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Title: Planning for the future : identifying conservation priority areas for Iberian birds under climate change

Year: 2018

Version:

Please cite the original version:

Triviño, M., Kujala, H., Araújo, M. B., & Cabeza, M. (2018). Planning for the future : identifying conservation priority areas for Iberian birds under climate change. Landscape Ecology, 33(4), 659-673. https://doi.org/10.1007/s10980-018-0626-z

Planning for the future: identifying conservation priority areas for Iberian birds under climate change.

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Accepted for publication in *Landscape Ecology*, doi: 10.1007/s10980-018-0626-z

Abstract

Context Species are expected to shift their distributions in response to global environmental changes and additional protected areas are needed to encompass the corresponding changes in the distributions of their habitats. Conservation policies are likely to become obsolete unless they integrate the potential impacts of climate and land-use change on biodiversity.

Objectives We identify conservation priority areas for current and future projected distributions of Iberian bird species. We then investigate the extent to which global change informed priority areas are: (i) covered by existing protected area networks (national protected areas and Natura 2000); (ii) threatened by agricultural or urban land-use changes.

Methods We use outputs of species distributions models fitted with climatic data as inputs in spatial prioritization tools to identify conservation priority areas for 168 bird species. We use projections of land-use change to then discriminate between threatened and non-threatened priority areas.

Results 19% of the priority areas for birds are covered by national protected areas and 23% are covered by Natura 2000 sites. The spatial mismatch between protected area networks and priority areas for birds is projected to increase with climate change. But there are opportunities to improve the protection of birds under climate change, as half of the priority areas are currently neither protected nor in conflict with urban or agricultural land-uses.

Conclusions We identify critical areas for bird conservation both under current and climate change conditions, and propose that they could guide the establishment of new conservation areas across the Iberian Peninsula complementing existing protected areas.

Keywords Bioclimatic envelope models • Breeding birds • Conservation planning • Land-use change • Natura 2000 • Portugal • Protected areas • Reserve networks • Spain • Zonation software.

Introduction

Protected areas are a popular planning instrument for conservation of natural ecosystems and biodiversity. They can be effective, if well managed, at stopping or reducing the negative effects of surrounding land uses (e.g., Eklund et al. 2011; ter Steege et al. 2015). However, the effectiveness of existing protected areas at minimising the negative effects of future climatic and land-use changes on biodiversity has been systematically questioned (e.g., Hannah et al. 2007; Alagador et al. 2014). The fact that protected areas are fixed in space makes them likely to undergo changes in their species composition and richness as climate changes (Hole et al. 2009; Araújo et al. 2011). Such changes in biodiversity are the result of different types of biological responses to climate change such as species range expansions, contractions, displacement, or elevational shifts (e.g., Davis and Shaw, 2001; Forero-Medina et al. 2011; Roth et al. 2014), as well as phenological and behavioural changes (e.g., Badeck et al. 2004). Even under scenarios of marked global environmental changes, protected areas are likely to remain important despite turnover in species composition and richness (Thomas et al. 2012; Thuiller et al. 2014a; Thomas and Gillingham 2015), because they are often the most pristine habitat in otherwise highly modified landscape matrices.

The Iberian Peninsula is part of the Mediterranean biodiversity hotspot (Myers et al. 2000) and harbours as much as half of the European terrestrial vertebrate and plant species (Araújo et al. 2007) as well as a high proportion of endemic species (Williams et al. 2000). Such relatively high biodiversity is probably the outcome of several combined factors, chiefly among them the high environmental and geographical heterogeneity that generates opportunities for concatenation of niches in relatively small areas (Baselga and Araújo 2010), and the role of Iberia as a glacial refugia for many European species during the Quaternary cold periods (Hewitt 2000). In addition, the Iberian Peninsula is recognized as one of the most vulnerable regions to climate change with expected extensive warming and increase of droughts (IPCC 2014). Moreover, the Iberian Peninsula is a highly populated region with approximately 53 million people and plays a key role in the European agricultural production (Civantos et al. 2012).

Iberia is covered by an extensive network of conservation areas that includes two major types: (i) nationally-designated protected areas; and (ii) European Union (EU)-designated Natura 2000 sites. Hereafter we use ‘conservation area networks’ to collectively refer to both types of conservation planning designations. The goal of the Natura 2000 network is to ensure the persistence of some of the most valuable species and habitats at the European level. It is comprised of Special Areas of Conservation (SACs) designated under the EU Habitats Directive to conserve rare and vulnerable non-bird animals, plants and habitats, and Special Protection Areas (SPAs) designated under the EU Birds Directive to preserve important sites for rare and vulnerable birds. The Iberian Peninsula plays a fundamental role in the Natura 2000 network. The network covers 27% of the Spanish territory, highest areal per country contribution across EU member countries (Europarc-España 2014), and 21% of the Portuguese territory (ICNF 2013). Despite the large extent of the Iberian conservation area networks, many species are still not covered by these areas. This is especially true for non-charismatic species groups like lichens or invertebrates which are usually underrepresented (e.g., Martínez et al. 2006; Araújo et al. 2007; Hernández-Manrique et al. 2012).

Bird species have been the target of multiple climate change impact studies (e.g., Kujala et al. 2013; Thuiller et al. 2014b). Being a mobile group, birds often respond to climatic changes by shifting their distributions following climate. For example, Tellería et al. (2016) showed that some birds in the Iberian Peninsula are already responding to climate change. However, bird distribution shifts are reportedly lagging behind temperature shifts at the European level (Devictor et al. 2012). There is a large body of literature showing that beyond climatic tolerances, bird distributions and behaviour also depend on a variety of factors related to life-history traits, availability of food, habitat and human disturbances, and the relative role of each of these factors can vary at different spatial and temporal scales (e.g., Triviño et al. 2013; Howard et al. 2015). For example, within the Iberian Peninsula, Triviño et al. (2011) showed that, at the spatial scale of 10 x 10 km, models for bird species fitted with climate data were always improved compared with models fitted with vegetation or landscape configuration variables. They also found that a large fraction of bird species would be highly exposed to future environmental changes: under A2 emission scenario 62% of the species were projected to contract their current distribution, while 38% were projected to experience range expansions. However, bird species projected to be highly exposed to future environmental changes in Iberia are, at the same time, less susceptible to local extinctions because they possess traits that increase their natural resilience (Triviño et al. 2013). An important question that remains to be answered is whether the current Iberian conservation area networks are adequate to conserve bird species under climate and land-use changes and, if not, where future conservation priorities should be.

There are two main strategies to incorporate concern for climate change within spatial conservation prioritization (Araújo 2009). Firstly, model species range dynamics and combine the outputs of the models with optimal conservation planning methodologies that seek to maximize species coverage within conservation areas (for a review see Alagador et al. 2016). Secondly, focus on geodiversity and climate change metrics as coarse filter strategy for the identification of climate resilient areas without recurring to complex modelling of individual species responses to climate change (e.g., Beier et al. 2015; Garcia et al. 2016). However, any of these approaches generally lacks consideration of the need of exploring trade-offs between climate change and land-use changes (but see Fordham et al. 2013). Here, we develop an approach whereby spatial conservation priorities are identified by accounting for projections of individual species distributional shifts under climate change while addressing threats and opportunities brought by projected land-use changes.

