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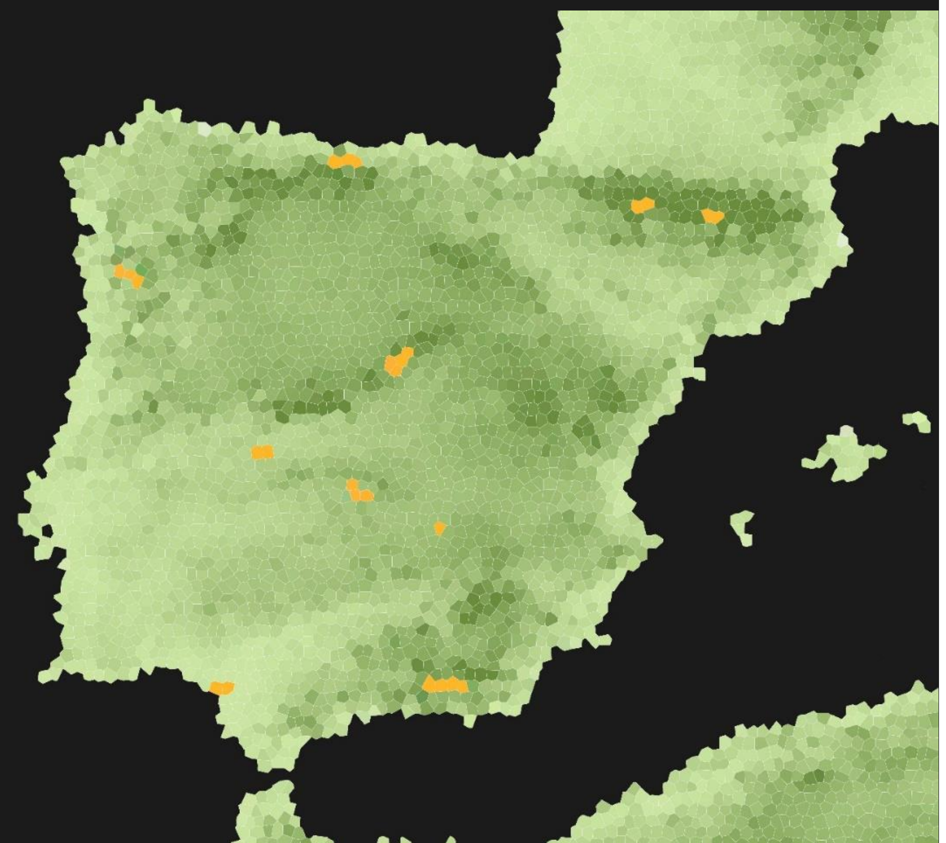

Representatividad climática de las áreas protegidas, su papel como áreas emisoras o receptoras ante el cambio climático, y su efecto atractor de las alteraciones antrópicas

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Sembrando trigo una vez, cosecharás una vez.

Plantando un árbol, cosecharás diez veces.

Instruyendo al pueblo cosecharás cien veces.

- Jiddu Krishnamurti –

A Jorge, Lourdes, Javier, Rosa, Andrés, Laura, Rob, Eva, Ángel, Guim, a mis compañeros del MNCN y a mis grandes amigos de Aluche. Gracias.

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RESÚMEN

Antecedentes

Actualmente estamos ante una pérdida de biodiversidad sin precedentes y la superficie natural continúa disminuyendo rápidamente. Los cambios, tanto en el clima como en el uso del suelo, son uno de los principales factores que influyen en la pérdida de biodiversidad. A esta actual tendencia, de pérdida de biodiversidad, hay que añadirle que el clima está cambiando aceleradamente y estos cambios continuarán, pudiendo llegar a ser dramáticos en un futuro próximo. Para detener, o al menos frenar, esta pérdida de biodiversidad las áreas protegidas han cobrado un verdadero valor conservacionista, apareciendo integradas en prácticamente todas las estrategias de conservación mundial. Además, se presentan como unos buenos indicadores de las consecuencias del cambio climático y de la interacción del ser humano con el mundo natural. Sin embargo, una de las principales amenazas de las áreas protegidas viene determinada por su propia naturaleza, ya que el carácter dinámico de los cambios de distribución de las especies contrasta con naturaleza estática de las áreas protegidas. Las condiciones climáticas representadas en un área protegida podrían desaparecer en el futuro y aparecer en otros lugares más o menos alejados del área protegida; estos lugares podrían ser considerados como áreas receptoras, potencialmente adecuadas para recibir propágulos del área protegida de origen.

Objetivos

El objetivo general de esta tesis doctoral consiste en proponer una metodología para adaptar a los parques nacionales ibéricos a los efectos del cambio climático, generando una red de espacios protegidos, así como comprender el efecto de los espacios protegidos sobre el territorio en el que se asientan.

Métodos

A lo largo de este trabajo se ha estimado la representatividad climática actual y futura de los parques nacionales ibéricos. De esta manera, se identifican las áreas que en el futuro tendrán un clima similar a las existentes ahora en los parques nacionales y, teniendo en cuenta el grado de alteración antropica y de protección, se estima el nivel de cambio que se producirá en sus condiciones climáticas actuales. Una vez identificadas las áreas receptoras se genera una red de corredores climáticos que las conecten dichas áreas con el parque nacional en cuestón, permitiendo discriminar aquellas áreas más conflictivas que impiden la conectividad de la red, debido al grado de transformación de los usos del suelo. Además, para comprender el efecto atractor de los parques nacionales, y examinar también si el patrón detectado tiene una estructura espacial, se han obtenido los cambios en la cobertura del suelo tanto dentro como en sus áreas circundantes.

Resultados

Los resultados muestran las áreas importantes para mantener la representatividad climática de los parques nacionales en el futuro, mostrando una reducción sustancial de la actual representatividad climática. Aunque la mayoría de las áreas receptoras tienen ahora usos del suelo forestales y seminaturales, los usos del suelo actuales obstruyen gravemente la red de corredores. Además, los resultados indican que la designación de un área protegida es, básicamente, un proceso capaz de facilitar el aumento de su condición natural en pocos años, proporcionando así un efecto beneficioso en su entorno. Sin embargo, el papel desempeñado por las áreas protegidas muestra una distribución espacialmente heterogénea, con claras y notables diferencias latitudinales.

Conclusiones

Los parques nacionales ibéricos se encuentran expuestos a una seria amenaza, como consecuencia de su naturaleza estática. Sin embargo, la metodología desarrollada en este trabajo se presenta como una herramienta sólida y eficaz, capaz de facilitar la adaptación al cambio climático de las especies que albergan estos espacios protegidos. El enfoque propuesto puede aplicarse en cualquier espacio protegido para examinar su capacidad de representar en el futuro las condiciones ambientales que motivaron su declaración. Este tipo de trabajos son fundamentales para desarrollar estrategias de adaptación eficaces, y para sugerir políticas capaces de proteger mejor las áreas protegidas y por lo tanto conservar la biodiversidad.

SUMMARY

Background

We are currently facing an unprecedented loss of biodiversity and natural areas continues decreasing rapidly. Changes in both climate and land use are one of the main drivers of biodiversity loss. In addition to this current biodiversity loss trend, the climate is changing rapidly and these changes will continue and may become dramatic in the near future. In order to halt, or at least slow down, this loss of biodiversity, protected areas have taken on a real conservation value, appearing to be integrated in practically all the world's conservation strategies. They are also good indicators of the consequences of climate change and human interaction with the natural world. However, one of the main threats to protected areas is determined by their very nature, as the dynamic nature of species distribution changes contrasts with the static nature of protected areas. The climatic conditions represented in a protected area could disappear in the future and appear in other places more or less distant from the protected area; these places could be considered as receiving areas, potentially suitable to receive propagules from the protected area of origin.

Objectives

The general objective of this doctoral thesis is to propose a methodology to adapt Iberian national parks to the effects of climate change, generating a network of protected areas, as well as to understand the effect of protected areas on the territory in which they are located.

Methods

Throughout this work, the current and future climatic representativeness of the Iberian national parks has been estimated. In this way, the areas that in the future will have a similar climate to those currently existing in the national parks are identified and, taking into account the degree of anthropic alteration and protection, the level of change that will occur in their current climatic conditions is estimated. Once the receptor areas have been identified, a network of climatic corridors is generated to connect these areas with the national park in question, making it possible to identify the most conflictive areas that impede the connectivity of the network, due to the degree of transformation of land use. In addition, in order to understand the attractor effect of national parks, and also to examine whether the detected pattern has a spatial structure, land cover changes both within and in the surrounding areas have been obtained.

Results

The results show which areas are important for maintaining the climatic representativeness of the national parks in the future, showing a substantial reduction of the current climatic representativeness. Although most of the receptor areas now have forest and semi-natural land uses, the current land uses severely obstruct the corridor network. Furthermore, the results indicate that the designation of a protected area is essentially a process capable of facilitating the enhancement of its natural condition within a few years, thus providing a beneficial effect on its environment. However, the role played by protected areas shows a spatially heterogeneous distribution, with clear and notable latitudinal differences.

Conclusions

Iberian national parks are exposed to a serious threat, as a consequence of their static nature. However, the methodology developed in this work is presented as a solid and effective tool, capable of facilitating the adaptation to climate change of the species found in these protected areas. The proposed approach can be applied to any protected area to examine its capacity to represent in the future the environmental conditions that led to its declaration. This type of work is essential to develop effective adaptation strategies, and to suggest policies capable of better protecting protected areas and thus conserving biodiversity.

INTRODUCCIÓN GENERAL

Tanto tú, lector, como yo, nos esforzamos por tener una buena calidad de vida, cada uno con diversas perspectivas sobre lo que se necesita para lograrlo, y conforme a esa idea basamos nuestras relaciones con otros, así como la interacción con la naturaleza. Dependiendo del contexto, el concepto de naturaleza según el marco occidental (Díaz et al., 2015) puede incluir la biodiversidad, los ecosistemas, la evolución de los organismos o la biosfera, pero para otros, como por ejemplo los pueblos indígenas, la naturaleza incluye la Madre Tierra o los sistemas de vida, y a menudo se ve como un elemento inherente al ser humano, más que como una entidad separada (Díaz et al., 2015). Sea cual sea nuestro contexto, resulta ineludible que la naturaleza nos provee de una serie de servicios indispensables para poder desarrollarnos como sociedad y, por lo tanto, ha estado, está y seguirá estando en la base del desarrollo humano (Isbell et al., 2017; Díaz et al., 2018). Con un simple gesto como el de levantar la vista, podemos observar los recursos que nos provee, así como observar la asombrosa biodiversidad que nos rodea. El término biodiversidad es ampliamente conocido y utilizado. Esta podría definirse como la variabilidad de organismos vivos y los complejos ecológicos de los que forman parte, comprendiendo la diversidad dentro de cada especie, entre las especies y de los ecosistemas, según quedó definido en el Convenio sobre Diversidad Biológica suscrito en 1992.

Las interacciones entre nosotros y la naturaleza tienen múltiples facetas (Isbell et al., 2017), pero el resultado global es que la humanidad ha estado remodelando patrones en la naturaleza durante muchos milenios (Newbold et al., 2015; Lyons et al., 2016). La huella de la humanidad ha alterado el 75% del mundo terrestre y gran parte de los océanos (Venter et al., 2016) y, en el contexto de los recursos limitados y la capacidad de asimilación de la Tierra, la huella ambiental actual de la humanidad no es sostenible (Hoekstra y Wiedmann, 2014). Resulta innegable que estamos ante una pérdida de biodiversidad sin precedentes (Barnosky et al., 2011; Pimm et al., 2014) y para este siglo se prevé una gran pérdida de hábitats, así como diversos cambios en la distribución y la abundancia de las especies, muy por encima de la tasa histórica (Pimm et al., 1995; Pereira et al., 2010).

Los cambios en el uso de la tierra son uno de los principales factores que influyen en la pérdida de biodiversidad (Vitousek et al., 1997; Fischer y Lindenmayer, 2007; Laliberté et al., 2010), siendo el uso del suelo agrícola y los asentamientos humanos las fuerzas responsables más importantes de este cambio (Maxwell et al., 2016). Actualmente, más de la mitad de la superficie terrestre está compuesta por tipos de cobertura de origen antrópico, que incluyen tierras agrícolas, pastizales y ciudades (Foley et al., 2005; Fuchs et al., 2013) y, aunque exista una gran diferencia en la influencia antrópica según el bioma (Riggio et al., 2020), la superficie natural relativamente libre de modificaciones humanas se encuentra cada vez más próxima a zonas ya alteradas (Kennedy et al., 2019). Además, mucha superficie de áreas naturales continúa disminuyendo rápidamente, debido a la tala industrial y a la expansión agrícola (Lambin et al., 2003; Potapov et al., 2008). Sin embargo, resulta difícil identificar las dinámicas que seguirán estas superficies en el futuro ya que son muchas las incertidumbres que subyacen a los múltiples impulsores del cambio del uso del suelo (Lambin et al., 2001; Rindfuss et al., 2004). Por ello, las posibles tendencias futuras se exploran en escenarios y modelos, tratando de analizar e integrar dichas incertidumbres. En general, estos escenarios indican que la tendencia acaecida hasta ahora será muy similar a la que se verá en las próximas décadas (van Vuuren et al., 2011; Hurtt et al., 2020).

Otro de los factores que condiciona el declive o la alteración de la biodiversidad de un territorio, junto a los cambios en los usos del suelo, es el clima (Dale, 1997). El clima tiene un papel fundamental sobre la biodiversidad (Parmesan, 2006; Chen et al., 2011) ya que suele ser el primer condicionante de las comunidades de organismos existentes y de las características de los sistemas ecológicos (Davis y Shaw, 2001; Woodward et al., 2004). Sin embargo, el clima está cambiando aceleradamente y se considera que estos cambios continuarán, pudiendo llegar a ser dramáticos en un futuro próximo (IPCC, 2018; 2021). El cambio climático inducido por el hombre es causado principalmente por un aumento en la concentración atmosférica de gases de efecto invernadero, incluido el vapor de agua, el dióxido de carbono, el metano y el óxido nitroso. De estos, el aumento de dióxido de carbono es el más preocupante porque está relacionado con actividades humanas generalizadas, principalmente la quema de combustibles fósiles y la deforestación (IPCC, 2021), y durante los últimos 150 años la concentración de este gas en la atmósfera ha aumentado a unas tasas sin precedentes (IPCC, 2018). Las variaciones naturales de las temperaturas globales son prácticamente despreciables en comparación con el calentamiento inducido por el ser humano y el calentamiento producido por los gases de efecto invernadero no tiene precedentes, en los últimos 10.000 años o más, superándose un umbral que no podría haberse superado de otra manera que no sea por la acción del ser humano. Algunos de los aspectos más relevantes del cambio climático, como son el aumento de temperatura y la irregularidad climática promovida por dicha emisión antrópica, tienen múltiples efectos sobre la biodiversidad como cambios en la fenología de los organismos (Parmesan, 2007; Wolkovich et al., 2012), cambios en las dinámicas de las distribuciones (Virkkala et al., 2008; Thuiller et al., 2014) e incluso en la funcionalidad de los ecosistemas (Blankinship et al., 2011).

La magnitud de los efectos producidos por el cambio climático y por el cambio en los usos del suelo es tal que, a pesar de muchos intentos para detener, o al menos frenar la tendencia, la biodiversidad continúa disminuyendo en todo el mundo (Mantyka-Pringle et al., 2012; Tilman, 2022). Mientras que las diferentes metas acordadas en los diferentes tratados, rara vez se han alcanzado y cuando lo han hecho parecen ser insuficientes ante el colapso de la biodiversidad (Tittensor et al., 2014; IPBES, 2019), los efectos negativos del ser humano sobre la biodiversidad no cesan (Hannah et al., 1994; Steffen et al., 2015; Riggio et al., 2020). Por lo que, la prevención de más extinciones requerirá tanto esfuerzos de conservación acelerados como enfoques proactivos diseñados para abordar posibles amenazas futuras (Margules y Pressey, 2000).

Una de las herramientas clave para la conservación de la biodiversidad son las áreas protegidas y prácticamente todas las instituciones tratan de integrarlas en sus estrategias de conservación nacionales e internacionales (Pressey et al., 2007;

Visconti et al., 2015; 2019). Podríamos definir las áreas protegidas como un espacio geográfico claramente definido, reconocido, dedicado y gestionado, para conservar a largo plazo la naturaleza, sus servicios ecosistémicos y sus valores culturales asociados (IUCN, 1994). Los objetivos y propósitos de las áreas protegidas han cambiado considerablemente durante el siglo pasado (Dudley, 2008), pasando de un énfasis inicial en valores como el paisaje, a visiones más amplias relacionadas con la conservación de la biodiversidad o la provisión de servicios ecosistémicos y socioculturales. Las áreas protegidas actúan como una herramienta clave en la mitigación de las amenazas asociadas a la actividad humana (Rodríguez-Rodríguez y Martínez-Vega, 2018b), frenando la pérdida de diversidad biológica (Dudley y Parish, 2006), manteniendo los ecosistemas naturales operativos (Ferraro y Hanauer, 2011), actuando como refugios para las especies (Lehikoinen et al., 2019) y protegiendo aquellos procesos ecológicos que son altamente sensibles a las actividades humanas. Por lo tanto, se presentan como unos buenos indicadores de las consecuencias de la interacción del ser humano con el mundo natural y su capacidad de conservación de los procesos y actores naturales (Dudley, 2008).

A pesar de que la conservación de la biodiversidad debe ser siempre un objetivo de conservación principal (Dudley, 2013), la mayor parte de las áreas protegidas declaradas hasta la fecha lo han sido por criterios de oportunidad más que por criterios u objetivos científicos, verificables y repetibles (Pressey et al., 1993; Baldi et al., 2017). Por lo cual, muchos de estos espacios protegen de una manera azarosa, o simplemente protegen zonas apartadas, con importantes valores estéticos, pero de escaso valor económico (McDonald y Boucher, 2011; Pressey et al., 2015), cuando en realidad deberían constituir una muestra representativa de la variabilidad ambiental y de la diversidad biológica del territorio en el que se asientan y pretenden conservar. No sólo eso, sino que además deberían facilitar el mantenimiento de los procesos biológicos y ambientales capaces de garantizar su permanencia a medio y largo plazo (Pressey, 1994; Dudley y Parish, 2006). Esto nos hace plantearnos que, a pesar de la gran superficie protegida a nivel global, 15% de la superficie terrestre y 7% superficie marina (UNEP-WCMC, 2020), aún quedan importantes pasos que dar respecto a la protección de áreas relevantes para la conservación de la biodiversidad.

La determinación de la eficacia en la representación y el mantenimiento de la biodiversidad de los espacios protegidos es una cuestión fundamental en la planificación de la conservación (Margules y Pressey, 2000) y plantea un gran desafío para la biología conservacionista (Laurance et al., 2012). De ahí que esta cuestión haya atraído la mirada de multitud de investigaciones para estimar el papel de las reservas en la protección de especies (Margules y Pressey, 2000; Haight y Hammill, 2019), las modificaciones en los usos del suelo que se han dado en estos espacios (Rodríguez-Rodríguez y Martínez-Vega, 2018a), su comportamiento ante el cambio climático (Hannah, 2010; Triviño et al., 2018), la evolución de sus modificaciones ambientales dentro de su perímetro y en sus alrededores (Radeloff et al., 2010; Hamilton et al., 2013; Castro-Prieto et al., 2017) o como la fragmentación afecta a sus capacidades (Santini et al., 2016; Costanza y Terando, 2019). Las publicaciones sobre estas materias han llegado a conclusiones contradictorias en algunos aspectos relacionados con la eficacia de las áreas protegidas. Por ejemplo, algunos estudios han demostrado que los espacios protegidos sí son eficaces como herramienta de conservación (Bruner et al., 2001; Joppa y Pfaff, 2011; Geldmann et al., 2013; Gray et al., 2016), mientras que otros indican que no han cumplido la función protectora para la que estaban destinados (Craigie et al., 2010; Lisón y Sánchez-Fernández, 2017; Rada et al., 2019). A pesar de estas discrepancias, no hay duda de que las áreas protegidas pueden proteger eficazmente y que, en la mayoría de los casos, así lo hacen (Joppa et al., 2008; Pringle, 2017; Haight y Hammill, 2019). No obstante, existen una serie de razones que pueden hacernos dudar de que su eficacia sea la máxima posible. Entre ellas encontramos que las poblaciones de muchas especies están disminuyendo tanto dentro de las áreas protegidas individuales como en naciones y continentes enteros (Craigie et al., 2010; Laurance et al., 2012; Barnes et al., 2016), y que los espacios protegidos se enfrentan a innumerables desafíos políticos, logísticos y de carencia de recursos (Lindsey et al., 2018; Jones et al., 2018). En definitiva, se podrían indicar muchas razones por las que la eficacia de las áreas protegidas no es máxima, pero una de las principales está íntimamente relacionada con los diversos objetivos de conservación y gestión que tienen las áreas protegidas (Game et al., 2013). La mayoría de las áreas protegidas persiguen objetivos individuales, basados en lo que sucede dentro de sus fronteras, siendo muy ambiguos y a veces, hasta inexistentes o inalcanzables. Sin embargo, para poder establecer y gestionar de manera adecuada las áreas protegidas estas metas de conservación, han de ser claras y explícitas (Game et al., 2013; Worboys y Trzyna, 2015), abordando las causas fundamentales que afectan la biodiversidad protegida en cada área.

Los efectos a gran escala del cambio climático y de los cambios del uso del suelo en los sistemas naturales necesariamente requerirán una evaluación continua de los objetivos de las áreas protegidas. Aunque la protección de la biodiversidad seguirá siendo la piedra angular de los esfuerzos de conservación (Maxwel et al., 2020), no será sostenible centrarse únicamente en evitar el declive dentro de los lugares protegidos. Debido a que los cambios impulsados por el clima inevitablemente empujan a muchos sistemas hacia cambios ecológicos abruptos (Brooks et al., 2008; Barnosky et al., 2012), los administradores deberán desempeñar un papel activo en la gestión de estas transiciones, garantizando que las áreas protegidas tengan más probabilidades de cumplir sus funciones conservacionistas (Pressey et al., 2015). De hecho, la gestión de la biodiversidad bajo el cambio climático podría describirse como una gestión que facilite la respuesta de la naturaleza (Prober y Dunlop, 2011), lo que sugiere la necesidad de enfatizar metas y estrategias que puedan promover el proceso de adaptación en un sentido evolutivo (Hoffmann y Sgrò, 2011). Aunque las listas de estrategias de adaptación están cada vez más disponibles (Heller y Zavaleta, 2009; Hagerman et al., 2010; Watson et al., 2012), simplemente adoptar estrategias ampliamente citadas y populares puede no ser el enfoque más adecuado y rentable para una situación particular (Carwardine et al., 2019). Es indispensable identificar cuáles son las amenazas particulares de cada área protegida, o de la región donde esta se alberga, proponiendo diferentes medidas centradas, concretamente, en esas amenazas específicas y de esta manera maximizar su eficacia conservacionista.

Una de las principales amenazas de las áreas protegidas viene determinada por la propia naturaleza de estas, ya que el carácter dinámico del clima y de los cambios de distribución de las especies contrasta con naturaleza estática de las áreas protegidas. Como resultado, las especies pueden perder las condiciones climáticas adecuadas dentro de las áreas protegidas (Lawler et al., 2015; Batllori et al., 2017) y, por lo tanto, tener que trasladarse a otros entornos desprotegidos y dominados por las acciones antrópicas (Araújo et al., 2004; Wessely et al., 2017). Esto no es algo novedoso, Peters y Darling (1985) y Peters y Lovejoy (1992) ya reconocieron que las áreas de distribución de las especies cambian en respuesta al clima, mientras que las áreas protegidas están fijas en el espacio. Además, hay que añadir que las áreas protegidas que aparecen en el bioma mediterráneo perderán en gran medida sus condiciones de temperatura actuales (Loaire, 2009; Hoffman, 2019). Por lo tanto, pensar que las áreas protegidas podrán resistir el cambio climático obligando a las especies a permanecer en un espacio geográfico, que puede ya no representar sus preferencias climáticas, resulta poco práctico e ineficiente. En este aspecto, es muy interesante abordar la idea de que, si el clima y las especies tienen un carácter dinámico y las áreas protegidas un carácter estático, las condiciones ambientales representadas actualmente por cada uno de estos espacios protegidos podrían desaparecer dentro de sus límites, convirtiéndose en espacios ineficaces para la conservación sostenida de la biodiversidad tal y como estaban previstos (Lawler et al., 2015). Sin embargo, el clima representativo de un área protegida puede aparecer en otra ubicación más allá de los límites del espacio protegido en cuestión y, en este caso, podríamos denominar esos lugares como “áreas receptoras”; lugares que recibirán las condiciones climáticas actualmente existentes en un área protegida. En otras palabras, el clima de muchas áreas protegidas variará hasta llegar a desaparecer dentro de sus límites, pero habrá otras áreas, fuera de los limites protegidos, donde pueda aparecer dicho clima y las especies, actualmente albergadas en un espacio protegido y delimitado, puedan tender a desplazarse a esas áreas receptoras del clima rastreando las condiciones climáticas más adecuadas para su correcto desarrollo.

Llegados a este punto, resulta determinante promover la eficacia conservacionista de las áreas protegidas ante el cambio climático, e identificar los lugares que serán más propicios para conservar la biodiversidad en el futuro. Son muchos los trabajos que se han basado en el principio rector según el cual las áreas protegidas deben acumularse en los lugares que serán puntos críticos para la biodiversidad en el futuro (Araujo et al., 2004; 2011; Triviño et al., 2018). Estos puntos críticos se identifican acudiendo a los llamados modelos de distribución de especies, los cuales pretenden predecir los cambios futuros en el rango geográfico de las especies a través de modelos correlacionales que relacionan las condiciones climáticas actuales y los datos disponibles sobre la distribución de las especies (Guisan y Zimmermann, 2000). Sin embargo, las distribuciones de la mayoría de las especies se caracterizan por una variación compleja y dinámica, determinada por la interacción de múltiples factores bióticos y abióticos que varían en el espacio y en el tiempo, como pueden ser el clima, la disponibilidad de hábitat, las tolerancias fisiológicas y las interacciones bióticas. Si bien es ampliamente reconocido que las limitaciones de dispersión y otros factores bióticos reducen el poder predictivo de estos modelos (Araújo y Guisan, 2006; Peterson y Soberón, 2012), es menos reconocido que los datos de las especies utilizados raramente están completos (Lobo, 2000; Sánchez-Fernández et al., 2021) y que rara vez se conocen verdaderamente los efectos de las interacciones capaces de explicar la distribución actual (Kappelle et al., 1999; Ferrier y Guisan, 2006). Si existen una serie de incertidumbres asociadas a la modelización de las distribuciones en el presente (Tessarolo et al., 2021), existen aún más interacciones, poco conocidas pero importantes, entre el cambio climático y otros impulsores del cambio global que influyen la distribución de las especies. ¿Cómo podemos ser capaces de proclamar cual será la distribución de una especie en el futuro? A esto hay que sumarle que las incertidumbres a nivel de especie se acumulan a nivel de comunidad, debido a las interacciones ecológicas, por lo que la composición y estructura de las comunidades en regímenes climáticos nuevos será difícil de predecir. Si el conocimiento de las especies es limitado, las fuentes de incertidumbre de los modelos de distribución relacionadas con los algoritmos utilizados, los escenarios climáticos, la influencia de los predictores, los problemas de validación o la carencia de datos de ausencia fiables (Synes y Osborne, 2011; Braunisch et al., 2013; Hertzog et al., 2014; Lobo, 2016) hacen que realmente esta sea una aproximación poco aconsejable para el objetivo de este trabajo. Por todo ello, una metodología basada en espacios y no en especies podría ser más sólida y requerir una menor asunción de incertidumbres asociadas. La identificación y localización de las áreas que se van a convertir en receptoras sería así una metodología más certera a la hora de proporcionar una estrategia para paliar los efectos del cambio climático sobre las áreas protegidas, convirtiéndose en una tarea necesaria e improrrogable.

De este modo, una vez identificadas estas áreas receptoras, el siguiente paso lógico es crear una red de corredores capaz de conectar el espacio protegido en cuestión, con sus áreas receptoras. Además, esta red de corredores debería transcurrir por aquellos lugares donde exista una mayor similitud al clima del área protegida en cuestión, mejorando la conectividad del paisaje y facilitando que las especies puedan desplazarse, siguiendo sus preferencias climáticas. La importancia de esta conectividad climática ha sido reconocida previamente (Peters y Darling, 1985; Hunter et al., 1988; Schmitz et al., 2015), siendo una de las estrategias de conservación citadas con mayor frecuencia para la adaptación climática (Heller y Zavaleta, 2009). Sin embargo, y a pesar de las protecciones ambientales y de las estrategias de gestión existentes, el aislamiento de las áreas protegidas debido al incremento de los usos antrópicos es una amenaza real (Hansen y Defries, 2007; Radeloff et al., 2010; Rodríguez-Rodríguez y Martínez-Vega 2019) y es probable que el aumento del dichos usos (Rounsevell et al., 2006; Van Asselen y Verburg, 2013; Hurt et al., 2020) aísle aún más las áreas protegidas (Joppa et al., 2008; Wilson et al., 2014; Martinuzzi et al., 2015), dificultando la conexión climática. Es indispensable darse cuenta de que las fuerzas del cambio en el uso del suelo están reduciendo las opciones de conservación, reduciendo las posibilidades para generar una red de corredores climáticos capaces de mitigar los efectos del cambio climático. Si bien aún existe una ventana, en algunos lugares muy pequeña y casi inapreciable, en la que maximizar la posibilidad de que las poblaciones puedan persistir a medida que cambia el clima, la gran velocidad a la que el ser humano deteriora la naturaleza está cerrando de golpe dicha ventana. Una vez que se cierre, habrá pocas opciones de ubicación para las áreas protegidas o para la generación de conexiones entre dichas áreas y sus áreas receptoras. Incluso si las especies estuvieran equipadas con la capacidad de adaptación o plasticidad para migrar frente a un clima cambiante, es probable que encuentren un paisaje tan alterado y antropizado que constituya una barrera infranqueable para la dispersión (Ordonez et al., 2014).

Son muchos, y diversos, los procesos que conducen a la fragmentación y aislamiento de las áreas protegidas, principalmente la expansión urbana, el desarrollo industrial y la expansión agrícola y de otras infraestructuras. Además, a estos procesos hay que añadirle un sesgo contextual en la ubicación de las áreas protegidas, propiciando que los factores de aislamiento raramente sean los mismos entre áreas protegidas. De este modo, es importante conocer, en primer lugar, cual es la capacidad de los espacios protegidos para propiciar la naturalización o la antropización en su interior o en sus alrededores, una cuestión directamente relacionada con el aislamiento y, en segundo lugar, conocer hasta qué punto estos efectos antropizadores o naturalizadores dependen del contexto espacial. Son muchos los trabajos que han señalado que cuando las áreas protegidas reducen las amenazas antrópicas dentro de sus límites, a menudo desplazan una parte de estas amenazas hacia áreas adyacentes, lo que socava los objetivos de conservación (Ewers y Rodrigues, 2008; Visconti et al., 2010). Este desplazamiento o traslado es conocido como “fuga” (*leakage* en inglés), e incluso las áreas protegidas bien gestionadas pueden proporcionar beneficios de biodiversidad inesperadamente bajos debido a este efecto (Renwick et al., 2015). Las distintas formas de fuga pueden operar a diferentes escalas que van desde lo local hasta lo internacional y esto, unido a que pueden diferir mucho a lo largo del territorio, hace que cuantificar la magnitud del efecto e identificar hacia dónde pueden desplazarse las amenazas sea un verdadero desafío para la conservación. Hay que enfatizar que, para que el establecimiento de un área protegida no consista simplemente en trasladar las amenazas hacia fuera del área protegida, es necesario abordar los impulsores subyacentes de la pérdida de biodiversidad. Además, comprender el comportamiento de las personas que usan el área es fundamental para realizar predicciones precisas y realistas de los resultados de la conservación (Ewers y Rodrigues, 2008).

Todos estos procesos están condicionados por el contexto inmediatamente externo, por el nivel social, económico y educativo de donde se asientan los espacios protegidos, así como por la gobernanza y la capacidad y los recursos de gestión invertidos. Pero el paso más importante es clarificar que la gestión de las áreas protegidas no comienza en el límite de la reserva, requiere cambios sistémicos, que van desde la declaración, la identificación de las amenazas, la gestión y la involucración de la población local. Sin dichos procesos de planificación territorial, es poco probable que incluso las áreas protegidas con buenos recursos tengan éxito. Este trabajo es un pequeño avance en este camino, un camino lleno de dificultades en el que hay que aprovechar las pocas oportunidades que la sociedad brinda para proteger la naturaleza, las pocas oportunidades que la sociedad brinda para protegerse de sí misma.

OBJETIVOS Y ESTRUCTURA

Para poder identificar cómo las diferentes amenazas afectarán a las áreas protegidas, este trabajo se centra en la figura de los parques nacionales ibéricos. Esto se debe principalmente a dos características. Por un lado, encontramos que los parques nacionales son una de las figuras de protección más protectoras que encontramos en la península ibérica, teniendo una larga tendencia temporal y siendo la categoría de área protegida más conocida, visitada, financiada y cuidadosamente gestionada del país (Múgica et al., 2018). Algunas de estas figuras fueron declaradas hace un siglo, por lo que es un momento óptimo para evaluar la contribución de estos parques a la conservación de la biodiversidad. Además, al hecho de que los parques nacionales son espacios privilegiados para monitorear los impactos del cambio climático y de los usos del suelo (Hansen et al., 2014), hay que añadir que representan una amplia distribución de gradientes climáticos, hábitats y de uso de la tierra albergados en la península ibérica. Un parque nacional se define como un “área terrestre y/o marina natural, designada para proteger la integridad ecológica de uno o más ecosistemas para las generaciones actuales y futuras, excluir los tipos de explotación y ocupación que sean hostiles al propósito con el cual fue designada y proporcionar un marco para actividades espirituales, educativas, recreativas y turísticas que sean compatible desde el punto de vista ecológico y cultural” (UICN, 1994). La Red de Parques Nacionales de España se estableció en 1916 y actualmente está formada por 16 Parques Nacionales, 10 de los cuales se encuentran en la península. La gestión de los parques es de carácter autonómico y sus herramientas de gestión son el Plan de Ordenación de los Recursos Naturales, el Plan Rector de Usos y Gestión y el Plan Director de la Red de Parques Nacionales (Múgica et al., 2018).

