 3.2, which allowed selection of additional patches of under-represented landscape types for connectivity.

Figure 1

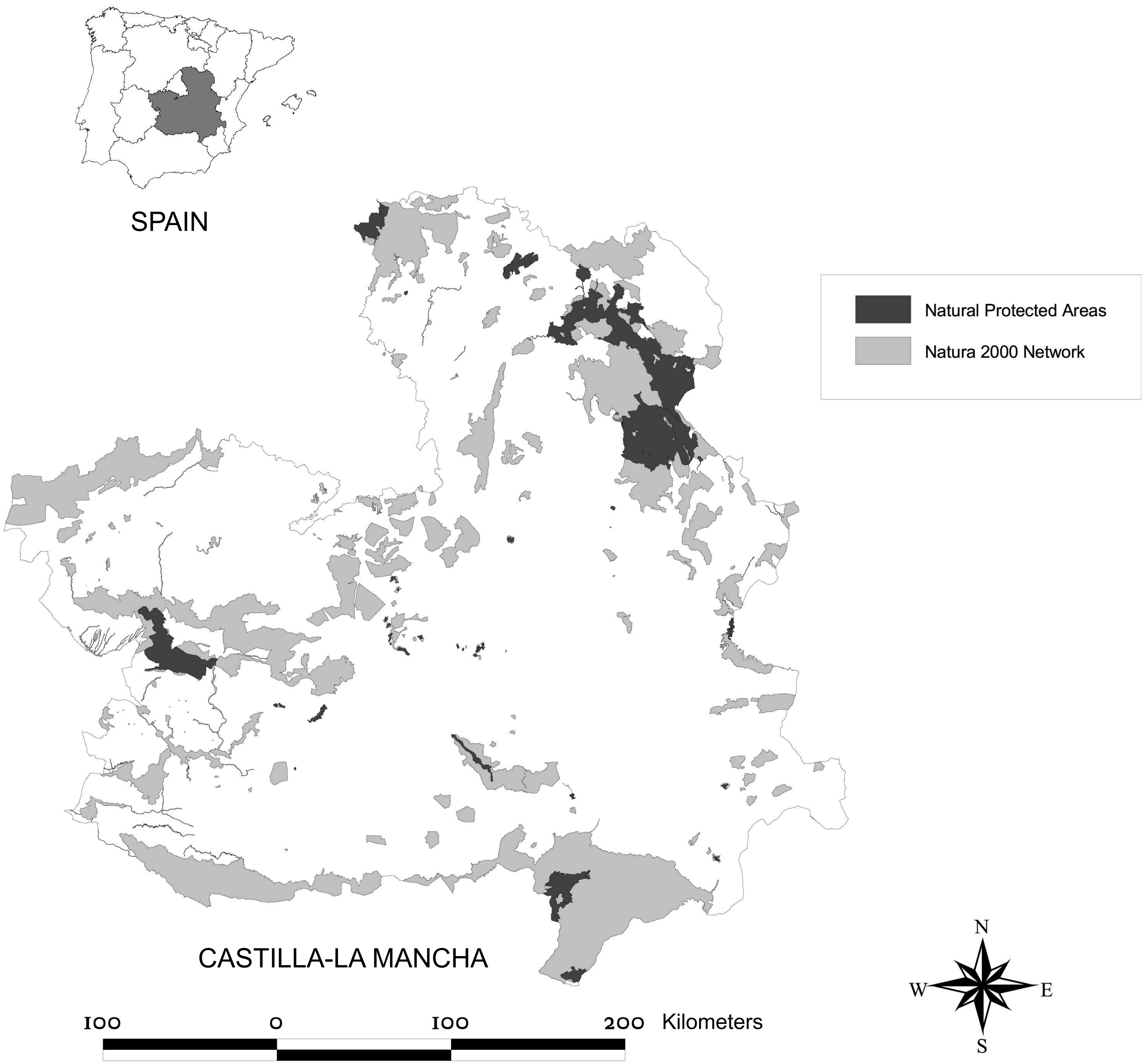
SPAIN
Natural Protected Areas
Natura 2000 Network
CASTILLA-LA MANCHA
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Figure 2

