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Mediterranean habitat loss under RCP4.5 and RCP8.5 climate change projections

Assessing impacts on the Natura 2000 protected area network

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Contents

Executive summary

This report describes the main findings of Task 10, Mediterranean habitat loss, of the Peseta III project (Climate Impacts and Adaptation in Europe, focusing on Extremes, Adaptation and the 2030s). Using an approach that integrates results from 11 sectors, the main objective of the Peseta III project is to make a consistent multi-sectorial assessment of the projected impacts of climate change in Europe.

The Mediterranean region is one of the 36 global hotspots of biological diversity [1] and the most rich biodiversity region in Europe. Almost half of the plants and animals and more than half of the habitats listed in the EU Habitats Directive [2] occur in the Mediterranean region. However, this reservoir of biodiversity is threatened by climate-driven habitat loss, which is one of the most serious concerns for this region [3].

The aim of this study is first to assess projected changes in the spatial range of the Mediterranean climate domain (MCD) in Europe and its conversion into arid climate domain (ACD) under scenarios of climate change, and second to assess Natura 2000 sites that will be affected by these changes. We used 11 bias-adjusted Regional Climate Model (RCM) simulations for two representative concentration pathways' scenarios at +4.5 W/m^2 (RCP4.5) and +8.5 W/m^2 (RCP8.5) for three periods: 2030s, 2 °C warming and 2080s. Furthermore, we analysed adaptation options and its estimated economic cost in Mediterranean Natura 2000 protected areas.

Main findings of this study indicate a projected contraction of the current extent of the MCD of 3% and 16% (an area close to half the size of Italy) under RCP4.5 and RCP8.5, respectively, by the end of the century (Figure I). The contraction is already evident in the 2030s and in the 2 °C warming period in both scenarios. Our results indicate that by the end of the century stable areas of the MCD are projected to only 89% and 71% of its current extent under RCP4.5 and RCP8.5, respectively.

Despite projected contractions of the current MCD, expansion areas of the MCD are projected in regions that are currently under different climatic types. The expansion is projected at 24% and 50% of its current extent under RCP4.5 and RCP8.5, respectively, by the end of the century. By the 2030s and under the 2 °C warming period the projected expansion process is also evident in both scenarios.

Regarding Natura 2000 areas within the MCD, by the end of the century MCD contraction (confident + likely) is projected to affect 3% and 20% of the area of the sites in RCP4.5 and RCP8.5, respectively. Earlier, in the 2030s and in the 2 °C warming period, projected contraction is already evident in both scenarios. The MCD contraction is projected to affect one in four sites under RCP8.5, and one in 18 sites under RCP4.5, for a total of 2 599 sites within the current MCD. Similarly, expansion of the MCD within Natura 2000 sites is projected to affect an area equivalent to 12% and 23% of area of the sites in RCP4.5 and RCP8.5, respectively, by the end of the century.