Por otro lado, encontramos que en la península ibérica se cumplen una serie de requisitos para que sea uno de los lugares más propicios para observar los efectos del cambio climático y los efectos del cambio en los usos del suelo. En primer lugar, su ubicación geográfica en latitudes medias como cruce de caminos entre África y Europa y el Océano Atlántico y el Mar Mediterráneo han contribuido a una gran heterogeneidad ambiental, además de la existencia de un elevado número de cadenas montañosas que han funcionado como refugios glaciares y áreas de aislamiento de especies endémicas (Hampe y Petit, 2005). Estas características han favorecido que la península ibérica sea uno de los lugares europeos con mayor biodiversidad (Medail y Quezel, 1999; Araújo et al., 2007). Sin embargo, la península ibérica se encuentra en uno de los puntos críticos del mundo en el que una cantidad excepcional de especies endémicas están sufriendo una pérdida alarmante de hábitat (Myers et al., 2000; Brooks et al., 2002). Varios estudios coinciden en que esta región es particularmente vulnerable al cambio climático (Schröter et al., 2005; Jiménez-Alfaro et al., 2014; McCullough et al., 2016) y sufrirá un calentamiento extenso y un aumento de las sequías (Barker, 2007; IPCC, 2018; 2021).

En segundo lugar, la península ibérica es un lugar con una reconocida trayectoria de cambios en los usos del suelo, debido a una secular presión antrópica, un destacable aumento de la densidad de población y urbanización (Cohen, 2004; López-Gay, 2014), así como al crecimiento del sector industrial y turístico (Antrop, 2004). Este gran desarrollo antrópico está remodelando ciertas partes, mientras que otras muchas zonas están sufriendo un gran abandono rural y el cese de prácticas tradicionales, factores que también contribuyen al impacto sobre los organismos. La biodiversidad de algunos ecosistemas mediterráneos está estrechamente relacionada con la gestión humana tradicional como la agricultura o la ganadería (Blondel, 2006; Plieninger et al., 2006) y estos cambios pueden resultar en una pérdida de biodiversidad, especialmente en la Cuenca del Mediterráneo (Plieninger et al., 2006; Falcucci et al., 2007). Por lo tanto, los parques nacionales de la península ibérica se presentan como un lugar único para poder analizar la efectividad de las áreas protegidas ante sus principales amenazas, el cambio climático y los cambios de uso del suelo. La preservación de la biodiversidad en esta región depende en gran parte de las áreas protegidas.

A lo largo de este trabajo se ha generado una metodología para identificar una red de áreas protegidas con capacidad para mitigar los efectos del cambio climático. Además, se analiza el efecto atractor de las alteraciones antrópicas por los parques nacionales, observando si las dinámicas de los cambios en el uso del suelo se dan de manera homogénea, o si existe una relación espacio-temporal, dentro y en los alrededores de estos espacios. Con todo esto se pretende aportar a los gestores de las áreas protegidas una serie de herramientas capaces de incorporar los efectos, tanto del cambio climático como de los usos del suelo, en las diversas estrategias conservacionistas y así demostrar cómo una red de espacios protegidos, bien gestionados serían capaces de proteger la importante biodiversidad que alberga la península ibérica.

Así el objetivo general de esta tesis doctoral es proponer una metodología para paliar los efectos del cambio climático sobre los parques nacionales ibéricos, y averiguar el efecto de los espacios protegidos sobre el territorio en el que se asientan. Este objetivo general se desglosa en los siguientes objetivos específicos, formulados a continuación como preguntas**:**

1. ¿Cuál es la representatividad climática de los parques nacionales ibéricos? Teniendo en cuenta que la selección de áreas protegidas suele ser un proceso oportunista, se pretende estimar la representatividad climática actual y futura de cada uno de los parques nacionales ibéricos, así como la variabilidad climática completa que representan todos ellos. **(Capítulos 1-3)**
2. ¿Cuáles son las áreas emisoras y receptoras de cada parque nacional ibérico? Teniendo en cuenta el carácter dinámico de las variables climáticas, se pretende estimar la ubicación futura en la península ibérica de las condiciones que alberga actualmente cada parque nacional (áreas receptoras), así como la ubicación actual de las áreas con condiciones similares a las que tendrá cada parque nacional en el futuro (áreas emisoras). **(Capítulos 1-3)**
3. ¿Cuáles son las principales características de las áreas receptoras de cada parque nacional? Debido a que las áreas emisoras y receptoras pueden variar entre los parques nacionales y entre escenarios climáticos, se obtendrá la ubicación de estas áreas calculando la extensión, fragmentación y ubicación de

las mismas teniendo en cuenta el grado actual de alteración antrópica de todo el territorio ibérico. **(Capítulos 1-3)**

4. ¿Existe conectividad entre los parques nacionales y las áreas receptoras? Dado que la estabilidad futura a largo plazo de los parques nacionales ibéricos dependerá, en gran medida, de la conectividad entre ellos, así como de la conectividad entre las propias áreas receptoras, se estimará y diseñará una red de corredores capaces de facilitar esta conectividad. En este proceso será prioritario reconocer específicamente aquellas localidades que actúan como "cuellos de botella", ya que obstruyen la conectividad de las diferentes áreas. **(Capítulo 3)**
5. ¿Cómo la antropización reciente podría modificar la conectividad climática entre los parques nacionales y las áreas receptoras? Teniendo en cuenta que la conectividad entre áreas puede estar condicionada por procesos de antropización recientes, se estudiarán los cambios de uso del suelo en los corredores delimitados **(Capítulo 3)**
6. ¿Han actuado los parques nacionales como atrayente de la antropización del territorio? Considerando el papel probable de los parques nacionales en la promoción de la antropización de áreas vecinas, se examinará el grado de alteración en los usos de la tierra durante los últimos 25-30 años en diferentes áreas de amortiguamiento alrededor de dichos espacios. (**Capítulo 4**)

Esta tesis está estructurada en cinco capítulos. Cada uno de los cuatro primeros capítulos está compuesto por las principales secciones típicas de un artículo publicado en una revista científica: resumen, introducción, material y métodos, resultados y discusión. Posteriormente, una discusión general trata de englobar los objetivos, permitiendo ensamblar la generación de conocimientos desarrollados a lo largo de los cuatro primeros capítulos. Además, se presenta un quinto capítulo, donde se muestran los diferentes trabajos de divulgación generados a lo largo de la tesis. Al final del trabajo se encuentra toda la bibliografía utilizada, ordenada alfabéticamente.

En el **primer capítulo** se ha desarrollado una metodología que permite identificar las áreas, a lo largo de la península ibérica, que en el futuro tendrán las condiciones climáticas y ambientales que alberga actualmente un parque nacional (áreas receptoras), así como la ubicación actual de las áreas con condiciones similares a las que tendrá dicho parque nacional en el futuro (áreas emisoras), utilizando para ello el Parque Nacional de Cabañeros como ejemplo.

Una vez generada la metodología descrita en el capítulo anterior y comprobando que su ejecución es capaz de producir resultados alentadores, en el **segundo capítulo** se ha desarrollado otro ejercicio, en otro espacio diferente generando, además, una simulación de los futuros usos del suelo. De esta manera se ha podido generar un escenario futuro más completo de los cambios ambientales que afectarían a las áreas receptoras, explicadas anteriormente. Para este ejercicio se ha utilizado como ejemplo el reciente Parque Nacional de la Sierra de Guadarrama.

A lo largo del **tercer capítulo** se han obtenido las áreas receptoras de todos los Parques Nacionales Ibéricos, generándose además una red de corredores con capacidad para conectar estas reservas con sus áreas receptoras, e identificando aquello lugares conflictivos, donde la conexión espacial de dicha red se ve interrumpida por el predominio de usos del suelo antrópicos.

Entendida la potencial problemática a la que se enfrentarán los parques nacionales, en el **cuarto capítulo**, se ha analizado si los parques nacionales de Europa han actuado como atractores de algún tipo de uso del suelo en particular, para ello se analizan las dinámicas que han sufrido, tanto en el interior como en las diversas áreas de influencia de cada uno de los parques nacionales europeos.

El último, y **quinto capítulo**, está compuesto por los diferentes trabajos, y notas de prensa, elaborados lo largo de la tesis cuya misión ha sido la de divulgar los resultados obtenidos. De esta manera, se hace hincapié en la responsabilidad del investigador en hacer un esfuerzo para que los resultados generados en un artículo científico lleguen a la población y se divulgue el conocimiento científico.

CAPÍTULO I

ENVIRONMENTAL REPRESENTATIVENESS AND THE ROLE OF EMITTER AND RECIPIENT AREAS IN THE FUTURE TRAJECTORY OF A PROTECTED AREA UNDER CLIMATE CHANGE.

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INTRODUCTION

Protected areas (PAs) are essential for the conservation of biodiversity and most institutions attempt to integrate them into their national and international conservation strategies (Pressey et al., 2007; Palomo et al., 2014a; Visconti et al., 2015). They are a crucial tool to mitigate threats related to human activity (Rodrigues et al., 2004), not only by limiting biodiversity loss (Dudley and Parish, 2006), but also by keeping natural ecosystems functional and by providing shelter for species therein. Historically, the creation of PAs has been driven by socio-economic, aesthetic and political criteria rather than by scientific or conservationist reasoning (Pressey, 1994; Fraschetti et al., 2002; Joppa and Pfaff, 2009), overlooking the fact that they should be ecologically and environmentally representative (Visconti et al., 2015). Determining the environmental representativeness of protected areas is thus a fundamental issue in systematic conservation planning and the maintenance of biodiversity (Margules and Pressey, 2000; Pressey et al., 2007; Laurance et al., 2012).

Climate plays a key role when estimating environmental diversity (Faith and Walker, 1996a; 1996b; Parmesan, 2006; Chen et al., 2011; Triviño et al., 2013; IPCC, 2014) as it is a major factor conditioning biological assemblages and ecosystem characteristics (Woodward et al., 2004). However, climate is changing rapidly as a consequence of human actions. Reports from the Intergovernmental Panel on Climate Change indicate that substantial variations in climate have occurred due to the emission of greenhouse gases, and that these changes will continue to occur in the near future (IPCC, 2007, 2014). Keeping in mind that Pas have spatially fixed boundaries and are often surrounded by a matrix of transformed land uses, one might wonder what the environmental representativeness of protected areas is when the climate is changing. PAs could be considered islands representing particular environmental and biotic conditions and they may also serve to avoid the negative influence of anthropic actions. However, the effects of climate change could make these areas ineffective for their intended purpose (Lobo, 2011). On one hand, if the species that inhabit a protected area are influenced in their distribution and abundance by climatic conditions, each PA would become a recipient of outside fauna and flora. On the other hand, protected areas would also emit or export individuals to other settlements which, in the future, would represent the environmental conditions currently existing in this area. These processes of change could lead to (i) the disappearance of individuals, populations or species (Bestion et al., 2015); (ii) an increase in the evolutionary forces that promote the in-situ adaptation to new conditions (Hoffmann and Sgrò, 2011); and (iii) the decline of populations and/or emigration of individuals into new territories (Mason et al., 2015; 'spatial adaptation' according to Hengeveld, 1997). Available evidence shows that the populations of some species have declined within PAs as consequence of climatic changes, while other species have undergone a population growth or colonized a reserve for the first time (Thomas and Gillingham, 2015).

Although PAs may act as natural shelters against the effects of climate change (Thomas and Gillingham, 2015; Gaüzere et al., 2016), creating corridors between them can facilitate their inter-connection (Haddad et al., 2015). PAs representing different climate conditions should be connected in order to minimize the threat of local extinction and maximize the adaptive and dispersive possibilities of organisms.

Most studies that select the location of possible reserves keeping climate change scenarios in mind have used distribution models able to anticipate the geographic response for each species to changes in climate (Jones et al., 2016). Such predictions have several drawbacks (Lobo, 2015). For example, they may produce inconsistent and unreliable results because they do not include estimations about the real and direct effect of climate variables in delimiting the occurrence and abundance of species (Araújo et al., 2011; Felicísimo et al., 2011). Using individual predictive species distribution models to estimate the possible future location of areas that should be protected is a hazardous strategy. This is because the many uncertainties of each individual model may lead to the misappropriation of conservation resources in some regions. Moreover, identifying climatically favourable territories for species without taking future and possible changes in land use into account can also lead to an inefficient selection of areas (Faleiro et al., 2013; Jones et al., 2016).

Instead of trying to estimate the effects of climate change on the species inhabiting a reserve, we here propose an approach based on estimating the location of areas with environmental conditions similar to those of a focal PA, both now and in the future. Assuming that the environmental conditions of a PA are the main determinants of its conservation value (Albuquerque and Beier, 2015), we propose estimating (i) the present location of the areas with similar conditions to those this PA will have in the future (emitter areas), and (ii) the future location of the areas that will have similar environmental conditions to those currently existing in the focal PA (recipient areas). If we cannot reliably predict the future distribution of each species because we do not know the true and contingent effects of climate on each one, the proposed approach aims to estimate the environmental representativeness of a protected area to derive conservation strategies. This knowledge can be used to anticipate and adapt PAs against future changes. In this work, we used an Iberian reserve that is representative of Mediterranean conditions, Cabañeros National Park, as an example of focal PA: (i) to estimate the current and future climate representativeness of this reserve; (ii) to evaluate the level of change that will occur in its current climatic conditions, calculating the extension, fragmentation, connectivity and location of the climatic conditions that Cabañeros currently represents and will represent in the future; and (iii) to identify recipients and emitter areas under a future climate change scenario, as well as the connectivity of these areas to the focal PA, taking into account the degree of anthropic alteration of the entire Iberian territory.

MATERIALS AND METHODS

The focal protected area Cabañeros was declared a National Park in 1995. It is located in the region of Montes de Toledo in central Spain (39.414 N, -4.509 W) between the provinces of Ciudad Real and Toledo. It covers an extension of 40,856 hectares. Its elevation oscillates between 520 and 1,448 m.a.s.l., with an average altitude of 788 m. Cabañeros bioclimatically represents the Mediterranean region. Most of the territory belongs to the mesomediterranean bioclimatic type (520-1,000 m), while the supramediterranean bioclimatic type (1,000-1,450 m) only appears in the NE part of the region (Rivas Martinez, 1987).

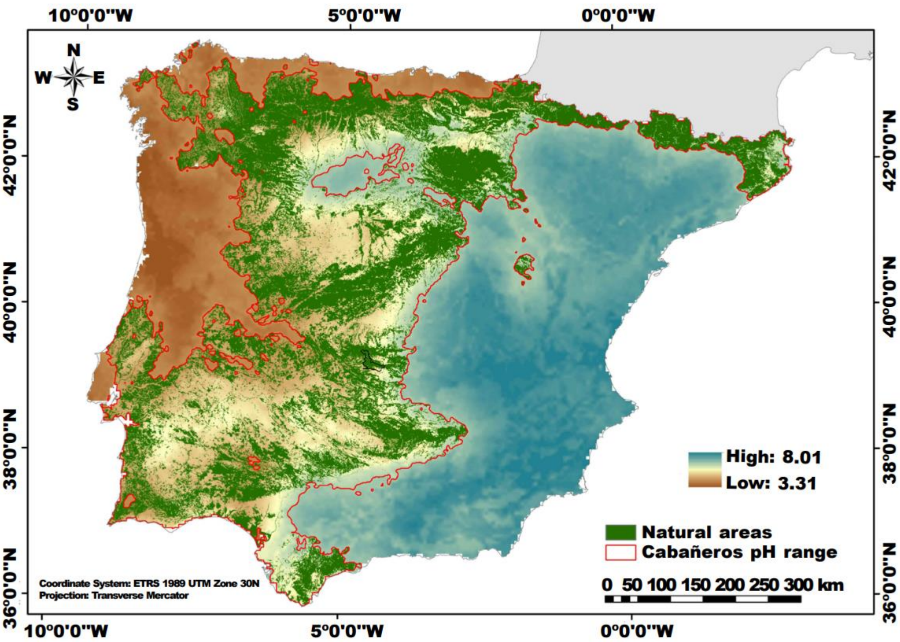

Figure 1. Regions with similar edaphic conditions to those existing in the Cabañeros National Park, which in addition have natural land uses. The color range represents pH variation.

Origin of climatic data

Data on current climate come from the University of Extremadura (see methodology in Felicísimo et al., 2011) and include data about mean maximum monthly daily temperature, minimum monthly daily temperature, average monthly temperature and total monthly precipitation from 1950 to 2007 for the whole Iberian Peninsula. Using this primary source of climatic information at a resolution of 1 km^2 UTM grid cells and the formulas of Valencia-Barrera et al., (2002) and López Fernández and López (2008) we built a total of 23 bioclimatic variables (Table 1). As Felicísimo et al., (2011) do not provide future monthly climatic data, we used WorldClim data (http://www.worldclim.org/) at a resolution of 30 arc seconds (~ a cell of 0.82 km^2). The model we selected was the IPSL-CM5A-LR from the Pierre Simon Laplace Institute (Dufresne et al., 2013), specifically that from the fifth assessment report (AR5) that predicts a mean increase in temperature of 1.3 ºC around 2050 (RCP6.0) (Van Vuuren et al., 2011). We selected this climatic projection for its intermediate character concerning greenhouse gas emissions and socioeconomic assumptions. We used the predicted values of the four primary climatic variables mentioned formerly for 2070 (mean maximum monthly daily temperature, minimum daily monthly temperature, average monthly temperature and total monthly precipitation) to derive the same 23 bioclimatic variables for the future as those obtained for present times following the explained procedure.

Other environmental data

Suitable climatic conditions do not guarantee that a given species can inhabit a locality. To restrict both recipients and emitter areas, we also considered soil characteristics and land uses. Unlike climate, soil features are not subject to short-term modifications and are relatively independent of climatic alterations, at least in short time spans. Therefore, if the occurrence of a species is conditioned by both edaphic and climatic characteristics, it will be necessary to consider both requirements to delimit its probable distribution. In this study, we used pH as a general surrogate of the edaphic characteristics.

Table 1. Bioclimatic variables obtained using the formulas provided by Valencia et al., (2002) and López Fernández and López (2008), and also correlations between the values of these variables and the three factors (F1, F2 and F3) that emerged from a Principal Component Analysis. Values > 0.7 are shown in bold.

Variable	F1	F2	F3
Precipitation seasonality	**0.9170**	0.2740	0.1457
Temperature seasonality	-0.4825	-0.1465	**-0.8254**
Isothermality	0.5271	0.0435	0.5471
Aridity index (Martonne)	**-0.8480**	0.4296	-0.2883
Continentality index	-0.2414	-0.1544	**-0.8325**
Precipitation contrast	**0.9212**	0.2569	0.1743
Thermal contrast	-0.4221	-0.1351	**-0.8939**
Ombrothermic index I0	**0.7930**	-0.5183	0.2807
Ombrothermic index I5	**0.8497**	-0.3215	0.3637
Annual precipitation	**0.9183**	-0.2122	0.3173
Precipitation in wettest month	**0.9464**	-0.0040	0.2985
Precipitation in driest month	0.3365	**-0.7076**	0.4210
Positive precipitation 0	**0.9131**	-0.1695	0.3315
Positive precipitation 5	**0.8672**	0.1156	0.3660
Emberger's pluviometric ratio	**0.7314**	-0.5931	0.1074
Maximum temperature of warmest month	-0.3436	0.6228	-0.6970
Average monthly maximum temperature	-0.3410	0.6318	-0.6898
Annual mean temperature	-0.1142	**0.9800**	-0.0915
Average monthly minimum temperature	0.1167	**0.9479**	0.2869
Minimum temperature of coldest month	0.1167	**0.9479**	0.2869
Absolute minimum temperature	0.0818	**0.9673**	0.2129
Positive temperature 0	-0.1120	**0.9784**	-0.0964
Positive temperature 5	-0.0763	**0.9772**	-0.0763

We obtained pH data from the European Soil Data Centre (http://esdac.jrc.ec.europa.eu; see Reuter et al., 2008) showing continuous pH values for each of the 1 km^2 UTM grid cells of the Iberian Peninsula. Additionally, we used information on land use from the CORINE Land Cover project (www.eea.europa.eu) to limit the edaphic-climatic areas to those with natural conditions. To do this, we reclassified the different land uses recognized in CORINE (level 2; resolution: 100 m^2) for 2011 into three categories: anthropic, semi-anthropic, and natural (Table 2), eliminating the localities categorized as anthropic or semi-anthropic from the climatic-edaphic suitable areas. Thus, suitable edaphic areas with natural land uses (Fig. 1) constitute the most restricted geographical scenario to represent recipient and emitter areas.

Finally, we downloaded a digital cartography representing the Iberian protected areas included in the Natura 2000 network from Protected Planet (www.protectedplanet.net) and used this to describe which are, and will be the PAs that have and will have similar environmental conditions to those in Cabañeros.

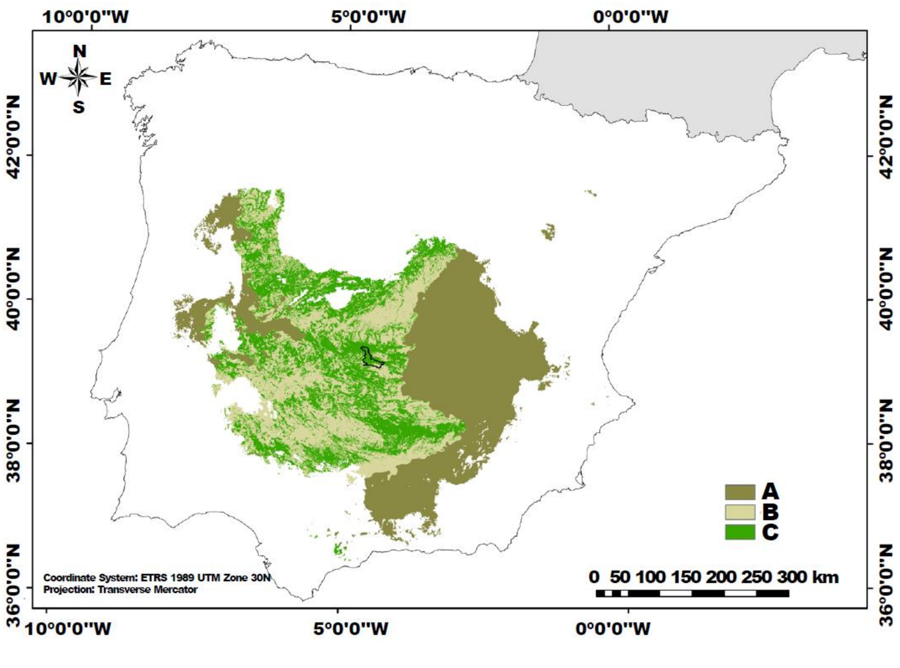

Figure 2. Regions with climatic (A), climatic and edaphic (B), and climatic-edaphic areas with land cover conditions similar to those currently found in the Cabañeros National Park (C).

Selection of climatic variables

After standardizing the values of all the considered climatic variables to mean zero and one standard deviation to eliminate the effect of different measurement scales, we conducted a principal components analysis (PCA) to reduce the number of climatic variables that would be used. PCA provided three non-correlated factors with eigenvalues higher than 1, representing 93.5 % of all the climatic variability in the Iberian Peninsula (factor 1 = 53.6 %, factor 2 = 31.7 %, factor 3 = 8.2 %). For each one of these three factors we chose the original variable with the highest factor loading; i.e., the primary variable best correlated with the values of each factor. The values of the first factor were positively correlated with different precipitation variables and negatively correlated with soil acidity (Table 1), selecting the precipitation of the wettest month as representative (factor loading = 0.9464). The second factor was positively correlated with different temperature variables and negatively correlated with the precipitation of the driest month (Table 1). On this occasion, the annual average temperature was chosen as the most representative variable (factor loading = 0.9800). Finally, the third factor was negatively correlated with temperature seasonality, continentality and thermal contrast (Table 1), selecting thermal contrast as the representative variable (factor loading = - 0.8939).

Like isothermality, average monthly maximum temperature and maximum temperature of the warmest month were relatively poorly represented by the selected PCA factors (Table 1); the first two were also selected to describe the climatic conditions of Cabañeros (only one of the two temperature variables was selected because both were highly and positively correlated; $r = 0.997$, $p < 0.0001$).

Data analysis

The five previously selected climatic variables were used to calculate the Mahalanobis distance (MD) from the conditions in the 1 km^2 cells of the National Park of Cabañeros to all remaining Iberian cells. We thus obtained a continuous measure able to represent not only the places with the same conditions to those of Cabañeros, but also the places with relatively similar conditions. The process was repeated both for present and for future climatic data. MD was chosen to measure climate similarity because this multidimensional measure takes into account the correlations of the variables and it is scale-invariant regardless of the units used for each variable (Farber and Kadmon, 2003; Xiang et al., 2008). We used the value corresponding to the 90th percentile of the MD values appearing in Cabañeros as the decision threshold to delimit the areas with a climate highly similar to that in the national park. Subsequently, a similar estimate was made taking into account both climatic and edaphic variables. For this purpose, we estimated the range of pH values appearing within Cabañeros (from 5 to 6), removing all the areas outside these pH values from the climatically favourable territory. However, considering that species can be relatively tolerant to pH variations (Prentice et al., 1992), pH ranges were modified in ± 0.5 (i.e., from 4.5 to 6.5) in order to include those with relatively similar pH conditions as edaphically favourable regions.

Table 2. The Iberian area currently represented by the climatic (C) or the climatic and edaphic (CE) conditions of Cabañeros National Park, and CE areas with natural land cover (CEN). CEN areas currently protected by any type of reserve, CEN areas within the Nature 2000 network (N2000), CEN area covered by large and continuous patches, total number of patches in CEN, and the value of the area-weighted mean shape index (AWMSI). The same values are provided for recipient areas (sites that in the future will have similar environmental conditions to those currently existing in Cabañeros) and emitter areas (that at present have similar conditions to those that Cabañeros will have in the future). C, CE and CEN percentages are computed considering the total area of the Iberian Peninsula, while remaining percentages are calculated on the basis of the CEN area.

	Current representativeness		**Future emitter areas**		**Future recipient areas**	
	Km^2	%	Km^2	%	Km^2	%
C	157,327	27.0	48,99	8.4	37,63	6.5
CE	92,28	15.9	35,244	6.1	9,048	1.6
CEN	42,03	7.2	16,1	2.8	5,023	0.9
Protected	19,355	46.05	6,806	42.27	2,218	44.17
N2000	17,419	41.45	5,937	36.87	2,002	39.86
Patches > 10000 km^2	25,509	60.7	0	0.0	0	0.0
Patches 1.000 - 10.000 km^2	5,442	12.9	11,508	71.5	1,382	27.5
Number of patches	6,985		2,881		1,505	
AWMSI	59.96		27.84		10.02	

Once identified and mapped, the areas with favourable climatic and edaphic conditions (i.e., those with MD values lower than the 90th percentile value calculated for Cabañeros) were overlapped with the current natural areas according to CORINE land cover as well as with the polygons representing Natura 2000 PAs. Finally, considering that fragmentation is one of the biggest threats to biodiversity conservation (Fahrig, 2003), we calculated the area, number and location of the groups of localities connected or adjacent (touching each other), assuming that a high fragmentation diminishes the conservation value of recipient and emitter areas. To do this, we used only those areas that are suitable from the climatic and edaphic point of view and, also have natural land uses. We also measured fragmentation using the area-weighted mean shape index (AWMSI). This index measures the average perimeter-to-area ratio, weighted by the size of the patches so that larger patches weigh more than smaller ones (McGarigal et al., 2012). This index is equal to 1 when all patches are circular, increasing in value without limit as patch shapes become more irregular.

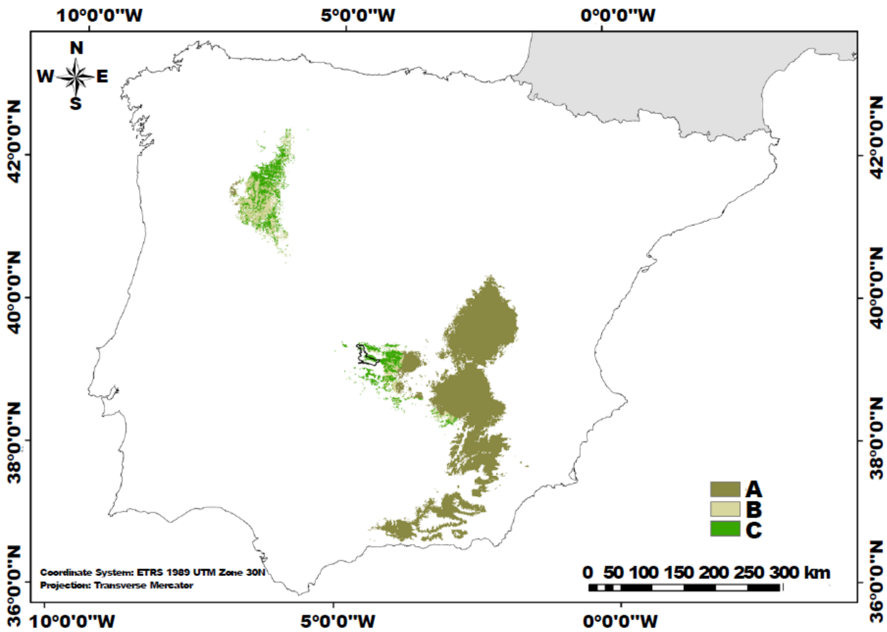

Figure 3. Regions with climatic (A), climatic and edaphic (B), and climatic-edaphic areas currently harbouring natural land cover conditions that, in the future, will have similar conditions to those currently existing at Cabañeros National Park (C). Climatic data come from the IPSL-CM5A-LR scenario of the fifth assessment report (AR5) (2060-2080).

RESULTS

Current representativeness

The climatic conditions of Cabañeros are found in a large area of the Iberian Peninsula (Fig. 2), accounting for 27 % (157,327 km^2) of its total area (Table 2). Part of the northern sub-plateau just above Serra da Estrela, almost all of the southern sub-plateau to the Guadalquivir valley, and the Sub-baetic mountains are climatically similar areas to those of Cabañeros. However, the region with similar climatic and edaphic conditions covers a considerably smaller area as the result of the elimination of eastern calcareous areas, totalling around 16 % (92,280 km^2) of the Iberian Peninsula (Fig. 2). That is a decrease of 41 % in the representative area (65,047 km^2 less). Within the National Park, only 12 % of the territory is dedicated to anthropic land uses. In contrast, the representative Iberian climatic and edaphic area is highly anthropized (34.5 %) and only 45.5 % of it harbours natural landscapes (around 42,030 km^2; see Fig. 2 and Table 2).

Taking into account the climatic and edaphic conditions with natural land cover, around 19,355 km^2 (46 % of this area) is included under some type of protection category, with 90 % corresponding to the Natura 2000 Network (Table 2). Connectivity between the climatic and edaphic favourable area and natural land cover is high and its fragmentation low. Only two patches have more than 10,000 km^2, representing 60.7 % of this total area, and another four patches embody 13 %. In total, there are 6,985 patches and the AWMSI index is 59.96 (Table 2).

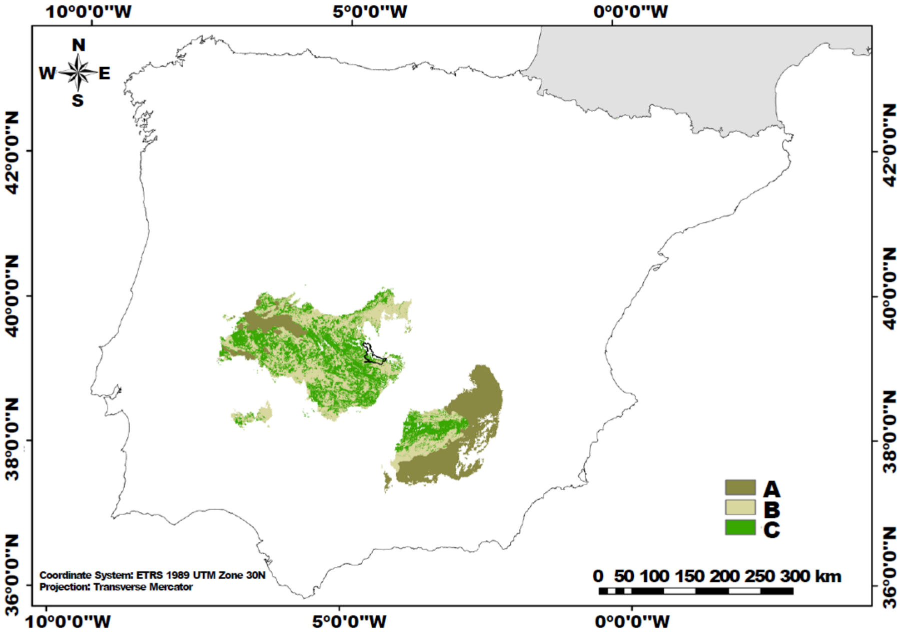

Figure 4. Regions with climatic (A), climatic and edaphic (B), and climatic-edaphic areas harbouring natural land cover conditions that currently have similar conditions to those that Cabañeros National Park will have in the future (C). Climatic data come from the IPSL-CM5A-LR scenario of the fifth assessment report (AR5) (2060-2080).

Future recipient areas

The places with the climatic conditions currently represented by Cabañeros are greatly reduced in the future scenario, and their geographical location also shifts (Fig. 3). The climatically favourable area would be divided into two fragments, a smaller area located in the South of the 'Montes de León', in the Portuguese region of Tras-Os-Montes and Spanish territories bordering with Portugal, and a larger area located in a strip from the eastern part of the southern plateau below the Iberian System to Sierra Nevada. As a consequence, between 2060 and 2080 around 120,000 km^2 of climatically representative area will have disappeared (Table 2). This change could establish a new climatically favourable region equivalent to approximately 6.5 % (37,630 km^2) of the total Iberian Peninsula area. When edaphic conditions are also considered, representative areas would cover a much smaller area (9,048 km^2; 1.6 % of total Iberian area). About half of this future climatically and edaphically favourable territory currently has natural land cover (5,023 km^2), being 44 % currently protected (2,218 km^2) (Fig. 3 and Table 2). In this case, no patch has more than 10,000 km^2 and only one patch has more than 1,000 km^2 representing 27.5 % of the total. Taken together, there are 1,505 patches and the value of the AWMSI index decreases to 10.2 (Table 2).