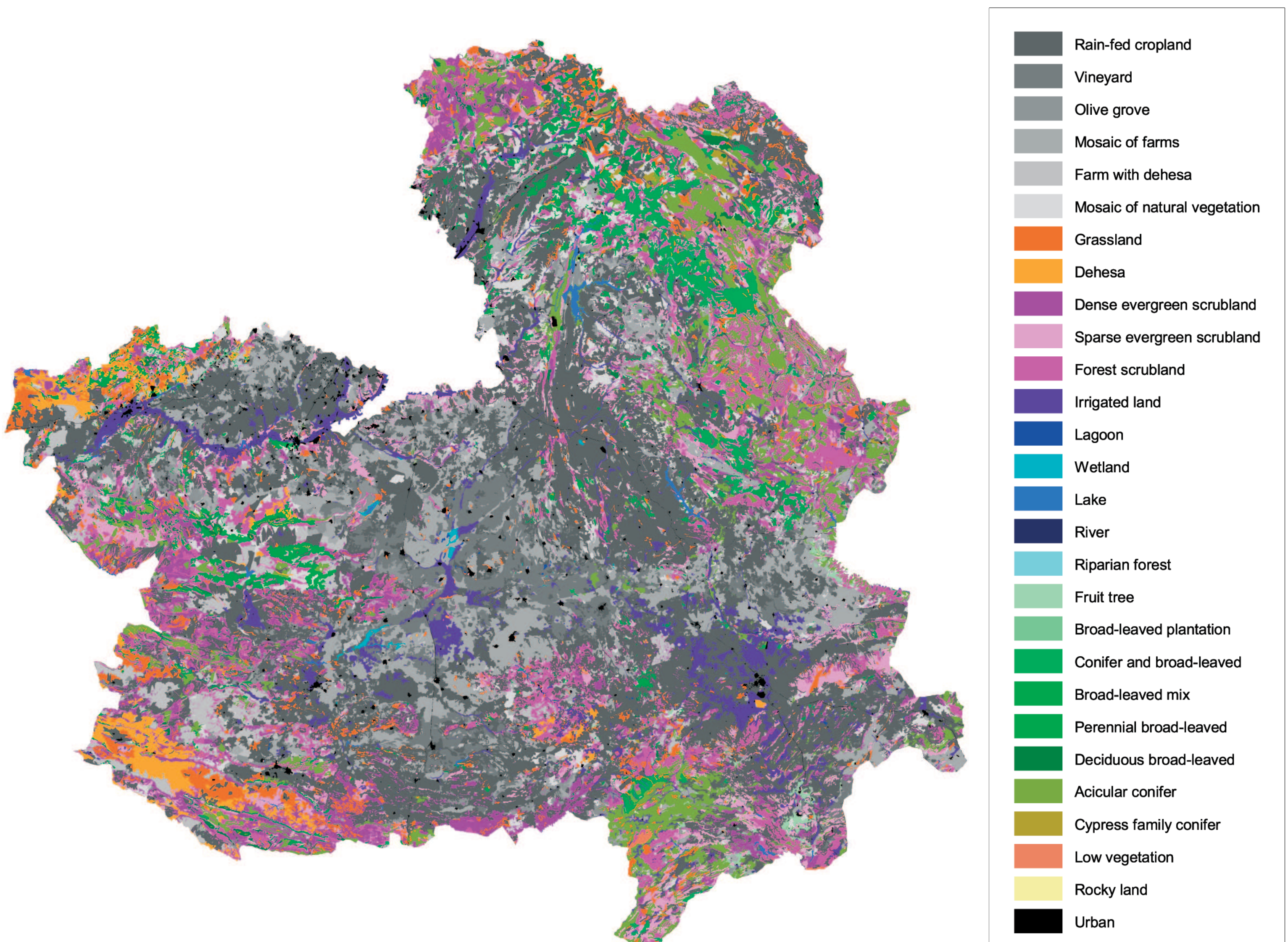