We exemplify the approach using birds as focal taxa and the Iberian conservation area networks as the context in which the conservation planning approach is developed. As first step we identify optimal conservation areas that maximise representation of both current and projected future distributions of terrestrial bird species within the Iberian Peninsula. Following, we ask: (1) what proportion of the identified priority areas are already protected under existing legislation; (2) what proportion of the identified priority areas is more and less threatened by projected agricultural or urban land-use changes. With such analyses we were able to identify the areas suitable for bird conservation under climate change and that were neither protected nor threatened by current or future land-use change.

Methods

Species and climate data

Assessments were undertaken using baseline and future projected distributions of 168 terrestrial native breeding birds in the Iberian Peninsula. Details of the models are provided in a previous study (Triviño et al. 2011). Our analyses of bird distributions excluded species with less than 20 records to avoid problems of modelling species with small sample size (Stockwell and Peterson 2002). The distributions are based on presence-absence data extracted from the breeding birds atlases of Spain (Martí and del Moral 2003) and Portugal (Equipa Atlas 2008), across 5,923 10x10 km resolution grid cells. Baseline and projected future distributions were modelled using climatic variables (see below) and two modelling techniques: Random Forests and Boosted Regression Trees. The maximum number of trees was 700 for Random Forests and 3000 for Boosted Regression Trees. All models were run using default options of the BIOMOD package (Thuiller et al. 2009). For each time period the average across the two models was used as the final output since evidence exists that averaging across model outputs can cancel outliers and improve overall projections (Araújo et al. 2005).

Baseline (period 1971-1990) and future climatic data (period 2051-2080) included three variables: mean winter temperature (ºC), annual precipitation (mm) and accumulated degree days (January to August). The baseline climatic data were obtained from the Portuguese and Spanish meteorological agencies (IM and AEMET, respectively), interpolated to a UTM 10×10 km grid (Araújo et al., 2012). Future climate scenarios from the EU framework program Assessing Large-scale environmental Risks for biodiversity with tested Methods (ALARM) were used. The chosen climate scenario was derived from a simulation with the global climate model HadCM3, using the BAMBU (Business As Might Be Usual) scenario (which corresponds to A2 SRES) of the ALARM project (see Triviño et al. 2011 for further details).

We subdivided the 168 breeding bird species into two groups: 'agricultural' and 'non-agricultural' species. The information was gathered from a Spanish Ornithological Society document (SEO/BirdLife, 2010) and complemented it by consultation with experts (see Appendix S4). In our study, there were 47 species associated with agricultural areas, representing 28% of the modelled species. Agricultural areas are more predominant in Natura 2000 sites than in national protected areas (croplands and permanent croplands represent 15% of the national protected areas whereas they represent almost 24% in Natura 2000, see Table 2).

Conservation areas data

We used two conservation areas datasets: the nationally-designated protected areas network and the European Union-designated Natura 2000 network (ICNF 2013; MAGRAMA 2013). We excluded areas that were solely designated by international conventions like UNESCO World Heritage sites (UNESCO Man and Biosphere reserves and Ramsar Wetlands of International Importance), because most international conventions have no regulatory power to enforce protection (Jenkins and Joppa 2010). Auxiliary analyses with the excluded areas are provided in the supplementary material (Appendix S1).

Land-use data

The projected land-use change scenarios were based on the Coordination of Information on the Environment (CORINE Land Cover 2000; EEA, 2000). CORINE 2000 dataset was used as a baseline for the downscaling of the future scenarios (2080) at a spatial resolution of 250 meters (see Rounsevell et al. 2006 and Dendoncker et al. 2007 for methodological details). The forty-four land cover classes from CORINE were aggregated into six classes: urban, cropland, permanent crops, grasslands, forest and others (for a complete description of the methodology see Dendoncker et al. 2007, despite in this reference they use the PELCOM dataset, CORINE 2000 dataset was used for this study). We further aggregated those six land-use categories into three coarse types (natural, agricultural and urban) that can reasonably be used as surrogates for threat because the association between land-use intensification and declines in bird populations has been well documented (e.g., Verhulst et al. 2004). We define 'natural' lands as those classified as natural vegetation (e.g., grasslands and forests) as well as others categories (e.g., bare rocks and burnt areas). We define 'agricultural' lands as those classified as croplands and permanent croplands. To have a better understanding of the composition of the two agricultural land-use types we calculated the percentage of surface covered by the land-use categories of CORINE Land Cover 2000 (see Appendix S2). Finally, we define 'urban' lands as those as built-up land cover categories.

Conservation prioritization

We identified areas of high bird conservation priority using the spatial prioritization software Zonation (Moilanen et al. 2012 and references therein) and accounting for: (i) the baseline and potential future distributions of all 168 bird species; and (ii) the connectivity between species' baseline and projected future distributions to facilitate the anticipated species range shifts under changing climatic conditions similarly to Kujala and colleagues (2013). Zonation is a conservation support tool that identifies areas that maximize the representation and habitat quality for multiple species across large regions. It produces a hierarchical ranking of sites across the entire study area, where increasing rank values indicate increasing priority for conservation and a relatively small proportion of the top-ranked sites typically represent most or all biodiversity features and their core habitats (Fig. 1). We used the core area zonation (CAZ) algorithm to determine the conservation value in each cell. All species were weighted equally and we did not include cost of land to the analyses. We note that here the term 'core' refers to areas of highest value or, as in this study, areas of highest climatic suitability, within each species distribution, without reflecting any geographical positioning.

To account for connectivity between baseline and projected future distributions, we used the 'species interactions' technique of Zonation, which allows calculation of connectivity between two distributions (Moilanen and Kujala 2008). This technique is based on the metapopulation connectivity measure, in which connectivity of any given focal site is dependent on its distance to other sites, the local value of both focal and other sites, and the dispersal ability of the respective species (Hanski 1998; Moilanen and Nieminen 2002). Based on information on observed bird range shifts in the last decades (Brommer and Møller 2010), we set the dispersal distance of all species to 11 km/decade, corresponding to a dispersal distance of 77.3 km for the time period considered in our study. We carried out a sensitivity analysis using different dispersal rates to analyse how dispersal affects the results (Appendix S3).