Future emitter areas

The areas that currently have similar climatic conditions to those that Cabañeros will have in the future occupy 48,990 km^2, which is equivalent to 8.4 % of the total area of the Iberian Peninsula (Fig. 4 and Table 2). These areas are located in two main parts of the southern plateau: one between the Guadiana and Tajo valleys (Montes de Toledo, Villuercas, etc.), and another in the southeast around the Subbaetic mountain chain. Furthermore, there are also 643 km^2 very close to the Tajo International Natural Park, located in the boundary between Spain and Portugal. When both the climatic and edaphic conditions are considered, this area is reduced to 35,244 km^2. Around 34 % of these favourable climatic and edaphic territories currently have an anthropic land use, while 46 % have natural land cover (Table 2). These favourable and natural areas are divided in two main patches (Fig. 4), and they include part of the current territory of the Cabañeros National Park. About 43 % of this climatic and edaphic area is currently protected (6,806 km^2), mainly by the Natura 2000 network (87 %). This area would be composed of 2,881 patches with an AWMSI value of 27.84 (Table 2).

DISCUSSION

The Iberian reserve selected in this exercise has a key role in terms of climate representativeness as it represents Mediterranean forest conditions better than other National Parks (Sánchez-Fernández et al., 2013), such as those in mountain areas (Lobo, 2011), which barely represent a few hectares beyond their protected area boundaries.

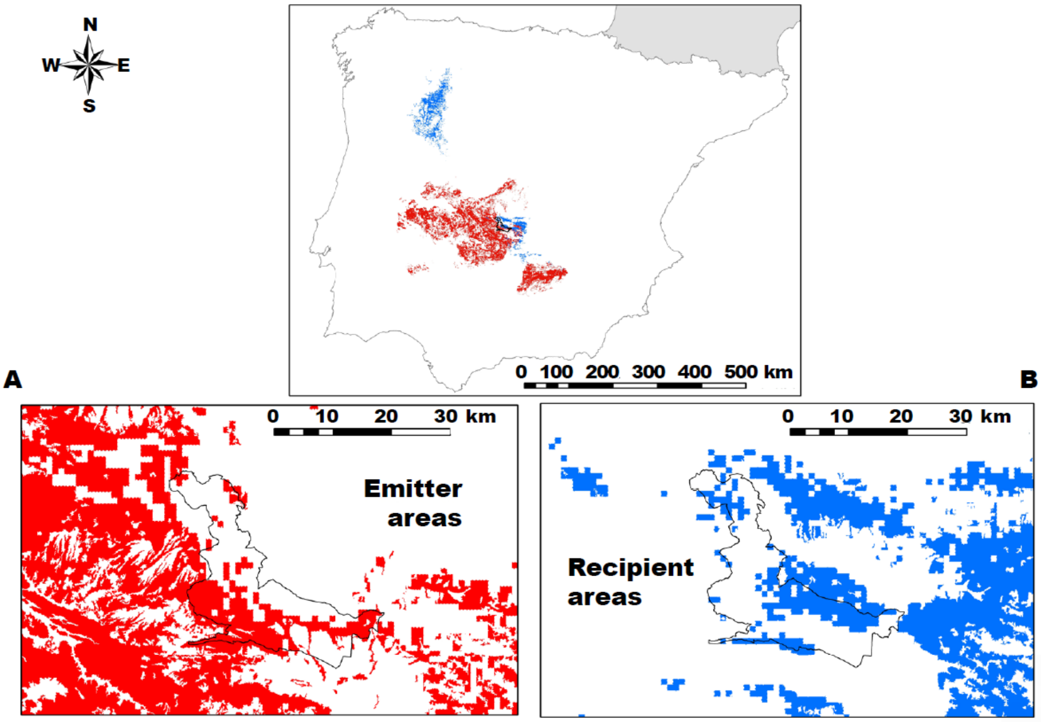

Figure 5. Regions that will act as emitter (A) or recipient areas (B) for the Cabañeros National Park in the future.

Even when both climatic and edaphic conditions are considered together, this Iberian reserve remained representative of a large part of the Iberian territory (around 16 %). If the Iberian territory represented by Cabañeros in regard to climatic and edaphic conditions is large, rather than non-fragmented, with little human impact and many protected areas, we can assume that the species inhabiting this reserve and environmentally similar areas have great potential to maintain their connected and conserved populations. Indeed, almost half of this territory currently possesses a high degree of wilderness, three-quarters is protected, and the general degree of fragmentation is very low; large and continuous patches cover 73 % of the suitable natural conditions. Thus, the potential environmental niche of many of the species sheltered in Cabañeros would also, a priori, appear in these other protected and natural areas, and vice versa.

Remarkably, it appears that the size of the areas representing the current environmental conditions of this reserve will be drastically reduced and fragmented in the future (future recipient areas). Climatic and edaphic future suitable areas that currently have natural land cover may be ten times smaller and only a quarter of them would be located in continuous and large patches. In addition, we should stress that only a small part of the territory that could act as a recipient area is located close to the examined reserve (Fig. 5); the conservation of these localities should be given priority because they may ensure the maintenance of some of the organisms currently protected by this reserve. In this specific case, the most important area with optimal conditions to act as a recipient area is the Special Protection Area of Montes de Toledo because the species currently inhabiting lowlands will find suitable climatic conditions in highland areas even when these are located within the park. This whole set of results suggests a strong reduction in the environmental conditions currently represented by Cabañeros, thus probably diminishing the climatic-edaphic niche of many of the species that currently inhabit Cabañeros. This could result in the export of faunistic and floristic elements to areas in which these conditions will appear in the future and, in general, to a drastic reduction of the Mediterranean conditions that motivated the creation of this national park.

According to our results, between 2060 and 2080, Cabañeros National Park will undergo changes in climatic conditions similar to those currently appearing in other areas. These probable emitter areas seem to be larger, currently protected, and not very fragmented (Fig. 5). Around 16,000 km^2 of natural land cover currently have climatic and edaphic conditions similar to those that Cabañeros will have in the future. A large part of this area is currently protected and located under continuous and larger patches that encompass the park itself. The International Tajo Natural Park, located on the border between Badajoz province and Portugal, will constitute the main protected emitter area, together with Sierra de las Villuercas, Tajo River, and Monfragüe National Park. These reserves can be important areas from which populations and species will eventually reach Cabañeros, but even the lower elevation parts of the National Park itself can act as emitter areas. It is necessary to promote the connectivity of these areas to facilitate the long-term stability of biodiversity (Haddad et al., 2015).

Taken together, these results suggest that the import of new populations and species in Cabañeros is more probable than the export of species. If climatic and edaphic conditions determine the fauna and flora of this National Park, climate change will generate a deep alteration of its biotic elements (Bestion et al., 2015), basically due to the entry of new elements. These changes could increase the populations of some colonizing species and largely decrease those of other native species. As such changes could lead to various conservation and management problems (Thomas and Gillingham, 2015), it is necessary to anticipate possible alterations and solutions, such as avoiding the isolation of the park and facilitating flow to and from the areas indicated in this study.

CAPÍTULO II

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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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 fixed spatial boundaries can maintain populations of species in the face of climate change and other anthropogenic pressures (Aráujo et al., 2004; Parmesan, 2006; Chen et al., 2011; Monzón et al., 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, it is crucial to design 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; López-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.

MATERIALS AND METHODS

Study area

GNP is located in the eastern part of the Iberian Central System (Fig. 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 pasture, pine forest, and bog, as well as a 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; 28 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 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).

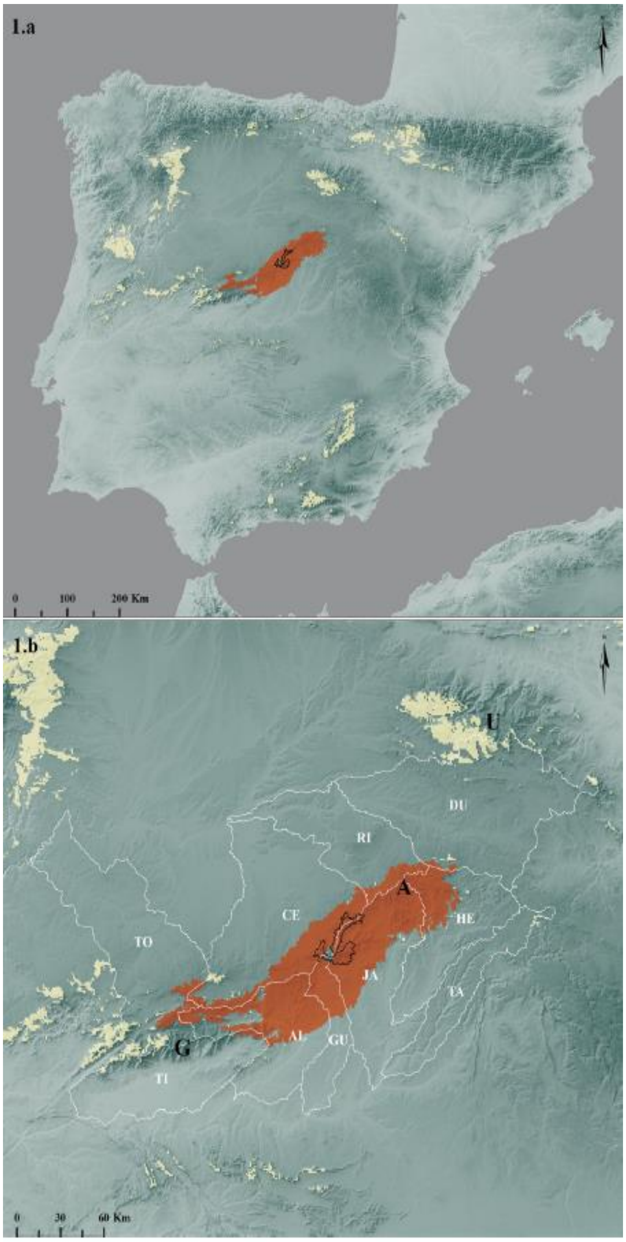

Figure 1. (a) Guadarrama National Park (GNP; black polygon) and current climate representative areas throughout the Iberian Peninsula (yellow) and throughout the river basins contiguous to the GNP (in brown). (b) detailed map representing the area composed by the river basins (white polygons) in which 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 are represented by the letter U (which belong to the Iberian System). All maps have been made with ETRS 89 UTM Zone 30N reference system.

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 et al., (2002), López Fernández and López (2008), and Hijmans et al., (2005) allowed us to build 23 bioclimatic variables for each 1 km^2 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 et al., 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 temperature, and annual average precipitation) were calculated in order to use them to derive the same five climatic variables selected using current climatic data.

Land cover data

Corine Land Cover (CLC) cartography was used to develop land-use and land-cover change simulations at a 100m raster spatial resolution. Thus, each 100m cell belongs to only a single land cover type (see https://land.copernicus.eu/pan-european/corineland-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 seminatural 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.

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 Fig. 1).

Land cover scenarios

The land-cover change 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 RCP 8.5 scenario 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 5x3 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 a 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 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.

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).

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

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 neighbourhood 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 (Fig. 2). The areas that in the future will harbour 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.

RESULTS

Climatic representativeness of GNP

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

For 2050, under the RCP 4.5 scenario (Fig. 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 Fig. 1). In the case of the RCP 8.5 scenario (Fig. 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).

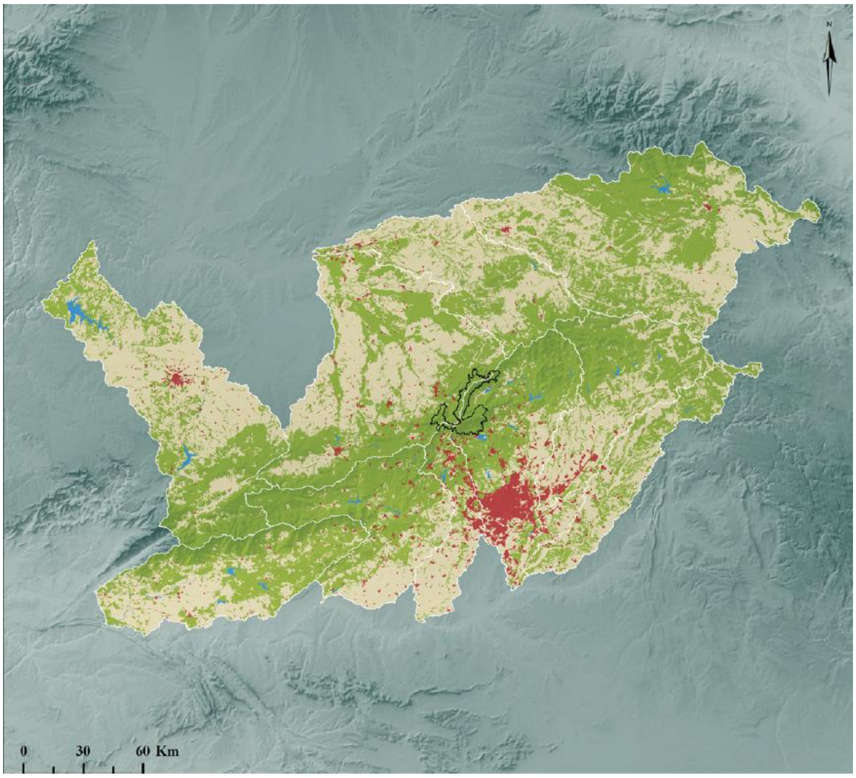

Figure 2. Selected study area with their corresponding land cover categories of level 1 according to the Corine Land Cover of 2012: artificial cover (red), agricultural areas (yellow), forest/natural vegetation (green), and water bodies (blue). River basins are represented by white polygons, and the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

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 (Fig. 4). In the RCP 4.5 scenario (Fig. 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 Mountains where climatically representative conditions are expected to persist (see Fig. 1). In contrast, in the RCP 8.5 or population development scenario (Fig. 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%).

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	188,915	1,592,010	3,194,739	24	28,005	5,003,693
RCP45	3.8 %	31.8 %	63.8 %	0.0 %	0.6 %	
2050	846,991	2,576,271	1,552,402	24	28,005	5,003,693
RCP85	16.9 %	51.5 %	31.0 %	0.0 %	0.6 %	

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.

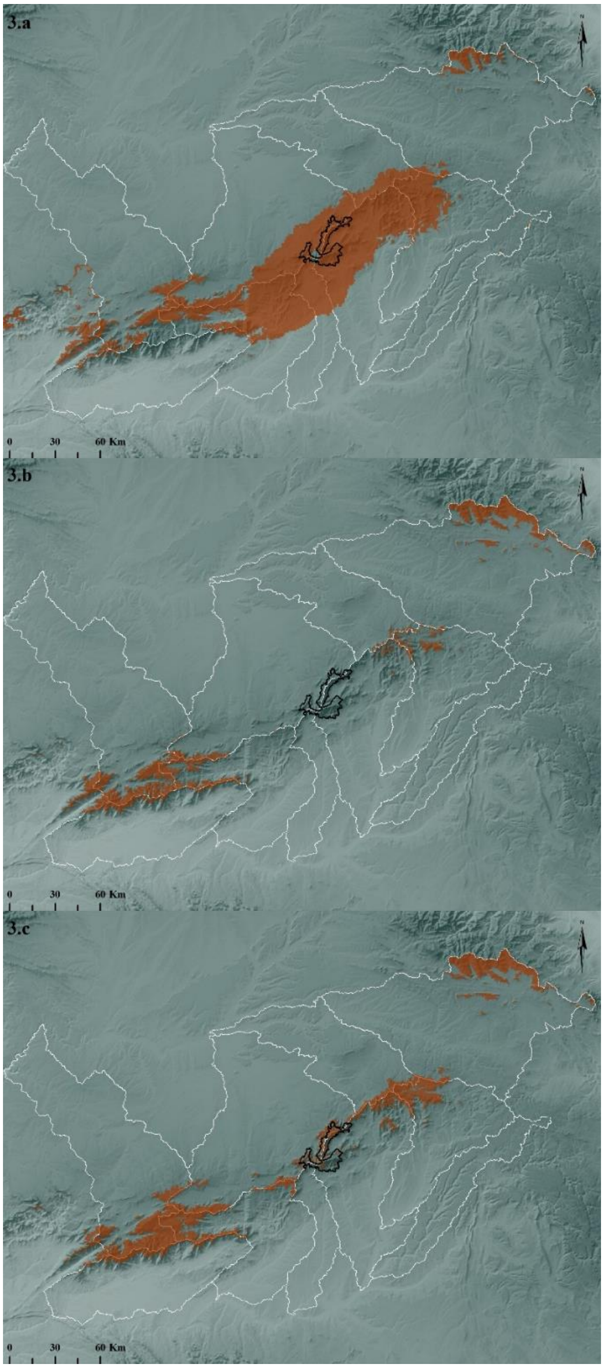

Figure 3. Current representative area with the climatic conditions prevailing in the Guadarrama National Park (in brown) for the present (a), the 2050 RCP 4.5 scenario (b), and the 2050 RCP 8.5 scenario (c). River basins are represented by white polygons, and the studied reserve by a black polygon.

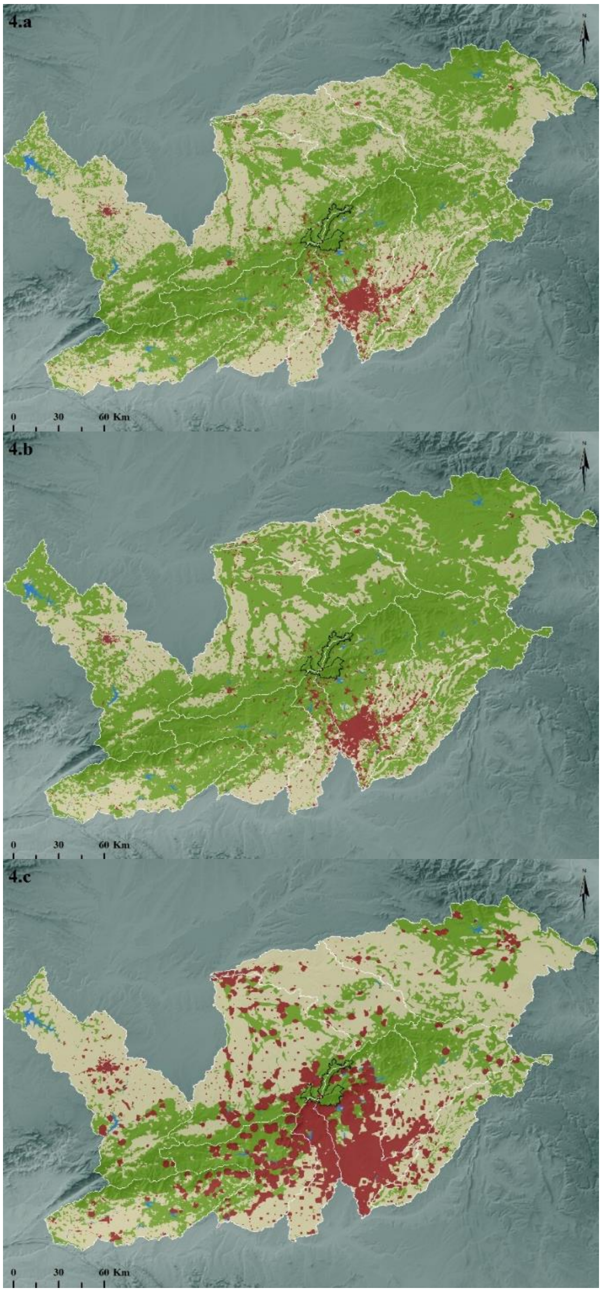

Figure 4. Distribution of land cover categories in the study region for the three periods: present (a), simulations for the year 2050 under the scenarios RCP 4.5 (b), and RCP 8.5 (c): artificial cover (red), agricultural areas (yellow), forest/natural vegetation (green), and water bodies (blue). River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

Possible futures for the GNP

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 (Fig. 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.

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 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.

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 et al., 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 favoured (Loarie et al., 2009; Scriven et al., 2015; Littlefield et al., 2017).

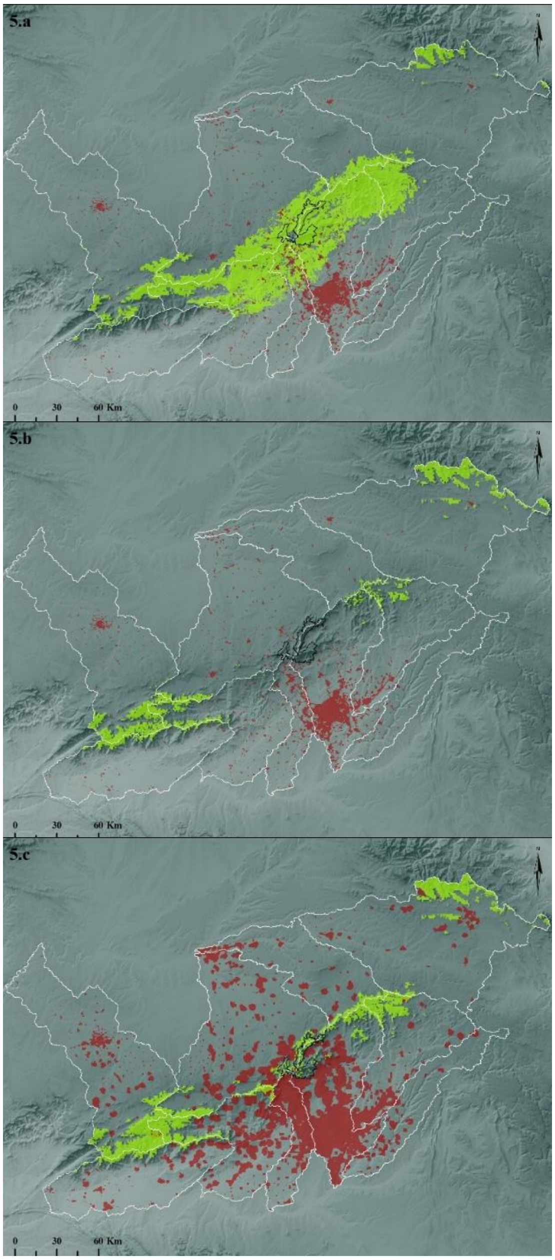

Figure 5. Climatically and land-use suitable areas according to the present conditions of the Guadarrama National Park (in green) and physical barriers (in red) composed by artificial land cover for the present (a) and for the two simulated future scenarios: RCP 4.5 (b) and RCP 8.5 (c). River basins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

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 et al., 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 et al., 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 scenario 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.

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 for 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.

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 landcover 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 neighbouring 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.

Acknowledgements

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SUPPLEMENTARY APPENDIX A1

Annual rate of change (%/year) of the different land cover categories and periods for each one of the considered river basins. ART = Artificial; AGR = Agricultural; FNV = Forest and Natural Vegetation; W = Wetlands; WB = Water Bodies

		CLC 1990 vs CLC 2000				
Basin	Without	ART	AGR	FNV	W	WB
Alberche	8.9442	0.0349	0.0424	0.0662	0.0000	0.0032
Alto Duero	8.9319	0.0055	0.1075	0.0452	0.0000	0.0008
Cega, Eresma and	8.9799	0.0214	0.0473	0.0370	0.0000	0.0052
Guadarrama	8.5633	0.3533	0.0444	0.1288	0.0000	0.0012
Henares	8.8927	0.0931	0.0438	0.0579	0.0000	0.0034
Jarama	8.5150	0.3851	0.0445	0.1366	0.0001	0.0096
Riaza and	8.9445	0.0207	0.0616	0.0629	0.0000	0.0012
Tajuña	8.9098	0.0210	0.0535	0.0996	0.0000	0.0071
Tiétar	8.8225	0.0067	0.1898	0.0680	0.0000	0.0039
Tormes	8.9113	0.0254	0.1145	0.0376	0.0000	0.0021
		CLC 2000 vs CLC2006				
Alberche	13.7152	0.0935	0.2347	0.2320	0.0000	0.0102
Alto Duero	13.6981	0.0141	0.2843	0.2864	0.0000	0.0028
Cega, Eresma and	13.7764	0.0595	0.2149	0.2330	0.0000	0.0019
Guadarrama	13.3589	0.5292	0.1824	0.1912	0.0000	0.0240
Henares	13.6308	0.1082	0.2704	0.2679	0.0000	0.0083
Jarama	13.2899	0.4905	0.2482	0.2273	0.0003	0.0295
Riaza and	13.6179	0.0223	0.3176	0.3242	0.0000	0.0037
Tajuña	13.5013	0.0877	0.3735	0.3180	0.0000	0.0053
Tiétar	13.6893	0.0245	0.2898	0.2664	0.0000	0.0157
Tormes	13.6858	0.0404	0.2762	0.2696	0.0000	0.0137
		CLC 2006 vs CLC 2012				
Alberche	14.2613	0.0081	0.0123	0.0039	0.0000	0.0000
Alto Duero	14.2644	0.0155	0.0034	0.0015	0.0000	0.0009
Cega, Eresma and	14.2511	0.0280	0.0052	0.0014	0.0000	0.0000
Guadarrama	14.0570	0.1485	0.0754	0.0047	0.0000	0.0000
Henares	14.2091	0.0628	0.0076	0.0062	0.0000	0.0000
Jarama	14.0318	0.2037	0.0470	0.0032	0.0000	0.0000
Riaza and	14.2724	0.0064	0.0041	0.0021	0.0000	0.0008
Tajuña	14.2307	0.0206	0.0306	0.0038	0.0000	0.0000
Tiétar	14.2375	0.0249	0.0148	0.0083	0.0000	0.0002
Tormes	14.2596	0.0125	0.0107	0.0022	0.0000	0.0007

SUPPLEMENTARY APPENDIX A2

Land use transition matrix for the two selected future scenarios. ART = Artificial; AGR = Agricultural; FNV = Forest and Natural Vegetation; W = Wetlands; WB = Water Bodies. Difference between present and future percentage, positive values indicate an increase in the future surface respect to the present, negative values indicate a decrease in the future surface respect to the present.

				2050 RCP 45			
		ART	AGR	FNV	W	WB	Total area
2012	ART	176,176	0	0	0	0	176,176 (3.52 %)
	AGR	12,739	1,592,010	616,435	0	0	2,221,184 (44.39 %)
	FNV	0	0	2,578,304	0	0	2,578,304 (51.53 %)
	W	0	0	0	24	0	24 (0.00 %)
	WB	0	0	0	0	28,005	28,005 (0.56 %)
	Total area	188,915 (3.78 %)	1,592,010 (31.82 %)	3,194,739 (63.84 %)	24 (0.00 %)	28,005 (0.56 %)	5,003,693
				2050 RCP 85			
2012	ART	176,176	0	0	0	0	176,176 (3.52 %)
	AGR	223,605	1,997,579	0	0	0	2,221,184 (44.39 %)
	FNV	447,210	578,692	1,552,402	0	0	2,578,304 (51.53 %)
	W	0	0	0	24	0	24 (0.00 %)
	WB	0	0	0	0	28,005	28,005 (0.56 %)
	Total area	846,991 (16.93 %)	2,576,271 (51.49 %)	1552,402 (31.03 %)	24 (0.00 %)	28,005 (0.56 %)	5,003,693

CAPÍTULO III

CONNECTING PROTECTED AREAS IN THE IBERIAN PENINSULA TO FACILITATE CLIMATE CHANGE TRACKING

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INTRODUCTION

Human pressure on nature is growing, resulting in unprecedented rates of biodiversity loss and natural landscape degradation (Laurance et al., 2014; Pimm et al., 2014). At present, the species extinction rate outpaces the historical background rate by a thousand times (Barnosky et al., 2011). One of the principal approaches to preserve natural places has been the declaration of protected areas (PAs), which represent a key strategy to address some of the global environmental challenges. PAs not only play a key role in mitigating threats related to human activity (Rodrigues et al., 2004; Rodríguez-Rodríguez et al., 2019), but they also sustain functional ecosystems and prevent or slow the loss of biodiversity (Joppa et al., 2008; UNEP-WCMC et al., 2018). Several studies have underlined the importance of PAs for mitigating the adverse effects of human development (Watson et al., 2014) and climate change (Hannah et al., 2002a; 2002b; Gaüzère et al., 2016; Lehikoinen et al., 2019) on biodiversity.

Due to socioeconomic and/or legal constraints, networks of PAs are usually the consequence of unplanned selection strategies that often generate spatially fixed and unconnected reserve designs (Pressey 1994, Joppa and Pfaff, 2009). However, nature is dynamic, and the static character of PAs seriously hinders their capacity to allow the persistence of biodiversity and the maintenance of the ecological processes for which these PAs were declared (Burns et al., 2003; Araújo et al., 2004). This is particularly true for climate (Monzón et al., 2011) and land-cover changes (Hansen and Defries, 2007). The ability of static PAs to conserve biodiversity is often questioned because, although they mitigate the negative effects within their boundaries, they are often extremely pressured on their borders. This frequently leaves PAs as conservation islands (Hole et al., 2009; Wilson et al., 2015) that may hamper the movement of species towards other areas with suitable climatic conditions, especially when the surroundings of PAs are human-dominated (Wessely et al., 2017). In essence, as climate shifts, PAs may tend to lose the particular climatic conditions represented in them and, as a result, may lose populations or even species associated with the particular set of conditions existing in them. Conversely, the environmental conditions formerly represented in a PA can appear in other locations outside this protected territory. All of these areas harbouring in the future the general environmental conditions currently hosted by a PA can be considered 'recipient areas' able to support individuals coming from the PA (sensu Mingarro and Lobo, 2018). The 'real' distribution of species under changing environmental conditions is difficult to predict because of the complexity of the factors that affecting it (Warren et al., 2001; Lobo 2016). Alternatively, the representative environmental regions of each PA can be located under present and future scenarios (Mingarro and Lobo, 2018) as a means of increasing the probability of preserving the ecosystem functions and biodiversity represented by PAs (Stralberg et al., 2020). Present representative and future recipient areas may thus be important from a conservation point of view because their protection could facilitate the safeguarding of the environmental conditions under which each PA was declared.

The identification of corridors and the connection between environmentally and biodiversity-important areas is a topic that is recognized as fundamental for the management of biodiversity and environmental resources in the face of climate change (Heller and Zavaleta, 2009; Carroll et al., 2015; Choe et al., 2017; Littlefield et al., 2017; 2019; Lawler et al., 2020; Parks et al., 2020). The capacity of present representative and future recipient areas to act as refuges for the organisms inhabiting a PA will depend on the availability of corridors allowing their connectivity. Thus, it is vital not only to locate where these climatically representative areas would appear in the future, but also to estimate where the corridors are that would connect these PAs with their future recipient areas (Alagador et al., 2012). We believe that performing these two tasks is essential to improving the sustainability of the biodiversity that PAs seek to safeguard and preserve. In this study, by considering several climatic variables, we delimit the current representative and the future recipient areas for all of the mainland Iberian national parks (INPs) to subsequently delimit the corridors that are able to connect these parks with their representative and recipient areas.

Thus, the main aims of this study are: (1) to estimate the location and extent of the present and future climatically representative areas for all of these INPs; (2) to describe the current land cover and conservation status of these areas; and (3) to delimit a network of corridors to connect these representatives (present) and recipient (future) areas with their respective parks. Through all of these tasks, we hope to offer some guidelines to improve the future sustainability of the Iberian PAs.

MATERIALS AND METHODS

Study area

Geographically isolated in south-western Europe (latitude 36-44°, longitude 10° and 5°), the Iberian Peninsula covers an area of 580,000 km^2 at the western limit of the Palaearctic region, a crossroads between Africa and Europe, and influenced both by the North Atlantic Ocean and by the Mediterranean Sea. These characteristics, together with an orography defined by large mountain ranges, mostly west-east orientated and with elevation gradients spanning 3,000 m, have a strong influence on the climate. Thus, the Iberian Peninsula harbours a wide range of climates, including desert, Mediterranean, Alpine and Atlantic. Furthermore, the Iberian Peninsula encompasses two main biogeographical regions: the Mediterranean and Atlantic, with a longitudinal gradient of precipitation and a latitudinal gradient of precipitation and temperature (Rivas-Martínez, 2005). It is also one of the European regions with the greatest diversity of ecosystems, habitats and biodiversity (Ramos et al., 2001), where the mountain geography has favoured the occurrence of isolated endemic species.

The INP protection status is among the most restrictive concerning land management according to Spanish legislation. There are ten INPs (Fig. 1a); nine belong to Spain (Aigüestortes i Estany de Sant Maurici, Ordesa y Monte Perdido, Cabañeros, Monfragüe, Sierra Nevada, Doñana, Sierra de Guadarrama, Tablas de Daimiel, Picos de Europa) and one to Portugal (Peneda-Gerês). The total INP area is 3982.5 km^2 (0.68% of the Iberian Peninsula; Table 1), of which the Sierra Nevada is the biggest (859 km^2) and Tablas de Daimiel is the smallest (30 km^2). In terms of elevational representativeness, only two of these INPs (Table 1) are below the mean elevation of the Iberian Peninsula (1,229.46 m above sea level); most of the INPs are in high and mountainous areas, as indicated by their mean elevation and elevational range (Table 1).

Current and future INP climatic representativeness

We used the monthly average values of maximum daily temperatures, minimum daily temperatures and total accumulated rainfall during each month, at 1 km^2 resolution, from 1950 to 2007 (see Felicísimo et al., 2011). The data of these three variables and the equations provided by Valencia-Barrera et al., (2002), López Fernández and López (2008) and Hijmans et al., (2005) allowed us to build 23 bioclimatic variables. Briefly, we submitted all of these variables to a principal component analysis (PCA) that generates three non-correlated factors with eigenvalues higher than unity, representing 93.5% of all the climatic variability in the Iberian Peninsula (see Mingarro and Lobo, 2018 for details). Considering each one of these three factors, we selected the original variable with the highest factor loading in order to use variables with clear interpretability. Furthermore, the original variables that were poorly represented by the three selected PCA factors were also included (see Mingarro and Lobo, 2018). This process enabled the final selection of five climatic variables with little or no correlation to each other: precipitation during the wettest month; annual average temperature; thermal contrast; isothermality; and average monthly maximum temperature.

Iberian future climatic data are from the WorldClim database (Hijmans et al., 2005) with a 0.86 km^2 resolution at the equator. The data provide two different temporal scenarios (2050 and 2070) and we chose six different global climate models (GCMs): BCC-CSM1-1 (Xin et al., 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). As the data of the two temporal scenarios offer very similar results (see Supplementary Fig. S1-S4), we chose to average them. Thus, we averaged the values of the three previously mentioned primary climatic variables (mean monthly values of maximum daily temperatures, mean monthly values of minimum daily temperatures and monthly precipitation) considering these 12 datasets (2 temporal scenarios × 6 climatic models) to offer a general picture of the future climate. We assume that the recipient areas identified using these averaged data could be important in the future, regardless of the scenario or time window and despite uncertainties in climate models. We used the derived climatic data to estimate the same five climatic variables selected in the case of the current climate (precipitation of the wettest month, annual average temperature, thermal contrast, isothermality and average monthly maximum temperature).