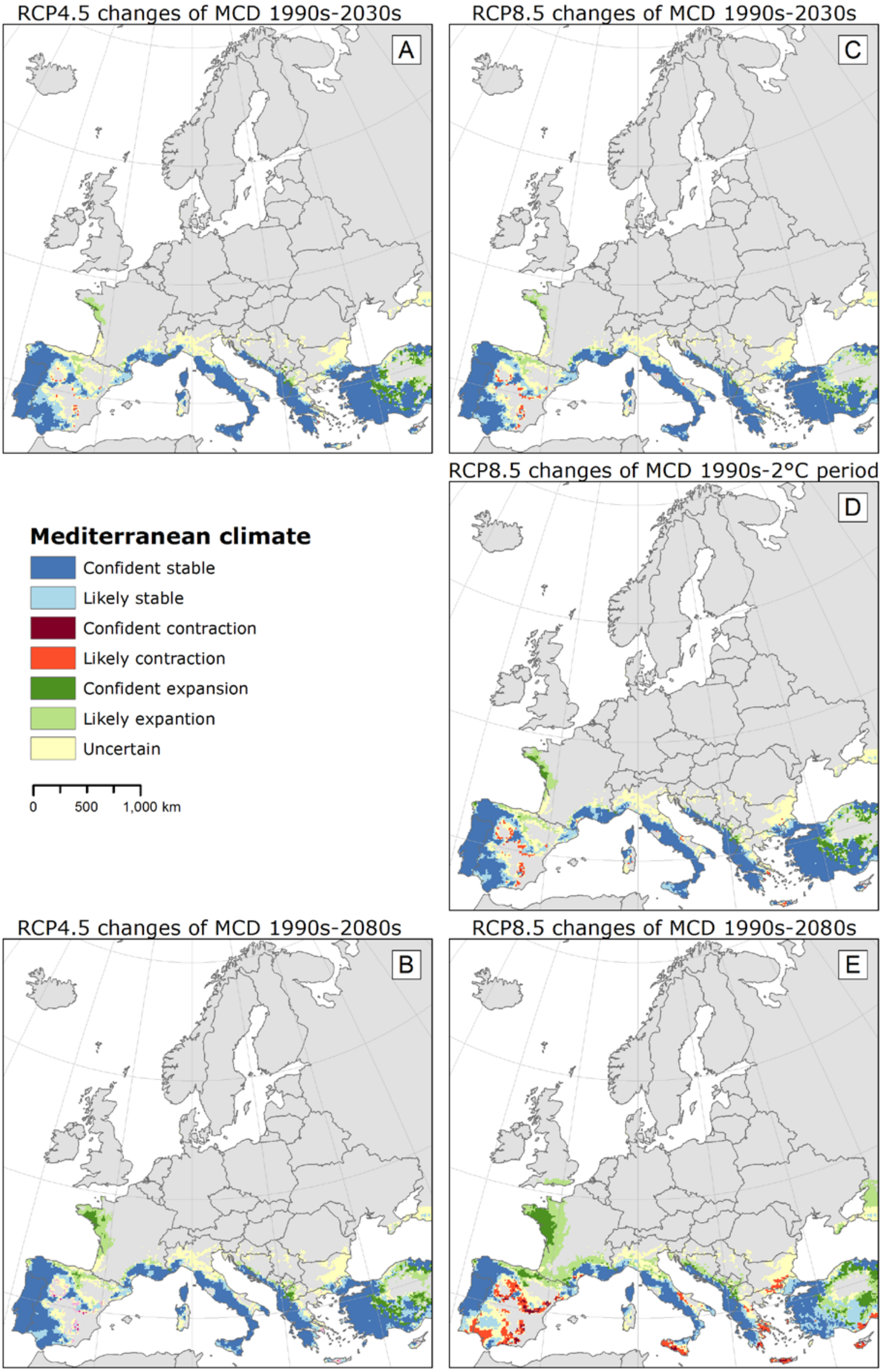
The ACD is instead projected to expand in both scenarios and across all periods. Moreover, the expansion of the ACD is projected to occur at the expenses of the MCD, for instance, under RCP8.5 in the 2080s, 99% of the MCD contraction is explained by the ACD expansion. The conversion of MCD into ACD suggests a decrease of biodiversity due to migration or local extinction of Mediterranean species unable to cope with the magnitude of habitat change, although the extent of the impact remains uncertain.

Adaptation of Natura 2000 sites in the Mediterranean region encompasses an array of nature-based measures oriented to reduce non-climate stressors and to restore degraded habitats (e.g. using Green Infrastructure), protective actions (within protected and non-protected areas projected to remain stable), additions/reconfiguration of the protected area network, and integration of protected areas with biodiversity-hospitable landscape outside the protected network (corridors and stepping stones). We present a series of adaptation measures oriented to the Natura 2000 network according to changes of the MCD and an estimation of the cost of management and adaptation options. Nevertheless, there are a large number of local adaptation measures that can be implemented in

Natura 2000 sites that depend on local features. Therefore, a closer look at the specific local characteristics of the sites and the surrounding habitats is required for proper design and implementation.

Projected climatic changes in the Mediterranean represent a threat to species composition and interactions and may drive transient and new assemblages of plants and animal species [4]. In addition, a transition towards hotter and drier conditions in the Mediterranean supports the hypothesis of an increase of other concomitant effects of climate change such as forest fires, drought, invasive alien species, and forest pests and diseases [5]. These changes suggest decreasing levels of biodiversity in the Mediterranean region.

Figure I (next page). Projected changes of the Mediterranean climate domain (MCD) under scenario RCP4.5 and RCP8.5 in three future periods (2030s, 2080s and 2 °C warming period) in relation to the current MCD. A) and B) Changes under scenario RCP4.5 in the 2030s and 2080s, respectively; C), D) and E) Changes under scenario RCP8.5 in the 2030s, 2 °C warming period and 2080s, respectively.