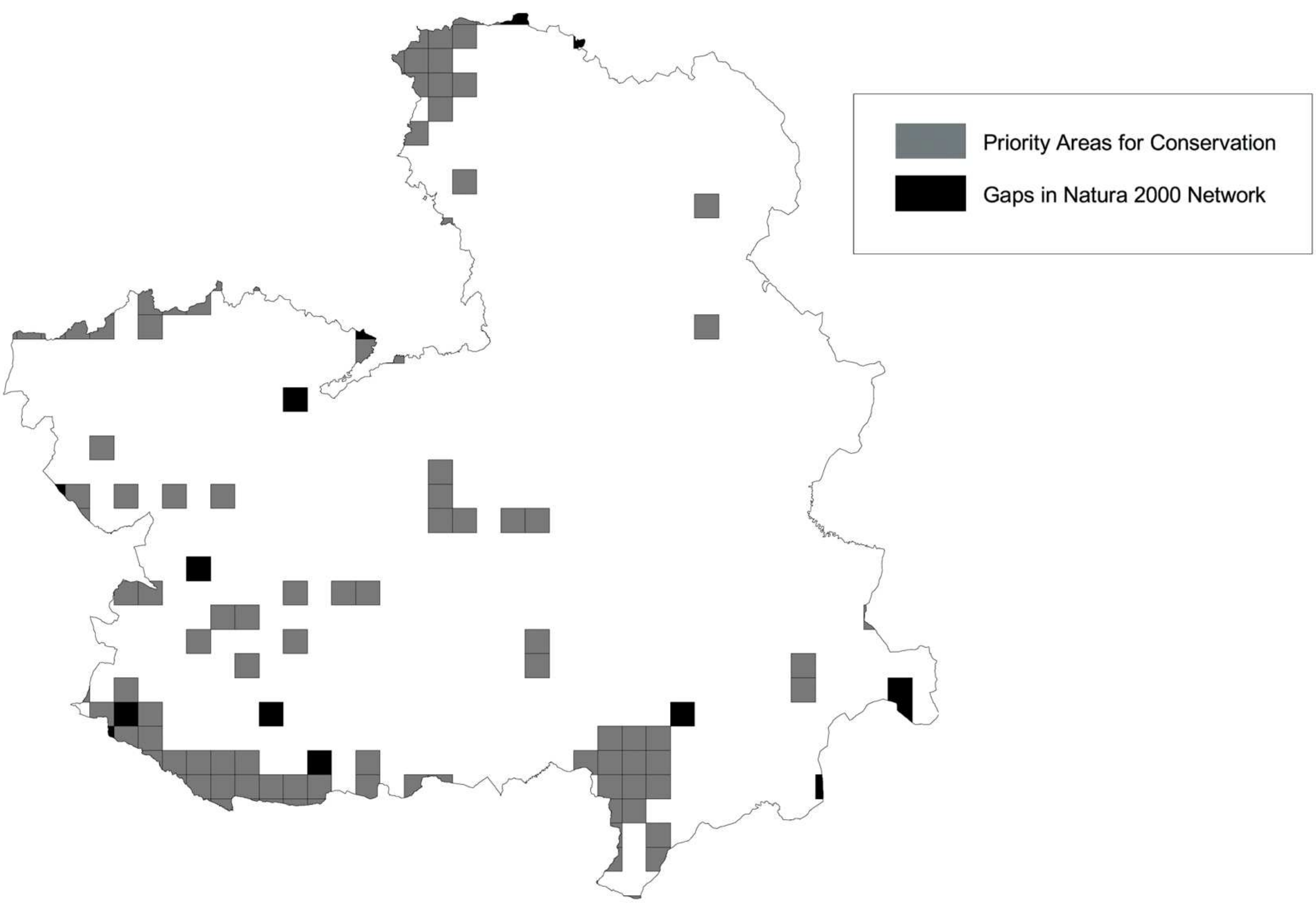
