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A methodology to assess the future connectivity of protected areas by combining climatic representativeness and land cover change simulations: the case of the Guadarrama National Park (Madrid, Spain)

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Protected areas are fundamental in conservation, but their intactness is increasingly threatened by the effects of climate and land cover changes. Here, a methodological procedure is proposed able to determine the representative climatic conditions of a protected area in central Spain (Guadarrama National Park) pinpointing the natural areas that will host future analogous conditions, but also assessing the effects of land cover changes on the connectivity of these areas. Future conditions provided by two 2050 IPCC climatic change scenarios and land cover change simulations were jointly used for this purpose. According to the results obtained, climate change will produce notable effects, displacing its representative climatic conditions as well as modifying the land cover in the neighbor localities. Three areas appear as fundamental for the future maintenance of this reserve: two within the Iberian Central System (Gredos Mountains and Ayllón Mountains) and one in the Iberian System (Urbión Mountains). The proposed approach can be implemented in any protected area to examine its capacity to represent in the future the environmental conditions for which it was created.

Keywords: climatic representativeness; future analogous conditions; land-use simulations; connectivity; Iberian Peninsula

1. Introduction

The establishment and management of protected areas (PAs) is a cornerstone of biodiversity conservation, with the aim of safeguarding characteristic environmental conditions, species, and ecological communities. To date, PAs have mitigated the threats associated with human activity (Rodrigues *et al.* 2004) and have slowed down the loss of biological diversity (Dudley and Parish 2006) and habitat alteration within their limits (Bruner *et al.* 2001). However, changes in land use and land cover in adjacent areas can influence the effectiveness of PAs as a conservation tool (Radeloff *et al.* 2010; Hamilton *et al.* 2013). In addition, there is increasing concern over whether PAs with

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fixed spatial boundaries can maintain populations of species in the face of climate change and other anthropogenic pressures (Araújo *et al.* 2004; Parmesan 2006; Chen *et al.* 2011; Monzón, Moyer-Horner, and Palamar 2011; Triviño *et al.* 2013).

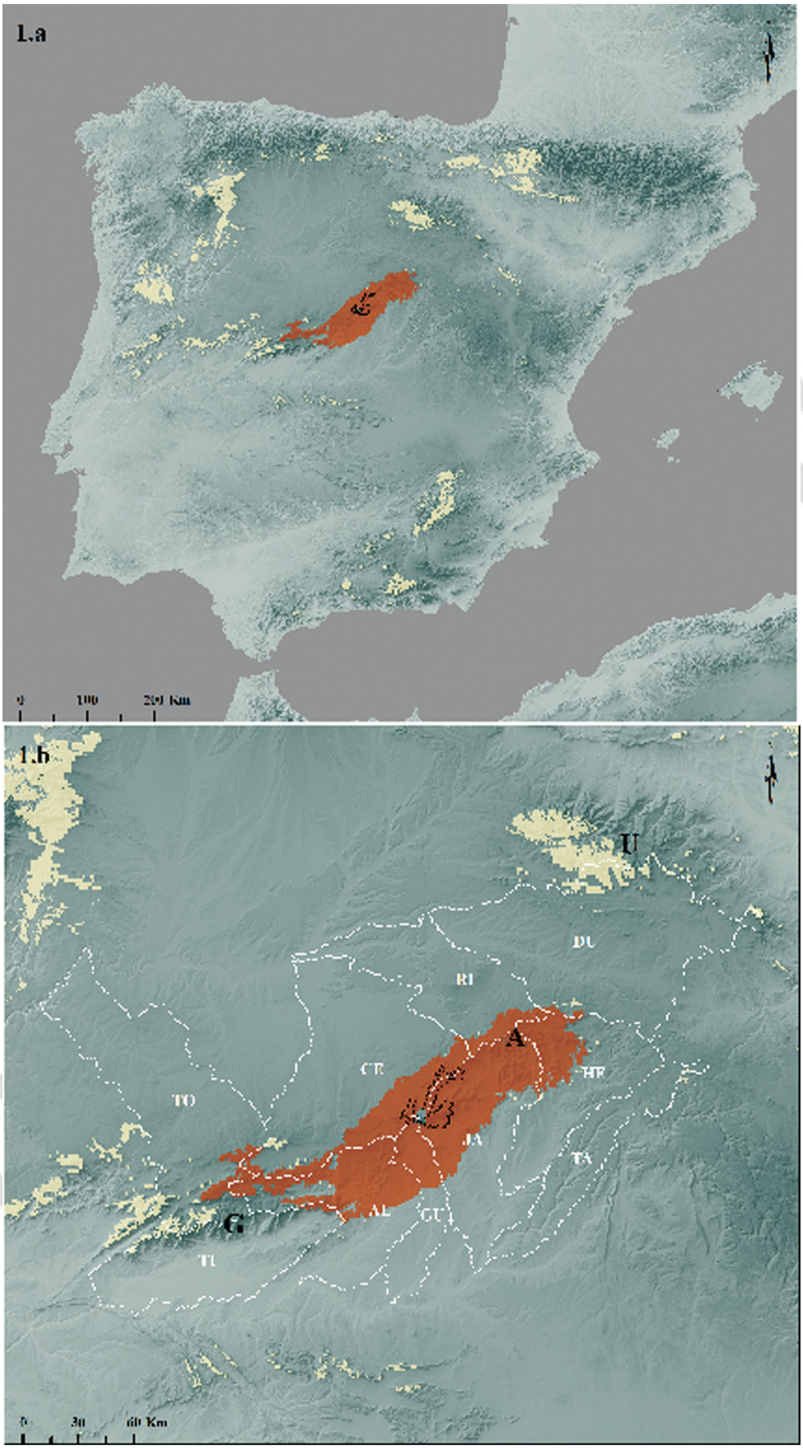
If changes in the climate due to greenhouse gas emissions continue (IPCC 2007, 2014), the alteration of climatic conditions could interact with direct land-use change (Dale 1997) to diminish the protective role played by PAs. Specifically, PAs could be rendered ineffective for their designated roles if they represent environmental conditions that are increasingly distinct from when they were established (Lobo 2011). Under these circumstances, protected areas could become "emitter" areas of characteristic flora and fauna toward other "recipient" areas that, in the future, would represent the environmental conditions currently hosted by a given PA (Thomas and Gillingham 2015). Hence, it is important to anticipate changes in the climatic conditions represented by each PA, to estimate the location of these recipient areas (Mingarro and Lobo 2018), and to simulate possible land-cover changes in them (Sleeter *et al.* 2012; Sohl *et al.* 2016). To perform these tasks is crucial to designing conservation adaptation strategies that, on the one hand, help facilitate the colonization of these recipient areas by threatened fauna and flora and, on the other, anticipate the environmental conditions in existing PAs.

In this study, the areas of future climatic and land-cover representativeness are identified for a recently established Spanish National Park, the Guadarrama National Park (GNP), which is subject to intense anthropogenic pressure due to its proximity to a highly populated city (Madrid) (Hewitt and Escobar 2011; Díaz-Pacheco and García-Palomares 2014; Lopez-Gay 2014). Climatic and land-cover scenarios are used to estimate the capacity of surrounding natural areas to represent the current biodiversity and environmental characteristics that motivated the protection of the GNP reserve and to delimit the most important zones hindering or promoting connectivity between these representative areas. Our applied aim is to establish a framework to assist environmental managers in the design of conservation strategies to mitigate future adverse effects of environmental change on the fauna and flora of protected areas, using the Guadarrama National Park as a case study.

2. Material and methods

2.1. Study area

GNP is located in the eastern part of the Iberian Central System (Figure 1), one of the main mountain systems of the Iberian Peninsula running in an ENE-WSW direction and splitting the inner Iberian plateau latitudinally into two parts. GNP is located in the Guadarrama Mountains at the northern boundary (around 35 km) of the highly populated metropolitan area, Madrid, with the Castilla and León Autonomous Community, and it is the most highly protected area in the Iberian Central Mountain System. The GNP was created in 2013 and covers 33,960 hectares, representing high mountain Mediterranean environments including scrub, alpine pastures, pine forests, and bogs, as well as glacial topography and unique geological elements (see López and Pardo 2018 for a synthesis of the environmental, historical and conservation characteristics of this region). The human pressure on GNP is very high; 26 municipalities are included within the reserve, and the surrounding villages harbor an approximate total resident human population of 150,000. Furthermore, GNP receives around **3,000,000** visitors per year (Rodríguez-Rodríguez *et al.* 2017), and the metropolitan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area of Madrid is one of the most populated areas in Europe (around **6,300,000** people), having experienced a substantial increase in population and urban land cover since the mid Twentieth Century (Hewitt and Escobar 2011; Díaz-Pacheco and García-Palomares 2014).