RCP4.5 changes of MCD 1990s-2030s
A
RCP8.5 changes of MCD 1990s-2030s
C
RCP8.5 changes of MCD 1990s-2°C period
D
Mediterranean climate
Confident stable
Likely stable
Confident contraction
Likely contraction
Confident expansion
Likely expantion
Uncertain
0
500
1,000 km
RCP4.5 changes of MCD 1990s-2080s
B
RCP8.5 changes of MCD 1990s-2080s
E

1. Introduction

The Mediterranean basin is a global hotspot of biological diversity and the most rich biodiversity region in Europe [1]. Almost half of the plants and animals and more than half of the habitats listed in the EU Habitats Directive [2] occur in the Mediterranean region. This region is one of the main reservoirs of plant diversity in the world with its 25 000 species, of which 13 000 are endemic species and represent 4.3% of the approximately 300 000 known species of vascular plants, just behind the Tropical Andes with its 20 000 species [1].

The European basin of the Mediterranean region extends from Portugal to Turkey including all mayor Mediterranean islands, the Canary Islands, Madeira Island and parts of Spain, France, Italy, Cyprus, Greece and Croatia, among other countries.

Climate-driven habitat loss is one of the most serious concerns for this region with potential impacts on biodiversity loss, risk of desertification, increased risk of forest fires and habitat shifts. Some effects of climate change are already evident in the Mediterranean region such as increased drought [6], tree mortality, fire danger and shifts of animal and plant species [3]. The Mediterranean climate is characterised by hot dry summers and cool wet winters. These climatic characteristics as well as human action have driven the evolution of communities of animal and plant species in this region.

Nowadays, anthropogenic climate change is one of the most serious threats for biodiversity conservation in the Mediterranean region [3]. One of the likely effects of climate change is Mediterranean habitat loss [5][7]. This effect can be exacerbated by the land consumption patterns occurring in the European Mediterranean basin [8]. Concomitantly, increased drought occurrence is an observed effect of climate change in the Mediterranean region [6]. The combined effect of the contraction of the current Mediterranean climate and the expansion of the arid climate may aggravate the impacts on plant and animal species in Mediterranean habitats [5].

The aim of this study is to assess the changes in the spatial range of the MCD in Europe and the conversion into ACD under scenarios of climate change. Additionally, the study assesses Natura 2000 sites projected to be affected by shifts of the MCD. Natura 2000 is a network of nature protection sites for animal and plant species, and for natural habitat types in the EU. This network is the cornerstone of the EU nature and biodiversity policies. The terrestrial part of the network covers around 26 000 sites representing about 18% of the EU territory [9]. Finally, the study proposes a series of adaptation measures for Natura 2000 sites. Results of this study are useful for mapping critical conservation areas and support decision-making on potential interventions such as Green Infrastructure [10] and other adaptation measures that facilitate animal and plant species migration to suitable habitats and conservation of the Mediterranean biodiversity.

2. Methods

The objective of the first part of the method is to compute changes in the MCD under two scenarios adopted by the Intergovernmental Panel on Climate Change (IPCC) in its *Fifth Assessment report* describing greenhouse gas concentration trajectories up to the year 2100 and named representative concentration pathways (RCPs). The first scenario, RCP4.5, is a trajectory describing radiative forcing of ~4.5 Wm^{-2} (~650 ppm CO^2 eq.) with a stabilisation after 2100, corresponding to policies that approximate the mitigation efforts proposed by the governments at the Paris COP21. The second scenario, RCP8.5, describes radiative forcing greater than 8.5 Wm^{-2} (~1 370 ppm CO^2 eq.) in 2100. This latter pathway is seen as a high emission scenario [11][12]. We used 11 RCM simulations in three periods centred on the 2030s (2021-2050) and the 2080s (2071-2100). Additionally, for RCP8.5, a variable period was computed, centred on the year when the driving general circulation model (GCM) projects a global 2 °C warming according to IMPACT2C [13] (Table 1). Changes in the MCD were computed in relation to the historical reference climate centred on the 1990s (1981-2010) of each simulation. Maps accounting for the four possible changes, i.e. stable, contraction, expansion and not Mediterranean, were implemented for the 11 simulations, the two scenarios and the three periods. Additionally, shifts of the ACD were computed for assessing the effects on MCD areas. The second part of the method aims at identifying Natura 2000 sites that are projected to be affected by changes of the MCD. The maps of MCD change were overlaid with a map of Natura 2000 sites, then the area and number of sites affected by the changes were computed. An assessment of potential adaptation measures is presented on the basis of the changes of the MCD.

Table 1. Regional climate model (RCM) simulations used in this study with central year and range when the driving general circulation model (GCM) projects a global 2 °C warming according to IMPACT2C [13].