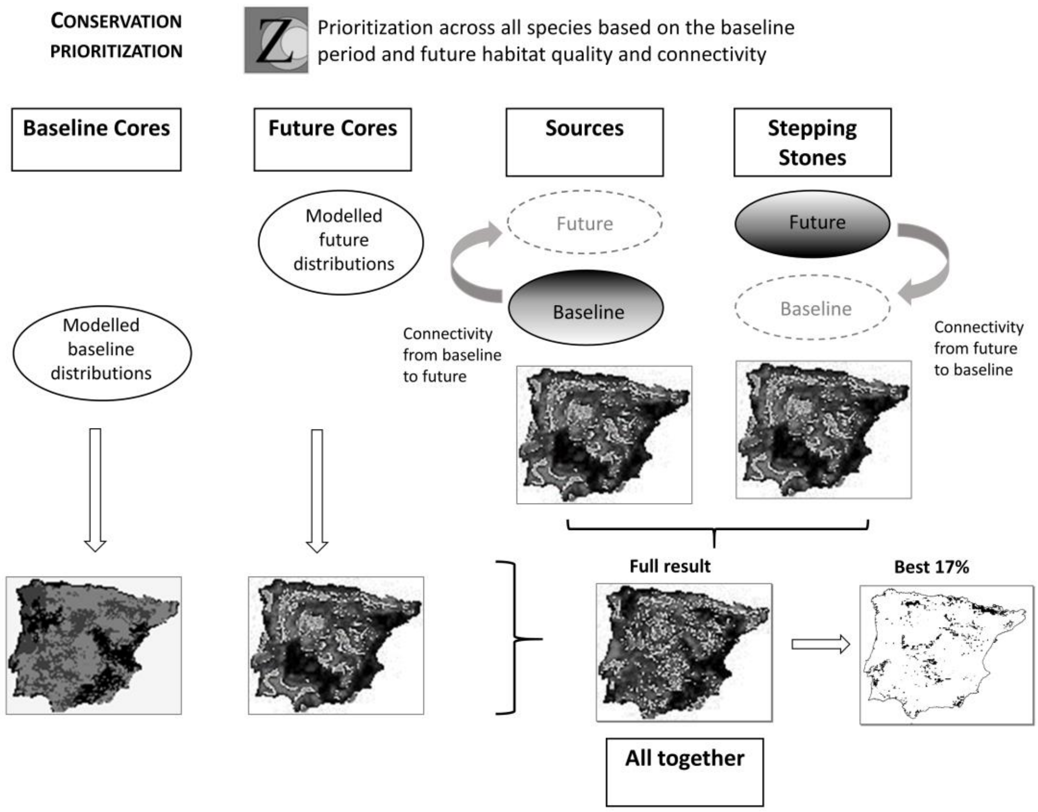

Fig. 1 Flow chart showing the five spatial conservation prioritization carried out. Modelled species distribution maps for baseline and future were created using the modelling techniques Random Forests and Boosted Regression Trees. Connectivity maps were created based on the baseline and future layers. The rest of the analyses and graphs are based on the top 17% priorities of each Zonation result.

We used two spatial connectivity measures per species to identify priority areas that facilitate dispersal to projected future distribution areas. The first connectivity was calculated from the baseline period to the future period, whereby highest values were given to areas within baseline distribution that are climatically most suitable for the species and geographically close to the expected future distribution given species dispersal limitations. Under climate change, these areas are expected to act as sources from where dispersal to future distributions takes place (hereafter called ‘source areas’). For the second measure, connectivity was similarly calculated from future to baseline, and highest values were given to those highly suitable future areas that are well connected to baseline areas and, thus, are expected to help species reach the core areas of their future distribution (hereafter called ‘stepping stones’).

Hence, for each species, there were four types of distributions relevant for the conservation prioritization: the modelled baseline distribution, hereafter called ‘baseline cores’ (BC), the modelled future distribution, hereafter called ‘future cores’ (FC), source areas (S) and stepping stones (SS). Using Zonation we produced conservation prioritizations for the Iberian Peninsula across all species by: (i) separately accounting for each of the relevant distributions per species (hence, four different solutions); and (ii) simultaneously accounting for all four relevant distributions per species (one solution, hereafter called ‘All together’, Alt). We assigned to each top priority cell within the ‘All together’ a value from the previous categories (BC, FC, S or SS) depending on which had the highest average value across the species. From each of these five prioritization results we selected the highest 17% ranking areas, corresponding to the Nagoya meeting goal of protecting 17% of terrestrial ecosystems by 2020 (Convention Biological Diversity 2010). See Fig. 1 for an illustrative diagram of the prioritization procedure.

Overlap between conservation priorities and conservation area networks

We measure the extent to which the identified bird conservation priorities are protected. We analysed how well the conservation area networks represented the important areas for birds by overlapping each conservation network with the identified conservation priority areas. We calculated three types of measure: (i) the percentage of priority cells that overlap with protected areas or Natura 2000 sites, (ii) the percentage of cells that overlap more than 50% and (iii) the mean percentage of overlap area.

We reanalysed the level of protection separately for the two groups of species: ‘agricultural’ and ‘non-agricultural’. We repeated both the spatial prioritization and the percentage of overlap analyses.

Land-use threats and potential for conservation

We used three broad land-use types (natural, agricultural and urban) as a surrogate to the threats for bird species posed by habitat loss. We considered natural as no threat and the two other land-use types as threat.

To determine the spatial distribution of land-use change we calculated the difference between the baseline and future projection in the proportion of area covered by natural, agricultural and urban areas within each one of the following categories: (i) protected (PAs and Natura 2000), (ii) non-protected (which refers to all areas outside PAs and Natura 2000 sites) and (iii) identified priority areas (All together, Baseline Cores and Future Cores). Finally, we identified areas with potential for conservation which are identified as priorities for bird species conservation under climate change but are neither protected nor projected to be threatened by agricultural or urban land-use change.

Results

Conservation priorities for Iberian bird species

Models projections showed that bird species generally shift ranges towards mountainous regions (most future cores are located in the Pyrenees) (Fig. 2). There was high spatial congruence between conservation priorities identified for 'all species' (N = 168) and 'non-agricultural species' (N = 121), although 'stepping stones' were notably lacking for the prioritization undertaken with 'non-agricultural species'. The spatial distribution of the conservation priorities for 'agricultural species' (N = 47) was more aggregated and compact across cropland areas (Fig. 2). Sensitivity analyses of how different dispersal rates affected conservation priorities showed that connectivity was only important for species with intermediate dispersal rates (50-77.3 km, estimates for the time period considered in our study). Lower dispersal rates meant that species were unable to track climatic changes, whereas species with higher dispersal rates did not require corridors or stepping-stones to disperse to future areas of suitable climate (see Appendix S3).