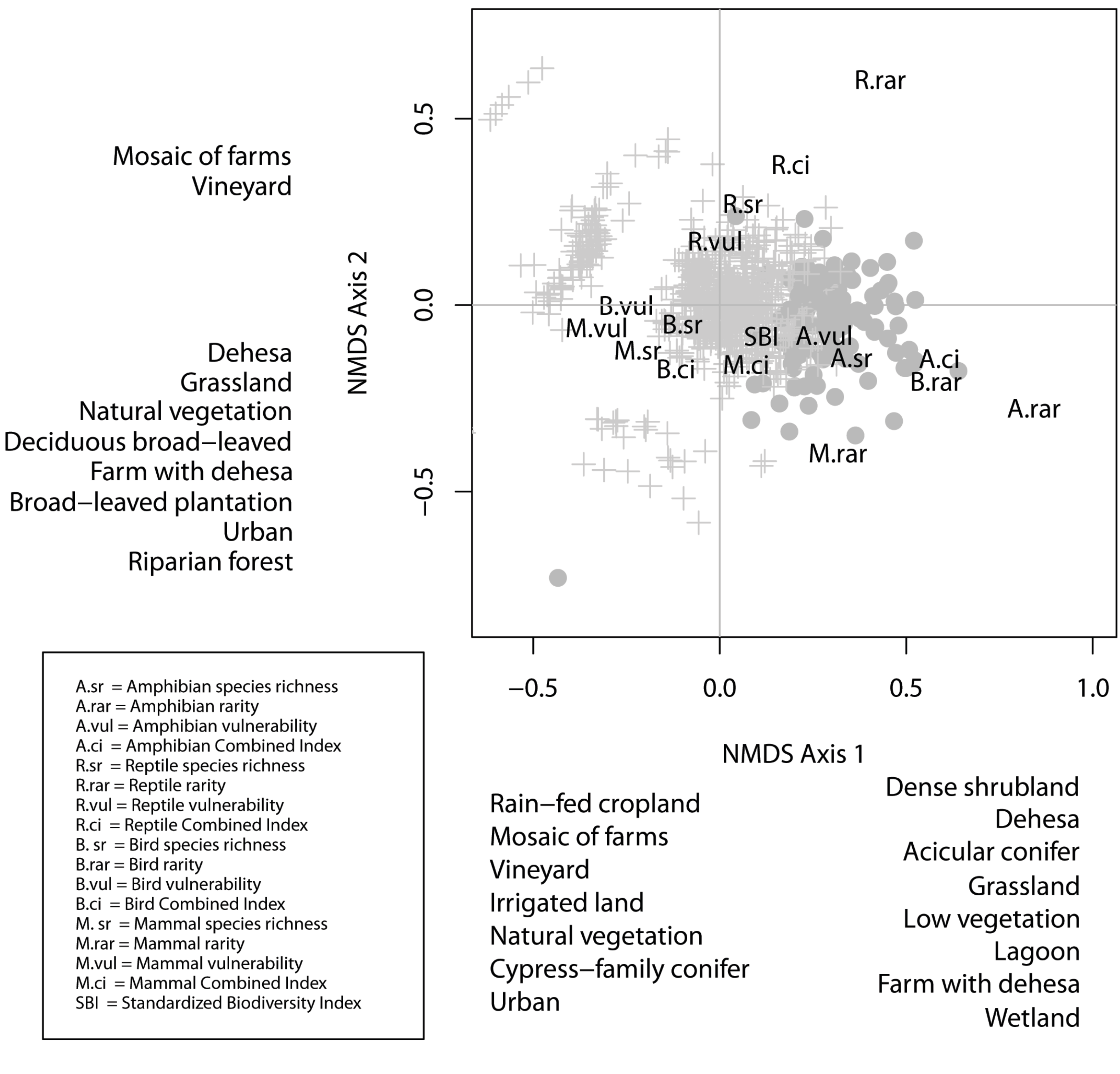