2.2. Climatic data

Current climatic data are based on interpolations using data from a total of 2,173 rainfall stations and 973 thermometric stations. These data represent the monthly average of maximum daily temperatures, monthly average of minimum temperatures, and both daily and total accumulated rainfall during each month; from 1950 to 2007 for the Iberian Peninsula (see methodology in Felicísimo *et al.* 2011). Using these data, digital cartography was carried out to represent monthly averages of each of these three variables for the whole set of years considered at a 1 km^2 resolution (Felicísimo *et al.* 2011). These data and the equations provided by Valencia-Barrera, Comtois, and Fernández-González (2002), López Fernández and López (2008), and Hijmans *et al.* (2005) allowed us to build 23 bioclimatic variables for each 1 km square over the 1950–2007 period (see Mingarro and Lobo 2018). These climatic predictors were submitted to a selection procedure in order to choose the minimum number of variables able to best represent overall climatic variability in the Iberian Peninsula. Briefly, all variables were submitted to a principal components analysis (PCA) generating three non–correlated factors with eigenvalues higher than 1, which represent 93.5% of the climatic variability of the Iberian Peninsula. For each one of these three factors the original variable with the highest factor loading was selected and also those variables poorly represented by the selected PCA factors (see Mingarro and Lobo 2018 for a complete description of the procedure). This process enabled the selection of five climatic variables: precipitation of the wettest month, annual average temperature, thermal contrast, isothermality, and average monthly maximum temperature.

Iberian future climatic data (year 2050) are derived from the WorldClim database with a 0.86 km^2 resolution at the equator. Data reflecting the average of six different global climate models (GCMs) were chosen: BCC-CSM1-1 (Xin, Wu, and Zhang 2013), CCSM4 (Gent *et al.* 2011), GISS-E2-R (Nazarenko *et al.* 2015), HadGEM2-ES (Jones *et al.* 2011), IPSL-CM5A-LR (Dufresne *et al.* 2013), and MRI-CGCM3 (Yukimoto *et al.* 2012). All these future climatic simulations were generated in the IPCC fifth evaluation report (AR5) according to two scenarios of representative concentration routes which differ markedly from each other, representing moderate (RCP 4.5) and high (RCP 8.5) rates of warming (Van Vuuren *et al.* 2011). Average values for the three primarily considered climatic variables (maximum temperature, minimum

Figure 1. (a) Guadarrama National Park (GNP; black polygon) and current climate representative areas throughout the Iberian Peninsula (yellow) and throughout the river basins contiguous to the GNP (in brown). (b) detailed map representing the area composed by the river basins (white polygons) in which there are areas with present climatic conditions similar to those of the GNP (in brown): (HE) Henares, (TA) Tajuña, (JA) Jarama, (GU) Guadarrama, (AL) Alberche, and (TI) Tiétar, (DU) Alto Duero, (RI) Riaza and Duratón, (CE) Cega, Eresma and Adaja and (TO) Tormes. Gredos Mountains are represented by the letter G, Ayllón Mountains by A (both belonging to the Iberian Central System), and Urbión Mountains representing by letter U (which belong to the Iberian System). All maps have been made with ETRS 89 UTM Zone 30 N reference system.

temperature, and annual average precipitation) were calculated in order to use them to derive the same five climatic variables selected using current climatic data.

2.3. Land cover data

Corine Land Cover (CLC) cartography was used to develop land-use and land-cover change simulations at a 100 m raster spatial resolution. Thus, each 100 m cell belongs to only a single land cover type (see https://land.copernicus.eu/pan-european/corine-land-cover). CLC data offers information from 1990 to 2012 (**1990, 2000, 2006,** and 2012) and was used considering the five main first-level land-cover categories: artificial areas, agricultural areas, forest and natural vegetation areas, wetlands and water bodies. The hydrographic basins of level 5 obtained from the WaterBase project (http://www.waterbase.org/) were used to delimit the study area.

2.4. Deriving climatic representativeness

The selection of areas with a climate similar to the one existing in GNP (climatic representativeness) was carried out following a previously published methodology (Mingarro and Lobo 2018). Briefly, the values of the five previously selected climatic variables were used to estimate the current Mahalanobis distance (MD) between the conditions in the 1 km^2 cells of the GNP and all the cells of the Iberian Peninsula. The 95th percentile of the MD values in GNP was chosen as the decision threshold to delimit the areas with a climate similar to that in the national park. The areas climatically representative of GNP were subsequently delimited to those existing in a surrounding area of **5,003,693** hectares covered by the 10 watersheds or sub-basins with areas within the target national park (called study area from now on; see Figure 1).

2.5. Land cover scenarios

The change in land cover was also simulated according to the same two scenarios from AR5 of the Intergovernmental Panel on Climate Change (IPCC 2014). In terms of land cover, RCP 4.5 represents a scenario of stable or decreased future greenhouse gas emissions associated with increased carbon stocks in forests and a decrease in agricultural land (Hurtt *et al.* 2011). On the contrary, the scenario RCP 8.5 is one with constant emissions and both population and anthropic land-cover increases (Van Vuuren *et al.* 2011; Hurtt *et al.* 2011).

To determine the area of each one of the five land cover categories that will change in the future scenarios, CLC data was first used to calculate real, observed changes. Thus, a 5×3 cross-tabulation table was built for each basin of the studied territory representing the changes that occurred in each land cover category over three consecutive periods (1990 vs **2000, 2000** vs 2006, and 2006 vs 2012; see Supplementary Appendix A1). The RCP 4.5 scenario indicates population stabilization and a reduction in the growth of artificial areas (Van Vuuren *et al.* 2011). The 10th percentile value of all the observed rates of the artificial land-cover growth was used to transform agricultural areas into artificial ones (0.0067% per year obtained for the Tiétar Basin during the 1990-2000 period; see Supplementary Appendix A1). This scenario also indicates a high natural and forest vegetation growth. Hence, the highest growth rate of forest and natural vegetation areas experienced in any basin and period

Table 1. Criteria used to assess the suitability of the different land cover categories and weights used obtained through an analytical hierarchy process (Saaty 1977) and following multicriteria evaluation techniques (Vaz et al. 2012). Constraint indicates criteria that were used to mask some of the areas out of the evaluation. A sigmoidal membership function with a monotonically decreasing curve was used to transform all criteria to the same range. ART = Artificial; AGR = Agricultural; FNV = Forest and Natural Vegetation.

Land use	Criteria	Weight
ART	Closeness to urban area	0.3306
	Closeness to road network	0.1443
	Slopes less than 10%	0.2206
	Closeness to Madrid municipality	0.3045
	Occurrence of a protected area	Constraint
AGR	Closeness to agricultural area	0.1406
	Closeness to forest and natural vegetation area	0.3056
	Closeness to road network	0.1855
	Slopes less than 15%	0.3683
	Occurrence of a protected area	Constraint
FNV	Closeness to forest and natural vegetation area	1

is also used to simulate the land-cover changes according to this scenario (0.3242% per year obtained in the Riaza and Duratón basin during the 2000–2006 period; see Supplementary Appendix A1).

The growth in population and artificial areas expected under the RCP 8.5 scenario (Van Vuuren *et al.* 2011) was represented by using the 90th percentile value for growth of artificial areas (0.3528% per year in the Guadarrama basin during the 1990–2000 period; see Supplementary Appendix A1) to transform forest areas into artificial ones and, to a lesser extent, agricultural areas into artificial ones. The median growth rate observed in agricultural areas (0.1898% per year in the Tiétar basin during the 1990–2000 period) was used to transform agricultural areas into forest and seminatural areas. The thresholds for the growth of artificial and agricultural areas were selected, contemplating that urban areas will grow at a faster rate than agricultural land, and also considering that the demand for increased agricultural production will be partly compensated by technological advances.