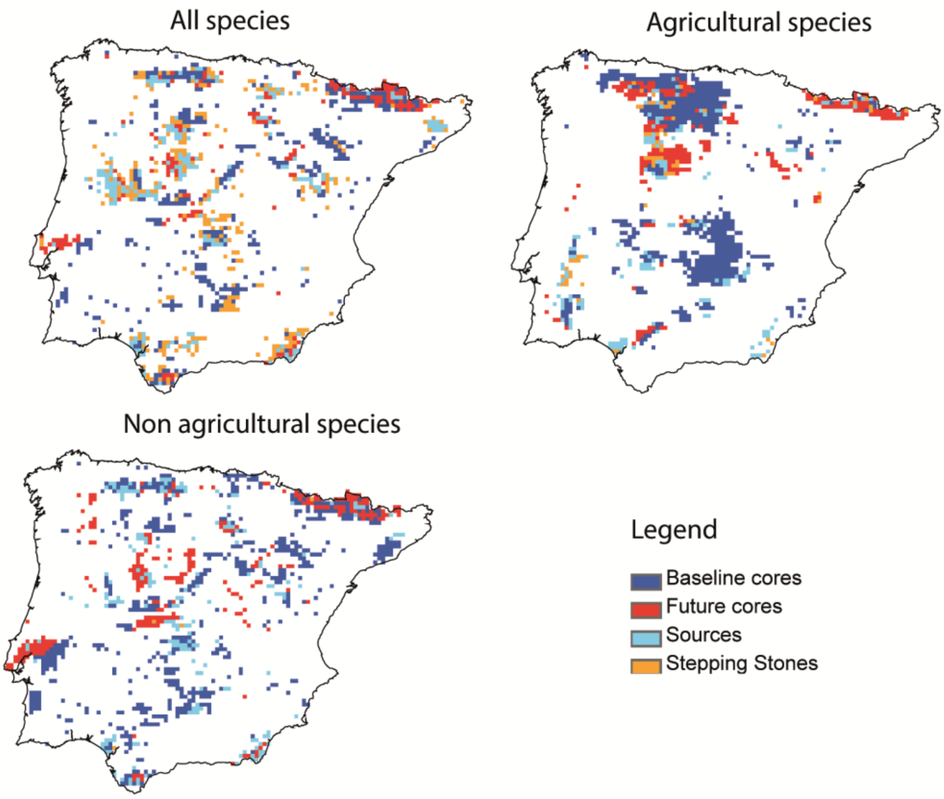

Fig. 2 Top conservation priority areas for Iberian bird species. These include baseline and future modelled distributions under climate change and the respective connectivity measures for the estimated mean dispersal distance of 77.3 km. Colours represent the classification of the top 17% priorities into their relative importance as baseline cores, future cores, sources and stepping stones.

Overlap between conservation priority areas and conservation area networks

The extent to which existing conservation networks covered key priority areas for Iberian birds under climate change depended on the species pool considered. Across all species, Natura 2000 sites covered the bird conservation priorities better (23% of mean overlap) than PAs (19%). However, when agricultural and non-agricultural species groups were analysed separately, Natura 2000 sites covered priorities of agricultural species better (28%) than those of the non-agricultural group (14%). In contrast, the PAs covered better the priorities for non-agricultural species (19%) than for agricultural species (12%) (Table 1).

Table 1. Overlap between conservation priority areas and conservation area networks.

Three measures of overlap (proportion of cells with any overlap; proportion of cells with >50% overlap, and the mean percentage of overlap) between identified conservation priority areas and the two conservation area networks: nationally-designated protected areas (PAs) and Natura 2000 (Natura). Overlaps are shown for three of the prioritization results (Alt = All together; BC = baseline distributions only; FC = future distributions only) and for all species and subsets of agricultural and non-agricultural species.

		All species			**Agricultural species**			**Non-agricultural species**		
		% cells	**% cells > 50%**	**Mean % overlap**	**% cells**	**% cells > 50%**	**Mean % overlap**	**% cells**	**% cells > 50%**	**Mean % overlap**
PAs	**Alt**	48.0%	18.0%	18.8%	33.9%	11.0%	11.9%	47.2%	18.0%	18.8%
	BC	49.0%	18.6%	19.4%	34.6%	10.9%	11.7%	50.7%	19.3%	20.3%
	FC	41.0%	14.6%	15.3%	34.0%	14.0%	14.2%	41.1%	14.6%	15.3%
Natura	**Alt**	51.6%	22.2%	22.9%	77.3%	24.8%	27.9%	27.4%	14.0%	14.1%
	BC	83.7%	37.3%	39.2%	77.4%	24.8%	27.9%	84.5%	38.6%	40.1%
	FC	75.3%	27.8%	29.8%	77.7%	29.4%	31.3%	75.4%	28.1%	30.0%

If we separate the overlap of the two networks, based on the baseline and the future potential distributions, current conservation networks had a higher overlap with baseline cores than with future cores (Fig. 3). Under climate change the expected decrease in the protection of core areas for all and non-agricultural species was higher for the Natura 2000 (9.4% and 10.1% respectively) than for the nationally-designated protected area network (4.1% and 5.0% respectively) (Table 1). However, agricultural species were projected to gain protection under climate change both in Natura 2000 (3.4%) and in the nationally-designated protected area network (2.5%) (Table 1).

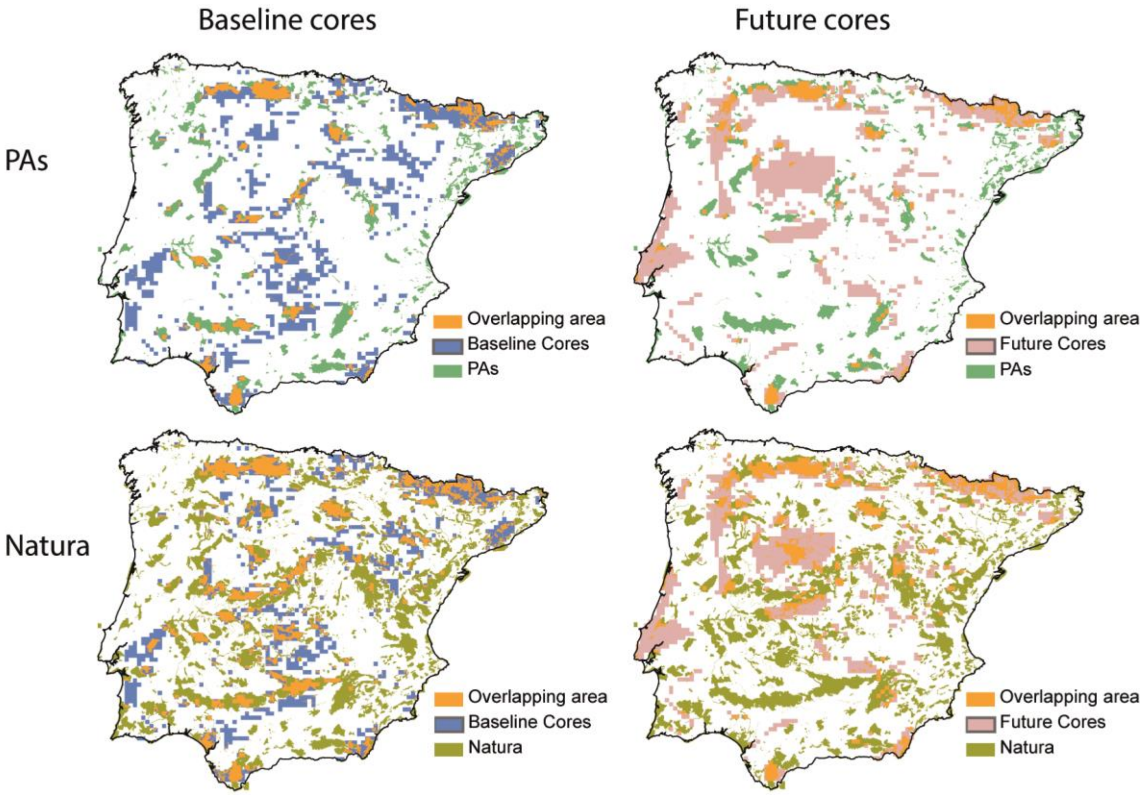

Fig. 3 Overlap between top conservation priority areas and conservation area networks. The maps show the overlap between identified priority areas for all species in the baseline (Baseline cores) and future (Future cores) time period and the two conservation area networks: Protected Areas (PAs) and Natura 2000 (Natura).