All of the considered future climatic simulations were generated in the fifth evaluation report (AR5) according to two scenarios of representative concentration routes. The Representative Concentration Pathway (RCP) 4.5 scenario represents a population stabilization scenario, with stable or decreasing future greenhouse gas emissions that are associated with increased carbon stocks in forests and a decrease of agricultural land (van Vuuren et al., 2011). In contrast, in the RCP 8.5 scenario, high human population growth rate is expected, with constant emissions and both population and anthropogenic land cover increases (Hurtt et al., 2011; van Vuuren et al., 2011). Climatic variables were thus calculated independently for each one of these two RCP scenarios.

Table 1. Main geophysical characteristics of the Iberian national parks and Euclidean distances, in kilometres, between each Iberian national park and the Iberian areas that, in the present and future, harbour the climatic conditions currently represented by them. When an Iberian national park loses its climate representativeness in the future, it will not have recipient areas, being represented as D. The acronyms of the Iberian national parks are those of Figure 1. Percentages are based on the total area of the Iberian Peninsula (583,113 km^2). A = area in km^2; D = disappear; E = mean elevation (in metres above sea level); ER = elevation range (in metres); Max = maximum distance; Mean = mean distance; Min = minimum distance.

				Present			Future		
	A	R	E	Min	Max	Mean	Min	Max	Mean
PG	698 (0.12%)	1,462	866	0	176	92	D	D	D
AE	139 (0.02 %)	1,683	2,369	0	173	82	D	D	D
C	409 (0.07 %)	912	801	0	237	142	181	272	231
SN	859 (0.15 %)	2,571	2,146	0	725	405	3	716	475
D	534 (0.09 %)	44	7	0	63	32	D	D	D
TD	30 (0.01 %)	5	08	0	16	10	D	D	D
M	180 (0.03 %)	565	356	0	322	75	183	334	282
SG	340 (0.06 %)	1,454	1,758	0	470	245	0.03	434	214
PE	61 (0.11 %)	2,561	1,346	0	700	210	D	D	D
OM	157 (0.03 %)	2,566	2,038	0	559	245	52	280	185

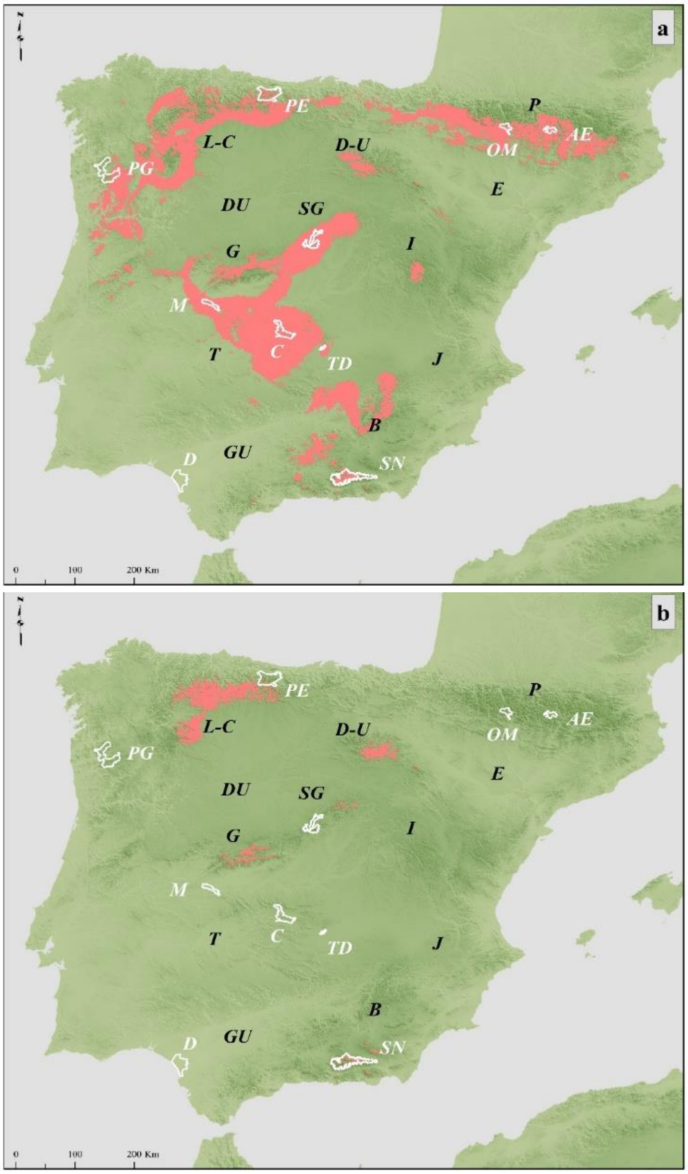


Figure 1. (a) Iberian areas with similar climatic at present to those INPs (in coral color). (b) Recipient areas (areas that, in the future, will harbour the climatic conditions currently represented by the INPs) for at least two INPs (core areas, in coral color). The contours of all of the INPs are shown (white polygons), named in order from north to south OM (Ordesa y Monte Perdido), AE (Aigüestortes i Estany de Sant Maurici), PE (Picos de Europa), PG (Peneda-Geres), SG (Sierra de Guadarrama), M (Monfragüe), C (Cabañeros), TD (Tablas de Daimiel), SN (Sierra Nevada) and D (Doñana). The main Iberian Mountain ranges are also shown: P (Pyrenees), L-C (Leon-Cantabric), D-U (Demanda-Urbión), I (Iberian Central System), G (Gredos), T (Montes de Toledo) and B (Baetics). The following principal valley systems are mentioned in the text: E (Ebro), D (Duero), J (Júcar) and G (Guadalquivir).

We delimited representative (present) and recipient (future) climatic areas for each INP following a previously published methodology (Mingarro and Lobo, 2018). The values of the five selected climatic variables were used to estimate the Mahalanobis distance (MD) between the conditions in the 1 km^2 cells of each INP and the cells of the whole Iberian Peninsula. MD was chosen to measure climate similarity because this multidimensional measure takes into account the correlations of the variables and it is scale-invariant regardless of the units used for each variable (Farber and Kadmon, 2003; Xiang et al., 2008). The 95th percentile of the MD values obtained in the cells located inside each INP was chosen as the decision threshold to delimit the areas with a climate similar to the one experienced in each INP (hereafter referred as climatically representative areas). In order to facilitate the design of corridors (see below), we reduced the selected MD threshold to the 80th percentile in the case of the climatically heterogeneous Sierra Nevada National Park to diminish its wide climatically representative area. We added together climatically representative areas belonging to all of the INPs in order to capture the extent and location of the Iberian areas now harbouring climatic conditions similar to those experienced in the INPs. When these climatically representative areas are shared by at least two INPs, they will be denominated as 'core areas'.

We used a similar procedure to delimit the recipient areas that in the future will harbour the climatic conditions currently represented by each INP. In this case, the same five climatic variables were used to calculate the MD between the current conditions in the 1 km^2 cells of each INP and all of the Iberian cells according to the two future RCP climatic scenarios. Once identified and mapped, we overlaid the future recipient areas according to the RCP 4.5 and RCP 8.5 scenarios to generate a unique representation of the probable location of recipient areas (Fig. S1-S4 show the locations of recipient areas for each climatic scenario). Afterwards, the derived recipient areas were overlapped with the land-cover data coming from the CORINE Land Cover project (2018 data at level 1; see www.eea.europa.eu) to delimit those areas representing in the future the climate of INPs that in turn have a forest or semi-natural land cover. Similarly, we overlapped the obtained recipient areas with the Iberian PAs included in the Protected Planet database (www.protectedplanet.net) in order to identify their current conservation status.

Creating a corridor network

For each INP, we created an ecological corridor network by connecting its location and the location of its representative and recipient areas, as described above. We used the Linkage Mapper ArcGIS tool for this purpose (McRae and Kavanagh, 2011), which is based on a cost-distance methodology considering a resistance surface. Resistance surfaces represent the relative cost, or permeability, of passing through a gridded mapped surface and can be used to calculate cost-weighted distance away from different patches (Villalba et al., 1998; Zeller et al., 2012). On the one hand, we used a raster file representing the MD between the current conditions in the 1 km^2 cells of each INP and the present conditions of all of the Iberian 1 km^2 cells. Moreover, we used another raster file representing the MD between the current conditions in the 1 km^2 cells of each INP and the future conditions of all of the Iberian 1 km^2 cells. These two raster files acted as a resistance surface, thus enabling the creation of corridors. We used cost-distance models because they are computationally efficient (Adriaensen et al., 2003) and allow us to determine routes with the least cost-weighted distance among the selected patches. The cost value is the cumulative resistance found when moving along the optimal route from one place to another through the resistance surface (Adriaensen et al., 2003; McRae et al., 2012). We chose a cost-weighted distance value of 10,000 as a threshold to obtain ecological corridors that are more limited in their extent (see McRae et al., 2012).

Once the corridor network was established for each INP, we added all the corridors together, in accordance with the considered climatic scenarios, to obtain a whole corridor network for all of the INPs. In addition, these results are shown, disaggregated by scenario and by period time, in the Supplementary Material (Fig. S4-S8). When two or more corridors overlapped in a 1km^2 cell, we selected the minimum cost value. To reduce the computational time, we discarded all of the representative areas with an area smaller than the smallest INP (Tablas de Daimiel with 30 km^2); however, due to the comparatively small extent of recipient areas, this area limitation was not used. This methodology allowed us to create an ecological corridor network in which all INPs were connected with their corresponding representative and recipient areas.

We used the CORINE Land Cover database of 2018 to identify the possible barriers to the connectivity of INPs with the future recipient areas by overlaying this corridor network with the current anthropogenic land uses. Two kinds of barriers were differentiated depending on the anthropogenic use of the land: artificial barriers and agricultural barriers. The first is regarded as a land use that acts as a barrier in which return to a natural status is unlikely. Agricultural barriers, on the other hand, are considered a land use that might become natural.

RESULTS

Climatic representativeness

The current climatic representativeness of the INPs covers 13.6% (c. 79,050 km^2) of the total area of the Iberian Peninsula. Most of the Iberian mountainous regions are included within this climatically representative area (Fig. 1a); the mean elevation of these areas is 1,220 m, with an elevation range of 2,199 m. Five areas climatically represent at least two INPs (core areas): the Pyrenees, the León-Cantabric Mountains, the Iberian Central System, nearby areas of the southern Iberian plateau and the Baetic Mountain Ranges (Fig. 1a).

Climatically representative areas will decline by 89% (c. 8,691 km^2) in the future. These future representative or recipient areas will be greatly reduced, both in area and number, or disappear in the south and central part of the Iberian Peninsula as well as in the Pyrenees (Fig. 1b). Thus, the main areas in the future are located in the Cantabrian and Leon mountains, the Gredos Mountains and the Demanda and Urbión Mountains. Importantly, the elevational range in these future climatically representative areas declines (1,163 m), while the mean elevation increases notably (1,770 m). At present, the distances between the outer border of the INPs and the continuous areas that represent their climate is always zero (Table 1), which means that all of the INPs have contiguous areas with a similar climate. However, in the future, many of the INPs will lose a large part of these climatically representative areas, and those remaining will appear in places far from the target INP. All of these representative areas increase their distances from INPs except in the case of the Ordesa y Monte Perdido National Park (Table 1).

Present climatically representative areas are almost three-quarters covered by forest and semi-natural areas and a quarter covered by agricultural areas (Table 2). However, future recipient areas are located in areas almost entirely covered by forest and semi-natural vegetation (Table 2). With regards to the protected status criteria, future recipient areas covered by forest and semi-natural vegetation that, at the same time, are included in any type of PA category represent 65% of the total (5,481 km^2), while c. 2,929 km^2 (35%) would not be covered by any PA category. The geographical distribution of these areas shows that the Cantabric Mountains at the north-western region, the Iberian Central System and the Urbión Mountains in the north-central region would be those harbouring the most important recipient areas that are currently protected.

Table 2. Areas of the different land-cover types (km^2) for the climatically representative areas of all the Iberian national parks in the present and future. The percentages in parentheses are calculated based on the total representative area.

	Ar	Ag	FsN	W	Wb
Present	844.2 (1.1 %)	20 304.8 (25.7 %)	57 369.0 (72.6 %)	33.0 (0.04 %)	483.9 (0.61 %)
Future	44.7 (0.5 %)	230.4 (2.6 %)	8 410.2 (96.8 %)	0.03 (0.00 %)	5.7 (0.07 %)

Corridor networks

The obtained corridor network allows all of the INPs to connect with one another, as well as to their corresponding climatically representative areas at present (Fig. 2a). The exception is the Doñana National Park, which remains isolated in the south-western Iberian Peninsula (see Fig. 1), and its representative areas are very close to the park itself. In total, the INP corridor network connecting present climatic representative areas covers almost 36% of the Iberian territory (Table 3). Interestingly, this corridor network connects most areas of the Iberian Peninsula except the southwestern portion (Fig. 2a), and just over half of its area is currently under forest and semi-natural land-cover categories (without agricultural and artificial barriers; Table 3).

The area of the corridor network decreases considerably when future recipient areas are considered (Fig. 2b). Three national parks (Doñana, Peneda-Gerês and Aiguestortes) will completely lose their climatically representative areas, and indeed, they are located far from the corridor network. The other two INPs (Picos de Europa and Tablas de Daimiel) will not have recipient areas in the future, but they could be connected with other PAs due to their proximity to the corridor network. The remaining five INPs will connect with each other and with their corresponding recipient areas (Fig. 2b). All corridors, which at present are spatially dispersed (Fig. 2a), could be summarized into four main corridors (Fig. 2b): (1) that connecting the Iberian Central System with the Sierra de Gredos to Leon and the Cantabrian mountains range; (2) that connecting the Iberian System with the occidental part of the Pyrenees; (3) that which joins the Baetic Mountains ranges with the Iberian System; and (4) that which allows the connection between the Baetic Mountain ranges and the Mediterranean national parks (Cabañeros and Monfragüe), located in the Toledo mountains (see Fig. 1a). Although the area of this corridor network decreases moderately in the future scenario, representing 32% of the Iberian area, half of this area is again currently covered by forest and semi-natural land uses (Table 3). Furthermore, the global cost-weighted distance mean is lower than in the network corridor connecting INPs at present with their climatically representative areas (Table 3).

The most conflicting and preventing areas of network connectivity with the future recipient areas can be discerned by examining the current extent of artificial and agricultural land uses within the corridor network. These main barriers to connectivity are located in the main Iberian basins (Fig. 3): Duero and Tajo (B1), Ebro (B2), Jucar (B3) and Guadalquivir (B4). These valleys, subject to substantial and ancient human impact, would seriously compromise the connectivity of INPs with the areas that in the future will harbour their current climatic conditions.

Table 3. Basic statistics of the corridor network connecting Iberian national parks with their climatically representative areas at present and for the future (recipient areas). A = total area (in km^2); AA = total area without artificial barriers (km^2 and percentage with respect to the total corridor network area); AAA = total area without artificial and agricultural barriers (km^2 and percentage with respect to the total corridors network area); CW = mean of the cost-weighted distance of the total area; CWA = mean of the cost-weighted distance of the total area without artificial barriers; CWAA = mean of the cost-weighted distance of the total area without artificial or agricultural barriers.

	A	**A_A**	**A_{AA}**	**C_W**	**C_{WA}**	**C_{WAA}**
Present	214,318	211,716 (98.79 %)	121,555 (56.72 %)	21.43	21.17	12.21
Future	193,818	191,597 (98.85 %)	99,114 (51.14 %)	19.42	19.21	10.28

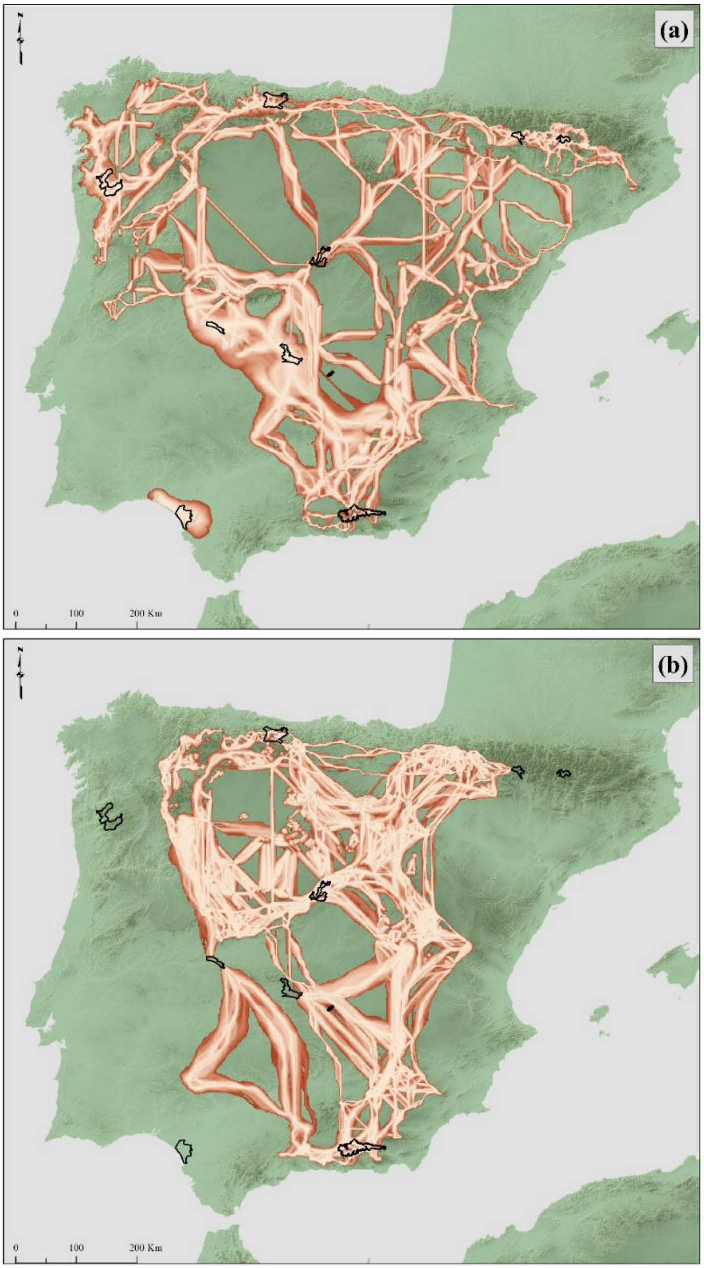


Figure 2. Network of corridors climatically connecting Iberian national parks with (a) their present representative areas and (b) their future recipient areas. The light grey (low) to dark grey (high) colour gradient indicates cost-weighted distance values. A lower cost-weighted distance value implies a better aptitude for corridor development. Light grey pathways show the corridors with lower cost-weighted distance values.

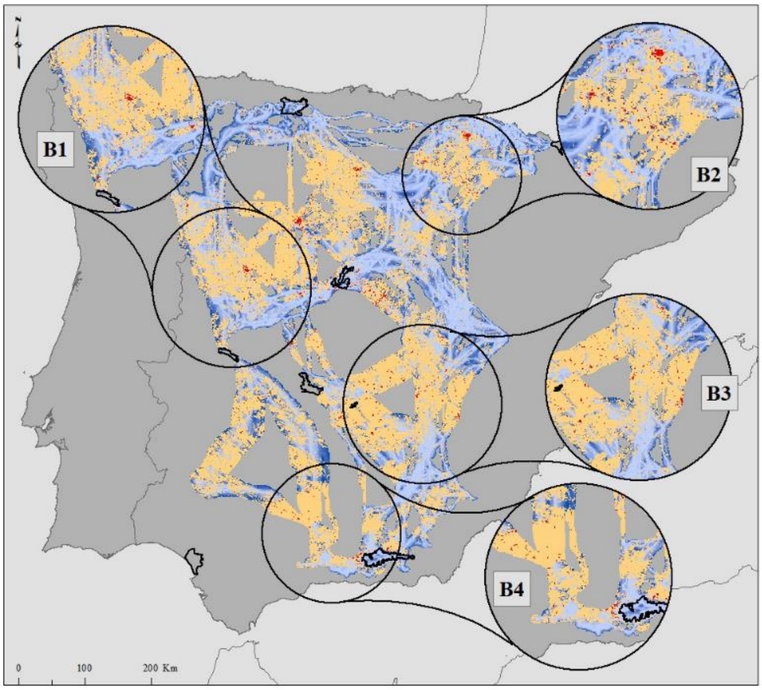


Figure 3. Main areas preventing the connectivity between Iberian national parks and their future recipient areas: Duero and Tajo basins (B1), Ebro basin (B2), Jucar basin (B3) and Guadalquivir basin (B4). Each area is enlarged in its corresponding circle. Artificial (in red) and agricultural barriers (in yellow) and networks of corridors (light blue to dark blue) are shown.

DISCUSSION

Although many approaches have been proposed to identify areas whose conservation would facilitate biodiversity persistence in the face of climate change (Lawler et al., 2015; 2020; Alagador et al., 2016; Jones et al., 2016), this study attempts to offer a different perspective. Our approach aims to promote the sustainability and conservation of PAs by considering their abiotic/climatic characteristics and the expected effects of climatic changes in altering the original environmental profile under which these PAs were established. We demonstrate here that the location and extent to which areas representing the climatic conditions of the Iberian national parks could in the future undergo a drastic transformation. The areas representing in the future the present climatic conditions of the INPs will be located c. 500 m higher in altitude and could have a total area nine times smaller than the areas representing the contemporary climate. Furthermore, half of the considered INPs will lack an equivalent climatic area on the Iberian Peninsula, and the climatically representative areas of the other half of the INPs will be situated 180-470 km away, often dissected by valleys greatly impacted by human activities. As a consequence, if the fundamental niche of the species is directly or indirectly determined by climatic variables, we could assume that many populations and species now inhabiting INPs will tend to disperse towards those areas in which these INP's conditions will appear in the future (Heller and Zavaleta, 2009; Mingarro and Lobo ,2018). However, the responses of the organisms to changes in land use can vary and depend on their dispersal capacity (Newbold et al., 2020). In general, the ability to adjust species' geographical distribution in response to climate change decreases in organisms as human land uses increase in intensity (Williams and Newbold, 2020). It is thus difficult, if not impossible, to understand how climate change will affect the future abundance and distribution of each one of the species inhabiting an INP. Each species may experience: (1) a decrease or even the disappearance of individuals and populations (Bestion et al., 2015); (2) an increase in the evolutionary forces promoting in situ adaptation to new conditions (Hoffmann and Sgrò, 2011); and (3) the dispersal of individuals towards new suitable territories (Mason et al., 2015, 'spatial adaptation' according to Hengeveld, 1997). We propose here to overcome this drawback by focusing on the characteristics of spaces and not on the probable response of the species (i.e., Sarkar et al., 2005; Hortal et al., 2009), considering that an approach directed at improving the representation of the climatic variability can act as a surrogate to represent biodiversity.

Our results identify some important areas for maintaining the climatic representativeness of INPs in the future. These regions are located in the northern half of the Iberian Peninsula, but also in the Sierra Nevada or in its proximity. The Gredos, Demanda-Urbion, León and Cantabric mountain areas have emerged as key regions for the future maintenance of INP climatic characteristics. Unfortunately, some of these areas do not have the severe restriction of human uses as in the INPs. Our results also indicate that in addition to the disappearance of climatically representative areas in half of the INPs, those maintaining future recipient areas may not be close to the INP itself, thus entailing its isolation. Consequently, it is necessary to anticipate possible alterations in order to avoid the functional isolation of each INP and facilitate the flow from the INP to the suitable recipient areas through a corridor network. Enhancing the connectivity among important biodiversity areas was considered as one of the most important conservation biodiversity approaches for coping with climate changes (Heller and Zavaleta, 2009). However, the benefit of connecting PAs may be limited if this fails to facilitate the interconnection between current PAs and their future recipient regions. Only in this way will it be possible for corridor networks to allow species to track their suitable climatic conditions, particularly in human-dominated landscapes such as those of the Iberian Peninsula. Hence, the successful development of the proposed corridor network not only requires the existence of natural or semi-natural habitats within it, but also discriminating the places where connectivity is prevented. Our results clearly show that current land uses in the Iberian Peninsula severely obstruct the corridor network connecting INPs and recipient areas. Thus, if we aim to promote the connectivity between these environmentally important areas, it is necessary to make an effort to restore the locations that can facilitate this connectivity. At this point, the involvement of public authorities, managers and policymakers will be essential to bring this project to a successful end.

PA categories such as those in the Natura 2000 network could dovetail and develop an essential role (Mazaris et al., 2013; Nila et al., 2019), as they promote sustainable development together with traditional use and conservation (Popescu et al., 2014; Jackson 2018). Conservation planners should focus on the possible transitions of agricultural land use, encouraging natural restoration in some 'hurdle' areas previously identified and agreed upon. In this study, we propose four main such areas where the land-use transition will determine the successful development of a corridor network capable of addressing the effects of climate change on INPs. Two of these areas are located close to the Sierra Nevada National Park, which has the widest representative climatic area. A third hurdle area would prevent the connection between the Gredos and Leon Mountain ranges along the Duero valley in the north-western part of the Iberian Peninsula. The fourth hurdle would make it difficult to connect the Pyrenees Mountains with other places due to the extensive agricultural land use in the Ebro valley.

The bleak picture that emerges from these results is mitigated to some extent because most of the recipient areas now having forest and semi-natural land uses and more than half of their whole area having protected status. Furthermore, the potential corridor network is hardly affected by current human land uses (which decreased by 18%), although it will be necessary to perform land-cover simulations under different climate change scenarios in order to better identify how future land-use changes may affect the observed connectivity between INPs and recipient areas (Mingarro et al., 2020). It is important to highlight that the Iberian Peninsula is largely mountainous and that this characteristic seems to be decisive in mitigating the effects of climatic change on biodiversity loss (Littlefield et al., 2019), in a way that is comparable to that seen during Pleistocene times (Schmitt, 2007). Hence, keeping these mountain ranges connected is likely the most ambitious conservation strategy that can be pursued in the Iberian Peninsula (Saura et al., 2018; WWF 2018). Our results demonstrate the need for proactive measures that are able to improve the capacity of PAs to host biodiversity and facilitate the movement of species, including efforts for the proper functioning of climate corridors.

Our results are based on the study of the PAs categorized as national parks, and other configurations can emerge when other protection categories are included. However, the network of INPs was established with the intention of constituting a representative sample of the major Iberian natural systems (see https://www.miteco.gob.es/es/red-parques-nacionales/divulgacion). Our analysis provides a general overview, and performing specific analyses for each INP at a higher resolution would allow us to detect fine-grained recipient areas. This work does not focus purely on PA connectivity as other studies have done (Choe et al., 2017; Littlefield et al., 2017; 2019; Lawler et al., 2020; Parks et al., 2020). The methodology developed in the present study provides the ability to identify all climates, current and future, analogous to those within existing PAs, to subsequently identify candidate corridors to connect them. Furthermore, the focus on climates representative of those of PAs is novel in that it is not limited to considering only the connectivity of existing PAs. Here, we performed a basic connectivity network analysis covering a huge study area, and so it is important to identify more precisely where to focus conservation strategies (Margules and Pressey, 2000). To improve this approach, a more exhaustive analysis could be carried out in which the connectivity between the recipient areas and the INPs is analysed in detail, attending to potential barriers and proposing different ecological corridor networks. Utilizing land-use simulations and later connecting the recipient areas with the INPs containing places where forest and semi-natural land use is maintained could become an ideal methodology to delimit where natural climatic corridors could be.

This study has identified some key areas that are going to fulfil a very relevant role in mitigating climate change effects and that lack the protection they deserve. On top of this, these areas currently have forest and semi-natural land uses, so we need to be ambitious with the protection status of these places. These results highlight an important step in the Iberian conservation strategies by indicating that connectivity could be an effective measure to adapt to the climate change threat faced in this region. Moreover, this work is well suited to the EU Biodiversity Strategy for 2030, which emphasizes that the protection and restoration of nature must be intensified. This will need to be done by improving and expanding the network of PAs and developing an ambitious EU Nature Restoration Plan, integrating ecological corridors as part of a true trans-European Nature Network. Therefore, the first steps to developing effective conservation strategies in the face of climate change could be the protection of those key places, but also the creation of a network of corridors capable of facilitating the species flow between national parks and their recipient areas, keeping the most demanding PA category effective against the effects of climate change.

Acknowledgements.

This study has been developed despite the lack of scientific funding.

SUPPLEMENTARY APPENDIX

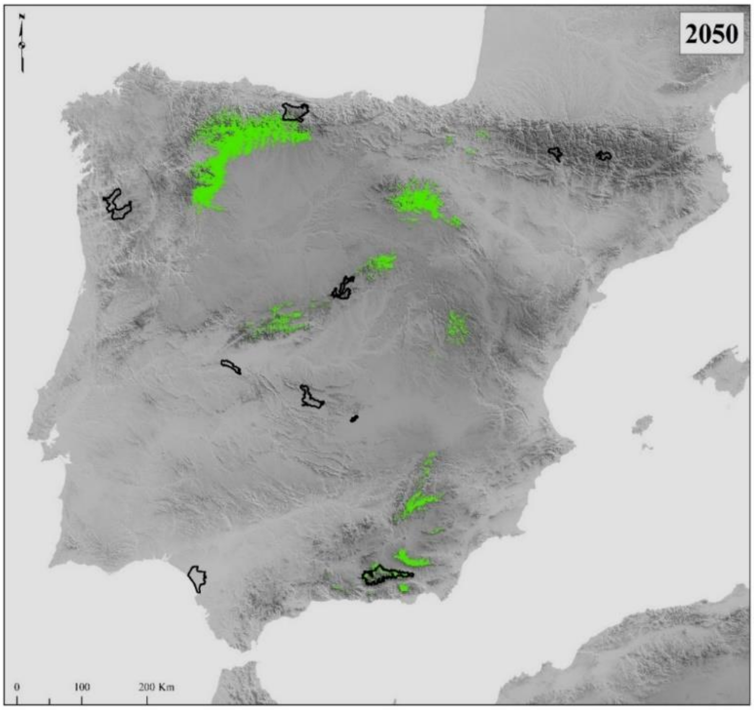


Figure S1. Recipient areas (areas that, in the future, will harbour the climatic conditions currently represented by the INPs) for at least two INPs (core areas, in green), corresponding to the year 2050.

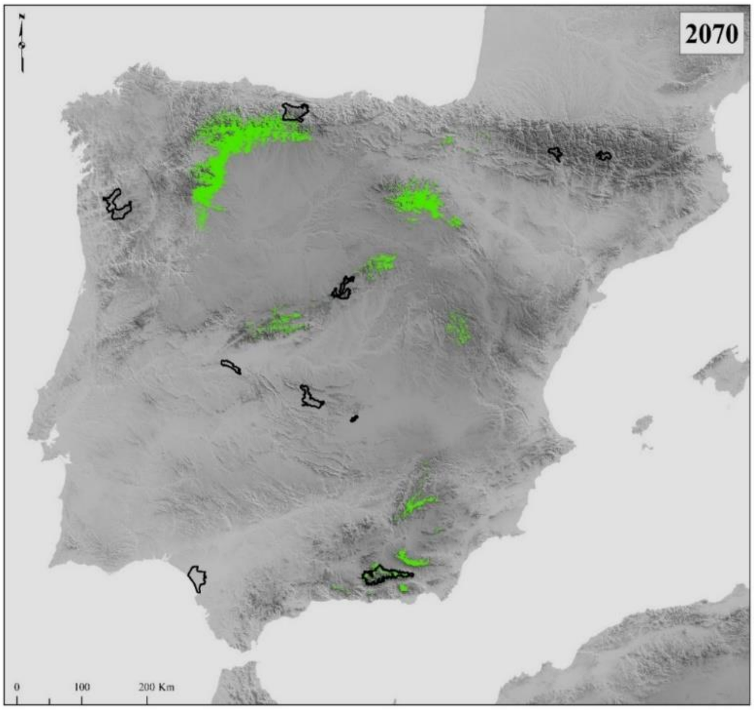


Figure S2. Recipient areas (areas that, in the future, will harbour the climatic conditions currently represented by the INPs) for at least two INPs (core areas, in green), corresponding to the year 2070.

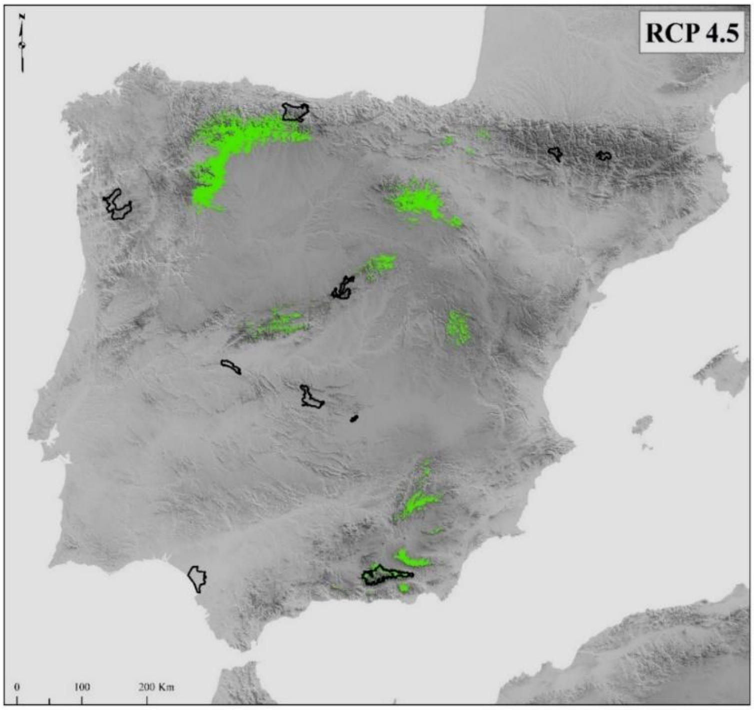


Figure S3. Recipient areas (areas that, in the future, will harbour the climatic conditions currently represented by the INPs) for at least two INPs (core areas, in green), corresponding to the RCP 4.5 scenario.