Institute	RCM	Driving GCM	+2 °C central year	+2 °C period
CLM-Community	CCLM4-8-17	CNRM-CERFACS-CNRM-CM5	2044	2030-2059
CLM-Community	CCLM4-8-17	ICHEC-EC-EARTH	2041	2027-2056
CLM-Community	CCLM4-8-17	MPI-M-MPI-ESM-LR	2044	2030-2059
DMI	HIRHAM5	ICHEC-EC-EARTH	2043	2029-2058
IPSL-INERIS	WRF331F	IPSL-IPSL-CM5A-MR	2035	2021-2050
KNMI	RACMO22E	ICHEC-EC-EARTH	2042	2028-2057
SMHI	RCA4	CNRM-CERFACS-CNRM-CM5	2044	2030-2059
SMHI	RCA4	ICHEC-EC-EARTH	2041	2027-2056
SMHI	RCA4	IPSL-IPSL-CM5A-MR	2035	2021-2050
SMHI	RCA4	MOHC-HadGEM2-ES	2030	2016-2045
SMHI	RCA4	MPI-M-MPI-ESM-LR	2044	2030-2059

High-resolution climate scenarios were sourced from the Coordinated Regional Downscaling Experiment (CORDEX) ([1]) data of the World Climate Research Programme (WCRP). As part of the CORDEX project, the EURO-CORDEX ([2]) initiative provides regional climate projections for Europe at 12.5 km spatial resolution by downscaling the global climate projections of the Coupled Model Intercomparison Project Phase 5 (CMIP5) [14] and the RCPs [11][12]. In this study we used RCP4.5 and RCP8.5 simulations of daily air temperature and precipitation at 12.5 km, which were previously corrected for bias by Dosio [15], following Dosio and Paruolo [16] and Dosio et al. [17]. Maps of mean

([1]) http://www.cordex.org
([2]) http://www.euro-cordex.net

monthly temperature and mean monthly precipitation were produced for the historical reference climate and the three 30-year projections for each simulation/scenario at the original resolution of 12.5 km.

2.1. Mapping Mediterranean climate domain and arid climate domain

The MCD and ACD were mapped using the Köppen-Geiger climate classification, which categorises world climates into five main groups and several subgroups on the basis of temperature and precipitation [18]. The Mediterranean climate is often described using the Cs type of the Köppen-Geiger classification, defined as ‘warm temperate climate with dry summer’ [19][7], while the arid climate is represented by the B type, ‘arid climates’ [19][20]. In this study we used the criteria for Cs and B climate types according to Peel et al. [20], Garcia et al. [21] and Barredo et al. [5].

The Cs climate is defined according to the following criteria.

1. Precipitation in the wettest month of the winter half of the year (P_{wmax}) is greater than three times the precipitation in the driest month of the summer half of the year (P_{smin}).
2. Precipitation in the driest month of the winter half of the year (P_{wmin}) is greater than precipitation in the driest month of the summer half of the year (P_{smin}).
3. Annual precipitation (P_{ann}) measured in centimetres is greater than a variable threshold value for arid climates (P_{th}). The threshold is dependent on the annual average temperature (T_{ann}) in °C and varies based on the total amount of precipitation that occurs in the winter and summer half of the year:

   $P_{th} = (2 * T_{ann}) + 28$

   if at least 70% of the annual precipitation occurs in the summer half of the year;

   $P_{th} = 2 * T_{ann}$

   if at least 70% of the annual precipitation occurs in the winter half of the year;

   $P_{th} = (2 * T_{ann}) + 14$

   otherwise.
4. The precipitation in the driest month of the summer half of the year (P_{smin}) is less than 40 mm.
5. The temperature of the coldest month of the year (T_{min}) is lower than 18 °C.
6. The temperature of the coldest month of the year is greater than 0 °C.
7. The temperature of the hottest month of the year (T_{max}) is greater than 10 °C.

The B climate is defined by one criterion.

1. Annual precipitation (P_{ann}) is less than 10 times P_{th}.

The winter half of the year is from October to March and the summer half of the year is from April to September. Precipitation is given in millimetres, unless otherwise indicated, and temperature in °C. In this study we have followed Peel et al. [20], Russell [22], Garcia et al. [21] and Barredo et al. [5] using the temperature of the coldest month greater than 0 °C, instead of –3 °C as used in the Köppen-Geiger classification in defining the temperate-cold climate boundary. According to the criteria described for Cs and B climates, both types are mutually exclusive, where the occurrence of one excludes the occurrence of the other. Unprojected latitude/longitude (WGS 84) climate data were used for mapping the MCD and ACD, and equal-area projected (ETRS 89 LAEA) maps were used for area-change computation, taking the curvature of the earth into consideration.