Rain-fed cropland
Vineyard
Olive grove
Mosaic of farms
Farm with dehesa
Mosaic of natural vegetation
Grassland
Dehesa
Dense evergreen scrubland
Sparse evergreen scrubland
Forest scrubland
Irrigated land
Lagoon
Wetland
Lake
River
Riparian forest
Fruit tree
Broad-leaved plantation
Conifer and broad-leaved
Broad-leaved mix
Perennial broad-leaved
Deciduous broad-leaved
Acicular conifer
Cypress family conifer
Low vegetation
Rocky land
Urban

Figure 3



Priority Areas for Conservation
Gaps in Natura 2000 Network

Figure 4


R.rar
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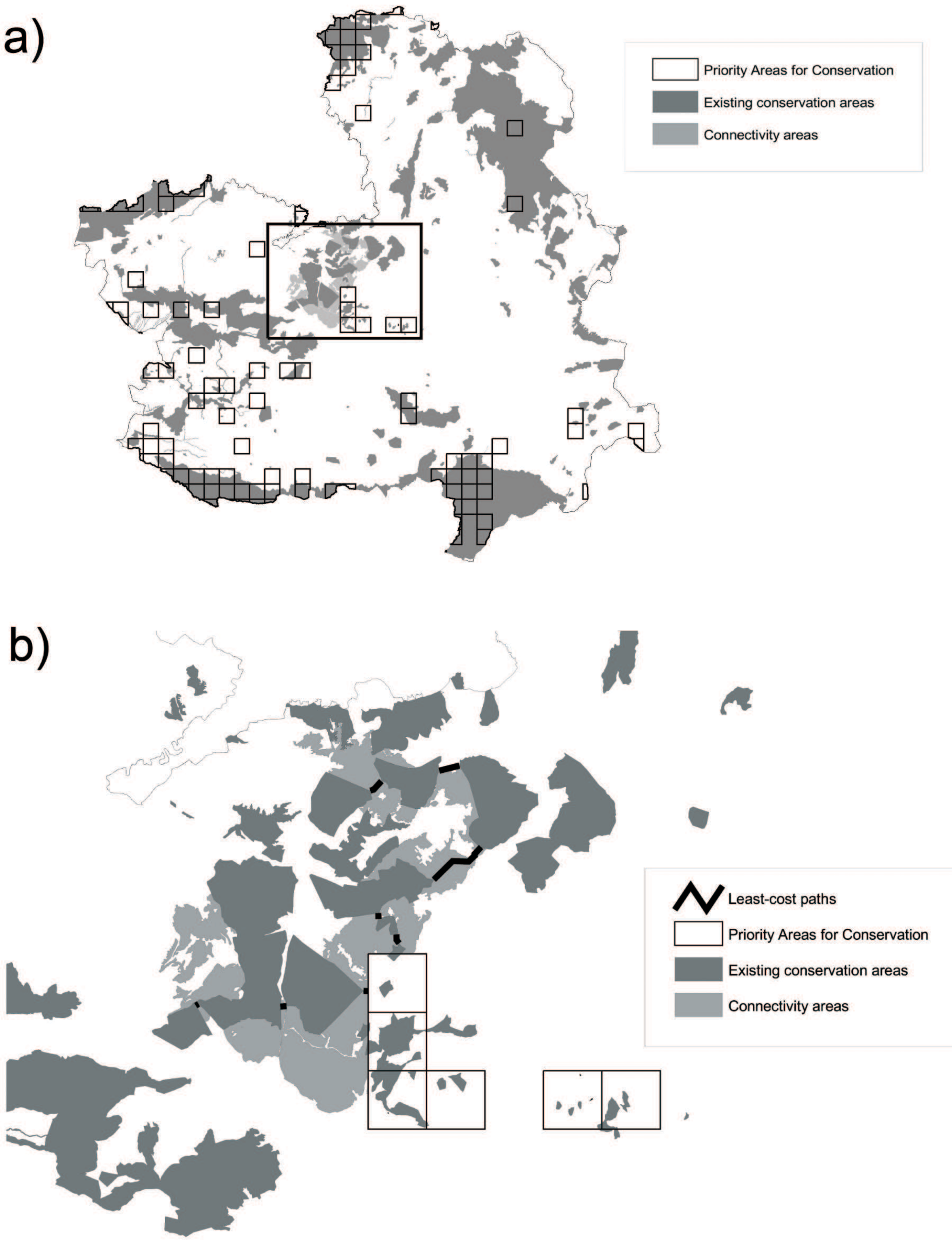
NMDS Axis 2
NMDS Axis 1
Mosaic of farms
Vineyard
Dehesa
Grassland
Natural vegetation
Deciduous broad−leaved
Farm with dehesa
Broad−leaved plantation
Urban
Riparian forest
Rain−fed cropland
Mosaic of farms
Vineyard
Irrigated land
Natural vegetation
Cypress−family conifer
Urban
Dense shrubland
Dehesa
Acicular conifer
Grassland
Low vegetation
Lagoon
Farm with dehesa
Wetland
A.sr = Amphibian species richness
A.rar = Amphibian rarity
A.vul = Amphibian vulnerability
A.ci = Amphibian Combined Index
R.sr = Reptile species richness
R.rar = Reptile rarity
R.vul = Reptile vulnerability
R.ci = Reptile Combined Index
B. sr = Bird species richness
B.rar = Bird rarity
B.vul = Bird vulnerability
B.ci = Bird Combined Index
M. sr = Mammal species richness
M.rar = Mammal rarity
M.vul = Mammal vulnerability
M.ci = Mammal Combined Index
SBI = Standardized Biodiversity Index

Figure 5



a)
Priority Areas for Conservation
Existing conservation areas
Connectivity areas
b)
Least-cost paths
Priority Areas for Conservation
Existing conservation areas
Connectivity areas