In all cases, the wetlands and water areas were considered stable because i) they represent less than 1% of the total area in the studied region, and ii) the temporal change in these land uses is not a concern in mountain areas due to the lack of overexploitation of the aquifers.

A multicriteria evaluation (MCE) was then carried out to weight seven location factors well known as drivers for land-use cover change in future scenario simulations (Vaz *et al.* 2012; Rozas-Vásquez *et al.* 2014) (Table 1). Previously, a sigmoidal membership function with a monotonically decreasing curve has been used to transform all these location factors to the same range (0-1 values) as implemented in the IDRISI Terrset software. The standard commonly used, Saaty's analytical hierarchy process, (AHP; Saaty 1977, 1980) was used for quantifying the weights on MCE according to experts' experiences, for the purpose of assigning a relative importance to each factor in determining the suitability of the stated objective (Eastman *et al.* 1995). AHP has been tested theoretically and empirically for a variety of decision-making situations, including spatial decision-making, and has been incorporated into a decision-making procedure based on GIS (Malczewski 1999). Finally, the weighted linear sum method was used as a straightforward method for the integration of standardized variables.

2.6. Simulating future changes

To locate where the climatic conditions that the GNP currently represents will appear in the future, the same five previously selected climatic variables were used to calculate the Mahalanobis distance between the current conditions in the 1 km^2 cells of the GNP and all the cells of the Iberian Peninsula according to the RCP 4.5 and RCP 8.5 future climate scenarios. This process allowed us to estimate the Iberian localities which, in the future, will provide the climatic conditions currently represented by the GNP ("recipient areas" *sensu* Mingarro and Lobo 2018).

In the land cover simulations, one of the most common approaches followed in the literature was used (Vaz *et al.* 2012; Rozas-Vásquez *et al.* 2014; Terra, dos Santos, and Costa 2014): the Cellular Automata-Markov module available in the IDRISI Terrset software (Eastman 2009). This task is based on simulation procedures which, although simple, have a great capacity to project trends in land-cover and land-use changes (López-López *et al.* 2009). The procedure is a spatially explicit stochastic model that simulates land-cover changes based on previous states (Luijten 2003), but it is not able to consider the variables that explain the local changes in some specific places. For this reason, the combination of Markov chains with MCE (specifically weighted linear summation) allows weighting and incorporation of location factors that adjust the results to the real characteristics of the territory (Vaz *et al.* 2012). In addition, the Cellular Automata-Markov module includes a Cellular Automata algorithm to simulate changes in dynamic systems in a regular and discrete space according to transition rules (Tobler 1979). This algorithm allows the incorporation of spatial neighborhood relations and dependence in the assignment of the probabilities of change for different covers (White and Engelen 1993; Li *et al.* 2017; Liang *et al.* 2018). In short, the Cellular Automata-Markov module works through iterations, each iteration corresponding to one year in this case. For each one-year-iteration, it uses as input the land-cover map on which the changes should be projected (starting from 2012 in this case), together with the Markov chain matrix and the images for each one of the classes obtained through the MCE, to simulate land-cover changes.

The final result of this iterative procedure is a land-cover map showing the land cover for the selected year in the future. Following the aforementioned approach, the simulation of land-cover changes in the study area was carried out in the two proposed future scenarios taking 2012 as the base year according to the available land-cover map (Figure 2). The areas that in the future will harbor similar climatic conditions to those currently existing in the GNP, along with those representing future changes in land cover, were used to delimit the climatically similar areas with forest and natural vegetation. All the other land-cover types were discarded as representative of the habitat conditions in the GNP. The possible anthropic barriers hindering the connectivity of the GNP with the so obtained recipient areas were identified.

3. Results

3.1. Climatic representativeness of GNP

The areas that currently harbor the climate of GNP represent approximately 3.7% of the complete Iberian area (Figure 1) and 17.4% of the 50,037 km^2 study area (Figure 3a). These areas are distributed throughout the Iberian Central System, including in mountain regions elsewhere on the central Iberian plateau (e.g. the Iberian System and the Gredos Mountains).

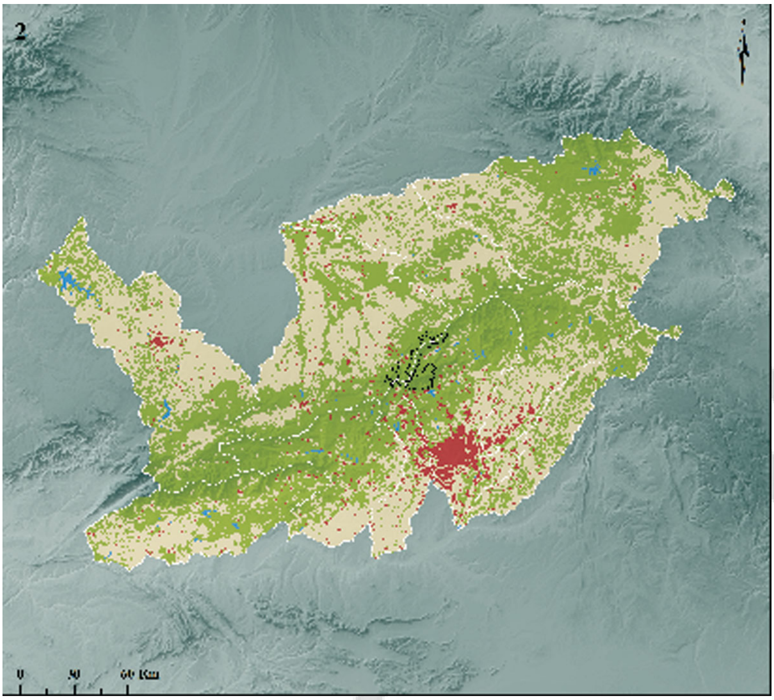

Figure 2. Selected study area with their corresponding land cover categories of level 1 according to the Corine Land Cover of 2012: artificial cover (red), agricultural areas (yellow), forest/natural vegetation (green), and water bodies (blue). River basins are represented by white polygons.

For 2050 under the RCP 4.5 scenario (Figure 3b), the overall area of climatic representativeness is reduced by 76%, so that it only represents 4.3% of the study area. Under this scenario, the area of the GNP itself does not contain any climatically representative areas, with only some small, and fragmented, area located in the Ayllón Mountains and in Gredos Mountains (see Figure 1). In the case of the RCP 8.5 scenario (Figure 3c), the climatic representative area was reduced from current conditions by 60%, so that it constituted around 7% of the study area, and the GNP retained 31% of climatically representative area (10,754.9 hectares).

3.2. Land cover simulations

The transition matrix elaborated for each one of the scenarios (Supplementary Appendix A2) was included in the model together with the location factors, thus generating two maps of possible future land-cover changes (Figure 4). In the RCP 4.5 scenario (Figure 4 and Table 2), the artificial coverage increases slightly (0.25%) in areas close to those already consolidated. The most striking variations are observed in agricultural land cover which loses 12.57% of its area, and in the increase of forest and natural vegetation areas (12.32%), mainly due to an increase of this land cover throughout the whole Iberian Central System. This increase in forest and natural vegetation facilitates connection of the GNP with the Gredos Mountains and the Urbión