Binary maps (0, 1) of MCD were implemented for each simulation, period and scenario. Thus, 44 maps (11 simulations times four periods) were produced for RCP8.5 and 33 maps (11 simulations times three periods) were produced for RCP4.5. Change maps were then computed for each simulation between the historical reference period and the 2030s, 2080s and 2 °C warming period. Consequently, the maps contain four potential categories of change: stable, contraction, expansion and non-Mediterranean. The change maps of each simulation and period were then summarised according to Table 2, following the IPCC [23], in one map for each scenario/period. Changes in regions in which more than 66% of the simulations agree are considered likely changes, and confident changes where more than 90% of the simulations agree. Regions exhibiting agreement of less than 66% are considered uncertain changes. Therefore, the uncertain category represents cases when stable or contraction occurs in a range between one to six simulations. For example, if 10 simulations suggest that a grid cell is within the MCD in the historical reference period and in the 2030s, then that grid cell is confident stable for that period. Summary maps will be created, first overlaying the categories of stable, contraction and expansion that are mutually exclusive, and second overlaying the category of uncertain only in the grid cells that were not previously taken by one of the first three categories. The same approach was implemented for mapping changes in the ACD. Finally, ACD grid cells that are confident or likely stable were excluded from the uncertain MCD grid cells in the corresponding map.

Table 2. Categories of projected change of the Mediterranean climate domain (MCD) to 2030s, 2080s and 2 °C warming period.

Projected change	Confidence	Number of simulations (out of 11)
Stable	Confident	10-11
	Likely	7-9
Stable/contraction	Uncertain	1-6
Contraction	Confident	10-11
	Likely	7-9
Expansion	Confident	10-11
	Likely	7-9

Shifts of the MCD were assessed on terrestrial Natura 2000 sites for each period/scenario by mapping Natura 2000 sites projected to be affected. We computed a series of maps showing sites in projected stable areas of the MCD and in areas where the MCD is projected to shift. From these maps we identified areas projected to require adaptation measures and increased connectivity for facilitating the migration of species.

2.2. Validation

A validation procedure was implemented to determine the ability of the RCM simulations to reproduce a faithful delineation of the Mediterranean biome in Europe. However, the validation was subjected to some constraints. First, there is not a widely accepted definition of the Mediterranean biome. On the contrary, different definitions have been proposed for delineating the area considered Mediterranean (e.g. [24][25][26][27][28]). Second, in this study we used a purely climatic approach for the delineation of the MCD, which is in contrast with the method used in available maps of the Mediterranean biome. These aspects create comparability issues and make it difficult to faithfully compare the resulting maps of this study and external datasets representing the Mediterranean biome.

The maps of the MCD produced using the historical reference period of the 11 simulations were compared with three commonly used maps that represent the Mediterranean biome, i.e. the Myers et al.'s biodiversity hotspots (BDH) for conservation priorities [1], the global ecological zones (GEZ) for FAO forest reporting [29] and the European

Environment Agency (EEA)'s biogeographical regions (BGR) [30]. Although these maps were implemented using different methodologies, in general the delineation relied largely on expert judgement. Therefore, climatic parameters, if used at all, are one of the many factors considered in the respective methodologies. The three input maps of the Mediterranean biome were clipped to a common extent, equalling that of the simulations, and were then rasterised to the same grid size of the climate simulations. We assessed only an area of interest covering the southern part of Europe to avoid large areas not considered Mediterranean that may bias the validation results towards agreement.

In the validation we assessed agreement of the categorical maps using two metrics, the Cohen's Kappa coefficient [31][32] and overall accuracy [33]. The Kappa coefficient indicates the degree of agreement between categorical maps, with metric ranges from 0 (total disagreement) to 1 (perfect agreement). It reflects the difference between actual agreement and the agreement expected to occur by chance. A commonly cited scale of the Kappa coefficient indicates moderate agreement in the range of 0.41-0.60, substantial agreement in the range of 0.61-0.80 and almost perfect agreement in the range of 0.81-0.99 [34]. Overall accuracy is one of the simplest descriptive techniques for map comparison, which is computed by dividing the total coincident number of grid cells in a comparison matrix.

3. Validation results

Despite the differences between the climatic approach used in this study and the expert knowledge approach used in the studies delineating the three maps of the Mediterranean biome, results of the validation indicates a reasonable level of agreement. Table 3 shows the Kappa coefficient and the overall accuracy obtained from the comparison between the MCD resulting from the 11 simulations and the three maps of the Mediterranean biome (Figure 1).