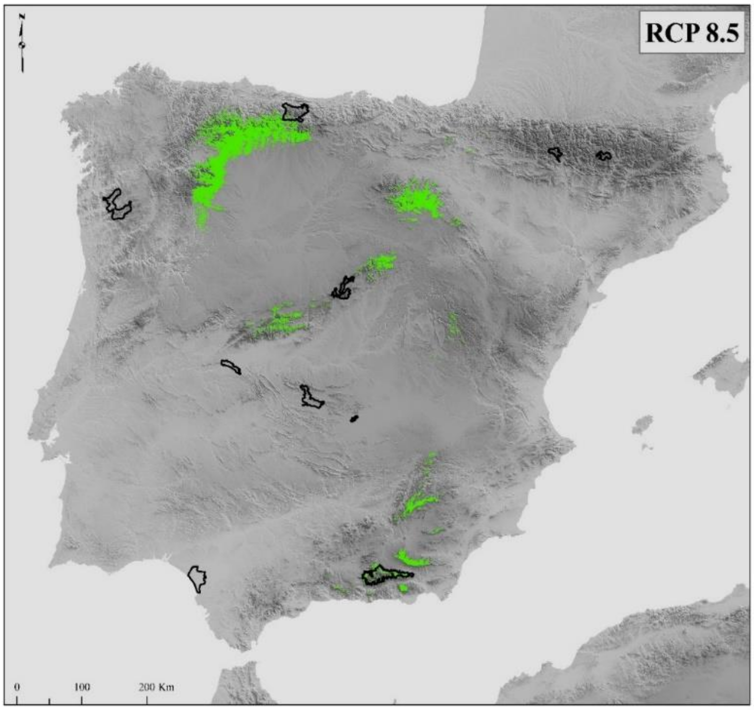


Figure S4. Recipient areas (areas that, in the future, will harbour the climatic conditions currently represented by the INPs) for at least two INPs (core areas, in green), corresponding to the RCP 8.5 scenario

Figure S5. Network of corridors connecting climatically representative areas in the first future period (2050). The green (low) - orange (high) colour gradient indicates cost-weighted distance values. Green colour pathways show the corridors with lower cost-weighted distance values. The contour of all the INPs is showed with black polygons.

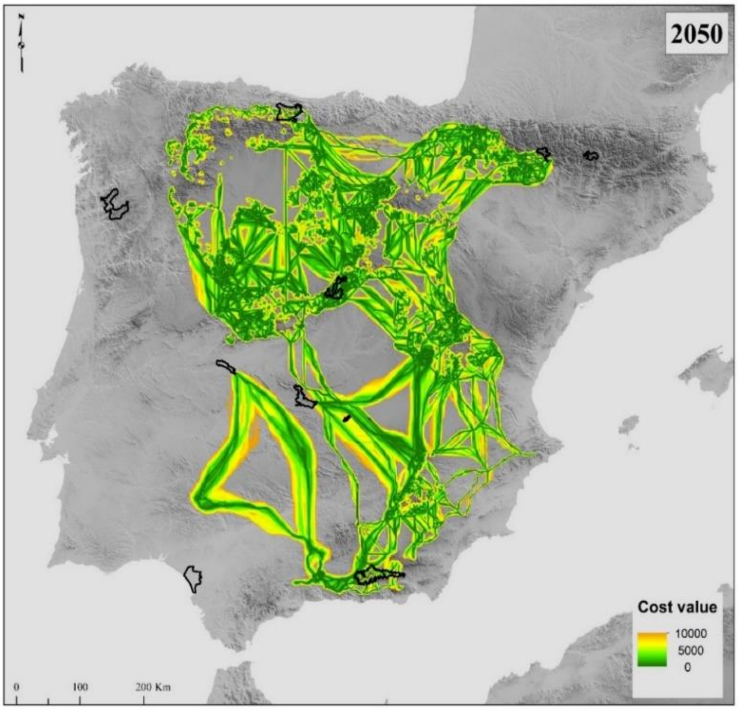
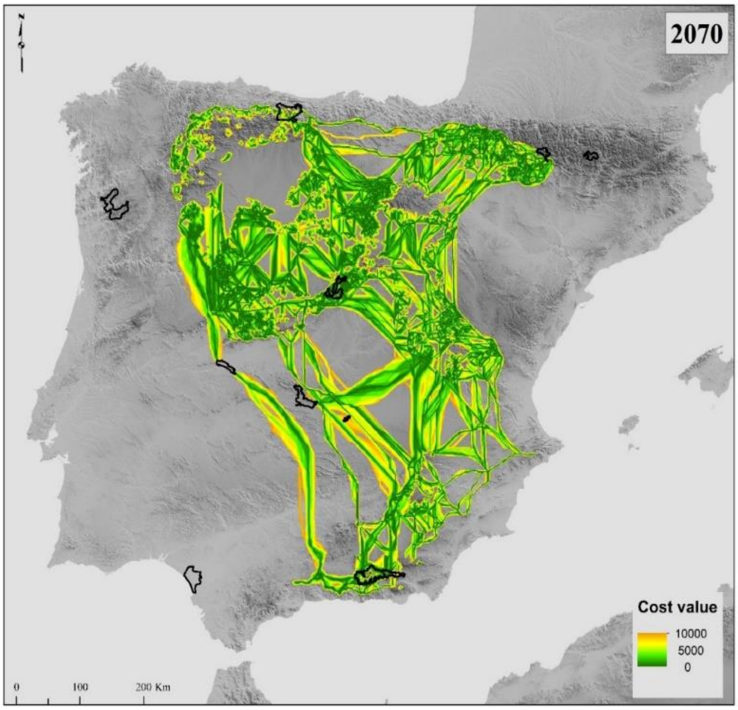


Figure S6. Network of corridors connecting climatically representative areas in the second future period (2070). The green (low) - orange (high) colour gradient indicates cost-weighted distance values. Green colour pathways show the corridors with lower cost-weighted distance values. The contour of all the INPs is showed with black polygons.



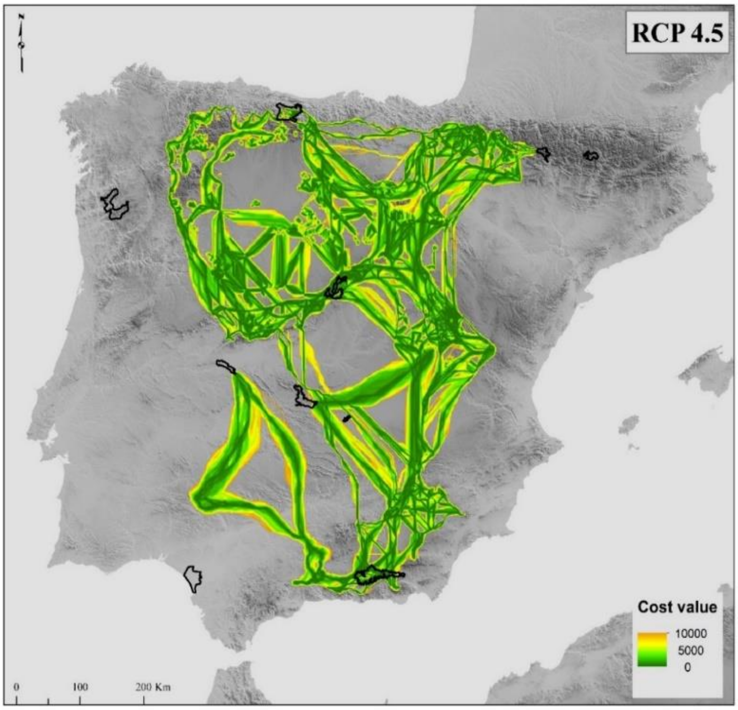


Figure S7. Network of corridors connecting climatically representative areas in the RCP 4.5 scenario. The green (low) - orange (high) colour gradient indicates cost-weighted distance values. Green colour pathways show the corridors with lower cost-weighted distance values. The contour of all the INPs is showed with black polygons.

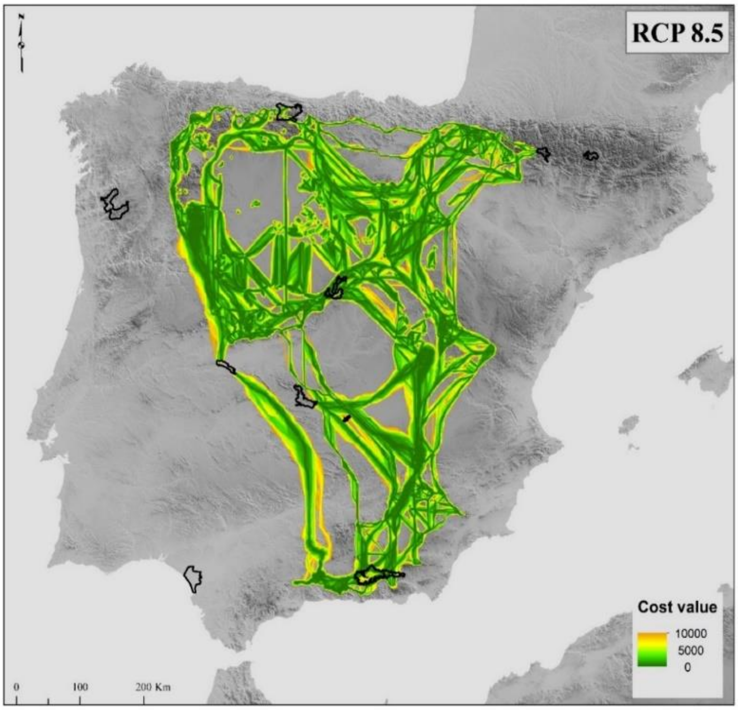


Figure S8. Network of corridors connecting climatically representative areas in the RCP 8.5 scenario. The green (low) - orange (high) colour gradient indicates cost-weighted distance values. Green colour pathways show the corridors with lower cost-weighted distance values. The contour of all the INPs is showed with black polygons.

CAPÍTULO IV

TEMPORAL LAND COVER DYNAMICS IN EUROPEAN NATIONAL PARKS SUGGEST THAT THEIR PROTECTIVE EFFECTS ARE GEOGRAPHICALLY HETEROGENEOUS

M. Mingarro and J.M. Lobo

In review in Land Use Policy (2021)

INTRODUCTION

Global biodiversity is changing at an unprecedented rate (Pimm et al., 1995; IPBES, 2019) in response to environment human-induced changes (Davies et al., 2006; Weinzettel et al., 2018). Land cover changes are singled out, together with climate change (Dale, 1997; Struebig et al., 2015), as the main threats for the long-term maintenance of biodiversity and ecosystem services (Vitousek et al., 1997; Laliberté et al., 2010; Maxwell et al., 2016). Conservation biology has proposed creative solutions to address these threats, focusing primarily on establishing protected areas (Hannah, 2010). Until now, it has been one of the main conservation strategies (Pressey et al., 2007; Watson et al., 2014), trying, through many conventions and international initiatives, to increase their coverage (Juffe-Bignoli et al., 2014; UNEP-WCMC and IUCN, 2016). However, this strategy has generated a great conservationist polemic, seen in some situations as insufficient to stop the loss of biodiversity and ineffective in dealing with the strong anthropic pressure that in recent times have been occurring (Liu et al., 2001; Curran et al., 2004). Protected areas are spatially fixed but ecological processes are spatially and temporally dynamic. Thus, area protection is incapable of alleviating all by itself the conservation and sustainable use of regional natural resources, even if reserves are well designed and managed (Carey et al., 2000; Oliveira et al., 2007; Geldmann et al., 2013; Watson et al., 2014; Lawrence et al., 2021).

There are many ways to measure the effectiveness of protected areas (Hockings, 2003). One of these could be how it acts against one of the main threats to biodiversity, that is, land cover change. This can be assessed by estimating the capacity of protected areas to stop, or at least slow down, the habitat loss within its limits but also in its surroundings (Bruner et al., 2001; Nagendra, 2008). Although socioeconomic status plays a major role in the effectiveness of protected areas in reducing human pressure (Geldmann et al., 2014), in some developing countries, protected areas have not been able to limit habitat loss within their limits (Liu et al., 2001; Curran et al., 2004). When they have managed to stop this habitat loss, changes in coverage in their surroundings have isolated them (DeFries et al., 2005; Hansen and DeFries, 2007). Even in developed countries, where conservation policies and institutions are generally stronger, it is assumed that the internal habitat loss is minimal, but the effectiveness of protected areas could be seriously conditioned by an increase in the intensity of land cover changes in their surrounding areas (Foley et al., 2005; Oliveira et al., 2007; Ewers and Rodrigues, 2008; Radeloff et al., 2010; Fuller et al., 2019; Lawrence et al., 2021; Mingarro et al., 2021).

The global protected areas network is composed by national networks, which have different historical trajectories, different policies, and motivations explaining the reasons for their enactment (Worboys et al., 2015; UNEP-WCMC, 2018). Currently, in Europe there is a large number of public protection figures with different policy targets and operational objectives (Juffe-Bignoli et al., 2014). In some protected areas good environmental management is prioritized in order to maintain a sustainable interaction between human pressure and conservation, while in others restricting any human intervention is the principal aim (Dudley, 2008; UNEP-WCMC, 2018). National Parks (NPs) can be considered as one of these demanding protection figures that, although managed differently in each country, share some characteristics and objectives that are synthesized by the IUCN as large natural areas or almost natural resources reserved to protect large-scale ecological processes, along with species and characteristic ecosystems (Dudley, 2008). The NPs success can be measured considering how much loss-for conservation of nature- has been avoided after their establishment (Pressey et al., 2015). As protected areas become increasingly isolated everywhere, understanding the changes in land use around them is critical (Beaumont and Duursma, 2012). In this study, we use the land cover information provided by Corine Land Cover project, from 1990 to 2018, and the NPs location in Europe to describe the rates of land cover change (anthropization and naturalization) experienced by these protected areas both inside and at distant surrounding areas. We also examine if the detected pattern is homogeneous across Europe in order to better known how the influence of protected areas varies geographically.

MATERIALS AND METHODS

Study area and collected land cover data

The study area has been established as the one encompassing all the European countries with available land cover data included within the Corine Land Cover (CLC) project (https://land.copernicus.eu/pan-european/corine-land-cover), coordinated by the European Environment Agency. These data are considered the longest, most accurate, comparable, and accessible source of information on land cover changes in Europe (Pérez-Hoyos et al., 2012). The CLC includes land cover status for 27 (CLC-1990) or 39 (CLC-2000, CLC-2006, CLC-2012 and CLC-2018)

European countries following a standard nomenclature that includes 44 land cover classes at a 100 m resolution. In our case, the used data correspond to 25 countries (Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Montenegro, Netherlands, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, and United Kingdom), which have data for all periods, covering a total area of 3,659,022.9 km^2. In all these countries, five temporal scenarios representing the status of land cover categories were considered: land cover data collected from 1986 to 1998 (CLC-1990), data collected from 1999 to 2001 (CLC-2000), data collected from 2005 to 2007 (CLC-2006), data collected from 2011 to 2012 (CLC-2012), and data collected from 2017 to 2018 (CLC-2018).

Land cover change data between the five consecutive land cover scenarios were used (CLC-1990/CLC-2000, CLC-2000/CLC-2006, CLC-2006/CLC-2012 and CLC-2012/CLC-2018) as available in https://land.copernicus.eu/pan-european/corine-land-cover. In addition, all level 1 land cover categories, excluding Wetlands and Water Bodies, were reclassified into two main types: anthropic (including artificial and agricultural areas) and natural (including forest and semi natural areas). Considering these reclassified land cover categories, we estimated the anthropized and naturalized area between the five consecutive land cover scenarios for all the existing NPs in the abovementioned European territory. NPs were selected because they are prime sites for monitoring climate and land use change impacts (Hansen et al., 2014), represent a wide variety of climate, habitat and land use gradients, and are an effective and similar protection figure across Europe.

In addition, for each national park we calculated the proportion of naturalized and anthropized area both within NPs and at three buffer distances: from the outer edge of each NP up to 1 km away from that edge, from 1 km to 5 km beyond the edge of the park, and from 5 km to 25 km from the park's edge. We analysed land cover changes at these three annular buffer distances to examine the influence of environmental protection on the territory and to estimate if this possible influence is distance dependent. Land cover changes at these annular buffer distances were calculated both including and excluding any other protected area inside them to differentiate the effects of NPs on the land cover dynamics of protected and non-protected areas.

Selection of protected areas.

Protected areas data was downloaded in February 2019 from the public version of the World Database on Protected Areas (WDPA), available in the web of Protected Planet (www.protectedplanet.net). WDPA is administered by the World Conservation Monitoring Centre of the United Nations Environment Program, in collaboration with the International Union for Conservation of Nature, and is compiled by using national and regional data (UNEP-WCMC and IUCN, 2016). NPs were divided according to their declaration date, before and after 1980. This threshold year was selected considering the temporal extent (from 1986 to 1998) of the first Corine Land Cover scenario (the so-called CLC-1990). Assuming that ten years is enough time to observe land use changes, this threshold year has been chosen to test whether the influence of protected areas on the territory can be detected independently of the date on which they were declared.

We found some countries with incomplete information in the WDPA database, such as Montenegro or Ireland. For this reason, both the location and the NPs boundaries have been revised and improved. To do so, we gathered specific information from web pages and also digitizing the boundary of the NPs when necessary. Subsequently, marine NPs and the marine portion of coastal NPs were excluded from our analysis by overlaying the NPs polygons with a terrestrial mask representing the boundaries of European countries obtained from Eurostat (https://ec.europa.eu/eurostat). In total, 298 NPs have been considered.

Data analysis

We used Generalized Linear/Nonlinear Models to model the change in the proportion of anthropized and naturalized area for each NP. Also, we used a Poisson-Gamma or Tweedie distribution for the response variable, which was related to the predictor variables via a logarithmic link function. Tweedie distribution is a special case of an exponential distribution which includes many zeroes (the so-called point mass), which allows one to manage a mixture of continuous non-negative data and zeroes when the response variable is zero inflated and exhibits overdispersion (Jørgensen and Kokonendji, 2016). We considered anthropization and naturalization as a process factor with two levels, while the changes between the five land cover periods are considered as a land cover scenario factor with four levels (CLC-1990/CLC-2000, CLC-2000/CLC-2006, CLC-2006/CLC-2012 and CLC-2012/CLC-2018). The year in which each NP was first declared was included in the model to discriminate those parks declared before and after 1980, around ten years before the first Corine Land Cover scenario. This declaration year factor with two levels (before 1980 and after 1980) aims to examine if the influence of NPs in the territory is time dependent and can be observed even when the park was declared before the estimation of land cover changes (i.e., whether land cover trends depend on the length of time elapsed since park declaration). Annular buffer distances were also included as buffer distance factor with three levels (1 km, 1-5 km, and 5-20 km). The logarithm of each NP area and their declaration year were used as covariates in some of the analyses to estimate the independent effect of the formerly mentioned factors. We ignored the statistical significance of the four main effects (process, land cover scenario, declaration year, and buffer distance) in the interpretation of the results when interactions between factors were statistically significant. We measured the statistical significance of the obtained regression coefficients with the Wald statistic (Ws) based on maximum likelihood estimates. We performed all these statistics using StatSoft's STATISTICA v 10.0 (StatSoft Inc., Tulsa, Oklahoma, USA).

RESULTS

Land cover changes within NPs

Taking into account the complete period with Corine Land Cover data (1990-2018), the process x declaration year interaction is statistically significant ($Ws = 13.99$; $p < 0.001$). Thus, anthropization percentages do not vary between protected areas before and after 1980 (0.04% vs. 0.06%), but naturalization percentages do (from 0.09% to 0.39%; Table 1). The residuals of this interaction are related against NP area and year of declaration, showing that anthropization, but mainly naturalization processes, do not seem to be homogeneously distributed across Europe (Fig. 1). Thus, a comparatively higher anthropization rate appears in the south, but mainly in eastern European NPs, while naturalization processes appear predominantly in Central and Northern European NPs.

In the NPs declared before 1980 the process x land cover scenario interaction is statistically significant ($Ws = 117.99$; $p < 0.0001$), so that anthropization proportions are higher than naturalization ones according to the 2000-2006 data, but naturalization processes are always higher during all the other scenarios (Table 1 and Fig. 2A). A protected area experienced a 0.8% of anthropization and a 1.2% of naturalization at most, although the land cover change averages never reached 0.1% of total area. However, in the NPs declared after 1980 the process x land cover scenario interaction is not statistically significant ($Ws = 1.84$; $p = 0.60$), but again naturalization is higher than anthropization proportions ($Ws = 71.56$; $p < 0.0001$), and the process of change is higher during the 1990-2000 scenario ($Ws = 28.57$; $p < 0.0001$) (Table 1 and Fig. 2B). For the 1990-2000 period, some NPs may experience almost a 3.8% of naturalization, although the mean value is 0.18% (Table 1).

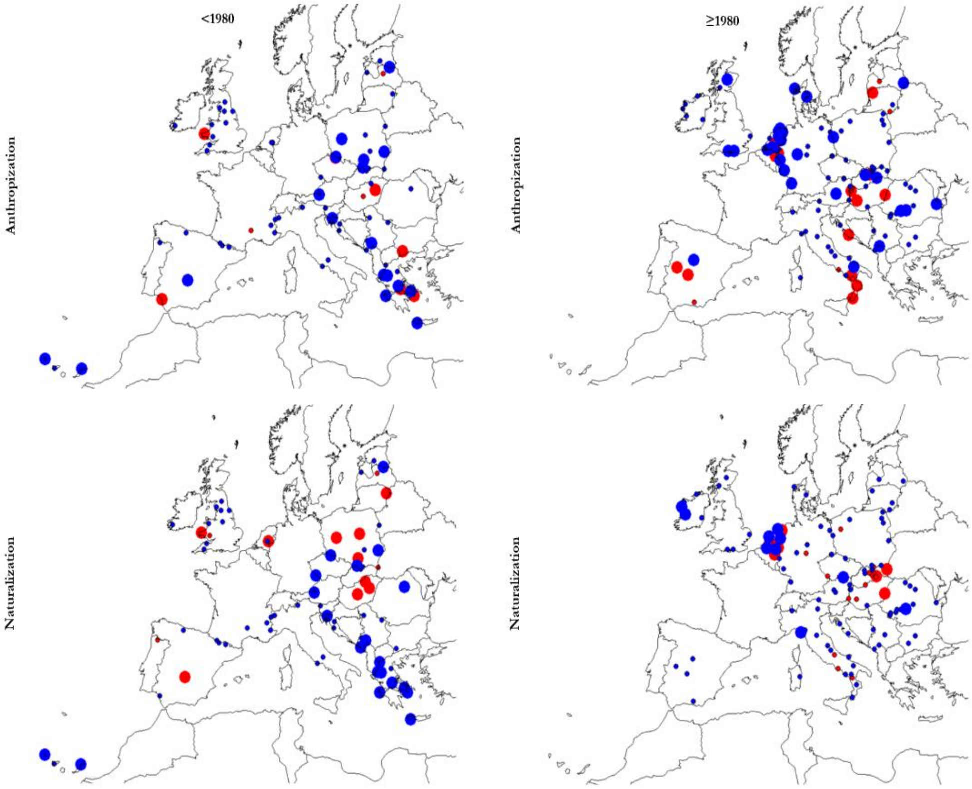


Figure 1. Geographical distribution of the GLZ model residuals between the percentages of anthropization and naturalization within National parks during the period 1990-2018 and each reserve area and their declaration year (predictors). The data corresponding to National parks declared as such before and after 1980 are shown in different maps. Residuals were divided in four equal intervals representing low and high negative residuals (small and big blue dots, respectively) and low and high positive residuals (small and big red dots, respectively). Big blue dots in anthropization maps represent National parks with a higher anthropization level than the average, while big red dots in naturalization maps represent National parks with naturalization level higher than average.

Table 1. Mean of hectares (± 95% confidence interval) anthropized and naturalized according to the four Corine Land Cover (CLCs) scenarios in the considered protected areas, declared as such before 1980 and after 1980 during the complete period (1990-2018). These data are also represented as percentages (%) over the complete area of each protected area.

			Before 1980			**After 1980**		
	CLCs	Process	Mean ± CI	Minimum	Maximum	Mean ± CI 95%	Minimum	Maximum
Has	2012-2018	naturalization	0.528±0.666	0.000	21.677	1.973±2.242	0.000	121.104
Has	2006-2012	naturalization	5.474±5.018	0.000	147.586	9.824±6.6	0.000	258.351
Has	2000-2006	naturalization	2.378±1.912	0.000	44.908	7.764±5.033	0.000	225.185
Has	1990-2000	naturalization	18.582±12.080	0.000	259.275	46.683±25.949	0.000	1.172.941
Has	2012-2018	anthropization	1.891±1.740	0.000	51.298	3.223±3.369	0.000	193.355
Has	2006-2012	anthropization	0.743±0.644	0.000	18.088	3.185±1.749	0.000	57.103
Has	2000-2006	anthropization	6.181±6.143	0.000	194.624	3.051±2.09	0.000	88.566
Has	1990-2000	anthropization	3.281±3.045	0.000	97.813	9.849±5.329	0.000	161.320
%	2012-2018	naturalization	0.010±0.020	0.000	0.720	0.034±0.044	0.000	2.283
%	2006-2012	naturalization	0.025±0.023	0.000	0.606	0.110±0.122	0.000	6.860
%	2000-2006	naturalization	0.009±0.012	0.000	0.411	0.065±0.058	0.000	2.507
%	1990-2000	naturalization	0.046±0.039	0.000	1.231	0.181±0.089	0.000	3.817
%	2012-2018	anthropization	0.003±0.003	0.000	0.095	0.007±0.006	0.000	0.260
%	2006-2012	anthropization	0.003±0.005	0.000	0.189	0.010±0.011	0.000	0.667
%	2000-2006	anthropization	0.022±0.027	0.000	0.843	0.010±0.009	0.000	0.492
%	1990-2000	anthropization	0.008±0.010	0.000	0.327	0.030±0.019	0.000	0.841
Has	1990-2018	naturalization	26.962±14.627	0.000	290.867	66.244±29.058	0.000	1.224.364
Has	1990-2018	anthropization	12.096±7.307	0.000	194.624	19.308±8.303	0.000	220.881
%	1990-2018	naturalization	0.091±0.057	0.000	1.326	0.391±0.186	0.000	7.474
%	1990-2018	anthropization	0.037±0.030	0.000	0.843	0.057±0.034	0.000	1.744

Land cover changes in increasing surrounding areas

The process x buffer distance interaction is statistically significant when the proportion of total land cover change in the 1990-2018 period is used as dependent variable (Ws = 12.94; p = 0.001). Thus, both anthropization and naturalization processes are higher and similar in each NP boundary annular buffer from 1 km to 5 km, while at the nearest and farthest distances naturalization is higher than anthropization (Fig. 3A). The area of the NPs (Ws = 19.87; p < 0.0001; 0.5% of total deviance) and mainly the year of declaration (Ws = 92.08; p < 0.0001; 3.5% of total deviance) seem to influence the proportion of land cover change (parameter estimates = -0.148 and 0.343, respectively). The most recently declared NPs would experience a higher proportion of naturalization and anthropization processes, although it seems that older and smaller NPs would also have experienced important naturalization rates (Fig. 4). When the area declared as protected in each land cover scenario is subtracted from the area of each annular buffer, the process x buffer distance interaction cannot be considered statistically significant (Ws = 5.30; p = 0.07). Naturalization dominates over anthropization processes in the annular buffers of 1 km and 1-5 km, but the extent of these two processes seems to be similar at the farthest considered buffer distance (Fig. 3B).

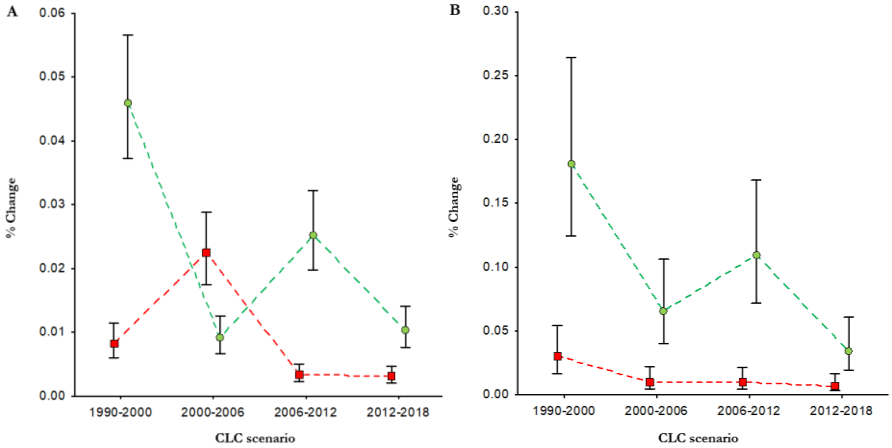


Figure 2. Adjusted means (± 95% CI) in the naturalization (green dots) and anthropization (red squares) percentage within National parks for each one of the four considered CLC scenarios after controlling for the effects of the area size and the declaration year of National parks established before 1980 (A) and after 1980 (B).

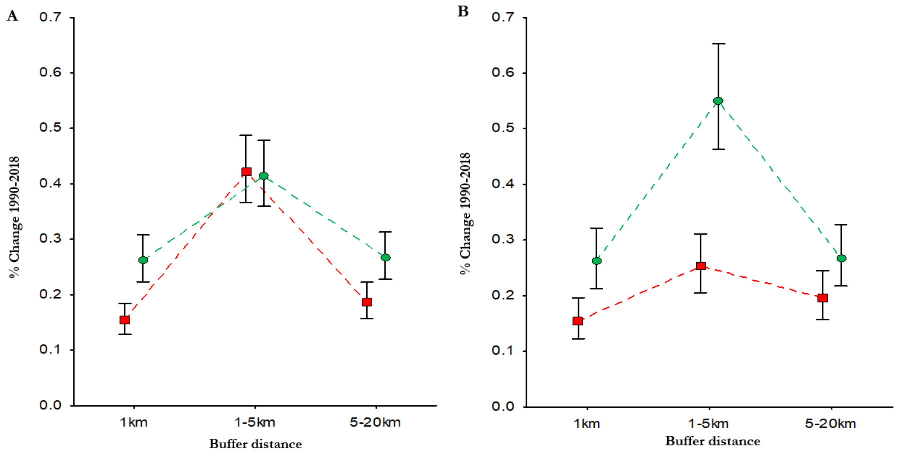


Figure 3. Adjusted means (± 95% CI) in the percentage of naturalization (green dots) and anthropization (red squares) during the 1990-2018 period for each one of the three considered annular buffers around each protected area, and after controlling for the effects of the area size and the declaration year of National parks. Total values (A) and figures when the area declared as protected in each CLC scenario is subtracted from the area of each annular buffer (B).

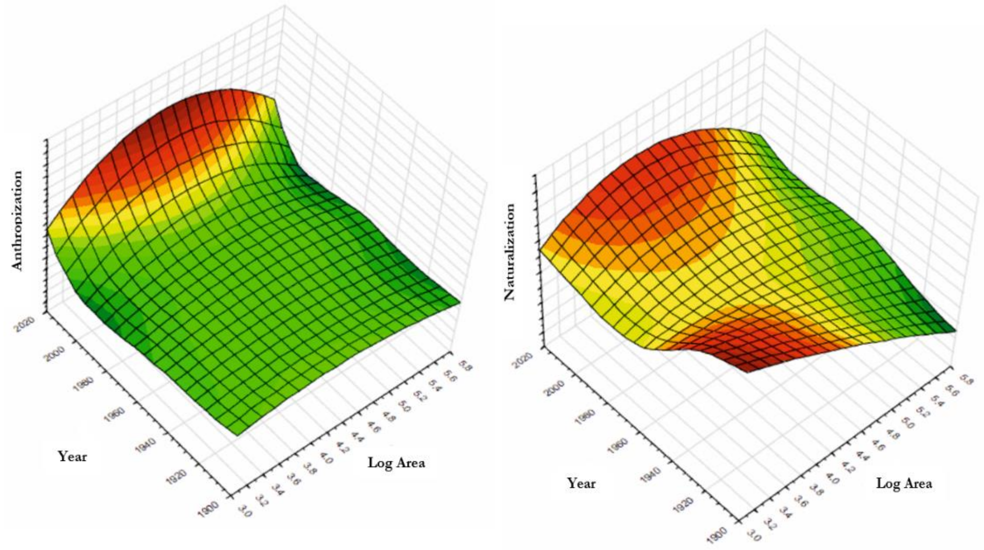


Figure 4. Third dimension surface plot (spline fit; 0.3 stiffness) representing the variation in the complete naturalization and anthropization change during the period 1990-2018 according to their area size and year they were first declared National parks.

In the NPs declared before 1980 the process x buffer distance interaction is statistically significant (Ws = 10.82; p = 0.004) because anthropization rates are lower in the annular buffer nearest to the NPs (Fig. 5A). This pattern remains similar when the area declared as protected is subtracted from the area of each annular buffer (Fig. 5B). In the NPs declared after 1980, the process x buffer distance interaction is also statistically significant (Ws = 16.24; p = 0.0003), but in this case the naturalization promoting effect is observed at all distances in the unprotected areas, but mainly at the 1-5 km annular buffer (Fig. 5C and D). Again, the residuals of these land cover changes against the two considered predictors (area and year of declaration of NPs) indicate that anthropization and naturalization processes are not homogeneously distributed across Europe. Anthropization seems to be comparatively higher in southern regions, while naturalization is higher in Central Europe (Fig. 6).