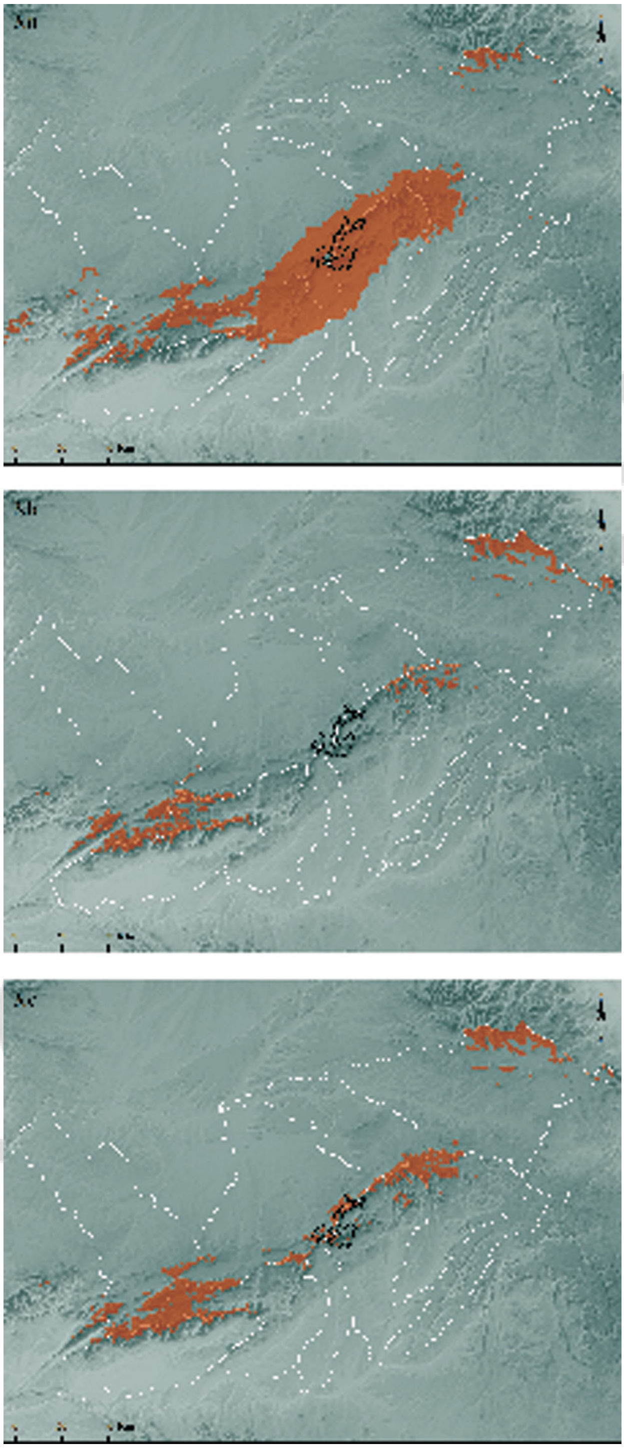

Figure 3. Current representative area with the climatic conditions prevailing in the Guadarrama National Park (in brown) for the present (a), the 2050 RCP 4.5 scenario (b), and the 2050 RCP 8.5 scenario (c). River basins are represented by white polygons.

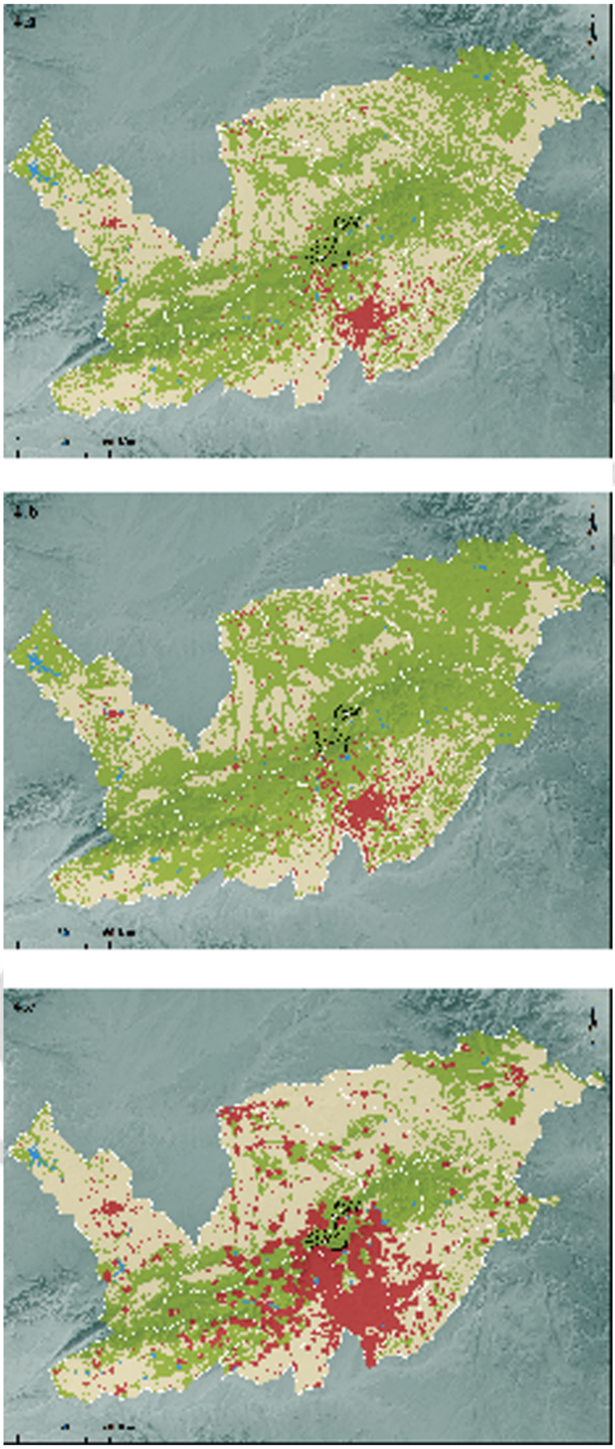

Figure 4. Distribution of land cover categories in the study region for the three periods: present (a), simulations for the year 2050 under the scenarios RCP 4.5 (b), and RCP 8.5 (c): artificial cover (red), agricultural areas (yellow), forest/natural vegetation (green), and water bodies (blue).

Table 2. Land cover area for each one of the five land cover categories in the study area (in hectares and in % of total) for the present (2012) and according to the results of the two considered 2050 simulations (RCP 4.5 and RCP 8.5 scenarios). ART = Artificial; AGR = Agricultural; FNV = Forest and Natural Vegetation; W = Wetlands; WB = Water Bodies.

	ART	AGR	FNV	W	WB	Total area
2012	176,176	2,221,184	2,578,304	24	28,005	**5,003,693**
	3.5 %	44.4%	51.5 %	0.0 %	0.6 %	
2050 RCP45	188,915	1,592,010	3,194,739	24	28,005	**5,003,693**
	3.8 %	31.8 %	63.8 %	0.0 %	0.6 %	
2050 RCP85	846,991	2,576,271	1,552,402	24	28,005	**5,003,693**
	16.9 %	51.5 %	31.0 %	0.0 %	0.6 %	

Mountains where climatically representative conditions are expected to persist (see Figure 1).

In contrast, in the RCP 8.5 or population development scenario (Figure 4 and Table 2), the differences from the present are much more marked. In this case, a high increase in coverage of artificial areas is observed; **176,176** hectares (3.52% of total study area) are artificial in 2012 while in 2050 this area increases to cover **846,991** hectares (16.92%). This growth becomes more noticeable for the artificial areas near to the Madrid metropolitan area. There is also an increase in the agricultural land cover (7.10%) and a large loss of forest and natural vegetation land cover (20.50%) practically throughout all the study area. This leads to a reduction in the natural connection of the GNP with the Gredos Mountains, the Urbión Mountains, and other parts of the Iberian Central System.

3.3. Possible futures for the guadarrama national park

Figure 5 shows, for each one of the two future scenarios, the areas with similar climatic characteristics and natural land-cover conditions as those currently present in the GNP. No areas appear within the GNP harboring these conditions for the RCP 4.5 scenario; the nearest suitable areas are located in the Gredos Mountains, the Iberian System and, to a lesser degree, in the westernmost part of the Iberian Central System. In total, **208,851** hectares can be considered representative under this scenario; approximately 10% less than the current area. For the RCP 8.5 scenario, the reduction of the area is slightly lower than under the RCP 4.5 scenario; **318,114** hectares were identified as suitable, around 9% less than those currently represented by GNP. Unlike the RCP 4.5 scenario, similar conditions to those of the GNP keep appearing in some localities of the GNP.

The barriers composed of artificial land cover that could prevent the spatial connectivity between the GNP and the suitable climatic and land-cover areas established for the RCP 4.5 scenario are highly isolated from each other (Figure 5). However, the remarkable increase in these anthropic areas in the RCP 8.5 scenario would seriously prevent connectivity between the GNP and the suitable areas located in the Gredos Mountains, but less with those of the Ayllón Mountains.