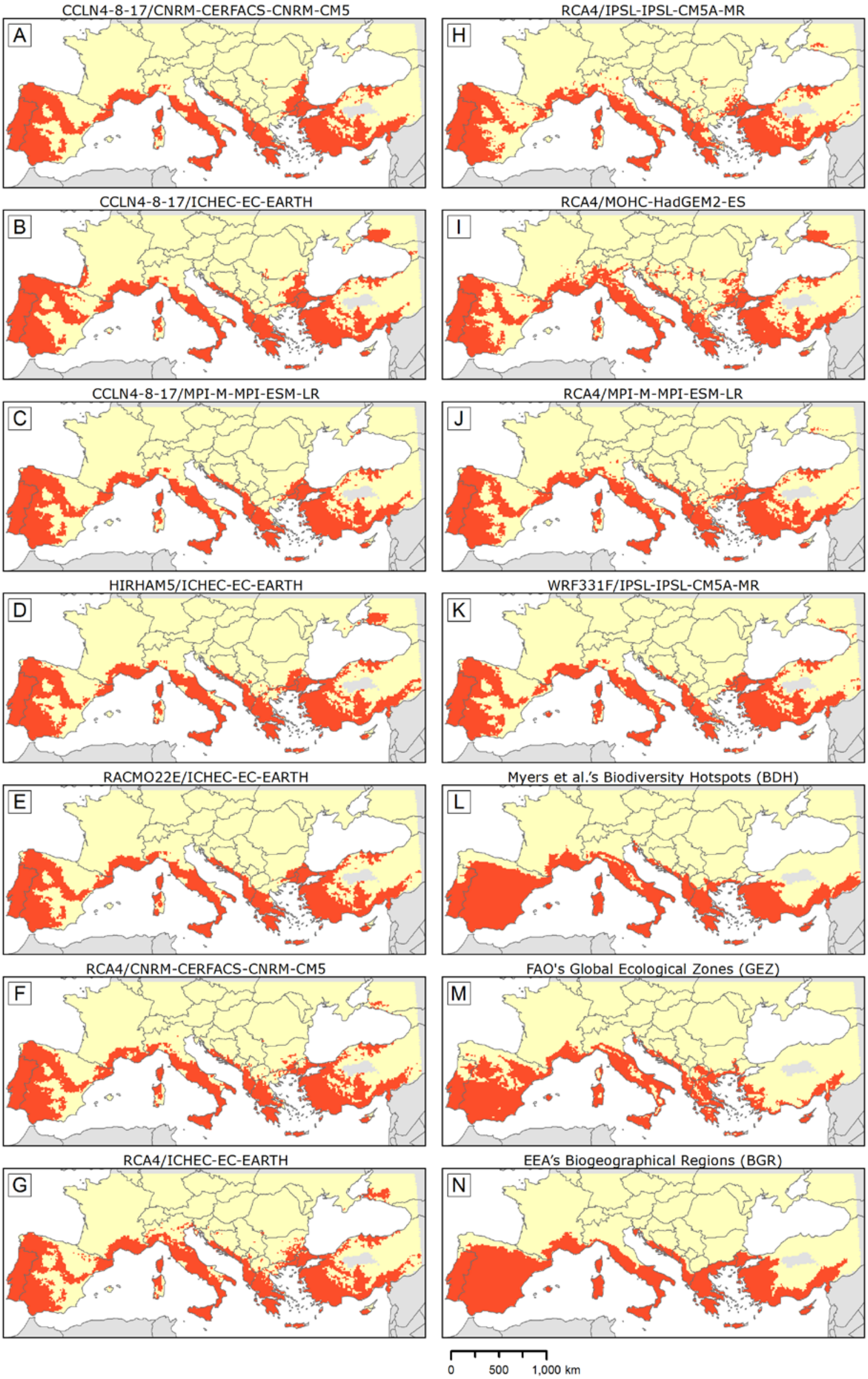
Results of the validation indicate that our maps are closer to the delineation produced by the EEA's BGR map. Here, substantial agreement is indicated by the Kappa coefficient and overall accuracy is greater than 83% across the 11 simulations. Although minor than with the first map, there is also substantial agreement with the Myers et al.'s BDH. In this case, the Kappa coefficient is marginally smaller than in the BGR and overall accuracy is greater than 82% across the simulations. Finally, the comparison with the FAO's GEZ exhibits only moderate agreement considering the Kappa coefficient and an overall accuracy greater than 79% across the simulations.