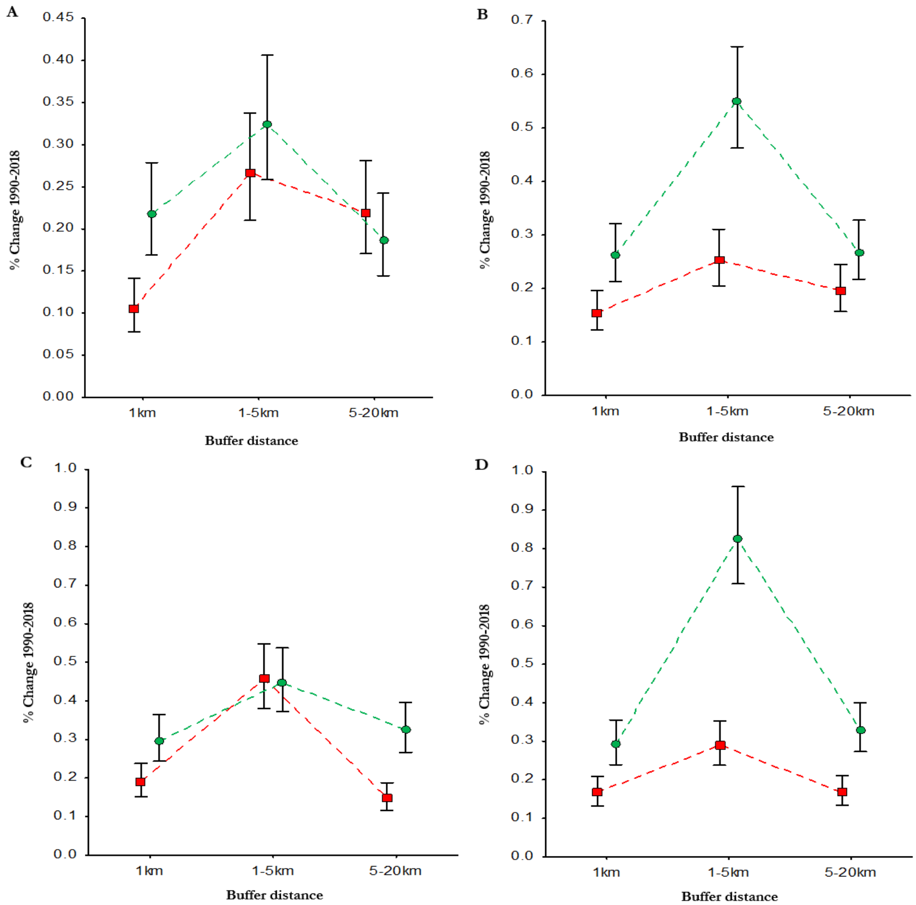


Figure 5. Adjusted means (± 95% CI) in the percentage of naturalization (green dots) and anthropization (red squares) for each one of the three considered annular buffers around each protected area, and after controlling for the effects of the area size and the declaration year of National parks. Charts A and C represent complete buffer values, while B and D, which charts the area declared as protected in each CLC scenario, is subtracted from the area of each annular buffer. National parks established before 1980 (A and B) and after 1980 (C and D) are differentiated.

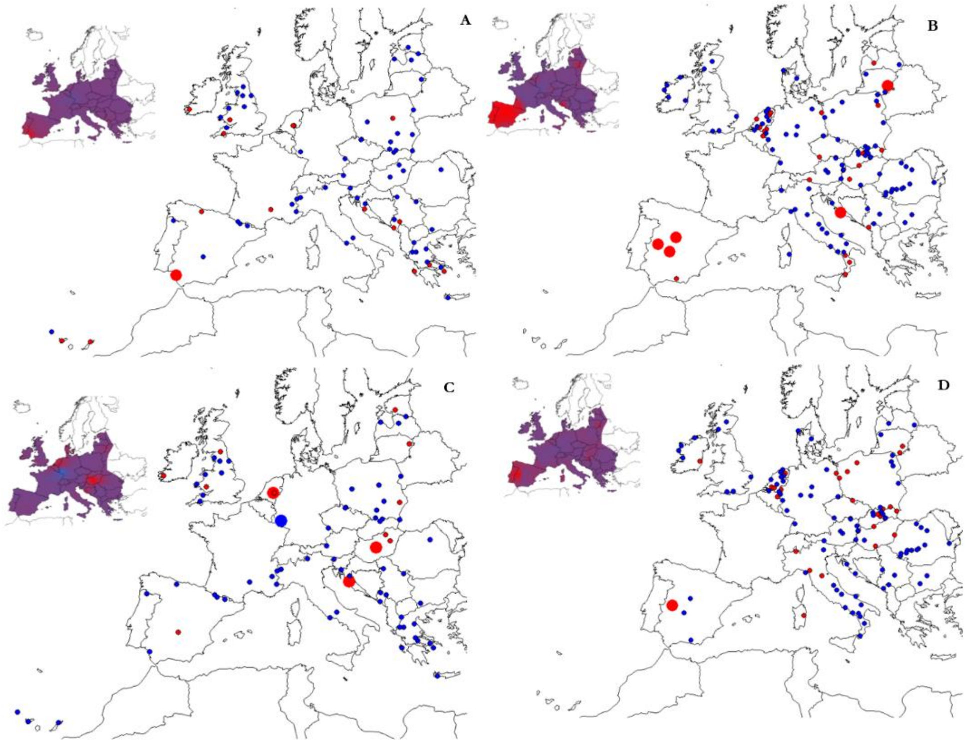


Figure 6. Geographic distribution of the GLZ model residuals regressing the percentages of naturalization and anthropization in the annular buffer from 1 km to 5 km of each national park boundary against their area and year of declaration. Anthropization before 1980 (A), anthropization after 1980 (B), naturalization before 1980 (C) and naturalization after 1980 (D). Land cover change values are calculated only considering unprotected areas within the annular buffer. The data corresponding to national parks declared as such before and after 1980 are shown in different maps. Residuals were divided into four equal intervals representing low and high negative residuals (small and big blue dots, respectively) and low and high positive residuals (small and big red dots, respectively). Big blue dots in anthropization maps represent national parks with a higher anthropization level than the average, while big red dots in naturalization maps represent national parks with naturalization levels higher than average. Interpolated maps using a distance-weighted average (2.0 exponent) are included to better visualize the pattern's geographical structure.

DISCUSSION

The percentage of protected land subjected to the naturalization process is, in general, higher than the area that has suffered anthropization when these changes are measured inside recently declared protected areas. Also, this naturalization processes dominance in recently declared protected areas is independent of the considered land cover scenario, although it hardly involves a change in more than 1% of the total area of a reserve. As frequently documented (Blanco et al., 2020), our results indicate that the declaration of a protected area is basically a process able to facilitate the increase of its natural condition within a few years (Jiang and Yu 2019). This is an encouraging result supporting the establishment of natural reserves as a key resource for nature conservation despite their limitations (Maxwell et al., 2020).

According to our results, establishing protected areas exerts a beneficial effect on their surrounding environment, which is in agreement with other studies (Rodríguez-Rodríguez and Martínez-Vega, 2018b; Jiang and Yu, 2019). Reserves could favour naturalization processes in their neighbouring regions (up to 5 km in our case), even when only unprotected close areas are considered. However, this effect would depend on the distance. Unprotected areas located between 5 km to 20 km from the boundary of protected areas could experience similar naturalization and anthropization rates, which could result in a progressive disappearance of the reserve's protective effect. Interestingly, this pattern differs according to the longevity in which protected areas act as such. The naturalization effect is only visible at the nearest buffer distance considered (≈1 km) in those reserves that have been protected for the longest time. However, in the most recent protected areas this naturalization effect is evident at all the considered distances, but mainly in the unprotected areas located within the 1-5 km annular buffer.

Not all of our results show a positive effect of protected areas. According to our results, the role played by protected areas appears as spatially heterogeneous; anthropization within protected areas seems to be comparatively higher in Southern and Eastern Europe, while naturalization would be higher in Central and Northern Europe. Furthermore, the favourable effects of protected areas in its surrounding areas also shows a spatial structure; in the annular buffer from 1 km to 5 km of each protected area boundary, anthropization is comparatively higher in Southern European regions (mainly Spain) but naturalization is comparatively higher in Central Europe. These results are in line with the recent findings of Concepción (2021), showing that Spain has been, during the period 2006-2015, one of the European countries with the highest rate of urban growth in Nature 2000. Protected areas can promote land use changes in their adjacent areas (Guerra et al., 2019) by acting as attractor nodes that increase the above-ground biomass (de la Fuente et al., 2020a), the expansion of built-up areas (de la Fuente et al., 2020b) and habitat fragmentation (Lawrence et al., 2021) in its surroundings. As our result suggest, this seems to have been the case in some Southern European countries. Although a high population density and an ancient agricultural and industrial tradition characterize European land uses (Kaplan et al., 2009; Gingrich et al., 2015), different historical, socioeconomic, political and cultural reasons may explain the observed north-south and east-west geographical patterns (Salvati et al., 2018). The conversion of natural land into urban areas and the increase of low-density and spatially-discontinuous settlements have been an important phenomenon in Mediterranean countries, especially in Spain where some regions experienced in more than 11% of their area land use changes (Hewitt and Escobar, 2011).

The notable spatial differences detected in this work should serve as a warning to policymakers that planning at the regional and local level is critical for effective management (Young et al., 2005), and managers need to involve and benefit local communities (Bruner et al., 2001; Hansen and DeFries, 2007). Ultimately, we suggest it would be useful to identify zones of interaction around all national parks (DeFries et al., 2010) in which additional conservation efforts should focus on the on getting neighbouring landowners to actively participate (Mathevet et al., 2016), with clear participation plans (Reed, 2008). It is critical to understand that beyond the limits of protected areas, conservation efforts able to promote management practices under local knowledge (Palomo et al., 2014b), without leaving out cultural issues and public policies are necessary, thus contributing to the sustainable development of research strategies with the involvement of the local community. Further studies are needed to decipher the underlying reasons for these regional discrepancies, but also to understand which variables are most able to explain anthropization or naturalisation processes around protected areas (Ewers and Rodrigues, 2008).

In this study we describe the influence of European national parks on the changes in land uses experienced around them. Although the exigent conservation figure representing national parks acts as a protective regional shield against the impact of anthropization processes, this positive effect is not homogeneous across Europe. The historical, legislative, and socioeconomic peculiarities of the different European countries could be influencing the beneficial effect of protected areas. The success of the European network of protected areas in safeguarding nature against human alterations may depend on unifying criteria to prevent land use changes around them.

DISCUSIÓN GENERAL

Las áreas protegidas se han presentado como una herramienta indispensable para la conservación de la biodiversidad (Watson et al., 2014) y como una parte fundamental de la adaptación al cambio climático (Thomas y Gillingham, 2015; Haight y Hammill, 2019). Sin embargo, las áreas protegidas se ven seriamente afectadas por este cambio climático (Virkkala et al., 2019; Mingarro y Lobo, 2021) y por los cambios de uso del suelo (Hansen et al., 2014). Por lo que, debemos ser inteligentes, aprender y proponer nuevas soluciones para que su eficacia sea mejor. Es necesario darse cuenta que la adaptación dentro de las áreas protegidas puede no resultar una buena estrategia conservacionista (Peters y Darling, 1985; Hoffmann et al., 2019) y cabe señalar que las áreas protegidas que se establecieron para conservar determinados recursos, condiciones o cualidades particulares, generalmente se crearon sin tener en cuenta el cambio climático (Pressey et al., 2007). Por lo que, con las tasas de cambio climático que estamos experimentando (IPCC, 2021), muchas áreas protegidas acabarán albergando hábitats y conjuntos de especies muy diferentes a los existentes cuando fueron diseñadas (Jones et al., 2016). Esto nos indica que es esencial considerar como el cambio climático, sus impactos ecológicos y los diferentes usos del suelo afectan en la efectividad de las áreas protegidas.

A lo largo de este trabajo se ha tratado de ofrecer una perspectiva con el único fin de convertir a la red de áreas protegidas en auténticas fortalezas que limiten los efectos adversos del cambio climático sobre la biodiversidad. Bajo la premisa de que el nicho fundamental de las especies está, directa o indirectamente, determinado por las variables climáticas, se podría suponer que muchas poblaciones y especies que ahora habitan en las áreas protegidas tenderán a dispersarse hacia aquellas zonas en las que aparezcan las condiciones de dichas áreas protegidas en el futuro (Hole et al., 2009; Mingarro y Lobo, 2018). Este enfoque intenta considerar las características abióticas y los efectos esperados de los cambios climáticos en la alteración del perfil ambiental original bajo el que se establecieron las áreas protegidas en cuestión. De esta manera, ha sido posible estimar el grado de variación de las condiciones distintivas de un área protegida, buscando aquellos territorios cercanos capaces de representar dichas condiciones en un futuro próximo. A diferencia de otros trabajos, que priorizan y seleccionan posibles redes de reservas considerando diversos escenarios de cambio climático a través del desarrollo de modelos de distribución de especies capaces de anticipar la respuesta geográfica de cada especie a los cambios climáticos (Triviño et al., 2013; Jones et al., 2016; Reside, Butt, y Adams 2018), este trabajo evita estas simulaciones ya que pueden producir resultados engañosos sobre los efectos del cambio climático, debido a nuestra falta de información sobre los factores complejos reales capaces de explicar la abundancia y distribución de las especies (Lobo, 2016). Cada especie puede experimentar (1) una disminución o incluso la desaparición de individuos y poblaciones (Bestion et al., 2015); (2) una adaptación *in situ* a las nuevas condiciones mediante mecanismos microevolutivos o plasticidad fenotípica (Hoffmann y Sgrò, 2011); o (3) la dispersión de individuos hacia nuevos territorios adecuados (Mason et al., 2015). Por lo tanto, es difícil, si no imposible, comprender cómo afectará el cambio climático a la abundancia y distribución futura de cada una de las especies que habitan un área protegida. Además de lo señalado anteriormente, múltiples estudios indican que, junto con el cambio climático (Dale, 1997; Michalak et al., 2018), el cambio en los usos del suelo es uno de los principales factores que influyen en la extinción de poblaciones y especies (Vitousek et al., 1997; Fischer, 2007; Laliberte et al., 2010). Esto ocurre principalmente como consecuencia del drástico aumento y extensión de las tierras agrícolas y los asentamientos humanos (Maxwell et al., 2016). Las respuestas de los organismos a los cambios en el uso del suelo pueden variar mucho y depender de su capacidad de dispersión (Newbold et al., 2020), pero indudablemente, estos cambios tienen un efecto negativo en la capacidad de dispersión de los organismos (Di Marco et al., 2018). Si a esto unimos el efecto deletéreo de la contaminación química sobre todo tipo de ecosistemas (Naidu et al., 2021), resulta evidente que la capacidad de ajuste de las especies en respuesta al cambio global disminuye a medida que aumenta la acción antrópica sobre los sistemas ecológicos (Williams y Newbold, 2020).

A lo largo de esta tesis se ha intentado superar nuestro desconocimiento específico sobre los efectos del cambio climático en las especies, utilizando un enfoque basado en las características de los espacios y no en la probable respuesta de las especies y atendiendo, además, tanto a los efectos del cambio climático como a las posibles trayectorias futuras de los usos del suelo. Este punto de vista está en consonancia con aquellas estrategias que consideran que mejorar la representación de la variabilidad climática puede actuar como sustituto para representar la biodiversidad (Sarkar et al., 2005; Hortal et al., 2009), siendo necesario enfatizar aquellas aproximaciones basadas en la previsión de los cambios climáticos en los espacios y no en las especies (Loarie et al., 2009; Scriven et al., 2015; Littlefield et al., 2017). Sin embargo, la identificación de territorios para la conservación sin tener en cuenta los futuros y posibles cambios en la cobertura del suelo puede dar lugar a la selección de áreas ineficientes (Faleiro et al., 2013; Jones et al., 2016). Por todo ello, es necesario combinar simulaciones climáticas con simulaciones de cambios espaciales en la cobertura del uso del suelo (Robillard et al., 2015), para así generar estimaciones más fiables sobre las regiones que, con mayor probabilidad, pueden actuar como áreas receptoras de las condiciones de cada área protegida en el futuro (Mingarro et al., 2020), independientemente de cuales sean las respuestas de las especies.

La red de parques nacionales es una muestra bastante representativa del resto de áreas protegidas albergadas en la península ibérica y, mediante la metodología desarrollada a lo largo de los trabajos de esta tesis, ha sido posible demostrar la seria amenaza a la que se enfrentan los espacios protegidos y como el cambio climático modificará las condiciones ambientales que promulgaron su declaración. Además, ha sido posible observar y cuantificar la drástica reducción de la superficie representativa de las condiciones climáticas de estas áreas protegidas, llegando a desaparecer en algunos casos dentro de sus límites. También ha sido posible identificar los lugares o regiones más importantes para mantener la representatividad climática de dichos espacios protegidos en el futuro, las denominadas "áreas receptoras". Estas regiones están situadas principalmente en los grandes sistemas montañosos de la península ibérica, principalmente en a lo largo del Sistema Ibérico, la Cordillera Cantábrica y Sistema Central pero también en Sierra Nevada y en sus proximidades. Desgraciadamente, algunas de estas regiones no poseen la severa restricción de los usos antrópicos y, en consecuencia, actualmente no son adecuadas para la conservación de la biodiversidad. No obstante, existen algunos lugares que nuestros resultados sugieren ser muy propicios para actuar como áreas receptoras y aún no están protegidos. Hay que tener en consideración que, a pesar de que existan lugares donde las condiciones naturales no sean adecuadas para la conservación, la declaración de un área protegida es un proceso capaz de facilitar el aumento de su condición natural en pocos años (Jiang y Yu, 2019; Blanco et al., 2020). Por lo que el establecimiento de áreas protegidas es un recurso clave para la conservación de la naturaleza a pesar de sus limitaciones (Maxwell et al., 2020). La identificación de estas áreas receptoras ha permitido localizar los lugares clave que deberían a cumplir un papel muy relevante en la conservación de la biodiversidad ante el cambio climático, por lo que hay que ser ambiciosos con la declaración de figuras de protección adecuadas en estos lugares.

Por supuesto, una vez identificados estos espacios, es necesario facilitar los flujos de especies hacia ellos (Mingarro y Lobo, 2021) evitando el aislamiento de las especies. En consecuencia, es necesario anticiparse a posibles alteraciones para evitar el aislamiento funcional de las áreas protegidas, proveyendo una cantidad de hábitats adecuados y lo suficientemente concentrados y conectados para que actúen como trampolines a través de paisajes fragmentados, permitiendo así que las especies colonicen nuevas áreas protegidas tan rápido como las poblaciones existentes desaparecen en sus espacios nativos. El establecimiento de una red de corredores podría facilitar el desplazamiento de las especies en estos escenarios cambiantes (Haddad et al., 2015), pero la efectividad de dicha red estará condicionada por la capacidad de dispersión de las especies, frecuentemente reducida en alta montaña.

El aumento de la conectividad entre las áreas con una alta biodiversidad se considera uno de los enfoques de conservación de la biodiversidad más importantes para hacer frente al cambio climático (Heller y Zavaleta, 2009). En este contexto, el beneficio de conectar las áreas protegidas actuales y sus futuras regiones receptoras puede ser muy positivo para proteger la biodiversidad que estos espacios albergan (Gilbert-Norton et al., 2010). Sólo así será posible que la red de corredores permita a las especies rastrear sus condiciones climáticas adecuadas, especialmente en paisajes con un fuerte dominio antrópico, como los que aparecen en el territorio ibérico. Además, es importante destacar que la península ibérica es mayoritariamente montañosa y que esta característica es decisiva para mitigar los efectos del cambio climático sobre la pérdida de biodiversidad (Littlefield et al., 2019), de forma comparable a lo observado en el Pleistoceno (Schmitt, 2007). En este caso, los sistemas montañosos pueden brindar a las especies oportunidades para que cambien sus distribuciones y patrones de abundancia a ubicaciones más adecuadas y próximas en el espacio (Levinsky et al., 2007). Por lo que, es interesante hacer la reflexión de que, si las áreas protegidas en zonas montañosas pueden facilitar condiciones más frías en las elevaciones más altas, las especies no tendrían que desplazarse fuera de los límites. Sin embargo, la eficacia de las áreas protegidas no viene determinada por el rango altitudinal que poseen, de igual manera que, la diversidad topográfica de las áreas protegidas tampoco garantiza la supervivencia de las especies (Thomas y Gillingham, 2015). De esta manera, generar una red de espacios protegidos capaces de conectar los grandes sistemas montañosos, donde aparecen la mayoría de las áreas receptoras, es probablemente la estrategia de conservación más ambiciosa que puede llevarse a cabo en la península ibérica (Saura et al., 2018; WWF, 2018; Mingarro y Lobo, 2021).

A lo largo de esta tesis se ha demostrado la necesidad de adoptar medidas proactivas, capaces de mejorar la capacidad de las áreas protegidas para proteger la biodiversidad, incluyendo esfuerzos para el desarrollo de los corredores climáticos. Además, para alcanzar un desarrollo exitoso de la red de corredores propuesta, es necesario identificar los lugares donde la conectividad está amenazada debido a que los usos actuales del suelo obstaculizan gravemente la red de corredores. Por todo ello, resulta imprescindible llevar a cabo acciones de planificación que limiten el incremento, y promuevan la reducción, de aquellas áreas antrópicas que actúan como barreras, ya que se presentan un grave riesgo con importantes consecuencias negativas. En definitiva, si verdaderamente se quiere crear una red de espacios, capaz de mitigar los efectos del cambio climático y capaz de salvaguardar la biodiversidad de las áreas protegidas, es necesario hacer un esfuerzo para restaurar los lugares que pueden facilitar dicha conectividad. En este punto, la implicación de las autoridades públicas, los gestores y los responsables políticos será esencial para poder desarrollar las diferentes estrategias mencionadas a lo largo de este trabajo. Los resultados obtenidos ponen de manifiesto que con este trabajo se ha dado un paso importante en las estrategias de conservación de la península ibérica, y especialmente de las áreas protegidas, demostrando que la conectividad es una medida eficaz para hacer frente a la fuerte amenaza del cambio climático a la que se enfrenta esta región.

Aunque las principales conclusiones aportadas por este estudio pueden permanecer inalteradas, existen algunas consideraciones metodológicas capaces de alterar los resultados obtenidos. A lo largo de este trabajo se han utilizado las proyecciones climáticas futuras generadas durante el quinto informe (AR5) del IPCC del 2014 (IPCC, 2014), correspondientes a dos escenarios muy diferentes. Sin embargo, recientemente, en el sexto informe (AR6) del IPCC (IPCC, 2021), se han generado nuevas proyecciones y escenarios, conocidos como Shared Socio-economic Pathways (SSP). Así, aunque la localización de las áreas climáticamente adecuadas podría verse parcialmente modificada por los diferentes escenarios utilizados, debido a las incertidumbres asociadas a los modelos climáticos (Eyring et al., 2019) y al carácter interpolado de los datos (Kundzewicz et al., 2018), el patrón general puede extraerse con gran certeza del procedimiento presentado en este trabajo. Además de las propias incertidumbres de los datos utilizados (Suggitt et al., 2017), nuestros resultados están también condicionados por las decisiones establecidas al modelizar el cambio en la cobertura del suelo como pueden ser los factores de localización utilizados (Vaz et al., 2012), así como la aparición de factores de perturbación natural como pueden ser los incendios. Por lo tanto, un estudio más exhaustivo que utilice factores de localización y ponderaciones adicionales, más sólidamente consensuados mediante un proceso participativo que incluya a diferentes expertos, o incluso que considere otros métodos diferentes de evaluación multicriterio, sería útil para examinar la consistencia de los resultados antes de su uso en la planificación de la conservación.

Como se ha mostrado, para crear una red de áreas protegidas eficaz contra las amenazas es necesario que esa red se desarrolle espacio por espacio, atendiendo a las dinámicas climáticas concretas de cada espacio protegido e identificando los verdaderos impulsores de cambio en los usos del suelo en esa región en particular. De este modo, para mejorar este enfoque, se podría realizar un análisis centrado en la conectividad, atendiendo a las posibles barreras que pudieran surgir en el futuro y proponiendo diferentes escenarios de conectividad específicos para cada área protegida. Por ello, la utilización de simulaciones a futuro del uso del suelo y la posterior conexión de los espacios protegidos y sus áreas receptoras mediante "caminos" en donde predominen los usos del suelo naturales y seminaturales podría convertirse en una metodología ideal para delimitar dónde podrían ubicarse los corredores climáticos. Sin embargo, los medios requeridos para realizar estas simulaciones en cada espacio protegido excedían claramente las capacidades de este trabajo y, por ello, solo han podido ser realizadas en el Parque Nacional de Guadarrama. Además, nuestro análisis proporciona una visión general, a nivel mesoclimático, pero la realización de análisis específicos para cada área protegida en particular a una mayor resolución, a nivel microclimático, permitiría detectar áreas receptoras con mayor detalle. Con esto, sería posible localizar refugios climáticos dentro de los parques nacionales donde poder tomar medidas de conservación como pueden ser la limitación de acceso o el establecimiento de una zona núcleo entre muchas otras.

También hay que destacar que el procedimiento propuesto pretende estimar las localidades con condiciones climáticas y de hábitat similares a las existentes en un área protegida, asumiendo que los valores de conservación y biodiversidad de este territorio están ligados a sus condiciones ambientales. Sin embargo, la búsqueda de estas localidades no garantiza la conservación de la biodiversidad ya que la existencia de otros factores como las interacciones bióticas, los limitantes de dispersión u otros factores contingentes podrían ser muy relevantes a la hora de condicionar la distribución y abundancia de los organismos. En este trabajo, sólo se ha propuesto un procedimiento para delimitar posibles regiones futuras para los organismos que habitan un área protegida, asumiendo que los factores ambientales actualmente presentes en esta área son probablemente fundamentales para la persistencia de las especies que la habitan. Asimismo, cabe destacar que no toda la biodiversidad vive en áreas protegidas y han sido muchos los trabajos que han señalado que regiones sin un estatus de protección albergan buena parte de la biodiversidad (Araujo et al., 2007). Por lo tanto, debido a los problemas existentes para estimar la distribución actual y futura de las especies, uno de los primeros pasos para desarrollar estrategias de conservación de la biodiversidad eficaces seria proteger las áreas receptoras identificadas en nuestra propuesta. Pero como se ha discutido, es necesaria la creación de una red de corredores capaces de facilitar el flujo de especies entre los parques nacionales y dichas áreas receptoras, brindando a los espacios protegidos una fortaleza frente a los efectos del cambio climático. De igual manera, sería útil identificar zonas de interacción en torno a todos los parques nacionales (DeFries et al., 2010) en las que los esfuerzos de conservación adicionales deberían centrarse en conseguir la participación activa de los propietarios de terrenos vecinos (Mathevet et al., 2016), con planes de participación claros que deberían estar incluidos en las políticas correspondientes (Reed, 2008). Hay que señalar que este trabajo se ajusta a la Estrategia de Biodiversidad de la UE para 2030, un ambicioso plan a largo plazo para proteger la naturaleza y detener la degradación de los ecosistemas, plan que hace hincapié en la necesidad de intensificar la protección y restauración de la naturaleza. Este propósito deberá llevarse a cabo mejorando y ampliando la red de áreas protegidas, desarrollando un Plan de Restauración de la Naturaleza que integre los corredores ecológicos como parte de una verdadera Red Transeuropea de la Naturaleza.

A medida que el patrimonio de áreas protegidas continúa expandiéndose y las amenazas a la biodiversidad siguen multiplicándose, los recursos necesarios para administrar y proteger estas áreas de manera efectiva también están aumentando. Aun así, se ha reconocido que las áreas protegidas carecen de recursos (Mansourian y Dudley, 2008; Lindsey et al., 2018). Esto se debe, en parte, a que no existe una comprensión completa de los múltiples beneficios que aportan (Balmford et al., 2002) y la realidad es que el establecimiento de áreas protegidas ejerce un efecto beneficioso sobre su entorno (Rodríguez-Rodríguez y Martínez-Vega, 2018a; Jiang y Yu, 2019), tal y como hemos mostrado en este trabajo. Sin embargo, hay que señalar que la declaración de los espacios protegidos puede tener efectos indirectos sobre la conservación y simplemente derivar las amenazas que tratan de frenar a otros lugares aledaños. A lo largo de este trabajo ha podido apreciarse que, en concordancia con lo hallado en otros trabajos (Ewers y Rodrigues, 2008; Visconti et al., 2010), las áreas protegidas reducen las amenazas antrópicas dentro de sus límites, pero que a menudo desplazan y/o atraen una parte de estas amenazas hacia áreas adyacentes. Este efecto atractor es difícilmente achacable a una causa. Se trata de un proceso interrelacionado con la localización geográfica del área protegida en cuestión, de las políticas, del numero de áreas protegidas próximas que existen, del contexto socioeconómico de la región, en definitiva, de la historia de la propia área protegida. Es importante enfatizar que no existen dos áreas protegidas con el mismo contexto y el análisis de los procesos tales como el efecto atractor de actividades antrópicas o el efecto de fugas suelen ser difíciles de generalizar. Es ahí donde radica la importancia de los análisis regionales y locales. El cuarto capitulo de este trabajo ha presentado las diferencias existentes entre diferentes regiones, próximas en el espacio y con políticas ambientales similares. Esto nos ha permitido generar un planteamiento que muestra un camino en las estrategias conservacionistas de las áreas protegidas. Es necesario comprender las verdaderas amenazas de las áreas protegidas a diferentes escalas, comenzando a nivel local o regional, para posteriormente poder integrar las estrategias regionales y obtener estrategias globales. Las amenazas no son homogéneas espacialmente y sus dinámicas suelen tener un patrón regional. Estas notables diferencias espaciales detectadas deberían servir de advertencia, para los responsables políticos y científicos, de que la planificación y el análisis a nivel regional y local es fundamental para una gestión eficaz (Young et al., 2005). Por lo que es importante señalar la necesidad de realizar primeramente análisis regionales para, posteriormente, generar buenos análisis globales.

El carácter regional de las estrategias conservacionistas pone en relevancia el papel de los gestores de estas áreas protegidas. En consecuencia, es imprescindible que los gestores i) impliquen y beneficien a las comunidades locales (Bruner et al., 2001; Hansen y DeFries, 2007); ii) entiendan que más allá de los límites de las áreas protegidas son necesarios esfuerzos de conservación capaces de promover prácticas de manejo bajo el conocimiento local (Palomo et al., 2014b), haciendo especial énfasis en la necesidad del carácter conservacionista para que esas prácticas puedan seguir desarrollándose en el futuro y; iii) se desarrollen medidas señaladas por la comunidad científica con la participación de la comunidad local, contribuyendo así al desarrollo sostenible de estrategias de investigación. Finalmente, no queda más que insistir en que la biodiversidad brinda una serie de servicios bien conocidos e indispensables para el correcto desarrollo de la sociedad. Probablemente, la pérdida de esos servicios repercuta primero, y con mayor intensidad, en los pobres dado que ellos suelen depender del entorno inmediato de una manera más directa. A pesar de todo, más temprano que tarde, los efectos se harán sentir en todas las sociedades, por lo que las medidas de conservación son necesarias para evitar esta creciente pérdida de biodiversidad y la consecuente pérdida de servicios indispensables para los humanos.

CONCLUSIONES GENERALES

1. Los parques nacionales ibéricos se encuentran expuestos a una seria amenaza como consecuencia del cambio climático. La mayoría de estas áreas protegidas van a perder las condiciones climáticas que actualmente albergan, afectando directamente a la biodiversidad que intentan proteger.

2. La identificación de las áreas receptoras, o áreas donde se desplazarán las condiciones climáticas de cada parque nacional, se presenta como una herramienta sólida y eficaz, capaz de facilitar la supervivencia de las especies que albergan estos espacios protegidos.

3. Este trabajo ha permitido situar las áreas receptoras de todos los parques nacionales ibéricos, permitiendo observar que muchas de estas áreas son compartidas por varios parques nacionales. Estas áreas deberían convertirse en enclaves transcendentes para la conservación de la biodiversidad ibérica.

4. La inclusión de las dinámicas en los usos del suelo ha fortalecido la metodología propuesta para localizar las áreas receptoras, permitiendo distinguir entre áreas receptoras con un uso del suelo natural y otras con un uso actual incompatible con la conservación de sus condiciones naturales.

5. La generación de una red de corredores capaz de conectar los parques nacionales con sus áreas receptoras a través de los lugares climáticamente similares que, además, tienen un uso del suelo natural, proporcionaría una herramienta útil para

mitigar los efectos del cambio climático, facilitando que las especies puedan seguir sus condiciones ambientales.

6. Los grandes valles se presentan como barreras infranqueables a la conexión espacial entre los parques nacionales y sus áreas receptoras. Es conveniente focalizar esfuerzos de conservación en estas regiones, permitiendo que las especies puedan desplazarse entre los distintos sistemas montañosos.

7. Debido a que la generación de una red nacional de corredores como la que ha sido presentada en este trabajo pueda ser inviable con los esfuerzos de conservación actuales, la conexión del Sistema Central y del Sistema Bético con el Sistema Ibérico podría ser una solución muy eficiente.

8. Este trabajo ha sido elaborado con unos datos, escenarios y simulaciones donde las diferentes decisiones unidas a las propias idiosincrasias de los modelos climáticos podrían modificar algunos resultados. Sin embargo, a grandes rasgos, los lugares prioritarios para proteger a los parques nacionales del cambio climático se mantendrán inalterados.

9. Una parte muy importante, a diferente escala, ha sido la realización del último capítulo. Ha sido posible demostrar la gran diferencia espacio-temporal de cambios de uso del suelo que sufren los parques nacionales a lo largo de Europa. Estos resultados ponen de manifiesto la necesidad de abordar esta metodología de una manera regional para terminar abarcando un área global.

10. Este trabajo proporciona una herramienta realmente eficaz ante la incesante pérdida de biodiversidad, por lo que abre un abanico de oportunidades y próximos pasos a seguir. Es necesario continuar con esta línea de investigación, generando para cada parque nacional una simulación de uso del suelo bajo diferentes escenarios. De esta menera se obtendría, junto con la obtención de las áreas receptoras y emisoras, una red de espacios protegidos implacable ante el cambio climático.

GENERAL CONCLUSIONS

1. Iberian national parks are under serious threat as a consequence of climate change. Most of these protected areas will lose the climatic conditions they currently harbour, directly affecting the biodiversity they attempt to protect.

2. The identification of receptor areas, or areas where the climatic conditions of each national park will be displaced, is presented as a solid and effective tool, capable of facilitating the survival of the species that these protected areas are home to.

3. This work has made possible to locate the receiving areas of all the Iberian national parks, enabling to observe that many of these areas are shared by several national parks. These areas should become transcendental enclaves for the conservation of Iberian biodiversity.

4. The inclusion of land-use dynamics has strengthened the proposed methodology for locating receptor areas, distinguishing between receptor areas with

a natural land use and others with a current use incompatible with the conservation of their natural conditions.

5. The generation of a network of corridors capable of connecting national parks with their receptor areas through climatically similar sites that also have a natural land use provides a useful tool to mitigate the effects of climate change, facilitating species to follow their environmental conditions.

6. Large valleys present unsurpassable barriers to spatial connection between national parks and their host areas. It is desirable to focus conservation efforts in these regions, allowing species to move between the different mountain systems.

7. Since the creation of a national network of corridors such as the one presented in this paper may not be feasible with current conservation efforts, the connection of the Sistema Central and Sistema Bético with the Sistema Ibérico could be a very efficient solution.