4. Discussion

In this paper, we have tried to offer a different perspective to promote the sustainability and conservation of protected areas. Rather than trying to anticipate the probable

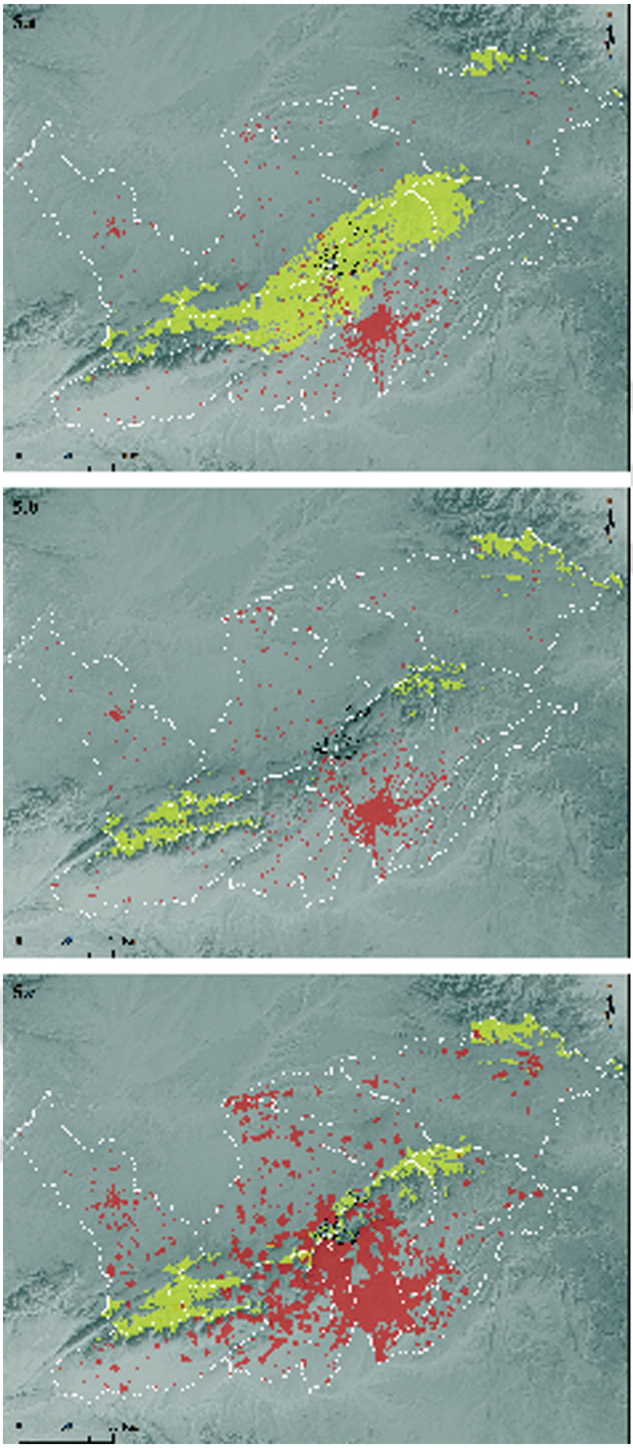

Figure 5. Climatically and land use suitable areas according to the present conditions of the Guadarrama National Park (in green) and physical barriers (in red) composed by artificial land cover for the present (a) and for the two simulated future scenarios: RCP 4.5 (b) and RCP 8.5 (c). River basins are represented by white polygons.

future distribution of species in response to climatic and land-cover changes, our proposal aims to estimate the degree of variation in the distinctive conditions of a protected area, searching for those close territories able to represent these conditions in the near future. In our specific case, a recently created protected area with a high anthropic pressure was studied, showing that the provided climatic and land-cover simulations allow us to discern where it is convenient to focus conservation efforts directed to guarantee the environmental representativeness of this national park.

4.1. Policy implications

Several studies prioritize and select possible reserve networks considering diverse climate change scenarios through the development of species distribution models capable of anticipating the geographical response of each species to climate changes (Triviño *et al.* 2013; Jones *et al.* 2016; Reside, Butt, and Adams 2018). However, these simulations can be misleading about the effects of climatic change because of our lack of information about the real complex factors able to explain the abundance and distribution of the species (Lobo 2016). As a consequence, we consider that approximations based on foreseeing the climatic changes of “spaces” and not “species” should be favored (Loarie *et al.* 2009; Scriven *et al.* 2015; Littlefield *et al.* 2017). Furthermore, multiple studies indicate that, together with climate change (Dale 1997; Michalak *et al.* 2018), the change in land cover is one of the primary factors influencing the extinction of populations and species (Vitousek *et al.* 1997; Fischer 2007; Laliberte *et al.* 2010). This happens mainly as a consequence of the drastic increase and extension of agricultural land and human settlements (Maxwell *et al.* 2016). Although protecting species from land-cover and land-use changes may be unnecessary inside protected areas (Radeloff *et al.* 2010), their preservation and resilience are intimately dependent on the changes occurring in their surroundings (Franklin and Lindenmayer 2009). Thus, identifying territories in conservation without considering future and possible changes in land cover may result in the selection of inefficient areas (Faleiro, Machado, and Loyola 2013; Jones *et al.* 2016). Therefore, it is necessary to combine climate with spatial land-cover change simulations to generate more reliable estimations about the regions that may most likely act as recipient areas for the conditions of each protected area in the future, irrespective of the species responses.

In our case, these recipient areas have been recently delimited for the Spanish national park, which presumably has a higher probability of being influenced by the anthropic activity of a densely populated city such as Madrid (Rodríguez-Rodríguez *et al.* 2017). Considering these simulations, it is possible to suggest locations in which conservation efforts should be focused to maintain the future natural integrity of this reserve and of the species inhabiting it. Of course, the persistence of species will be conditioned by their dispersal capacity (frequently reduced in high mountains) and phenotypic plasticity, as well as by the connectivity between suitable areas across the considered territory. Apart from these natural limitations, our results suggest that, under the two future scenarios considered, there will be a strong reduction in the area that will represent the current climatic conditions of GNP, especially within the limits of this reserve. This implies that GNP will undergo a drastic change in its environmental conditions and that in the foreseeable future this would suppose the appearance of remarkably different environmental conditions from those that were considered in its creation as a national park. This could be a risk for the persistence of this reserve and the biodiversity that inhabits it. The GNP is one of the protected areas in which the high Mediterranean mountain is represented, one of the most sensitive Iberian ecosystems to climate change (Sanz-Elorza *et al.* 2003), and a site where natural values are concentrated and dispersion capacities are limited. Some studies have focused their efforts on this national park, showing different aspects about the evolution of land uses (Hewitt, Pera, and Escobar 2016; Gallardo and Martinez-Vega 2018), tourist pressure (Rodríguez-Rodríguez *et al.* 2017), or how vegetation is affected by pollutants arriving from the city of Madrid (Elvira *et al.* 2016). All these studies raise alarm over the risks and negative impacts that may appear in this national park. Our study attempts to help find alternative and close areas able to receive the environmental conditions and the organisms that could suffer the consequences of a climate and land-cover change.

In the two simulated future scenarios, our results indicate that the areas with similar climatic and land-cover conditions to those currently existing in the GNP would be similarly located in the same regions but with a different extension. These sites appear basically at both ends of the Iberian Central System, one in the western part of this massif, at the Gredos Mountains, and another in the eastern sector, at the Ayllón mountain range. This indicates that the Iberian Central System as a whole should constitute a key element to guarantee the conservation of the GNP. Establishing a dynamic network of corridors could facilitate the displacement of species under these changing scenarios (Haddad *et al.* 2015). In parallel, it is necessary to highlight the significant role that the Urbión Mountains may exercise in safeguarding the entire Iberian Central System biodiversity. The Urbión Mountains can be considered an inter-mountain climatic transition area that would be of interest to protect and connect to the other parts of the Iberian Central System. There are important differences between the considered scenarios in relation to the barriers of artificial cover that likely prevent the connection between all these areas with the GNP. Although under the RCP 4.5 scenarios these areas would cover a more limited area, our results indicate that they could be barely affected by the presence of barriers. The RCP 8.5 scenario would suppose the existence of more extensive areas with similar climatic conditions, but with an increase in the occurrence of artificial areas. Be that as it may, the spatial connection between the Gredos Mountains and the GNP always appears to be broken, thus splitting the Iberian Central System into two isolated areas that would limit the future persistence of the species populations characterizing this protected area. However, the connection between the GNP and the Ayllón Mountains is feasible in the two scenarios considered, as well as the connection with the Iberian System. The existence of barriers able to prevent the connectivity of natural areas with similar environmental characteristics needs to be considered as a serious risk with significant negative consequences. Planning actions are necessary to limit the increase of those artificial areas that promote the occurrence of these barriers.