Land-use threats and potential for conservation

Using the three land-use categories ('natural', 'agricultural' and 'urban') to calculate the spatial distribution of threats, i.e., considering everything not natural as a threat, we found that half of the non-protected area, and approximately 40% of the identified conservation priority areas were currently threatened by land-use practices. Within the conservation networks, the majority of the land is in natural state (76% within Natura 2000 sites and 84% within PAs), but notably almost one-quarter of the Natura 2000 network is dominated by agricultural and urban zones. While agricultural lands currently overlap most extensively with conservation areas, their extent is expected to decrease in the future (Table 2). Urban areas constitute only a small fraction of current and future threats, but their role is nevertheless expected to increase by the year 2080. Natural forests and grasslands currently cover over 50% of all analysed areas and their proportion is expected to further increase in the future. Overall, in all land types (‘protected’, ‘non-protected’, ‘priority areas’) natural areas are expected to increase whereas agricultural and urban areas are expected to decrease and remain relatively stable, respectively, by 2080. This change coincides to some degree with species estimated range shifts, as the future cores are expected to experience the steepest increase in natural lands (5.1%) and highest decrease in ‘agricultural’ areas (5.2%) in comparison to the current state of these locations. Despite these favourable developments, one-third of all identified priority areas are projected to be threatened by land use in the future (Table 2).

Table 2. Spatial distribution of land-use change.

Natural area is represented by *Grasslands*, *Forests* and *Others* land-use categories; Agricultural area is represented by *Croplands* and *Permanent Croplands* land-use categories and Urban areas is represented by *Urban* land-use category. *Non-protected* refers to all areas outside Protected Areas (PAs) and Natura 2000 sites.

		% Natural area		% Agricultural area		% Urban area	
Zone	Area (km^2)	2080	Change 2000-2080	2080	Change 2000-2080	2080	Change 2000-2080
PAs	65,771	86.45%	2.02	12.89%	-2.20	0.66%	0.22
Natura 2000	155,805	78.73%	2.66	20.89%	-2.73	0.39%	0.08
Non-protected	497,302	55.26%	4.74	42.69%	-5.00	2.05%	0.26
Conservation priorities							
All together	102,800	64.18%	3.01	34.66%	-2.99	1.17%	-0.01
Baseline Cores	102,800	64.49%	3.30	33.96%	-3.20	1.55%	0.10
Future Cores	102,800	66.28%	5.14	32.40%	-5.16	1.31%	0.01

When estimating the level of protection and land-use threats for conservation we found only small differences between the five types of identified conservation priorities. Among all priority areas, the percentage of protection was lower than 20% and the level of threat posed by current land-use practices was close to 40%. Over 50% of all identified priority areas were not protected and currently not threatened by land-uses, future cores having the greatest potential for conservation (55.5%) (Table 3). These areas were mainly located in mountainous regions like the southern part of the Pyrenees or the Cantabrian as well as in the southwest of the Iberian Peninsula (Fig. 4).

Table 3. Reclassification of conservation priority areas to show potential for conservation. 'Protected': mean average overlap between the priority areas and the nationally-designated protected area network; 'Threatened': percentage of cells of each one of the priority areas that overlap with agricultural and urban areas from baseline time period; 'Potential for conservation': percentage of cells that are neither protected nor threatened at the baseline time period. Note that numbers in each row do not necessarily sum up to 100% as the percentage of protected was calculated as the mean average overlap whereas the percentage of threatened was calculated as the percentage of cells that overlap with agricultural and urban areas.

	Protected	Threatened	Potential for conservation
Alt	18.8%	38.8%	54.1%
BC	19.4%	38.6%	54.3%
FC	15.3%	38.9%	55.5%
S	18.1%	40.0%	53.2%
SS	17.9%	40.0%	53.1%

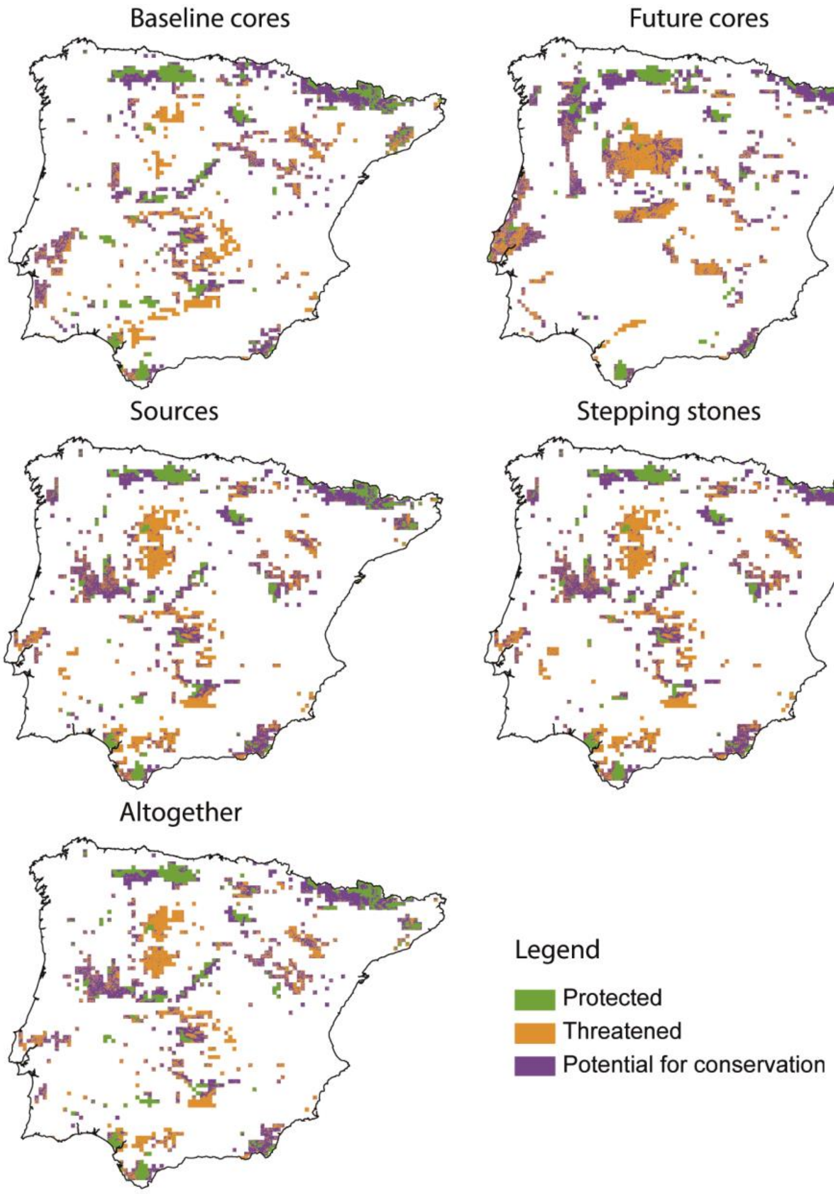

Fig. 4 Reclassification of top conservation priority areas to show potential for conservation. The maps show the top conservation priority areas for Iberian bird species reclassified into three categories: 'Protected': priority areas that overlap with the nationally-designated protected area network; 'Threatened': priority areas that overlap with baseline agricultural and urban areas; 'Potential for conservation': priority areas that are neither protected nor threatened at the baseline period. The five panels represent the five different conservation prioritization options.