A point emerging from the validation is that the MCD maps that were computed using the simulations show comparable values of the Kappa coefficient and overall accuracy in relation to each of the three maps of the Mediterranean biome. For instance, the difference between the largest and the smallest Kappa coefficient in relation to the BDH is only 0.06 and 3% regarding overall accuracy. This suggests that, despite some differences in the simulations, they resemble the external maps used in the validation. In other words, they are spatially consistent and do not substantially differ from the external validation maps.

Table 3. Comparison of the Mediterranean climate domain (MCD) delineated using the Köppen-Geiger climate classification and 11 RCM simulations (historical reference climate 1981-2010) versus Myers et al.'s Biodiversity Hotspots (BDH) [1], the FAO's Global Ecological Zones (GEZ) [29] and the EEA's Biogeographical regions (BGR) [30], using Cohen's Kappa coefficient and overall accuracy.

Simulations (RCM/GCM)	BDH		GEZ		BGR	
	Kappa	Overall accuracy (%)	Kappa	Overall accuracy (%)	Kappa	Overall accuracy (%)
CCLM4-8-17/CNRM-CERFACS-CNRM-CM5	0.63	85	0.50	81	0.66	86
CCLM4-8-17/ICHEC-EC-EARTH	0.60	83	0.48	80	0.64	85
CCLM4-8-17/MPI-M-MPI-ESM-LR	0.65	86	0.52	82	0.69	87
HIRHAM5/ICHEC-EC-EARTH	0.64	85	0.51	81	0.66	86
RACMO22E/ICHEC-EC-EARTH	0.66	86	0.53	82	0.69	87
RCA4/CNRM-CERFACS-CNRM-CM5	0.66	86	0.53	82	0.68	87
RCA4/ICHEC-EC-EARTH	0.63	85	0.52	81	0.65	85
RCA4/IPSL-IPSL-CM5A-MR	0.62	84	0.49	81	0.66	86
RCA4/MOHC-HadGEM2-ES	0.60	83	0.50	80	0.62	84
RCA4/MPI-M-MPI-ESM-LR	0.66	86	0.54	82	0.69	87
WRF331F/IPSL-IPSL-CM5A-MR	0.64	85	0.50	81	0.66	86

Figure 1 (next page). Mediterranean climate domain (MCD) delineated using the historical reference period (1981-2010) of 11 RCM simulations (A-K) and the Mediterranean biome according to: (L) Myers et al.'s Biodiversity Hotspots (BDH) for conservation priorities [1]; (M) the global ecological zones (GEZ) for FAO forest reporting [29]; and (N) the EEA's biogeographical regions (BGR) [30]. Note that the maps L, M and N were clipped to a common extent equalling that of the climate simulations.