4.2. Limitations of the study and future prospects

Although the main conclusions provided by this study can remain unchanged, there are some methodological considerations capable of altering the provided results. The interpolated climatic variables used in the analyses can influence the results obtained. Thus, the climate baseline period employed to estimate the climatic distance can alter the location and extent of recipient areas. In our case, the temporal interval selected as the baseline (1950–2007) encompasses a large part of the recent period of temperature increase, thus partially representing the dynamic nature of climate. The final selected variables can also influence the results. For example, the climate representativeness within the GNP disappears in the RCP 4.5 scenario, despite being a scenario that supposedly represents a lower climate change than in the more drastic RCP 8.5 scenario. This paradoxical result is due to the fact that the estimated changes in the values for precipitation during the wettest month and thermal contrast are higher in the RCP 4.5 scenario than in the RCP 8.5 scenario. Thus, although the location of climatically suitable localities can be partially modified by the climatic uncertainties associated with the interpolated character of the data (Kundzewicz *et al.* 2018), we consider that the general pattern can safely be drawn from our procedure.

The results are also conditioned by the amount of change in land cover, the location factors used (Vaz *et al.* 2012), and the occurrence of natural disturbance factors such as fires or the increase of linear features such as roads. Hence, a more exhaustive study using additional location factors and weights, more robustly agreed on by means of a participatory process including different experts, or even considering other different MCE methods would be useful for examining the consistency of our results before their use in conservation planning.

It is important to emphasize that the proposed procedure is intended to estimate the localities with similar climatic and habitat conditions to those existing in a protected area, assuming that the conservation and biodiversity values of this territory are linked to their environmental conditions. However, the search for these locations does not guarantee the conservation of biodiversity because other biotic, contingent, environmental or dispersal factors can be relevant. We only propose a procedure to delimit possible future regions for the organisms inhabiting a protected area, assuming that the environmental factors currently present in this area are probably fundamental for the persistence of the species that inhabit it. As a required next step, it would be necessary to analyze the spatial connectivity between recipient areas and the possible need of translocation initiatives. Also important is the identification of wildlife corridors capable of connecting the study area with other intact landscapes (Saura *et al.* 2018). A previous study identified priority ecological corridors for the Iberian forest habitats included within the Natura 2000 protected areas network (WWF, 2018). Interestingly, one of the twelve main detected ecological corridors (the Iberian Central System corridor) covers both the GNP and the recipient areas estimated in this study.

5. Conclusions

This study aims to develop a scientific and repeatable methodology for the discrimination of those areas able to increase the resilience of a reserve to climate and land-cover change. This methodological proposal suggests that climate change will produce notable effects in the upcoming decades on the Guadarrama National Park, displacing its specific representative climatic conditions to other places, as well as modifying the land cover in their neighbor localities. Basically, three areas appear as most important for the future maintenance of the environmental conditions of this reserve: two located within the Iberian Central System (Gredos Mountains and Ayllón Mountains) and one placed in the Iberian System (Urbión Mountains). In order to avoid the consequences of these anticipated changes, it is important to address artificial barriers that may limit the connectivity of these areas in the future.

The proposed methodology should serve to facilitate the design of preventive measures able to improve the capacity of representing in the future the environmental conditions for which protected areas were created. The accomplishment of this procedure in a network of protected areas, with different climatic conditions and spatial-temporal land-use dynamics, may allow testing its robustness against future alterations.

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References

Araújo, M. B., M. Cabeza, W. Thuiller, L. Hannah, and P. H. Williams. 2004. "Would Climate Change Drive Species out of Reserves? An Assessment of Existing Reserve-Selection Methods." *Global Change Biology* 10 (9): 1618–1626. doi:10.1111/j.1365-2486.2004.00828.x.

Batllori, E., M. Parisien, A. S. A. Parks, M. A. Moritz, and C. Miller. 2017. "Potential Relocation of Climatic Environments Suggests High Rates of Climate Displacement within the North American Protection Network." *Global Change Biology* 23 (8): 3219–3230. doi:10.1111/gcb.13663.

Bruner, A. G., R. E. Gullison, R. E. Rice, and G. A. B. Da Fonseca. 2001. "Effectiveness of Parks in Protecting Tropical Biodiversity." *Science (New York, N.Y.)* 291 (5501): 125–128. doi:10.1126/science.291.5501.125.

Carroll, C., S. A. Parks, S. Z. Dobrowski, and D. R. Roberts. 2018. "Climatic, Topographic, and Anthropogenic Factors Determine Connectivity between Current and Future Climate Analogs in North America." *Global Change Biology* 24 (11): 5318–5331. doi:10.1111/gcb.14373.

Chen, I., J. K. Hill, R. Ohlemüller, D. B. Roy, and C. D. Thomas. 2011. "Rapid Range Shifts of Species associated with high levels of climate warming." *Science (New York, N.Y.)* 333 (6045): 1024–1026. doi:10.1126/science.1206432.

Dale, V. H. 1997. "The Relationship between Land-Use Change and Climate Change." *Ecological Applications* 7 (3): 753–769. doi:10.1890/1051-0761(1997)007[0753:TRBLUC]2.0.CO;2.

Díaz-Pacheco, J., and J. C. García Palomares. 2014. "A Highly Detailed Land-Use Vector Map for Madrid Region Based on Photo-Interpretation." *Journal of Maps* 10 (3): 424–433. doi:10.1080/17445647.2014.882798.

Dudley, N., and J. Parish. 2006. *Closing the Gap. Creating Ecologically Representative Protected Area Systems: A Guide to Conducting the Gap Assessments of Protected Area Systems for the Convention on Biological Diversity.* Technical Series. No. 24, 108. pp. Montreal, Canada: Secretariat of the Convention on Biological Diversity.

Dufresne, J.-L., M.-A. Foujols, S. Denvil, A. Caubel, O. Marti, O. Aumont, Y. Balkanski., *et al.* 2013. "Climate Change Projections Using the IPSL-CM5 Earth System Model: From

CMIP3 to CMIP5." *Climate Dynamics* 40 (9–10): 2123–2165., doi:10.1007/s00382-012-1636-1.

Eastman, R. 2009. *Guide to GIS and Image Processing, Systems Research*. Worcester, MA: Clark University.

Eastman, R., W. Jin, P. A. Kyem, and J. Toledano. 1995. "Raster Decisions Multi-Criteria/Multi-Objective Decisions." *Photogrammetric Engineering and Remote Sensing* 61 (5): 539–547.

Elvira, S., I. González-Fernández, R. Alonso, J. Sanz, and V. Bermejo-Bermejo. 2016. "Ozone Levels in the Spanish Sierra de Guadarrama Mountain Range Are above the Thresholds for Plant Protection: Analysis at 2262, 1850, and 995 m.a.s.l." *Environmental Monitoring and Assessment* 188 (10): 593. doi:10.1007/s10661-016-5581-z..

Faleiro, F. V., R. B. Machado, and R. D. Loyola. 2013. "Defining Spatial Conservation Priorities in the Face of Land-Use and Climate Change." *Biological Conservation* 158: 248–257.. doi:10.1016/j.biocon.2012.09.020.

Felicísimo, Á., J. Muñoz, J. Villalba, and R. Mateo. 2011. *Impactos, vulnerabilidad y adaptación al cambio climático de la biodiversidad española. 1. Flora y vegetación. Oficina Española de Cambio Climático*. Madrid, España: Ministerio de Medio Ambiente y Medio Rural y Marino.

Fischer, T. 2007. *The Theory and Practice of Strategic Enviromental Assessment: Towards a More Systematic Approach*. London: Earthscan.

Franklin, J. F., and D. B. Lindenmayer. 2009. "Importance of Matrix Habitats in Maintaining Biological Diversity." *Proceedings of the National Academy of Sciences of the United States of America* 106 (2): 349–350. doi:10.1073/pnas.0812016105.