Discussion

We present an approach to identify priorities for climate change adaptation and explore threats and opportunities posed by land-use changes. Our results highlight a spatial mismatch between the established Iberian conservation area networks and the identified priority areas for birds under climate change. We also found that there are several opportunities to improve the protection of bird species under climate change, as half of the identified conservation priority areas are currently not protected and do not conflict with urban or agricultural land-uses. Finally, land-use pressures are predicted to decrease in both conservation area networks towards the end of the century potentially creating opportunities to alleviate some of the negative impacts of climate change. Climate change, on the other hand, will increase the spatial mismatches between established protected areas and the newly identified priorities, particularly for non-agricultural bird species.

Are conservation priority areas for birds well represented within Iberian conservation area networks?

Previous studies have shown that Iberian bird species are currently reasonable well represented within the conservation area networks (Carrascal and Lobo 2003; Araújo et al. 2007). However, when taking into account the needs of birds under climate change we found that existing conservation networks were insufficient to account for both current and future potential distributions of these species. Our study highlights that only 19% of the conservation priority areas, which cover the core climatic conditions of species' current and future potential distributions as well as the connectivity between them, are protected. We also found that the overlap of Natura 2000 sites with both baseline and future conservation priority areas was higher than for the nationally-designated protected areas. This difference in coverage can be partly attributed to the larger extent of the Natura 2000 network which is more than double the size of the nationally-designated protected area network. Another explanation is that Natura 2000 specifically targets bird conservation, as Natura 2000 sites include Special Protection Areas (SPAs), designated under the Birds Directive (Assunção-Albuquerque et al. 2012; Regos et al. 2016). On the other hand, the level of protection of Natura 2000 sites is usually lower than that of protected areas as a wide range of human activities are allowed within the network. Furthermore, as more flatlands are generally included in Natura 2000 sites than in protected areas (Araújo et al. 2011), species inhabiting Natura 2000 network sites are expected to be more vulnerable as proportional range losses under climate change are greater there (Peterson 2003).

Does the effectiveness of Iberian conservation networks decrease under climate change?

Since conservation networks are generally designed to isolate current species distributions from existing external threats, it comes with no surprise that they would represent baseline priority areas better than future ones. This finding is in line with earlier studies that showed that current protected areas would generally not retain suitable climatic conditions for many of the species for which they were originally designated under scenarios of climate change (Araújo et al. 2004; Huntley et al. 2008; Hole et al. 2009; Lung et al. 2014; Garden et al. 2015). Within Iberia the same pattern holds true: future bird priority areas display a small level of overlay with existing conservation networks owing to projected shifts in the distributions of Iberian birds as a result of climatic, land-use, vegetation and fire regimes changes (Triviño et al. 2011; Araújo et al. 2012; Regos et al. 2016). When examining patterns for species with specific habitat requirements, we found that forest bird species are expected to be less vulnerable to climate change because models project increases in forest cover, hence there will be more opportunities for colonisation (Araújo et al. 2008) and because forests could serve as a possible buffer to the impacts of climate change (Jarzyna et al. 2016). Species favouring agricultural lands were expected to be able to track climatic changes, but land-use projections indicate a decrease of agricultural area in the future. Therefore, while agricultural species seems to have great ability to colonise new areas as they become suitable they will also require active management of the countryside if suitable habitat is to be maintained for them.

Threats posed by land-use pressures

Our results show that a substantial percentage of conservation priority areas are threatened by land-use pressures both currently (~40%) and in the future (~30%). Urban areas are expected to expand in the future whereas agricultural areas are expected to decrease, which is in line with previous studies (Araújo et al. 2008; Underwood et al. 2009). At the same time, natural areas are expected to expand, following an increase in forest cover. Indeed, the Iberian Peninsula is already experiencing large scale forest regeneration due to abandonment of agricultural areas and this trend is expected to continue (Rey Benayas et al. 2007; Gil-Tena et al. 2009; Álvarez-Martínez et al. 2011). Such changes are likely to favour expansion of forest bird species, especially forest specialists, but not species associated with traditional agricultural systems (Gil-Tena et al. 2007). In this study we assumed all agricultural practices, as identified by CORINE land cover data (Table S4 in Appendix S2), to be threats to the studied bird species. We acknowledge that not all agricultural species will be impacted by these practices in the same way: a more realistic approach would differentiate between traditional and intense agricultural practices. However, in order to capture the differences between traditional agricultural practices (beneficial for conservation) and intense agricultural practices a more detailed data on land-use categories would be needed. In addition, in the Mediterranean region of the Iberian Peninsula fire plays a key role in the maintenance of bird diversity by enhancement of open habitats and landscape heterogeneity (e.g., Vallecillo et al. 2008; Regos et al. 2016). We acknowledge that there are other threats affecting Iberian birds besides climate and land-use changes such as roads (Torres et al. 2011), poison or human disturbance of nest sites among others (Madroño et al. 2004). However, these threats are beyond the scope of our study and not manageable at this spatial resolution.

Potential for conservation for Iberian bird species under climate change

The fact that climate change may increase the spatial mismatch between already established protected areas and conservation priority areas urgently calls for adaptive conservation measures. A common strategy to reduce the negative impacts of climate change on biodiversity will certainly include the establishment of new protected areas to increase the available habitat for species and ensure the existence of suitable pathways for species dispersal (Heller and Zavaleta 2009; Mawdsley et al. 2009). The large proportion of natural or semi-natural land within projected important areas for bird conservation that is still not protected could be viewed as a conservation opportunity. It would probably be cost-efficient to implement conservation actions on the areas that we identified being of high value for bird conservation and low conflict with other land-uses. On the other hand, land sharing (Fischer et al. 2014) could be a good strategy for areas with high conservation value but in high conflict with other land-uses. Studies, like this one, that combine forecasts of species range shifts under climate change with spatial conservation planning tools are needed to respond proactively to the new conservation challenges (Williams et al. 2005; Phillips et al. 2008; Carroll et al. 2010). However, given the many sources of uncertainty and the complexities, dialogs and compromises encountered in conservation decision making, we acknowledge that solutions proposed need to be flexible enough, yet highlight important conservation needs that can easily be accounted for. Finally, we acknowledge that our approach is centered on a climate adaptation strategy which promotes the conservation of species. However, there are other approaches for adapting conservation to climate change that are also worth considering such as identifying spaces of climatic resilience, without the need of projecting species specific responses (e.g., Beier et al. 2015).