8. This work has been elaborated with data, scenarios and simulations where different decisions together with the idiosyncrasies of the climate models themselves could modify some results. However, broadly speaking, the priority sites for protecting national parks from climate change will remain unchanged.

9. A very important part, on a different scale, has been the realisation of the last chapter. It has been possible to demonstrate the large spatio-temporal difference in land use changes in national parks across Europe. These results show the need to approach this methodology in a regional way in order to cover a global area.

10. This work provides a truly effective tool in the face of the incessant loss of biodiversity, opening up a range of opportunities and next steps. It is necessary to continue with this line of research, generating a simulation of land use under different scenarios for each national park. In this way, together with obtaining the receiving and emitting areas, a network of protected areas implacable in the face of climate change would be obtained.

DIFUSIÓN DE RESULTADOS

NOTAS DE PRENSA

Jueves, 08 octubre 2020

Desarrollan una metodología para adaptar las áreas naturales y mejorar la conservación de los espacios protegidos

https://www.mncn.csic.es/es/Comunicación/desarrollan-una-metodologia-para-adaptar-las-areas-naturales-y-mejorar-la-conservacion

Tras analizar cómo afectará el cambio climático y los cambios en los usos del suelo en la estructura ambiental del Parque Nacional de Guadarrama, investigadores del Museo Nacional de Ciencias Naturales (MNCN-CSIC) han desarrollado una metodología para favorecer que la gestión de espacios protegidos se adapte a las principales amenazas a las que se enfrentan y se pueda mantener una conservación exitosa. La metodología desarrollada se puede implementar en cualquier área protegida ya que permite examinar en cada caso si el área en cuestión mantendrá en el futuro su capacidad de representar las condiciones ambientales por las que se estableció como área destinada a la conservación.

Las áreas protegidas son zonas delimitadas en un espacio estático que se enfrentan a amenazas para la protección de la biodiversidad, como el cambio climático y los cambios del uso del suelo, que tienen una dinámica espacial. “Debido al dinamismo que caracterizan tanto a las condiciones climáticas como a los usos del suelo, las zonas protegidas podrían perder las características que motivaron su protección”, explica Mario Mingarro, investigador del MNCN. “En el futuro, las mismas condiciones que actualmente caracterizan dichos espacios podrían aparecer en otros lugares, más o menos alejados de la zona que en principio se protegió”, continúa Mingarro.

En este trabajo se ha estimado la representatividad climática actual y futura de una de las áreas protegidas más importantes y recientes de la península ibérica, el Parque Nacional de la Sierra de Guadarrama, identificando áreas futuras con un clima similar a las existentes ahora en dicha reserva. Una vez obtenidas estas áreas receptoras, se han realizado simulaciones de los usos del suelo, permitiendo evaluar la viabilidad de dichas áreas receptoras, y los efectos de los cambios en la cobertura del suelo sobre la conectividad de estas áreas con el propio parque nacional.

“Lo que hemos logrado ha sido desarrollar una metodología que es aplicable a otras áreas protegidas del planeta y que permite adecuar la gestión atendiendo a las principales amenazas, así como localizar la futura ubicación de esos lugares receptores de las condiciones ambientales actualmente protegidos. Resulta imprescindible focalizar los esfuerzos de conservación en estos lugares para tener una red de áreas protegidas que realmente protejan la biodiversidad”, indica Jorge Lobo, investigador del MNCN.

El papel de los espacios protegidos

La presión humana sobre la naturaleza crece sin parar y la tasa actual de extinción de biodiversidad no tiene precedentes. Uno de los intentos por preservar los lugares naturales ha consistido en crear y diseñar áreas protegidas, reservas que tienen como objetivo mitigar algunas de las amenazas antrópicas, manteniendo la funcionalidad de los ecosistemas y preservando o reduciendo la pérdida de biodiversidad. “Las áreas protegidas han pasado a ser herramientas indispensables en la conservación, sin embargo, su integridad está cada vez más amenazada y si queremos una buena eficacia conservacionista resulta necesario una red de espacios protegidos conectados entre sí”, explica Mingarro.

Establecen las áreas determinantes para la conservación de los parques nacionales ante el cambio climático.

Miércoles, 19 mayo 2021

https://www.mncn.csic.es/es/Comunicación/establecen-las-areas-determinantes-para-la-conservacion-de-los-parques-nacionales-ante

Los parques nacionales albergan unas condiciones ambientales específicas que posibilitan el desarrollo de determinadas especies, lo que los convierte en regiones de especial relevancia natural. Con esta figura se delimita un área a la que se aplican medidas específicas de protección, pero ¿qué pasa cuando esas condiciones cambian o se trasladan? Uno de los efectos que provoca el cambio climático es la variación de las características de un área determinada, lo que modifica las condiciones que la convertían en un área relevante para la conservación. Por eso, los investigadores del Museo Nacional de Ciencias Naturales (MNCN-CSIC), Mario Mingarro y Jorge M. Lobo, han analizado qué áreas de la península ibérica van a jugar un papel relevante en el futuro, ya que mantendrán las condiciones climáticas de los parques actuales, y han establecido los corredores naturales que habría que respetar si queremos mantener el patrimonio natural y los beneficios que aportan estas áreas protegidas.

Los sistemas montañosos, en especial el sistema ibérico, el central y las cordilleras béticas, son algunas de estas áreas que albergarán, en el futuro, las condiciones actuales de los parques. “Las áreas protegidas son zonas que, a diferencia de las especies que las habitan, no pueden desplazarse. Sin embargo, el efecto del cambio climático está provocando que las condiciones ambientales, las mismas que promovieron su protección, cambien rápidamente, de manera que las especies que en la actualidad habitan estos espacios necesiten desplazarse en busca de condiciones más favorables”, apunta Mingarro. “Gracias a este estudio hemos determinado, basándonos en diferentes modelos climáticos, qué regiones ibéricas jugarán un papel relevante en el futuro ya que tendrán las condiciones ambientales de un buen número de parques nacionales que existen actualmente”, continúa. Al delimitar estos espacios han comprobado que muchos son comunes. Además, han identificado las conexiones entre dichas áreas y los diferentes parques, estableciendo los puntos que pueden provocar conflictos en la conectividad, haciendo que esos corredores naturales no puedan actuar como zonas de comunicación.

El flujo de la vida

“Lo que llevamos comprobando gracias a numerosos estudios, es que los parques reciben poblaciones y especies de las regiones que llamamos áreas emisoras, a la vez que las exportan a otras zonas, las áreas receptoras”, comenta Lobo. Lo que han logrado es delimitar cuáles son esas regiones y estimar con bastante precisión las mejores rutas de conexión entre las áreas receptoras y los actuales parques nacionales. “Una vez analizados esos corredores hemos determinado cuáles son las zonas altamente humanizadas o con usos del suelo incompatibles con su función conectora, y nos hemos dado cuenta de que es vital que la Administración actúe ya para delimitar y proteger esos corredores", expone el investigador del MNCN.

Los análisis se han realizado utilizando dos modelos climáticos extremos entre sí, pero los cambios en la red de corredores, basados en la similitud ambiental con las condiciones de las áreas protegidas, cuando se usa uno u otro apenas son relevantes. "Una vez establecidas esas 'carreteras' hemos analizado los problemas (usos del suelo, excesiva humanización, etc.) a los que se enfrentará esa protección tan necesaria si queremos mantener el patrimonio natural", terminan los investigadores.

ARTÍCULOS DIVULGATIVOS

Mingarro M y Lobo JM (2021) Parques Nacionales ¿Podrían dejar de ser eficaces para la conservación? Naturalmente, 30: 40-45.

Los espacios protegidos actúan como refugios naturales capaces de permitir la adaptación y adecuación espacial de los organismos ante el cambio climático. En España, la Red de Parques Nacionales es una de las mejores muestras de su Patrimonio Natural. Una figura internacionalmente reconocida por su alto valor ecológico y cultural. Sin embargo, el dinamismo natural de los sistemas ecológicos y del clima obligan a diseñar redes de comunicación que conecten los actuales parques nacionales con las zonas que en el futuro tendrán las condiciones ambientales que ahora albergan. Una red como esta permitiría reducir el impacto medioambiental en los parques nacionales y maximizar su función principal: la de conservar espacios de relevancia para la biodiversidad.

Las áreas protegidas se consideran la principal estrategia para la conservación de la biodiversidad. Podríamos definirlas como un espacio geográfico claramente delimitado, reconocido, gestionado y dedicado a preservar la naturaleza, sus servicios ecosistémicos y sus valores culturales a largo plazo. Las áreas protegidas han incrementado exponencialmente en número y extensión desde mediados del siglo XX, hasta llegar a abarcar casi un 15% de la superficie terrestre mundial y un 7% de la superficie marina. En España, los espacios protegidos suponen un 28% de la superficie terrestre y casi un 13% en el caso de las reservas marinas. Además de su función prioritaria de conservación, las áreas protegidas constituyen un recurso fundamental para el bienestar de la humanidad. Facilitan el desarrollo de actividades singulares en el medio natural, el disfrute estético de los paisajes, así como otros valores de interés espiritual, científico o educativo. Todas estas cualidades, unidas al deterioro progresivo de las superficies naturales, han hecho que las áreas protegidas se conviertan en una de las demandas sociales más compartidas. Desgraciadamente, la situación de la biodiversidad y de los sistemas ecológicos no deja de empeorar con un número creciente de hábitats, especies y variedades genéticas extintos o en peligro de extinción.

La funcionalidad de las áreas protegidas consiste en reducir o impedir la acción antrópica sobre el territorio, el medio abiótico y los organismos que en él habitan, para que estos puedan crecer, sobrevivir durante más tiempo y dejar descendencia. Esto favorece el crecimiento de las poblaciones y, por ende, la disminución del riesgo de extinción. Sin embargo, la mayor parte de las áreas protegidas declaradas hasta la fecha lo han sido, principalmente, por criterios de oportunidad más que por criterios u objetivos científicos verificables y reproducibles. No es de extrañar, por lo tanto, que la red de espacios protegidos de un país o región no suela representar la variabilidad ambiental y la diversidad biológica mucho mejor que la de cualquier conjunto aleatorio de espacios naturales de la misma extensión. Su ubicación suele elegirse, además, en zonas apartadas con importantes valores estéticos, pero de escaso valor económico, en lugar de ser espacios elegidos por su capacidad para representar la variabilidad ambiental y la diversidad biológica. Es decir, territorios en los que se reduzca notablemente la acción antrópica para la conservación de la naturaleza y que garanticen la permanencia de la biodiversidad a medio y largo plazo.

Son muchos los lugares con unas condiciones únicas que convendría proteger, pero esta es una decisión política motivada no solo por las características propias del espacio en cuestión. Durante el siglo pasado, los objetivos y propósitos de las áreas protegidas han cambiado considerablemente, pasando de un énfasis inicial basado en valores paisajísticos a visiones más amplias relacionadas con la conservación de la biodiversidad, la provisión de servicios ecosistémicos u otros beneficios para las comunidades humanas. Esta variedad de razones para establecer un espacio protegido ha originado en la actualidad que las figuras de protección sean muy variadas. Simplemente en España existen 48 figuras de protección diferentes, muchas de ellas superpuestas espacialmente. Debido a esta heterogeneidad es bastante difícil comparar su eficiencia en la conservación del patrimonio natural. La Unión Internacional para la Conservación de la Naturaleza (UICN), organismo que ha llevado el liderazgo en la definición y gestión de las áreas protegidas, ha tratado de establecer un orden y una sistematización de los distintos tipos de espacios protegidos. Esta categorización pretende establecer un número limitado de clases de amparo que permita la equiparación entre áreas protegidas a nivel mundial.

Una de las figuras que ha sido internacionalmente considerada y comparable a nivel mundial es la de Parque Nacional. En España, los parques nacionales cuentan con una legislación propia y son la figura de protección estrella al tener un alto valor ecológico y cultural y estar poco transformados por el ser humano. Además, poseen unos valores ecológicos, estéticos, culturales, educativos y científicos destacados. El primer espacio de la red de parques nacionales españoles, el de Picos de Europa, se estableció en 1918 y actualmente la red está formada por 15 zonas protegidas. Desde luego, los parques nacionales son beneficiosos y eficaces ante los retos que impone la acción humana. Pero no debemos olvidar que se trata de áreas ancladas al territorio, que ineludiblemente experimentan continuos cambios ambientales y que están incluidas en una matriz espacial que les afecta y a la que también influyen. Es decir, lo que sucede dentro de un área protegida está influenciado por lo que acontece en sus alrededores, por ejemplo, los usos del suelo de las zonas colindantes. Ante esto, cabe plantearse lo siguiente: ¿cuál es la capacidad de representación de los parques nacionales ante un escenario climático cambiante? Lamentablemente, los efectos del cambio climático y las dinámicas de los usos del suelo pueden convertir los parques nacionales en áreas ineficaces y contrarias a su propósito inicial, ya que en un futuro tenderían a representar condiciones ambientales diferentes de las existentes cuando se constituyeron. De este modo, si los seres vivos que aparecen en un parque nacional están influidos en su distribución y abundancia por las condiciones climáticas, cada parque nacional tendería a convertirse en un "emisor" de su flora y fauna característica hacia otros enclaves receptores que, en el futuro, representarían las condiciones ambientales que actualmente alberga ese parque nacional.

Para maximizar la función de los parques nacionales y mitigar los efectos perjudiciales del cambio climático y de los usos del suelo sobre las poblaciones y las especies, es necesario analizar cómo variará la representatividad de estos dos condicionantes. Teniendo en cuenta la fragmentación y alteración actual de los paisajes, se pueden diseñar estrategias de planificación y de gestión efectiva que anticipen y permitan adaptar el espacio ante futuros cambios, identificando así los lugares donde convendría focalizar los esfuerzos de conservación. Mediante la combinación de simulaciones de cambio en las condiciones climáticas bajo diferentes escenarios próximos en el tiempo y simulaciones en los cambios de uso del suelo, es posible identificar áreas potenciales que podrían albergar en el futuro la fauna y la flora de un determinado parque nacional.

Desde el MNCN, hemos realizado diferentes trabajos para tratar de entender cómo afectará el cambio climático y la modificación de los usos del suelo a los parques nacionales. Se ha determinado que en la mayoría de los parques nacionales Ibéricos terrestres aparecen unas zonas receptoras comunes. Estas se sitúan principalmente en los sistemas montañosos, concretamente en el Sistema Ibérico, el Sistema Central y las Cordilleras Béticas. En estos lugares se darán en un futuro gran parte de las condiciones climáticas que actualmente están representadas en la red de parques nacionales. Es posible delimitar los caminos o corredores naturales que conectarían los parques nacionales con esas áreas “receptoras” pero, desgraciadamente, la conexión está impedida en muchos casos por la profunda alteración de los hábitats naturales. En definitiva, ha sido posible entender que los efectos del cambio climático serán muy notables en la red de parques nacionales en la península ibérica y que muchos de ellos perderán las condiciones climáticas que tenían cuando se declararon. Ante esta problemática, urge planificar los diversos usos del territorio y diseñar una red de conexiones que facilite la interconexión entre los espacios protegidos en un mundo dinámico. Solo así podrán cumplir la función por la que han sido establecidos.

De esta manera, y utilizando el Parque Nacional de la Sierra de Guadarrama como ejemplo, hemos propuesto una metodología que permite identificar los efectos del cambio climático y realizar una simulación de los usos del suelo, en aquellas áreas donde aparecerá el clima representado por este reciente parque nacional. Los resultados muestran que gran parte del parque perderá las condiciones climáticas que representa actualmente. Sin embargo, estas áreas aparecerán en lugares no muy distantes. Mediante este trabajo se ha enfatizado la necesidad de conectar espacialmente la Sierra de Gredos, la Sierra de Guadarrama y la Sierra de Ayllón, dando al Parque Nacional de la Sierra de Guadarrama la posibilidad de hacer frente al cambio climático y a la fuerte presión antrópica que sufre. Aún queda mucho trabajo por realizar, pero mediante estudios de este tipo será posible minimizar los riesgos de extinción local y maximizar las posibilidades adaptativas y dispersivas de los organismos, permitiendo así que los espacios protegidos cumplan su función principal: la de conservar la maravillosa biodiversidad que nos rodea.

APARICIÓN EN MEDIOS

- Cómo poner a salvo los tesoros de los parques nacionales frente al cambio climático, 2021. El País (https://elpais.com/clima-y-medio-ambiente/2021-05-25/como-poner-a-salvo-los-tesoros-de-los-parques-nacionales-frente-al-cambio-climatico.html)
- Investigadores abogan por conectar áreas protegidas para facilitar el seguimiento del cambio climático, 2021. Europapress (https://www.europapress.es/epagro/noticia-investigadores-abogan-conectar-areas-protegidas-facilitar-seguimiento-cambio-climatico-20210522130601.html)
- Conservar los parques nacionales ante el cambio climático, 2021. Ambientum (https://www.ambientum.com/ambientum/cambio-climatico/conservar-parques-nacionales-ante-el-cambio-climatico.asp)
- Un estudio fija las áreas "relevantes" para conservar los parques nacionales, 2021. Cope (https://www.cope.es/actualidad/vivir/biodiversidad/noticias/estudio-fija-las-areas-relevantes-para-conservar-los-parques-nacionales-20210519_1298193)
- Establecen las áreas determinantes para la conservación de los parques nacionales ante el cambio climático, 2021. El correo de España (https://elcorreodeespana.com/caza-y-naturaleza/654118866/Establecen-las-areas-determinantes-para-la-conservacion-de-los-parques-nacionales-ante-el-cambio-climatico.html)

- El Cambio Climático trastocará los santuarios naturales, 2021. La tribuna de Ciudad Real (https://www.latribunadeciudadreal.es/noticia/ZA0748A37-BDB8-B42F-6661FD0262BDB2C5/202105/el-cambio-climatico-trastocara-los-santuarios-naturales?)
- Conectar áreas protegidas para mejorar la biodiversidad, 2021. Ecoavant (https://www.ecoavant.com/medio-ambiente/conectar-areas-protegidas-mejorar-biodiversidad_6533_102.html)
- La enorme importancia de conectar las áreas protegidas de España, 2021. Ecoticias (https://www.ecoticias.com/cambio-climatico/209936/enorme-importancia-areas-protegidas-Espana)
- Investigadores del CSIC abogan por conectar áreas protegidas de la península ibérica para facilitar el seguimiento del cambio climático, 2021. Lanza (https://www.lanzadigital.com/general/investigadores-del-csic-abogan-por-conectar-areas-protegidas-de-la-peninsula-iberica-para-facilitar-el-seguimiento-del-cambio-climatico/?fbclid=IwAR2oGN4In2I8ZgaxuynZwoA40j6bv8JlEQ25fOHASqpoBEhXa9Hl89sUlPI
- Desarrollan metodología para mejorar la gestión de los espacios protegidos, 2020. EFEverde (https://www.efeverde.com/noticias/metodologia-gestion-espacios-protegidos)
- El MNCN-CSIC desarrolla un método de gestión de espacios protegidos adaptado a las amenazas 'ad hoc' a la conservación, 2020. Europapress

(https://www.europapress.es/sociedad/noticia-mncn-csic-desarrolla-metodo-gestion-espacios-protegidos-adaptado-amenazas-ad-hoc-conservacion-20201008141600.html)

- Mejorar la conservación de los espacios protegidos, 2020. Ambientum (https://www.ambientum.com/ambientum/medio-natural/mejorar-la-conservacion-de-los-espacios-protegidos.asp)
- Desarrollan metodología para adaptar áreas naturales y mejorar conservación, 2020. La vanguardia (https://www.lavanguardia.com/vida/20201015/484101287607/desarrollan-metodologia-para-adaptar-areas-naturales-y-mejorar-conservacion.html)

REFERENCIAS

Adriaensen F, Chardona JP, De Blust G, Swinnen E, Villalba S, et al. (2003) The application of 'least-cost' modelling as a functional landscape model. Landscape and Urban Planning, 64: 233-247.

Alagador D, Cerdeira JO and Araújo MB (2016) Climate change, species range shifts and dispersal corridors: an evaluation of spatial conservation models. Methods in Ecology and Evolution 7: 853-866.

Alagador D, Triviño M, Cerdeira JO, Brás R, Cabeza M, et al. (2012) Linking like with like: optimising connectivity between environmentally similar habitats. Landscape Ecology, 27: 291-301.

Albuquerque F and Beier P (2015) Global patterns and environmental correlates of high-priority conservation areas for vertebrates. Journal of Biogeography, 42: 1397-1405.

Antrop M (2004) Landscape change and the urbanization process in Europe. Landscape and Urban Planning, 67: 9-26.

Araújo MB and Guisan A (2006) Five (or so) challenges for species distribution modelling. Journal of Biogeography, 33: 1677-1688.

Araújo MB, Cabeza M, Thuiller W, Hannah L and Williams PH (2004) Would climate change drive species out of reserves? An assessment of existing reserve-selection methods. Global Change Biology, 10: 1618-1626.

Araújo MB, Guilhaumon F, Neto DR, Pozo-Ortego I and Gómez-Calmaestra R (2011) Impactos, vulnerabilidad y adaptación al cambio climático de la biodiversidad española. 2 Fauna de Vertebrados. Dirección general de medio Natural y Política Forestal. Ministerio de Medio Ambiente, y Medio Rural y Marino, España.

Araújo MB, Lobo JM and Moreno JC (2007) The effectiveness of Iberian protected areas in conserving terrestrial biodiversity. Conservation Biology, 21: 1423-1432

Baldi G, Texeira M, Martin OA, Grau HR and Jobbágy EG (2017) Opportunities drive the global distribution of protected areas. PeerJ, 5: e2989.

Barker T, Davidson OR, Bosch PR, Dave R and Meyer LA (2007) Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Metz B, et al. Eds.). Cambridge University Press, United Kingdom and United States.

Barnes MD, Craigie ID, Harrison LB, Geldmann J, Collen B, et al. (2016) Wildlife population trends in protected areas predicted by national socio-economic metrics and body size. Nature Communications, 7: 1-9.

Barnosky AD, Matzke N, Tomiya S, Wogan GOU, Swartz B, et al. (2011) Has the Earth's sixth mass extinction already arrived? Nature, 471: 51-57.

Batllori EM, Parisien A, Parks SA, Moritz MA and Miller C (2017) Potential Relocation of Climatic Environments Suggests High Rates of Climate Displacement within the North American Protection Network. Global Change Biology, 23: 3219-3230.

Beaumont LJ and Duursma D (2012) Global Projections of 21st Century Land-Use Changes in Regions Adjacent to Protected Areas. PLoS ONE, 7: e43714.

Bestion E, Teyssier A, Richard M, Clobert J and Cote J (2015) Live fast, die young: experimental evidence of population extinction risk due to climate change. PLoS Biology, 13: e1002281.

Blanco J, Bellón B, Fabricius C, de O Roque F, Pays O, et al. (2020) Interface processes between protected and unprotected areas: A global review and ways forward. Global Change Biology, 26: 1138-1154.

Blankinship JC, Niklaus PA and Hungate BA (2011) A meta-analysis of responses of soil biota to global change. Oecologia, 165: 553-565.

Blondel J (2006) The "design" of Mediterranean landscapes: A millennial story of humans and ecological systems during the historic period. Human Ecology, 34: 713-729.

Braunisch V, Coppes J, Arlettaz R, Suchant R, Schmid H et al. (2013) Selecting from correlated climate variables: a major source of uncertainty for predicting species distributions under climate change. Ecography, 36: 971–983.

Brook BW, Sodhi NS and Bradshaw CJ (2008) Synergies among extinction drivers under global change. Trends Ecology and Evolution, 23: 453-460.

Brooks TM, Mittermeier RA, Mittermeier CG, Da Fonseca GAB, Rylands AB, et al. (2002) Habitat Loss and Extinction in the Hotspots of Biodiversity. Conservation Biology, 16: 909-923.

Bruner AG, Gullison RE, Rice RE and Da Fonseca GAB (2001) Effectiveness of Parks in Protecting Tropical Biodiversity. Science 291: 125-128.

Burns CE, Johnston KM and Schmitz OJ (2003) Global climate change and mammalian species diversity in U.S. national parks. Proceedings of the National Academy of Sciences of the United States of America, 100: 1474-1477.

Carey C, Dudley N and Stolton S (2000) Squandering paradise? The importance and vulnerability of the world's protected areas. WWF, Switzerland.

Carroll C, Lawler JJ, Roberts DR and Hamann A (2015) Biotic and climatic velocity identify contrasting areas of vulnerability to climate change. PLoS ONE, 10: e0142024.

Carroll C, Parks SA, Dobrowski SZ and Roberts DR (2018) Climatic, Topographic, and Anthropogenic Factors Determine Connectivity between Current and

Future Climate Analogs in North America. Global Change Biology, 24: 5318-5331.

Carwardine J, Martin TG, Firn J, Reyes RP, Nicol S, et al. (2019) Priority Threat Management for biodiversity conservation: a handbook. Journal of Applied Ecology, 56: 481-490.

Castro-Prieto J, Martinuzzi S, Radeloff VC, Helmers DP, Quiñones M, et al. (2017) Declining human population but increasing residential development around protected areas in Puerto Rico. Biological Conservation, 209: 473-481.

Chen I, Hill J, Ohlermüller R, Roy DB and Thomas CD (2011) Rapid range shifts of species associated with high levels of climate warming. Science, 333: 1024-1026.

Choe H, Thorne JH, Hijmans RJ, Kim J, Kwon H, et al. (2017) Meta-corridor solutions for climate-vulnerable plant species groups in South Korea. Journal of Applied Ecology, 54: 1742-1754.

Cohen B (2004) Urban growth in developing countries: A review of current trends and a caution regarding existing forecasts. World Development, 32: 23-51.

Concepción ED (2021) Urban sprawl into Natura 2000 network over Europe. Conservation Biology, 35: 1063-1072.

Costanza JK and Terando AJ (2019) Landscape Connectivity Planning for Adaptation to Future Climate and Land-Use Change. Current Landscape Ecology Reports, 4: 1-13.

Craigie ID Baillie JEM, Balmford A, Carbone C, Collen B, et al. (2010) Large mammal population declines in Africa's protected areas. Biological Conservation. 143: 2221-2228.

Curran LM, Trigg SN, McDonald AK, Astiani D, Hardiono YM, et al. (2004) Lowland Forest Loss in Protected Areas. Science, 303: 1000-1003.

Dale VH (1997) The relationship between land-use change and climate change. Ecological Applications, 7: 753-769.

Davies RG, Orme CDL, Olson V, Thomas GH, Ross SG, et al. (2006) Human impacts and the global distribution of extinction risk. Proceedings of the Royal Society B: Biological Sciences, 273: 2127-2133.

Davis MB and Shaw RG (2001) Range shifts and adaptive responses to quaternary climate change. Science, 292: 673-679.

de la Fuente B, Weynants M, Bertzky B, Delli G, Mandrici, et al. (2020a) Land productivity dynamics in and around protected areas globally from 1999 to 2013. PLoS ONE, 15: e0224958.

de la Fuente B, Bertzky B, Delli G, Mandrici A, Conti M, et al. (2020b) Built-up areas within and around protected areas: Global patterns and 40-year trends. Global Ecology and Conservation, 24: e01291.

DeFries R, Hansen A, Newton AC and Hansen MC (2005) Increasing isolation of protected areas in tropical forests over the past twenty years. Ecological Applications, 15: 19-26.

DeFries R, Karanth KK and Pareeth S (2010) Interactions between protected areas and their surroundings in human-dominated tropical landscapes. Biological conservation, 143: 2870-2880.

Di Marco M, Venter O, Possingham HP and Watson JEM (2018). Changes in human footprint drive changes in species extinction risk. Nature Communications, 9: 4621.

Díaz S, Demissew S, Carabias J, Joly C, Lonsdale M, et al. (2015) The IPBES Conceptual Framework connecting nature and people. Current Opinion in Environmental Sustainability, 14: 1-16.

Díaz S, Pascual U, Stenseke M, Martín-López B, Watson RT, et al. (2018) Assessing nature's contributions to people. Science, 359: 270-272.

Díaz-Pacheco J and García Palomares JC (2014) A Highly Detailed Land-Use Vector Map for Madrid Region Based on Photo-Interpretation. Journal of Maps, 10: 424-433.

Dudley N (2008). Guidelines for Applying Protected Area Management Categories. Gland, Switzerland.

Dudley N and Parish J (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. Secretariat of the Convention on Biological Diversity, Canada.

Dufresne JL, Foujols MA, Denvil S, Caubel A, Marti O, et al. (2013) Climate change projections using the IPSL-CM5 Earth System Model from CMIP3 to CMIP5. Climate Dynamics, 40: 2123-2165.

Eastman R (2009) Guide to GIS and Image Processing, Systems Research. Clark University, United Stated.

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

Elvira S, González-Fernández I, Alonso R, Sanz J and Bermejo-Bermejo V (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: 593.

Ewers RM and Rodrigues ASL (2008) Estimates of reserve effectiveness are confounded by leakage. Trends in Ecology and Evolution, 23: 113-116.

Eyring V, Cox PM, Flato GM, Gleckler PJ, Abramowitz G, et al. (2019) Taking climate model evaluation to the next level. Nature Climate Change, 9: 102-110.

Fahrig L (2003) Effects of habitat fragmentation on biodiversity. Annual Review of Ecology, Evolution and Systematics, 34: 487-515.

Faith D and Walker P (1996a) Environmental diversity: on the best-possible use of surrogate data for assessing the relative biodiversity of sets of areas. Biodiversity and Conservation, 5: 399-415.

Faith D and Walker P (1996b) How do indicator groups provide information about relative biodiversity of different sets of areas? On hotspots, complementarity and pattern-based approaches. Biodiversity Letters, 3: 18-25.

Falcucci A, Maiorano L and Boitani L (2007) Changes in land-use/land-cover patterns in Italy and their implications for biodiversity conservation. Landscape Ecology, 22: 617-631.

Faleiro FV, Machado RB and Loyola RD (2013) Defining spatial conservation priorities in the fase of land-use and climate change. Biological Conservation, 158: 248-257.

Farber O and Kadmon R (2003) Assessment of alternative approaches for bioclimatic modeling with special emphasis on the Mahalanobis distance. Ecological Modelling, 160: 115-130.

Felicísimo ÁM, Muñoz J, Villalba J and Mateo RG (2011). Impactos, vulnerabilidad y adaptación al cambio climático de la biodiversidad española. 1 Flora y vegetación. Oficina española de cambio climático, Ministerio de Medio Ambiente y Medio Rural y Marino, España.

Ferraro PJ and Hanauer MM (2011) Protecting ecosystems and alleviating poverty with parks and reserves: “Win-win” or tradeoffs? Environmental and Resource Economics, 48: 269-286.

Ferrier S and Guisan A (2006) Spatial modelling of biodiversity at the community level. Journal of Applied Ecology, 43: 393-404.

Fischer J and Lindenmayer DB (2007) Landscape modification and habitat fragmentation: a synthesis. Global Ecology and Biogeography, 16: 265-280.

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

Foley JA, Defries R, Asner GP, Barford C, Bonan G, et al. (2005) Global consequences of land use. Science, 309: 570-574.

Franklin JF and Lindenmayer DB (2009) Importance of Matrix Habitats in Maintaining Biological Diversity. Proceedings of the National Academy of Sciences, 106: 349-350.

Fraschetti S, Terlizzi A, Micheli F, Benedetti-Cecchi L and Boero F (2002) Marine protected areas in the Mediterranean Sea: Objectives, effectiveness and monitoring. Marine Ecology, 23: 190-200.

Fuchs R. Herold M, Verburg PH and Clevers JGPW (2013) A high-resolution and harmonized model approach for reconstructing and analysing historic land changes in Europe. Biogeosciences, 10: 1543-1559.

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

Game ET, Kareiva P and Possingham HP (2013) Six common mistakes in conservation priority setting. Conservation Biology, 27: 480-485.

Gaüzère P, Jiguet F and Devictor V (2016) Can protected areas mitigate the impacts of climate change on bird's species and communities? Diversity and Distributions, 22: 625-637.

Geldmann J, Barnes M, Coad L, Craigie ID, Hockings M, et al. (2013) Effectiveness of terrestrial protected areas in reducing habitat loss and population declines. Biological Conservation, 161: 230-238.

Geldmann J, Joppa LN and Burgess ND (2014) Mapping change in human pressure globally on land and within protected areas. Conservation Biology, 28: 1604-1616.

Gent PR, Danabasoglu G, Donner LJ, Holland MM, Hunke EC, et al. (2011) The Community Climate System Model Version 4. Journal of Climate, 24: 4973-4991.

Gilbert-Norton L, Wilson R, Stevens JR and Beard KH (2010) A meta-analytic review of corridor effectiveness. Conservation Biology, 24: 660-668.

Gingrich S, Niedertscheider M, Kastner T, Haberl H, Cosor G, et al. (2015) Exploring long-term trends in land use change and aboveground human appropriation of net primary production in nine European countries. Land Use Policy, 47: 426-438.

Gray CL, Hill SLL, Newbold T, Hudson LN, Börger L, et al. (2016) Local biodiversity is higher inside than outside terrestrial protected areas worldwide. Nature Communications, 7: 12306.

Guerra CA, Rosa IMD and Pereira HM (2019) Change versus stability: are protected areas particularly pressured by global land cover change? Landscape Ecology, 34: 2779-2790.

Guisan A and Zimmermann NE (2000) Predictive habitat distribution models in ecology. Ecological Modelling, 135: 147-186.

Haddad NM, Brudvig LA, Clobert J, Davies KF, Gonzalez A, et al. (2015) Habitat fragmentation and its lasting impact on Earth's ecosystems. Science Advances, 1: e1500052.

Hagerman S, Dowlatabadi H, Chan KMA and Satterfield T (2010) Integrative propositions for adapting conservation policy to the impacts of climate change. Global Environmental Change, 20: 351-362.

Haight J and Hammill E (2019) Protected areas as potential refugia for biodiversity under climatic change. Biological Conservation, 241: 108258.

Hamilton CM, Martinuzzi S, Plantinga AJ, Radeloff VC, Lewis DJ, et al. (2013) Current and Future Land Use around a Nationwide Protected Area Network. PLoS ONE, 8: e55737.

Hampe A and Petit RJ (2005) Conserving biodiversity under climate change: the rear edge matters. Ecology Letters, 8: 461-467.

Hannah L (2010) A global conservation system for climate-change adaptation: Special section. Conservation Biology, 24, 70-77.

Hannah L, Midgley GF, Lovejoy TE, Bond WJ, Bush M, et al. (2002a) Conservation of biodiversity in a changing climate. Conservation Biology, 16: 264-268.