Gallardo, M., and J. Martinez-Vega. 2018. "Future Land Use Change Dynamics in Natural Protected Areas - Madrid Region Case Study." In *GISTAM 2017 - Proceedings of the 3rd International Conference on Geographical Information Systems Theory, Applications and Management*, 370–377.

Gent, Peter R., Gokhan Danabasoglu, Leo J. Donner, Marika M. Holland, Elizabeth C. Hunke, Steve R. Jayne, David M. Lawrence., *et al.* 2011. "The Community Climate System Model Version 4." *Journal of Climate* 24 (19): 4973–4991. doi:10.1175/2011JCLI4083.1.

Haddad, N. M., L. A. Brudvig, J. Clobert, K. F. Davies, A. Gonzalez, R. D. Holt, T. E. Lovejoy., *et al.* 2015. "Habitat Fragmentation and Its Lasting Impact on Earth's ecosystems." *Science Advances* 1 (2): e1500052–e1500052. doi:10.1126/sciadv.1500052.

Hamilton, C. M., S. Martinuzzi, A. J. Plantinga, V. C. Radeloff, D. J. Lewis, W. E. Thogmartin, P. J. Heglund, and A. M. Pidgeon. 2013. "Current and Future Land Use around a Nationwide Protected Area Network." *PLoS One* 8 (1): e55737. doi:10.1371/journal.pone.0055737.

Hewitt, R., and F. Escobar. 2011. "The Territorial Dynamics of Fast-Growing Regions: Unsustainable Land Use Change and Future Policy Challenges in Madrid, Spain." *Applied Geography* 31 (2): 650–667. doi:10.1016/j.apgeog.2010.11.002.

Hewitt, R., F. Pera, and F. Escobar. 2016. "Cambios Recientes en la Ocupación Del Suelo de Los Parques Nacionales Españoles y Su Entorno." *Cuadernos Geográficos de La Universidad de Granada* 55 (2): 46–84.

Hijmans, R. J., S. E. Cameron, J. L. Parra, P. G. Jones, and A. Jarvis. 2005. "Very High Resolution Interpolated Climate Surfaces for Global Land Areas." *International Journal of Climatology* 25 (15): 1965–1978. doi:10.1002/joc.1276.

Hurtt, G. C., L. P. Chini, S. Frolking, R. A. Betts, J. Feddema, G. Fischer, J. P. Fisk., *et al.* 2011. "Harmonization of Land-Use Scenarios for the Period 1500-2100: 600 Years of Global Gridded Annual Land-Use Transitions, Wood Harvest, and Resulting Secondary Lands." *Climatic Change* 109 (1-2): 117–161. doi:10.1007/s10584-011-0153-2.

IPCC. 2007. *Climate Change: Synthesis Report. Contribution of Working Groups I, II y III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Core Writing Team, R. Pachauri, and A. Reisinger. Geneva, Switzerland: IPCC.

IPCC. 2014. *Climate Change: Impacts, Adaptation, y Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by C. Field, V. Barros, D. Dokken, K. Mach, M. Mastryrea, T. Bilir, M. Chatterjee, K. Ebi, Y. Estrada, R. Genova, B. Girma, E.

Kissel, A. Levy, S. MacCracken, P. Mastryrea, and L. White. Cambridge, UK: Cambridge University Press.

Jones, C. D., J. K. Hughes, N. Bellouin, S. C. Hardiman, G. S. Jones, J. Knight, S. Liddicoat., *et al*. 2011. “The HadGEM2-ES Implementation of CMIP5 Centennial Simulations.” *Geoscientific Model Development* 4 (3): 543–570. doi:10.5194/gmd-4-543-2011.

Jones, K. R., J. E. M. Watson, H. P. Possingham, and C. J. Klein. 2016. “Incorporating Climate Change into Spatial Conservation Prioritisation: A Review.” *Biological Conservation* 194: 121–130. doi:10.1016/j.biocon.2015.12.008.

Kundzewicz, Z. W., V. Krysanova, R. E. Benestad, Ø. Hov, M. Piniewski, and I. M. Otto. 2018. “Uncertainty in Climate Change Impacts on Water Resources.” *Environmental Science & Policy* 79: 1–8. doi:10.1016/j.envsci.2017.10.008.

Laliberté, Etienne, Jessie A. Wells, Fabrice Declerck, Daniel J. Metcalfe, Carla P. Catterall, Cibele Queiroz, Isabelle Aubin., *et al*. 2010. “Land-Use Intensification Reduces Functional Redundancy and Response Diversity in Plant Communities.” *Ecol. Lett* 13 (1): 76–86. doi: 10.1111/j.1461-0248.2009.01403.x.

Li, X., G. Chen, X. Liu, X. Liang, S. Wang, Y. Chen, F. Pei, and X. Xu. 2017. “A New Global Land-Use and Land-Cover Change Product at a 1-Km Resolution for 2010 to 2100 Based on Human–Environment Interactions.” *Annals of the American Association of Geographers* 107 (5): 1040–1059. [Mismatch] doi:10.1080/24694452.2017.1303357.

Liang, X., X. Liu, X. Li, Y. Chen, H. Tian, and Y. Yao. 2018. “Delineating Multi-Scenario Urban Growth Boundaries with a CA-Based FLUS Model and Morphological Method.” *Landscape and Urban Planning* 177: 47–63. doi:10.1016/j.landurbplan.2018.04.016.

Littlefield, C. E., B. H. McRae, J. L. Michalak, J. J. Lawler, and C. Carroll. 2017. “Connecting today's climates to future climate analogs to facilitate movement of species under climate change.” *Conservation Biology : The Journal of the Society for Conservation Biology* 31 (6): 1397–1408. doi:10.1111/cobi.12938.

Loarie, S. R., P. B. Duffy, H. Hamilton, G. P. Asner, C. B. Field, and D. D. Ackerly. 2009. “The Velocity of Climate Change.” *Nature* 462 (7276): 1052–1055. doi:10.1038/nature08649.

Lobo, J. M. 2011. “Vulnerabilidad de las áreas protegidas y de zonas de interés para la biodiversidad ante el cambio climático.” In *Biodiversidad en España. Base de la Sostenibilidad Ante el Cambio Global*, edited by P. Álvarez-Uría and J. De la Cruz, 360–368. Madrid, España: Observatorio de la Sostenibilidad de España, Ministerio de Medio Ambiente y Medio Rural y Marino.

Lobo, J. M. 2016. “The Use of Occurrence Data to Predict the Effects of Climate Change on Insects.” *Current Opinion in Insect Science* 17: 62–68. doi:10.1016/j.cois.2016.07.003.

López Fernández, M. L., and M. S. López. 2008. “Clasificación Bioclimática Mundial y Cartografía Bioclimática de La España Peninsular y Balear.” *Publicaciones de Biología de la Universidad de Navarra, Serie Botánica* 17: 1–2.

López, I., and M. Pardo. 2018. “Socioeconomic Indicators for the Evaluation and Monitoring of Climate Change in National Parks: An Analysis of the Sierra de Guadarrama National Park (Spain).” *Environments* 5 (2): 25. [Mismatch] doi:10.3390/environments5020025..

López-Gay, A. 2014. “Population Growth and Re-Urbanization in Spanish Inner Cities: The Role of Internal Migration and Residential Mobility.” *Revue Quetelet/Quetelet Journal* 1 (2): 67–92. doi:10.14428/rqj2013.01.02.03.

López-López, P., A. Soutullo, C. García-Ripollés, V. Urios, L. Cadahía, and M. Ferrer. 2009. “Markov Models of Territory Occupancy: Implications for the Management and Conservation of Competing Species.” *Biodiversity and Conservation* 18 (5): 1389–1402. doi: 10.1007/s10531-008-9469-2.

Luijten, J. C. 2003. “A Systematic Method for Generating Land Use Patterns Using Stochastic Rules and Basic Landscape Characteristics: Results for a Colombian Hillside Watershed.” *Agriculture, Ecosystems and Environment* 95 (2–3): 427–441. doi:10.1016/S0167-8809(02)00219-0.

Malczewski, J. 1999. *GIS and Multi-Criteria Decision Analysis*.” New York: Wiley.

Maxwell, S. L., R. A. Fuller, T. M. Brooks, and J. E. M. Watson. 2016. “Biodiversity: The Ravages of Guns, Nets and Bulldozers.” *Nature* 536 (7615): 143–145. doi:10.1038/536143a.