Acknowledgments

M.T. thanks Wilfried Thuiller, the participants of the Ibiochange Lab Retreat, the jury of her PhD defense and people from the Journal Club in Jyväskylä for insightful comments and suggestions. M.T. also thanks the Metapopulation Research Centre at the University of Helsinki for providing the supportive environment in which much of this work was developed. We thank two anonymous reviewers and the associated editor for their helpful comments. M.T. is supported by a FPI-MICINN fellowship and KONE foundation; H.K. by the LUOVA Doctoral Programme and the Australian National Environmental Research Program (NERP); M.C. by the Academy of Finland (grant #257686).

References

Alagador D, Cerdeira JO, Araújo MB (2014) Shifting protected areas: scheduling spatial priorities under climate change. J Appl Ecol 51:703–713.

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

Álvarez-Martínez JM, Suárez-Seoane S, De Luis Calabuig E (2011) Modelling the risk of land cover change from environmental and socio-economic drivers in heterogeneous and changing landscapes: The role of uncertainty. Landsc Urban Plan 101:108–119.

Araújo MB, Nogués-Bravo D, Reginster I, et al (2008) Exposure of European biodiversity to changes in human-induced pressures. Environ Sci Policy 11:38–45.

Araújo, M.B. 2009 Climate Change and Spatial Conservation Planning. In Spatial Conservation Prioritization: quantitative methods and computational tools (eds. A. Moilanen, H. Possingham & K. Wilson), pp. 172-184. Oxford, Oxford University Press.

Araújo MB, Alagador D, Cabeza M, et al (2011) Climate change threatens European conservation areas. Ecol Lett 14:484–492.

Araújo MB, Cabeza M, Thuiller W, et al (2004) Would climate change drive species out of reserves? An assessment of existing reserve-selection methods. Glob Chang Biol 10:1618–1626.

Araújo MB, Guilhaumon F, Neto DR, et al (2012) Biodiversidade e Alterações Climáticas /Biodiversidad y Alteraciones Climáticas. Ministério do Ambiente e Ordenamento do Território & Ministerio de Medio Ambiente y Medio Rural y Marino, Lisboa /Madrid

Araújo MB, Lobo JM, Moreno JC (2007) The effectiveness of Iberian protected areas in conserving terrestrial biodiversity. Conserv Biol 21:1423–1432.

Araújo MB, Whittaker RJ, Ladle RJ, Erhard M (2005) Reducing uncertainty in projections of extinction risk from climate change. Glob Ecol Biogeogr 14:529–538.

Assunção-Albuquerque MJT, Rey Benayas JM, Albuquerque FS, Rodríguez MÁ (2012) The geography of high-value biodiversity areas for terrestrial vertebrates in Western Europe and their coverage by protected area networks. Web Ecol 12:65–73.

Badeck F-W, Bondeau A, Böttcher K, et al (2004) Responses of spring phenology to climate change. New Phytol 162:295–309.

Baselga A, Araújo MB (2010) Do community-level models describe community variation effectively? J Biogeogr 37:1842–1850.

Beier P, Hunter ML, Anderson M (2015) Introduction to Special Section: Conserving Nature's Stage. Conserv Biol 29:613–617.

Brommer JE, Møller AP (2010) Range margins, climate change, and ecology. In: Møller AP, Fieldler W, Berthlod P (eds) Effects of Climate Change on Birds. Oxford University Press,

Carrascal LM, Lobo JM (2003) Respuestas a viejas preguntas con nuevos datos: estudio de los patrones de distribución de la avifauna española y consecuencias para su conservación. In: Ministerio de Medio Ambiente – SEO/BirdLife M (ed) Atlas de las aves reproductoras de España (ed. by R. Martí and J.C. Del Moral),. pp 651–668, 718–721

Carroll C, Dunk JR, Moilanen A (2010) Optimizing resiliency of reserve networks to climate change: multispecies conservation planning in the Pacific Northwest, USA. Glob Chang Biol 16:891–904.

Civantos E, Thuiller W, Maiorano L, et al (2012) Potential impacts of climate change on ecosystem services in Europe: the case of pest control by vertebrates. Bioscience 62:658–666.

Convention Biological Diversity (2010) Aichi biodiversity targets of the strategic plan 2011–2020. http://www.cbd.int/sp/targets/.

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

Dendoncker N, Rounsevell M, Bogaert P (2007) Spatial analysis and modelling of land use distributions in Belgium. Comput Environ Urban Syst 31:188–205.

Devictor V, van Swaay C, Brereton T, et al (2012) Differences in the climatic debts of birds and butterflies at a continental scale. Nat Clim Chang 2:121–124.

Eklund J, Arponen A, Visconti P, Cabeza M (2011) Governance factors in the identification of global conservation priorities for mammals. Philos Trans R Soc B Biol Sci 366:2661–2669.

Equipa Atlas (2008) Atlas das aves nidificantes em Portugal (1999-2005). Assírio & Alvim, Lisboa.

Europarc-España (2014) EUROPARC-España Anuario 2013 del estado de las áreas protegidas en España.

European Environmental Agency (2000) CORINE Land Cover. European Environmental Agency, Luxembourg.

Fischer J, Abson DJ, Butsic V, et al (2014) Land Sparing Versus Land Sharing: Moving Forward. Conserv Lett 7:149–157.

Fordham DA, Akçakaya HR, Brook BW, et al (2013) Adapted conservation measures are required to save the Iberian lynx in a changing climate. Nat Clim Chang 3:899–903.

Forero-Medina G, Terborgh J, Socolar SJ, Pimm SL (2011) Elevational ranges of birds on a tropical montane gradient lag behind warming temperatures. PLoS One 6:e28535.

Garcia RA, Cabeza M, Altwegg R, Araújo MB (2016) Do projections from bioclimatic envelope models and climate change metrics match? Glob Ecol Biogeogr 25:65–74.

Garden JG, O'Donnell T, Catterall CP (2015) Changing habitat areas and static reserves: challenges to species protection under climate change. Landsc Ecol 30:1959–1973.

Gil-Tena A, Brotons L, Saura S (2009) Mediterranean forest dynamics and forest bird distribution changes in the late 20th century. Glob Chang Biol 15:474–485.

Gil-Tena A, Saura S, Brotons L (2007) Effects of forest composition and structure on bird species richness in a Mediterranean context: Implications for forest ecosystem management. For Ecol Manage 242:470–476.

Hannah L, Midgley G, Andelman S, et al (2007) Protected area needs in a changing climate. Front Ecol Environ 5:131–138.

Hanski I (1998) Metapopulation dynamics. Nature 396:41–49.

Heller NE, Zavaleta ES (2009) Biodiversity management in the face of climate change: A review of 22 years of recommendations. Biol Conserv 142:14–32.