Hannah L, Midgley GF and Millar D (2002b) Climate change-integrated conservation strategies. Global Ecology and Biogeography, 11: 485-495.

Hansen AJ and Defries R (2007) Ecological Mechanisms Linking Protected Areas. Ecological Applications, 17: 974-988.

Hansen AJ, Piekielek N, Davis C, Haas J, Theobald DM, et al. (2014) Exposure of U.S. National Parks to land use and climate change 1900-2100. Ecological Applications, 24: 484-502.

Heller NE and Zavaleta ES (2009) Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological Conservation, 142: 14-32.

Hengeveld R (1997) Impact of biogeography on a population biological paradigm shift. Journal of Biogeography, 24: 541-547.

Hertzog LR, Besnard A and Jay-Robert P (2014) Field validation shows bias-corrected pseudo-absence selection is the best method for predictive species-distribution modelling. Diversity and Distribution, 20: 1403-1413.

Hewitt R and Escobar F (2011) The Territorial Dynamics of Fast-Growing Regions: Unsustainable Land Use Change and Future Policy Challenges in Madrid, Spain. Applied Geography, 31: 650-667.

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

Hijmans RJ, Cameron SE, Parra JL, Jones PG and Jarvis A (2005) Very High Resolution Interpolated Climate Surfaces for Global Land Areas. International Journal of Climatology, 25: 1965-1978.

Hockings M (2003) Systems for Assessing the Effectiveness of Management in Protected Areas. BioScience, 53: 823-832.

Hoekstra AY and Wiedmann TO (2014) Humanity's unsustainable environmental footprint. Science, 344: 1114-1117.

Hoffmann A and Sgrò CM (2011) Climate change and evolutionary adaptation. Nature, 470: 479-485.

Hoffmann S, Irl SDH and Beierkuhnlein C (2019) Predicted climate shifts within terrestrial protected areas worldwide. Nature Communications, 10: 1-10.

Hole DG, Willis SG, Pain DJ, Fishpool LD, Butchart SH, et al. (2009) Projected impacts of climate change on a continent-wide protected area network. Ecology Letters, 12: 420-431.

Hortal J, Araújo MB and Lobo JM (2009) Testing the effectiveness of discrete and continuous environmental diversity as a surrogate for species diversity. Ecological Indicators, 9: 138-149.

Hunter ML, Jacobson GL and Webb T (1988) Paleoecology and the coarse-filter approach to maintaining biological diversity. Conservation Biology, 2: 375–85

Hurtt GC, Chini LP, Frolking S, Betts RA, Feddema J, 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: 117-161.

Hurtt GC, Chini LP, Sahajpal R, Frolking S, Bodirsky BL, et al. (2020) Harmonization of Global Land-Use Change and Management for the Period 850-2100 (LUH2) for CMIP6. Geoscientific Model Development Discussions, 13: 1-65.

IPBES (2019) Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Díaz S, et al. Eds.). IPBES secretariat, Germany.

IPCC (2007) Climate Change: Synthesis Report. Contribution of working groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Pachauri R and Reisinger A Eds.). IPCC, Switzerland.

IPCC (2014) Climate Change: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of working group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Field C, et al. Eds.). Cambridge University Press, United Kingdom and United States.

IPCC (2018) Special Report on Global Warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (Masson-Delmotte V, et al. Eds). Cambridge University Press, United Kingdom and United States.

IPCC (2021) Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Masson-Delmotte V, et al. Eds). Cambridge University Press, United Kingdom and United States.

Isbell F, Gonzalez A, Loreau M, Cowles J, Díaz S, et al. (2017) Linking the influence and dependence of people on biodiversity across scales. Nature, 546: 65-72.

IUCN (1994) Guidelines for Protected Area Management Categories. Gland, Switzerland and Cambridge.

Jackson ALR (2018) Conserving Europe's Wildlife: Law and Policy of the Natura 2000 Network of Protected Areas. Routledge, United Kingdom.

Jiang L and Yu L (2019) Analyzing land use intensity changes within and outside protected areas using ESA CCI-LC datasets. Global Ecology and Conservation, 20: e00789.

Jiménez-Alfaro B, Gavilán R, Escudero A, Iriondo JM and Fernández-González F (2014) Decline of dry grassland specialists in Mediterranean high-mountain communities influenced by recent climate warming. Journal of Vegetation Science, 25: 1394-1404.

Jones CD, Hughes JK, Bellouin N, Hardiman SC, Jones GS, et al. (2011) The HadGEM2-ES Implementation of CMIP5 Centennial Simulations. Geoscientific Model Development, 4: 543-570.

Jones KR, Watson JEM, Possingham HP and Klein CJ (2016) Incorporating climate change into spatial conservation prioritisation: A review. Biological Conservation, 194: 121-130.

Joppa LN and Pfaff A (2009) High and far: biases in the location of protected areas. PLoS ONE, 4: e8273.

Joppa LN and Pfaff A (2011) Global protected area impacts. Proceedings of the Royal Society B: Biological Sciences, 278: 1633-1638.

Joppa LN, Loarie S and Pimm S (2008) On the protection of protected areas. Proceedings of the National Academy of Sciences of the United States of America, 105: 6673-6678.

Jørgensen B and Kokonendji CC (2016) Discrete dispersion models and their Tweedie asymptotics. Advances in Statistical Analysis, 100: 43-78.

Juffe-Bignoli D, Burgess ND, Bingham H, Belle EMS, de Lima MG, et al. (2014) Protected Planet Report 2014. UNEP-WCMC, United Kingdom.

Kappelle M, Van Vuuren MMI and Baas P (1999) Effects of climate change on biodiversity: a review and identification of key research issues. Biodiversity and Conservation, 8: 1383-1397.

Kottek M, Grieser J, Beck C, Rudolf B and Rubel F (2006) World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift, 15: 259-263.

Kundzewicz ZW, Krysanova V, Benestad RE, Hov O, Piniewski M, et al. (2018) Uncertainty in Climate Change Impacts on Water Resources. Environmental Science and Policy, 79: 1-8.

Laliberté E, Wells JA, Declerck F, Metcalfe DJ, Catterall CP, et al. (2010) Land-use intensification reduces functional redundancy and response diversity in plant communities. Ecology Letters, 13: 76-86.

Lambin EF, Geist HJ and Lepers E (2003) Dynamics of land-use and land-cover change in tropical regions. Annual Review of Environment and Resources, 28: 205-241.

Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, et al. (2001) The causes of land-use and land-cover change: Moving beyond the myths. Global Environmental Change, 11: 261-269.

Laurance WF, Sayer J and Cassman KG (2014) Agricultural expansion and its impacts on tropical nature. Trends in Ecology and Evolution, 29: 107-116.

Laurance WF, Useche DC, Rendeiro J, Kalka M, Bradshaw CJ, et al. (2012) Averting biodiversity collapse in tropical forest protected areas. Nature, 489: 290-294.

Lawler JJ, Ackerly DD, Albano CM, Anderson MG, Dobrowski SZ, et al. (2015) The theory behind, and the challenges of, conserving nature's stage in a time of rapid change. Conservation Biology, 29: 618-629.

Lawler JJ, Rinnan DS, Michalak JL, Withey JC, Randels CR, et al. (2020) Planning for climate change through additions to a national protected area network: implications for cost and configuration. Philosophical Transactions of the Royal Society B: Biological Sciences, 375: 20190117.

Lawrence A, Friedrich F and Beierkuhnlein C (2021) Landscape fragmentation of the Natura 2000 network and its surrounding areas. PLoS ONE, 16: e0258615.

Lehikoinen P, Santangeli A, Jaatinen K, Rajasärkkä A and Lehikoinen A (2019) Protected areas act as a buffer against detrimental effects of climate change: evidence from large-scale, long-term abundance data. Global Change Biology, 25: 304-313.

Levinsky I, Skov F, Svenning JC and Rahbek C (2007) Potential impacts of climate change on the distributions and diversity patterns of European mammals. Biodiversity Conservation, 16: 3803-3816.

Li X, Chen G, Liu X, Liang X, Wang S, et al. (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: 1040-1059.

Liang X, Liu X, Li X, Chen Y, Tian H et al. (2018) Delineating Multi-Scenario Urban Growth Boundaries with a CA-Based FLUS Model and Morphological Method. Landscape and Urban Planning, 177: 47-63.

Lindsey PA, Miller JRB, Petracca LS, Coad L, Dickman AJ, et al. (2018) More than $1 billion needed annually to secure Africa's protected areas with lions. Proceedings of the National Academy of Sciences of the United States of America, 115: 10788-10796.

Lisón F and Sánchez-Fernández D (2017) Low effectiveness of the Natura 2000 network in preventing land-use change in bat hotspots. Biodiversity and Conservation, 26: 1989-2006.

Littlefield CE, Krosby M, Michalak JL and Lawler JJ (2019) Connectivity for species on the move: supporting climate-driven range shifts. Frontiers in Ecology and the Environment, 17: 270-278.

Littlefield CE, McRae BH, Michalak JL, Lawler JJ and Carroll C (2017) Connecting today's climates to future climate analogs to facilitate movement of species under climate change. Conservation Biology, 31: 1397-1408.

Liu J, Linderman M, Ouyang Z, An L, Yang J, et al. (2001) Ecological degradation in protected areas: The case of Wolong nature reserve for giant pandas. Science, 292: 98-101.

Loarie SR, Duffy PB, Hamilton H, Asner GP, Field CB, et al. (2009) The velocity of climate change. Nature, 462: 1052-1055.

Lobo JM (2000) ¿Es posible predecir la distribución geográfica de las especies basándonos en variables ambientales? (Martin-Piera F, Morrone JJ y Melic A Eds.). Sociedad Entomológica Aragonesa, España.

Lobo JM (2011) Vulnerabilidad de las áreas protegidas y de zonas de interés para la biodiversidad ante el cambio climático (Álvarez-Uría P y De la Cruz J Eds.). Observatorio de la Sostenibilidad de España, España.

Lobo JM (2015). ¿Debemos fiarnos de los modelos de distribución de especies? (Herrero A and Zavala M Eds.). Ministerio de Agricultura, Alimentación y Medio Ambiente, España.

Lobo JM (2016) The use of occurrence data to predict the effects of climate change on insects. Current Opinion in Insect Science, 17: 62-68.

López Fernández ML and López MS (2008) Clasificación bioclimática mundial y cartografía bioclimática de la España peninsular y balear. Publicaciones de Biología de la Universidad de Navarra, España.

López I and Pardo M (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: 25.

López-Gay A (2014) Population Growth and Re-Urbanization in Spanish Inner Cities: The Role of Internal Migration and Residential Mobility. Revue Quetelet Journal, 1: 67-92.

López-López P, Soutullo A, García-Ripollés C, Urios V, Cadahía L, et al. (2009) Markov Models of Territory Occupancy: Implications for the Management and Conservation of Competing Species. Biodiversity Conservation, 18: 1389-1402.

Luck GW (2007) The relationships between net primary productivity, human population density and species conservation. Journal of Biogeography, 34: 201-212.

Luijten JC (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: 427-441.

Lyons SK, Amatangelo KL, Behrensmeyer AK, Bercovici A, Blois JL, et al. (2016) Holocene shifts in the assembly of plant and animal communities implicate human impacts. Nature, 529: 80-83.

Malczewski J (1999) GIS and Multi-Criteria Decision Analysis. Wiley, United Stated.

Mantyka-Pringle CS, Martin TG and Rhodes JR (2012) Interactions between climate and habitat loss effects on biodiversity: A systematic review and meta-analysis. Global Change Biology, 18: 1239-1252.

Margules CR and Pressey RL (2000) Systematic conservation planning. Nature, 405: 243-253.

Martinuzzi S, Radeloff VC, Joppa LN, Hamilton CM, Helmers DP, et al. (2015) Scenarios of future land use change around United States' protected areas. Biological Conservation, 184: 446-455.

Mason SC, Palmer G, Fox R, Gillings S, Hill JK, et al. (2015) Geographical range margins of many taxonomic groups continue to shift polewards. Biological Journal of the Linnean Society, 115: 586-597.

Mathevet R, Thompson JD, Folke C and Chapin FS (2016) Protected areas and their surrounding territory: socioecological systems in the context of ecological solidarity. Ecological applications, 26: 5-16.

Maxwell SL, Cazalis V, Dudley N, Hoffmann M, Rodrigues ASL, et al. (2020) Area-based conservation in the twenty-first century. Nature, 586: 217-227.

Maxwell SL, Fuller RA, Brooks TM and Watson JEM (2016) Biodiversity: The Ravages of Guns, Nets and Bulldozers. Nature 536: 143-145.

Mazaris AD, Papanikolaou AD, Barbet-Massin M, Kallimanis AS, Jiguet F, et al. (2013) Evaluating the connectivity of a protected areas' network under the prism of global change: the efficiency of the European Natura 2000 network for four birds of prey. PLoS ONE, 8: e59640.

McCullough IM, Davis FW, Dingman JR, Flint LE, Flint AL, et al. (2016) High and dry: high elevations disproportionately exposed to regional climate change in Mediterranean-climate landscapes. Landscape Ecology. Springer Netherlands, 31: 1063-1075.

McDonald RI and Boucher TM (2011) Global development and the future of the protected area strategy. Biological Conservation, 144: 383-392.

McGarigal K, Cushman SA and Ene E (2012) FRAGSTATS v4: Spatial pattern analysis program for categorical and continuous maps. University of Massachusetts, United States.

McRae BH, Hall SA, Beier P and Theobald DM (2012) Where to restore ecological connectivity? Detecting barriers and quantifying restoration benefits. PLoS ONE, 7: e52604.

McRae BH and Kavanagh DM (2011) Linkage Mapper Connectivity Analysis Software. The Nature Conservancy, United States.

Medail F and Quezel P (1999) Biodiversity hotspots in the Mediterranean Basin: Setting global conservation priorities. Conservation Biology, 13: 1510-1513.

Michalak JL, Lawler JJ, Roberts DR and Carroll C (2018) Distribution and Protection of Climatic Refugia in North America. Conservation Biology, 32: 1414-1425.

Mingarro M and Lobo JM (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: 333-344.

Mingarro M, Aguilera-Benavente F and Lobo JM (2020). 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). Journal of Environmental Planning and Management, 64: 734-753.

Mingarro M and Lobo JM (2021) Connecting protected areas in the Iberian peninsula to facilitate climate change tracking. Environmental Conservation, 48: 1-10.

Monzón J, Moyer-Horner L and Baron Palamar M (2011) Climate Change and Species Range Dynamics in Protected Areas. BioScience, 61: 752-761.

Múgica M, Martínez C, Puertas J, Atauri JA, Gómez-Limón J, et al. (2018). EUROPARC- España. Anuario 2018 del estado de las áreas protegidas en España. Fundación Fernando González Bernáldez, España.

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB and Kent J (2000) Biodiversity hotspots for conservation priorities. Nature, 403: 853-858.

Nagendra H (2008) Do Parks Work? Impact of Protected Areas on Land Cover Clearing. AMBIO: A Journal of the Human Environment, 37: 330-337.

Naidu R, Biswas B, Willett IR, Cribb J, Singh BK, et al. (2021) Chemical pollution: a growing peril and potential catastrophic risk to humanity. Environmental International, 156: 106616.

Nazarenko L, Schmidt GA, Miller RL, Tausnev N, Kelley M, et al. (2015) Future Climate Change under RCP Emission Scenarios with GISS ModelE2. Journal of Advances in Modeling Earth Systems, 7: 244-267.

Newbold T, Bentley LF, Hill SLL, Edgar MJ, Horton M, et al. (2020) Global effects of land use on biodiversity differ among functional groups. Functional Ecology, 34: 684-693.

Newbold T, Hudson LN, Hill SLL, Contu S, Lysenko I, et al. (2015) Global effects of land use on local terrestrial biodiversity. Nature, 520: 45-50.

Nila US, Beierkuhnlein C, Jaeschke A, Hoffmann S and Hossain L (2019) Predicting the effectiveness of protected areas of Natura 2000 under climate change. Ecological Processes, 8: 13.

Oliveira PJC, Asner GP, Knapp DE, Almeyda A, Galván-Gildemeister R, et al. (2007) Land-Use Allocation Protects the Peruvian Amazon. Science, 317: 1233-1236.

Ordonez A, Martinuzzi S, Radeloff VC and Williams JW (2014) Combined speeds of climate and land-use change of the conterminous US until 2050. Nature Climate Change 4: 811–816.

Palomo I, Martín-López B, Alcorlo P and Montes C (2014a) Limitations of protected areas zoning in Mediterranean cultural landscapes under the ecosystem services approach. Ecosystems, 17: 1202-1215.

Palomo I, Montes C, Martín-López B, González J-A, García-Llorente M, et al. (2014b) Incorporating the Social-Ecological approach in protected areas in the anthropocene. BioScience, 64: 181-191.

Parks SA, Carroll C, Dobrowski SZ and Allred BW (2020) Human land uses reduce climate connectivity across North America. Global Change Biology, 26: 2944-2955.

Parmesan C (2006) Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution and Systematics, 37: 637-669.

Parmesan C (2007) Influences of species, latitudes and methodologies on estimates of phenological response to global warming. Global Change Biology, 13: 1860-1872.

Pereira HM, Leadley PW, Proença V, Alkemade R, Scharlemann JPW, et al. (2010) Scenarios for global biodiversity in the 21st century. Science, 330: 1496-1501.

Pérez-Hoyos A, García-Haro FJ and San-Miguel-Ayanz J (2012) Conventional and fuzzy comparisons of large scale land cover products: Application to CORINE, GLC2000, MODIS and GlobCover in Europe. ISPRS Journal of Photogrammetry and Remote Sensing, 74: 185-201.

Peters RL and Darling JDS (1985) The greenhouse-effect and nature reserves. BioScience, 35: 707-717.

Peters RL and Lovejoy TE (1992) Global warming and biological diversity. Yale University Press, United Kingdom.

Peterson AT and Soberón J (2012) Species distribution modeling and ecological niche modeling: getting the concepts right. Nature Conservation, 10: 102-107.

Pimm SL, Jenkins CN, Abell R, Brooks TM, Gittleman JL, et al. (2014) The biodiversity of species and their rates of extinction, distribution, and protection. Science, 344: 1246752.

Pimm SL, Russell GJ, Gittleman JL and Brooks TM (1995) The future of biodiversity. Science, 269: 347-350.

Plieninger T, Höchtl F and Spek T (2006) Traditional land-use and nature conservation in European rural landscapes. Environmental Science and Policy, 9: 317-321.

Popescu VD, Rozylowicz L, Niculae IM, Cucu AL and Hartel T (2014) Species, habitats, society: an evaluation of research supporting EU's Natura 2000 network. PLoS ONE, 9: e113648.

Potapov P, Yaroshenko A, Turubanova S, Dubinin M, Laestadius L, et al. (2008) Mapping the World's Intact Forest Landscapes by Remote Sensing. Ecology and Society, 13: 51.

Prentice IC, Cramer W, Harrison SP, Leemans R, Monserud RA et al. (1992) A global biome model based on plant physiology and dominance, soil properties and climate. Journal of Biogeography, 19: 117-134.

Pressey RL (1994) Ad hoc reservations: forward or backward steps in developing representative reserve systems? Conservation Biology, 8: 662-668.

Pressey RL, Cabeza M, Watts ME, Cowling RM and Wilson KA (2007) Conservation planning in a changing world. Trends in Ecology and Evolution, 22: 583-592.

Pressey RL, Humphries CJ, Margules CR, Vane-Wright RI and Williams PH (1993) Beyond opportunism: Key principles for systematic reserve selection. Trends in Ecology and Evolution, 8: 124-128.

Pressey RL, Visconti P and Ferraro PJ (2015) Making parks make a difference: poor alignment of policy, planning and management with protected-area impact, and ways forward. Philosophical Transactions of the Royal Society B: Biological Sciences, 370: 20140280.

Pringle RM (2017) Upgrading protected areas to conserve wild biodiversity. Nature, 546: 91-99.

Prober SM and Dunlop M (2011) Climate change: A cause for new biodiversity conservation objectives but let's not throw the baby out with the bathwater. Ecological Management and Restoration, 12: 2-3.

Rada S, Schweiger O, Harpke A, Kühn E, Kuras T, et al. (2019) Protected areas do not mitigate biodiversity declines: A case study on butterflies. Diversity and Distributions, 25: 217-224.

Radeloff VC, Stewart SI, Hawbaker TJ, Gimmi U, Pidgeon AM, et al. (2010) Housing Growth in and near United States Protected Areas Limits Their Conservation Value. Proceedings of the National Academy of Sciences, 107: 940-945.

Ramos MA, Lobo JM, Esteban M (2001) Then years inventorying the Iberian fauna: results and perspectives. Biodiversity Conservation, 10: 19-28.

Reed MS (2008) Stakeholder participation for environment management: a literature review. Biological Conservation, 141: 2417-2431.

Renwick AR, Bode M and Venter O (2015) Reserves in Context: Planning for Leakage from Protected Areas. PLoS ONE 10: e0129441.

Reside AE, Butt N and Adams VM (2018) Adapting Systematic Conservation Planning for Climate Change. Biodiversity and Conservation, 27: 1-29.

Reuter HI, Lado LR, Hengl T and Montanarella L (2008) Continental-scale digital soil mapping using European Soil Profile Data: Soil pH. Hamburger Beiträge zur Physischen Geographie und Landschaftsökologie, 19: 91-102.

Riggio J, Baillie JEM, Brumby S, Ellis E, Kennedy CM, et al. (2020) Global human influence maps reveal clear opportunities in conserving Earth's remaining intact terrestrial ecosystems. Global Change Biology, 26: 4344-4356.

Rindfuss RR, Walsh SJ, Turner II BL, Fox J and Mishra V (2004) Developing a science of land change: Challenges and methodological issues. Proceedings of the National Academy of Sciences of the United States of America, 101: 13976-13981.

Rivas Martínez S (1987) Memoria y mapa de series de vegetación de España 1: 400.000. Ministerio de Agricultura, Pesca y Alimentación. España.

Rivas-Martínez S (2005) Mapa de Series, Geoseries y Geopermaseries de Vegetación de España. In: Memoria del Mapa de Vegetación Potencial de España. Universidad Complutense, España.

Robillard CM, Coristine LE, Soares RN and Kerr JT (2015). Facilitating climate change induced range shifts across continental land use barriers. Conservation Biology, 29: 1586-1595.

Rodrigues ASL, Akçakaya HR, Andelman SJ, Bakarr MI, Boitani L, et al. (2004) Global gap analysis: priority regions for expanding the global protected-area network. Bioscience, 54: 1092-1100.

Rodríguez-Rodríguez D and Martínez-Vega J (2018a) Protected area effectiveness against land development in Spain. Journal of Environmental Management, 215: 345-357.

Rodríguez-Rodríguez D and Martínez-Vega J (2018b) Representation and protection of threatened biodiversity by the largest Spanish regional network of protected areas. Endangered Species Research, 35: 125-139.

Rodríguez-Rodríguez D and Martínez-Vega J (2019) Analysing subtle threats to conservation: A nineteen year assessment of fragmentation and isolation of Spanish protected areas. Landscape and Urban Planning, 185: 107-116.

Rodríguez-Rodríguez D, Ibarra P, Martínez-Vega J, Echeverría M and Echavarría P (2017) Fine-tuning of a protected area effectiveness evaluation tool: Implementation on two emblematic Spanish National Parks. Environments, 4: 68.

Rodríguez-Rodríguez D, Sebastiao J, Salvo Tierra AE and Martínez-Vega J (2019) Effect of protected areas in reducing land development across geographic and climate conditions of a rapidly developing country, Spain. Land Degradation and Development, 30: 991-1005.

Rounsevell MDA, Reginster I, Araújo MB, Carter TR, Dendoncker N, et al. (2006) A coherent set of future land use change scenarios for Europe. Agriculture, Ecosystems and Environment, 114: 57-68.

Rozas-Vásquez D, Peña-Cortés F, Geneletti D and Rebolledo G (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, 162: 1450014.

Saaty TL (1977) A Scaling Method for Priorities in Hierarchical Structures. Journal of Mathematical Psychology, 15: 234-281.

Saaty TL (1980) The Analytic Hierarchy Process, Planning, Piority Setting, Resource Allocation. McGraw-Hill, United States.

Salvati L, Zambon I, Chelli FM and Serra P (2018) Do spatial patterns of urbanization and land consumption reflect different socioeconomic contexts in Europe? Science of Total Environment, 625: 722-730.

Sánchez-Fernández D, Abellán P, Picazo F, Millán A, Ribera I, et al. (2013) Do protected areas represent species' optimal climatic conditions? A test using Iberian water beetles. Diversity and Distributions, 19: 1407-1417.

Sánchez-Fernández D, Fox R, Dennis RLH, and Lobo JM (2021) How complete are insect inventories? An assessment of the british butterfly database highlighting the influence of dynamic distribution shifts on sampling completeness. Biodiversity Conservation, 30: 889-902.

Santini L, Saura S and Rondinini C (2016) Connectivity of the global network of protected areas. Diversity and Distributions, 22: 199-211.

Sanz-Elorza M, Dana ED, González A and Sobrino E (2003) Changes in the high-mountain vegetation of the central Iberian Peninsula as a probable sign of global warming. Annals of Botany, 92: 273-280.

Sarkar S, Justus J, Fuller T, Kelley C, Garson J, et al. (2005) Effectiveness of environmental surrogates for the selection of conservation area networks. Conservation Biology, 19: 815-825.

Saura S, Bertzky B, Bastin L, Battistella L, Mandrici A, et al. (2018) Protected area connectivity: Shortfalls in global targets and country-level priorities. Biological Conservation, 219: 53-67.

Schmitt T (2007) Molecular biogeography of Europe: Pleistocene cycles and postglacial trends. Frontiers in Zoology, 4: 11.

Schmitz OJ, Lawler JJ, Beier P, Groves G, Knight G, et al. (2015) Conserving biodiversity: practical guidance about climate change adaptation approaches in support of land-use planning. Natural Areas Journal, 35: 190-203.

Schröter D, Cramer W, Leemans R, Prentice IC, Araújo MB, et al. (2005) Ecosystem service supply and vulnerability to global change in Europe. Science, 310: 1333-1337.

Scriven SA, Hodgson JA, McClean CJ and Hill JK (2015) Protected areas in Borneo may fail to conserve tropical forest biodiversity under climate change. Biological Conservation, 184: 414-423.

Sleeter BM, Sohl TL, Bouchard MA, Reker RR, Soulard CE, 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: 896-914.

Sohl TL, Wimberly MC, Radeloff VC, Theobald DM and Sleeter BM (2016) Divergent Projections of Future Land Use in the United States Arising from Different Models and Scenarios. Ecological Modelling, 337: 281-297.

Steffen W, Richardson K, Rockstrom J, Cornell SE, Fetzer I, et al. (2015) Sustainability. Planetary boundaries: guiding human development on a changing planet. Science, 347: 1259855.

Stralberg D, Carroll C and Nielsen SE (2020) Toward a climate-informed North American protected areas network: incorporating climate-change refugia and corridors in conservation planning. Conservation Letters, 13: e12712.

Struebig MJ, Wilting A, Gaveau DLA, Meijaard E and Smith RJ (2015) Targeted conservation to safeguard a biodiversity hotspot from climate and land-cover change. Current Biology, 25: 372-378.

Suggitt AJ, Platts J, Barata IM, Bennie JJ, Burgesset MD, et al. (2017) Conducting robust ecological analyses with climate data. Oikos, 126: 1533-1541.

Synes NW and Osborne PE (2011) Choice of predictor variables as a source of uncertainty in continental-scale species distribution modelling under climate change. Global Ecology and Biogeography, 20: 904-914.

Terra TN, dos Santos RF and Costa DC (2014) Land Use Changes in Protected Areas and Their Future: The Legal Effectiveness of Landscape Protection. Land Use Policy, 38: 378-387.

Tessarolo G, Ladle RJ, Lobo JM, Rangel TF and Hortal J (2021) Using maps of biogeographical ignorance to reveal the uncertainty in distributional data hidden in species distribution models. Ecography, 44: 1743-1755.

Thomas CD and Gillingham PK (2015) The performance of protected areas for biodiversity under climate change. Biological Journal of the Linnean Society, 115: 718-730.

Thuiller W, Pironon S, Psomas A, Barbet-Massin M, Jiguet F, et al. (2014) The European functional tree of bird life in the face of global change. Nature Communications, 5: 118.

Tilman D (2022) Extinction, climate change and the ecology of Homo sapiens. Journal of Ecology, 00: 1-7.

Tittensor DP, Walpole M, Hill SLL, Boyce DG, Britten GL, et al. (2014) A mid-term analysis of progress toward international biodiversity targets. Science, 346, 241–244.

Tobler W (1979) Cellular geography (Gale S and Olsson G Eds.). Reidel, Netherlands.

Triviño M, Cabeza M, Thuiller W, Hickler T and Araújo MB (2013) Risk assessment for Iberian birds under global change. Biological Conservation, 168: 192-200.

Triviño M, Kujala H, Araújo MB and Cabeza M (2018) Planning for the future: identifying conservation priority areas for Iberian birds under climate change. Landscape Ecology, 33: 659-673.

UNEP-WCMC and IUCN (2016) Protected Planet Report 2016. UNEP-WCMC and IUCN, United Kingdom and Switzerland.

UNEP-WCMC, IUCN and NGS (2018) Protected Planet Report 2018. UNEP-WCMC, IUCN and NG, United Kingdom, Switzerland and United States.

Valencia-Barrera RM, Comtois P and Fernández-González D (2002) Bioclimatic indices as a tool in pollen forecasting. International Journal of Biometeorology, 46: 171-175.

Van Asselen S and Verburg PH (2013) Land cover change or land-use intensification: simulating land system change with a global-scale land change model. Global Change Biology, 19: 3648-3667.

Van Vuuren DP, Edmonds J, Kainuma M, Riahi K, Thomson A, et al. (2011) The representative concentration pathways: an overview. Climatic Change, 109: 5-31.

Vaz EN, Nijkamp P, Painho M, Caetano M and Gaetano M (2012) A Multi-Scenario Forecast of Urban Change: A Study on Urban Growth in the Algarve. Landscape and Urban Planning, 104: 201-211.

Venter O, Sanderson EW, Magrach A, Allan JR, Beher J, et al. (2016) Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. Nature Communications, 7: 1-11.

Villalba S, Gulinck H, Verbeylen G and Matthysen E (1998) Relationship between patch connectivity and the occurrence of the European red squirrel, Sciurus vulgaris (Dover JW and Bunce RGH Eds.). International Association for Landscape Ecology, United Kingdom.

Virkkala R, Heikkinena RK, Leikola N and Luoto M (2008) Projected large-scale range reductions of northern-boreal land bird species due to climate change. Biological Conservation, 141: 1343-1353.

Visconti BP, Butchart SHM, Brooks TM, Langhammer PF, Marnewick D, et al. (2019) Protected area targets post-2020. Science, 364: 239-241.

Visconti P, Bakkenes M, Smith RJ, Joppa L and Sykes R (2015) Socio-economic and ecological impacts of global protected area expansion plans. Philosophical Transactions of Royal Society B, Biological Sciences, 370: 20140284.

Visconti P, Pressey RL, Bode M and Segan DB (2010) Habitat vulnerability in conservation planning-when it matters and how much. Conservation Letters, 3: 404-414.

Vitousek PM, Mooney HA, Lubchenco J and Melillo JM (1997) Human Domination of Earth' s Ecosystems. Science, 277: 494-499.

Warren MS, Hill JK, Thomas JA, Asher J, Fox R, et al. (2001) Rapid responses of British butterflies to opposing forces of climate and habitat change. Nature, 414: 65-69.

Watson JEM, Dudley N, Segan DB and Hockings M (2014) The performance and potential of protected areas. Nature, 515: 67-73.

Watson JEM, Rao M, Ai-Li K and Yan X (2012) Climate change adaptation planning for biodiversity conservation: A review. Advances in Climate Change Research, 3: 1-11.

Weinzettel J, Vačkář D and Medková H (2018) Human footprint in biodiversity hotspots. Frontiers in Ecology and the Environment, 16: 447-452.

Wessely J, Hülber K, Gattringer A, Kuttner M, Moser D, et al. (2017) Habitat-based conservation strategies cannot compensate for climate-change-induced range loss. Nature Climate Change, 7: 823-827.

White R and Engelen G (1993) Cellular Automata and Fractal Urban Form: A Cellular Modelling Approach to the Evolution of Urban Land-Use Patterns. Environment and Planning A, 25: 1175-1199.

Williams JJ and Newbold T (2020) Local climatic changes affect biodiversity responses to land use: a review. Diversity and Distributions, 26: 76-92.

Wilson TS, Sleeter BM and Davis AW (2015) Potential future land use threats to California's protected areas. Regional Environmental Change, 15: 1051-1064.

Wilson TS, Sleeter BM, Sleeter RR and Soulard CE (2014) Land-Use Threats and Protected Areas: A Scenario-Based, Landscape Level Approach. Land, 3: 362-389.

Wolkovich EM, Cook BI, Allen JM, Crimmins TM, Betancourt JL, et al. (2012) Warming experiments underpredict plant phenological responses to climate change. Nature, 485: 494-497.

Woosward F, Lomas M and Kelly C (2004) Global climate and the distribution of plant biomes. Philosophical Transactions of the Royal Society B, 359: 1465-1476.

Worboys GL, Graeme L and Trzyna T (2015) Managing Protected Areas (Worboys GL, et al. Eds.). Protected Area Governance and Management, Australia.

WWF (2018) Autopistas Salvajes (Rodríguez G, et al. Eds.). WWF, España.

Xiang S, Nie F and Zhang C (2008) Learning a Mahalanobis distance metric for data clustering and classification. Pattern Recognition, 41: 3600-3612.

Xin XG, Wu TW and Zhang J (2013) Introduction of CMIP5 experiments carried out with the climate system models of Beijing Climate Center. Advances in Climate Change Research, 4: 41-49.

Young J, Watt A, Nowicki P, Alard D, Clitherow J, et al. (2005) Towards sustainable land use: identifying and managing the conflicts between human activities and biodiversity conservation in Europe. Biodiversity Conservation, 14: 1641-1661.

Yukimoto S, Adachi Y, Hosaka M, Sakami T, Yoshimura H, 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, 90: 23-64.

Zeller KA, McGarigal K, Whiteley AR (2012) Estimating landscape resistance to movement: a review. Landscape Ecology, 27: 777-797.