Michalak, J. L., J. J. Lawler, D. R. Roberts, and C. Carroll. 2018. “Distribution and Protection of Climatic Refugia in North America.” *Conservation Biology : The Journal of the Society for Conservation Biology* 32 (6): 1414–1425. doi:10.1111/cobi.13130.

Mingarro, M., and J. M. Lobo. 2018. "Environmental Representativeness and the Role of Emitter and Recipient Areas in the Future Trajectory of a Protected Area under Climate Change." *Animal Biodiversity and Conservation* 41 (2): 333–344. doi:10.32800/abc.2018.41.0333.

Monzón, J., L. Moyer-Horner, and M. Baron Palamar. 2011. "Climate Change and Species Range Dynamics in Protected Areas." *BioScience* 61 (10): 752–761. doi:10.1525/bio.2011.61.10.5.

Nazarenko, L., G. A. Schmidt, R. L. Miller, N. Tausnev, M. Kelley, R. Ruedy, G. L. Russell., *et al*. 2015. "Future Climate Change under RCP Emission Scenarios with GISS ModelE2." *Journal of Advances in Modeling Earth Systems* 7 (1): 244–267. doi:10.1002/2014MS000403.

Parmesan, C. 2006. "Ecological and Evolutionary Responses to Recent Climate Change." *Annual Review of Ecology, Evolution, and Systematics* 37 (1): 637–669. doi:10.1146/annurev.ecolsys.37.091305.110100.

Radeloff, V. C., S. I. Stewart, T. J. Hawbaker, U. Gimmi, A. M. Pidgeon, C. H. Flather, R. B. Hammer, and D. Helmers. 2010. "Housing Growth in and near United States Protected Areas Limits Their Conservation Value." *Proceedings of the National Academy of Sciences of the United States of America* 107 (2): 940–945. doi:10.1073/pnas.0911131107.

Reside, A. E., N. Butt, and V. M. Adams. 2018. "Adapting Systematic Conservation Planning for Climate Change." *Biodiversity and Conservation* 27 (1): 1–29. doi:10.1007/s10531-017-1442-5.

Rodrigues, A. S. L., H. R. Akçakaya, S. J. Andelman, M. I. Bakarr, L. Boitani, T. M. Brooks, J. S. Chanson., *et al*. 2004. "Global Gap Analysis: Priority Regions for Expanding the Global Protected-Area Network." *BioScience* 54 (12): 1092–1100.[1092:GGAPRF]2.0.CO;2. doi:10.1641/0006-3568(2004)054.

Rodríguez-Rodríguez, D., P. Ibarra, J. Martínez-Vega, M. Echeverría, and P. Echavarría. 2017. "Fine-Tuning of a Protected Area Effectiveness Evaluation Tool: Implementation on Two Emblematic Spanish National Parks." *Environments* 4 (4): 68. doi:10.3390/environments4040068.

Rozas-Vásquez, D., F. Peña-Cortés, D. Geneletti, and G. Rebolledo. 2014. "Scenario Modelling to Support Strategic Environmental Assessment: Application to Spatial Planning of Coastal Wetlands in La Araucanía Region, Chile." *Journal of Environmental Assessment Policy and Management* 16 (02): 1450014. doi:10.1142/S1464333214500148.

Saaty, T. L. 1977. "A Scaling Method for Priorities in Hierarchical Structures." *Journal of Mathematical Psychology* 15 (3): 234–281. doi:10.1016/0022-2496(77)90033-5.

Saaty, T. L. 1980. *The Analytic Hierarchy Process, Planning, Piority Setting, Resource Allocation*. New York: McGraw-Hill.

Sanz-Elorza, M., Dana, E. D. E. D. A. González, and E. Sobrino. 2003. "Changes in the High-Mountain Vegetation of the Central Iberian Peninsula as a Probable Sign of Global Warming." *Annals of Botany* 92 (2): 273–280. doi:10.1093/aob/mcg130.

Saura, S., B. Bertzky, L. Bastin, L. Battistella, A. Mandrici, and G. Dubois. 2018. "Protected Area Connectivity: Shortfalls in Global Targets and Country-Level Priorities." *Biological Conservation* 219: 53–67. doi:10.1016/j.biocon.2017.12.020.

Scriven, S. A., J. A. Hodgson, C. J. McClean, and J. K. Hill. 2015. "Protected Areas in Borneo May Fail to Conserve Tropical Forest Biodiversity under Climate Change." *Biological Conservation* 184: 414–423. doi:10.1016/j.biocon.2015.02.018.

Sleeter, B. M., T. L. Sohl, M. A. Bouchard, R. R. Reker, C. E. Soulard, W. Acevedo, G. E. Griffith., *et al*. 2012. "Scenarios of Land Use and Land Cover Change in the Conterminous United States: Utilizing the Special Report on Emission Scenarios at Ecoregional Scales." *Global Environmental Change* 22 (4): 896–914. doi:10.1016/j.gloenvcha.2012.03.008.

Sohl, T. L., M. C. Wimberly, V. C. Radeloff, D. M. Theobald, and B. M. Sleeter. 2016. "Divergent Projections of Future Land Use in the United States Arising from Different Models and Scenarios." *Ecological Modelling* 337: 281–297. doi:10.1016/j.ecolmodel.2016.07.016.

Terra, T. N., R. F. dos Santos, and D. C. Costa. 2014. "Land Use Changes in Protected Areas and Their Future: The Legal Effectiveness of Landscape Protection." *Land Use Policy* 38: 378–387. doi:10.1016/j.landusepol.2013.12.003.

Thomas, C. D., and P. K. Gillingham. 2015. "The Performance of Protected Areas for Biodiversity under Climate Change." *Biological Journal of the Linnean Society* 115 (3): 718–730. doi:10.1111/bij.12510.

Tobler, W. 1979. "Cellular Geography." In *Philosophy in Geography*, edited by S. Gale and G. Olsson, 379–386. Dortrecht: Reidel.

Triviño, M., M. Cabeza, W. Thuiller, T. Hickler, and M. B. Araújo. 2013. "Risk Assessment for Iberian Birds under Global Change." *Biological Conservation* 168: 192–200. doi:10.1016/j.biocon.2013.10.005.

Valencia-Barrera, R. M., P. Comtois, and D. Fernández-González. 2002. "Bioclimatic Indices as a Tool in Pollen Forecasting." *International Journal of Biometeorology* 46 (4): 171–175. doi:10.1007/s00484-002-0138-y.

Van Vuuren, D. P., J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard, G. C. Hurtt., *et al*. 2011. "The Representative Concentration Pathways: An Overview." *Climatic Change* 109 (1–2): 5–31. doi:10.1007/s10584-011-0148-z.

Vaz, E. N., P. Nijkamp, M. Painho, M. Caetano, and M. Gaetano. 2012. "A Multi-Scenario Forecast of Urban Change: A Study on Urban Growth in the Algarve." *Landscape and Urban Planning* 104 (2): 201–211. doi:10.1016/j.landurbplan.2011.10.007.

Vitousek, P. M., H. Mooney, J. Lubchenco, and J. M. Melillo. 1997. "Human Domination of Earth' s Ecosystems." *Science* 277 (5325): 494–499. doi:10.1126/science.277.5325.494.

White, R., and G. Engelen. 1993. "Cellular Automata and Fractal Urban Form: A Cellular Modelling Approach to the Evolution of Urban Land-Use Patterns." *Environment and Planning A: Economy and Space* 25 (8): 1175–1199. doi:10.1068/a251175.

WWF. 2018. "Autopistas Salvajes." wwf.es.

Xin, X., T. Wu, and J. Zhang. 2013. "Introduction of CMIP5 Experiments Carried out with the Climate System Models of Beijing Climate Center." *Advances in Climate Change Research* 4 (1): 41–49. doi:10.1016/S0169-4332(96)00220-6.

Yukimoto, S., Y. Adachi, M. Hosaka, T. Sakami, H. Yoshimura, M. Hirabara, T. Tanaka., *et al*. 2012. "A New Global Climate Model of the Meteorological Research Institute: MRI-CGCM3. Model Description and Basic Performance." *Journal of the Meteorological Society of Japan* 90A: 23–64. doi:10.2151/jmsj.2012-A02.