Hernández-Manrique OL, Numa C, Verdú JR, et al (2012) Current protected sites do not allow the representation of endangered invertebrates: the Spanish case. Insect Conserv Divers 5:414–421.

Hewitt G (2000) The genetic legacy of the Quaternary ice ages. Nature 405:907–913.

Hole DG, Willis SG, Pain DJ, et al (2009) Projected impacts of climate change on a continent-wide protected area network. Ecol Lett 12:420–431.

Howard C, Stephens PA, Pearce-Higgins JW, et al (2015) The drivers of avian abundance: patterns in the relative importance of climate and land use. Glob Ecol Biogeogr 24:1249–1260.

Huntley B, Collingham YC, Willis SG, Green RE (2008) Potential impacts of climatic change on European breeding birds. PLoS One 3:e1439.

ICNF (2013) Instituto da Conservação da Natureza e das Florestas (<http://www.icnf.pt/portal/naturaclas/rn2000/rn-pt/rn-PT> accesed 10/08/2015).

IPCC (2014) Climate Change 2014: 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. Cambridge University Press, Cambridge and New York, 1132 pp.

Jarzyna MA, Zuckerberg B, Finley AO, Porter WF (2016) Synergistic effects of climate and land cover: grassland birds are more vulnerable to climate change. Landsc Ecol 1–16.

Jenkins CN, Joppa L (2010) Considering protected area category in conservation analyses. Biol Conserv 143:7–8.

Kujala H, Moilanen A, Araújo MB, Cabeza M (2013) Conservation planning with uncertain climate change projections. PLoS One 8:e53315.

Lung T, Meller L, van Teeffelen AJA, et al (2014) Biodiversity funds and conservation needs in the EU under climate change. Conserv Lett 7:390–400.

Madroño A, González C, Atienza JC (2004) Libro rojo de las aves de España. Dirección General para la Biodiversidad -SEO/Birdlife, Madrid.

MAGRAMA (2013) Ministerio de Agricultura, Alimentación y Medio Ambiente (< http://www.magrama.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/cartografia_informacion_disp.aspx>).

Martínez I, Carreño F, Escudero A, Rubio A (2006) Are threatened lichen species well-protected in Spain? Effectiveness of a protected areas network. Biol Conserv 133:500–511.

Martí R, del Moral JC (2003) Atlas de las aves reproductoras de España. Madrid: Dirección General de Conservación de la Naturaleza & Sociedad Española de Ornitología.

Mawdsley JR, O'Malley R, Ojima DS (2009) A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. Conserv Biol 23:1080–1089.

Moilanen A, Kujala H (2008) Zonation spatial conservation planning framework and software v. 2.0.

Moilanen A, Meller L, Leppänen J, et al (2012) Zonation – Spatial conservation planning framework and software. Version 3.1. User manual. 285 p. Accesible at: http://www.helsinki.fi/bioscience/consplan/software/Zonation/index.html, Helsinki, Finland

Moilanen A, Nieminen M (2002) Simple connectivity measures in spatial ecology. Ecology 83:1131–1145.

Myers N, Mittermeier RA, Mittermeier CG, et al (2000) Biodiversity hotspots for conservation priorities. Nature 403:853–858.

Peterson AT (2003) Projected climate change effects on Rocky Mountain and Great Plains birds: generalities of biodiversity consequences. Glob Chang Biol 9:647–655.

Phillips SJ, Williams P, Midgley G, Archer A (2008) Optimizing dispersal corridors for the Cape Proteaceae using network flow. Ecol Appl 18:1200–1211.

Regos A, D'Amen M, Titeux N, et al (2016) Predicting the future effectiveness of protected areas for bird conservation in Mediterranean ecosystems under climate change and novel fire regime scenarios. Divers Distrib 22:83–96.

Rey Benayas JM, Martins A, Nicolau JM, Schulz JJ (2007) Abandonment of agricultural land: an overview of drivers and consequences. Perspect Agric Vet Sci Nutr Nat Resour 2:No. 57.

Roth T, Plattner M, Amrhein V (2014) Plants, birds and butterflies: short-term responses of species communities to climate warming vary by taxon and with altitude. PLoS One 9:e82490.

Rounsevell MDA, Reginster I, Araújo MB, et al (2006) A coherent set of future land use change scenarios for Europe. Agric Ecosyst Environ 114:57–68.

Stockwell DRB, Peterson AT (2002) Effects of sample size on accuracy of species distribution models. Ecol Modell 148:1–13.

Tellería JL, Fernández-López J, Fandos G (2016) Effect of climate change on Mediterranean winter ranges of two migratory passerines. PLoS One 11:e0146958.

ter Steege H, Pitman NCA, Killeen TJ, et al (2015) Estimating the global conservation status of more than 15,000 Amazonian tree species. Sci Adv 1:1:e1500936.

Thomas CD, Gillingham PK (2015) The performance of protected a reas for biodiversity under climate change. Biol J Linn Soc 115:718–730.

Thomas CD, Gillingham PK, Bradbury RB, et al (2012) Protected areas facilitate species' range expansions. Proc Natl Acad Sci 109:14063–14068.

Thuiller W, Guéguen M, Georges D, et al (2014a) Are different facets of plant diversity well protected against climate and land cover changes? A test study in the French Alps. Ecography 37:1254–1266.

Thuiller W, Lafourcade B, Engler R, Araújo MB (2009) BIOMOD - a platform for ensemble forecasting of species distributions. Ecography 32:369–373.

Thuiller W, Pironon S, Psomas A, et al (2014b) The European functional tree of bird life in the face of global change. Nat Commun 5:3118.

Torres A, Palacín C, Seoane J, Alonso J (2011) Assessing the effects of a highway on a threatened species using Before–During–After and Before–During–After-Control–Impact designs. Biol Conserv 144:2223–2232.

Triviño M, Cabeza M, Thuiller W, et al (2013) Risk assessment for Iberian birds under global change. Biol Conserv 168:192–200.

Triviño M, Thuiller W, Cabeza M, et al (2011) The contribution of vegetation and landscape configuration for predicting environmental change impacts on Iberian birds. PLoS One 6:e29373.

Underwood EC, Viers JH, Klausmeyer KR, et al (2009) Threats and biodiversity in the mediterranean biome. Divers Distrib 15:188–197.

Vallecillo S, Brotons L, Herrando S (2008) Assessing the response of open-habitat bird species to landscape changes in Mediterranean mosaics. Biodivers Conserv 17:103–119.

Verhulst J, Báldi A, Kleijn D (2004) Relationship between land-use intensity and species richness and abundance of birds in Hungary. Agric Ecosyst Environ 104:465–473.

Williams P, Hannah L, Andelman S, et al (2005) Planning for climate change: Identifying minimum-dispersal corridors for the Cape proteaceae. Conserv Biol 19:1063–1074.

Williams PH, Humphries C, Araújo MB, et al (2000) Endemism and important areas for conserving European biodiversity: a preliminary exploration of atlas data for plants and terrestrial vertebrates. Belgian J Entomol 2:21–46.