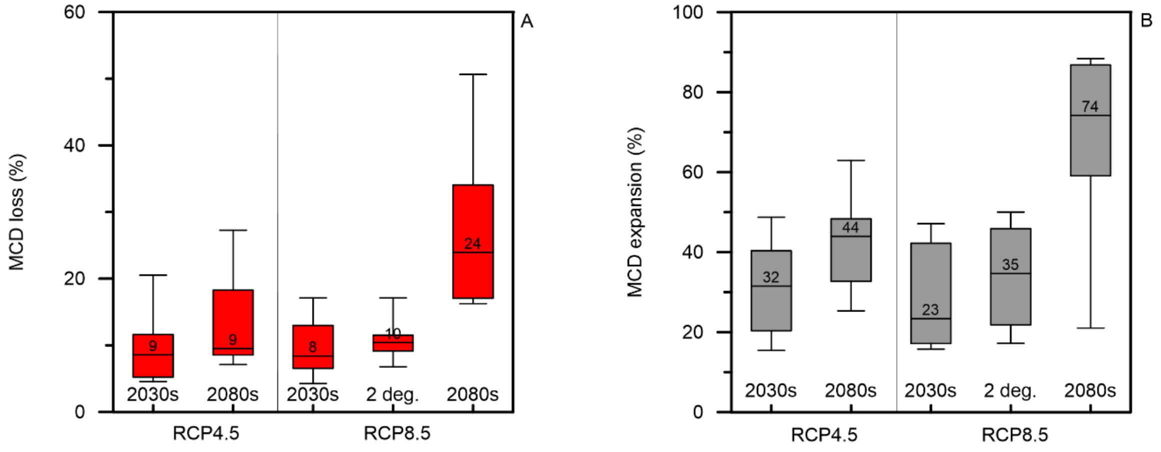

CCLN4-8-17/CNRM-CERFACS-CNRM-CM5
A
RCA4/IPSL-IPSL-CM5A-MR
H
CCLN4-8-17/ICHEC-EC-EARTH
B
RCA4/MOHC-HadGEM2-ES
I
CCLN4-8-17/MPI-M-MPI-ESM-LR
C
RCA4/MPI-M-MPI-ESM-LR
J
HIRHAM5/ICHEC-EC-EARTH
D
WRF331F/IPSL-IPSL-CM5A-MR
K
RACMO22E/ICHEC-EC-EARTH
E
Myers et al.'s Biodiversity Hotspots (BDH)
L
RCA4/CNRM-CERFACS-CNRM-CM5
F
FAO's Global Ecological Zones (GEZ)
M
RCA4/ICHEC-EC-EARTH
G
EEA's Biogeographical Regions (BGR)
N
0
500
1,000 km

4. Results

The extent of the current MCD and ACD within the spatial domain of the RCM simulations is around 1 022 000 km^2 and 297 000 km^2, respectively, according to the Köppen-Geiger definition. The extent was computed by selecting grid cells where seven or more RCM simulations predicted MCD or ACD in the historical reference climate (1990s).

All the simulations projected a shrink of the current MCD under both RCP4.5 and RCP8.5 (Figure 2A). By the 2030s, both scenarios projected a comparable median loss of the MCD of around 8-9%. However, by the 2080s the projected median shrink is more marked in RCP8.5, exhibiting 24%, in relation to RCP4.5, which projected 9%. Under RCP8.5, in the 2 °C warming period the projected median shrink is 10%.

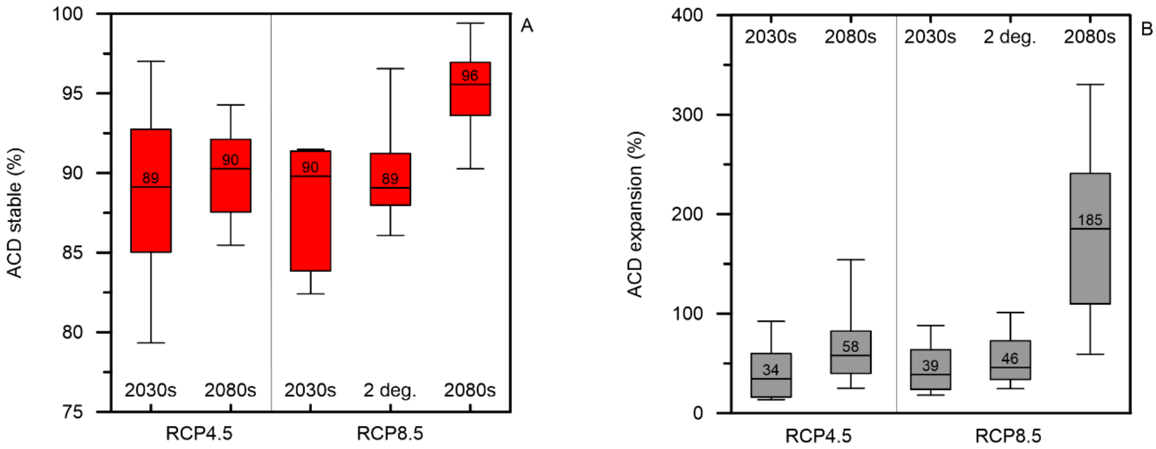
Figure 2. Projected relative changes of the Mediterranean climate domain (MCD) under scenario RCP4.5 and RCP8.5 in three future periods (2030s, 2080s and 2 °C warming period) in relation to the current MCD (1990s). Box-and-whisker plots show minimum, maximum, median (number), lower quartile (25%) and upper quartile (75%) of the 11 RCM simulations. A) MCD loss; B) Shifts of the MCD in other climatic domains.



Despite the fact that the current range of the MCD is projected to shrink, all the simulations projected shifts of the MCD in other climate domains. By the 2030s the projected median expansion (new areas) of MCD represent 32% and 23% of the current extent under RCP4.5 and RCP8.5, respectively (Figure 2B). Therefore, all the simulations projected an increase of the overall extent of the MCD in relation to the current extent. Shifts of the MCD are projected to increase towards the end of the century, being more marked in RCP8.5, exhibiting a median expansion of 74%, than in RCP4.5, projecting 44%.

All simulations projected large stable areas of the current ACD above 89% across all periods and in both scenarios (Figure 3A). The simulations also agreed in the projected expansion of the ACD in other climatic domains (Figure 3B). This holds in both scenarios in all periods with projected median expansions between 34% and 185% in relation to the current extent.

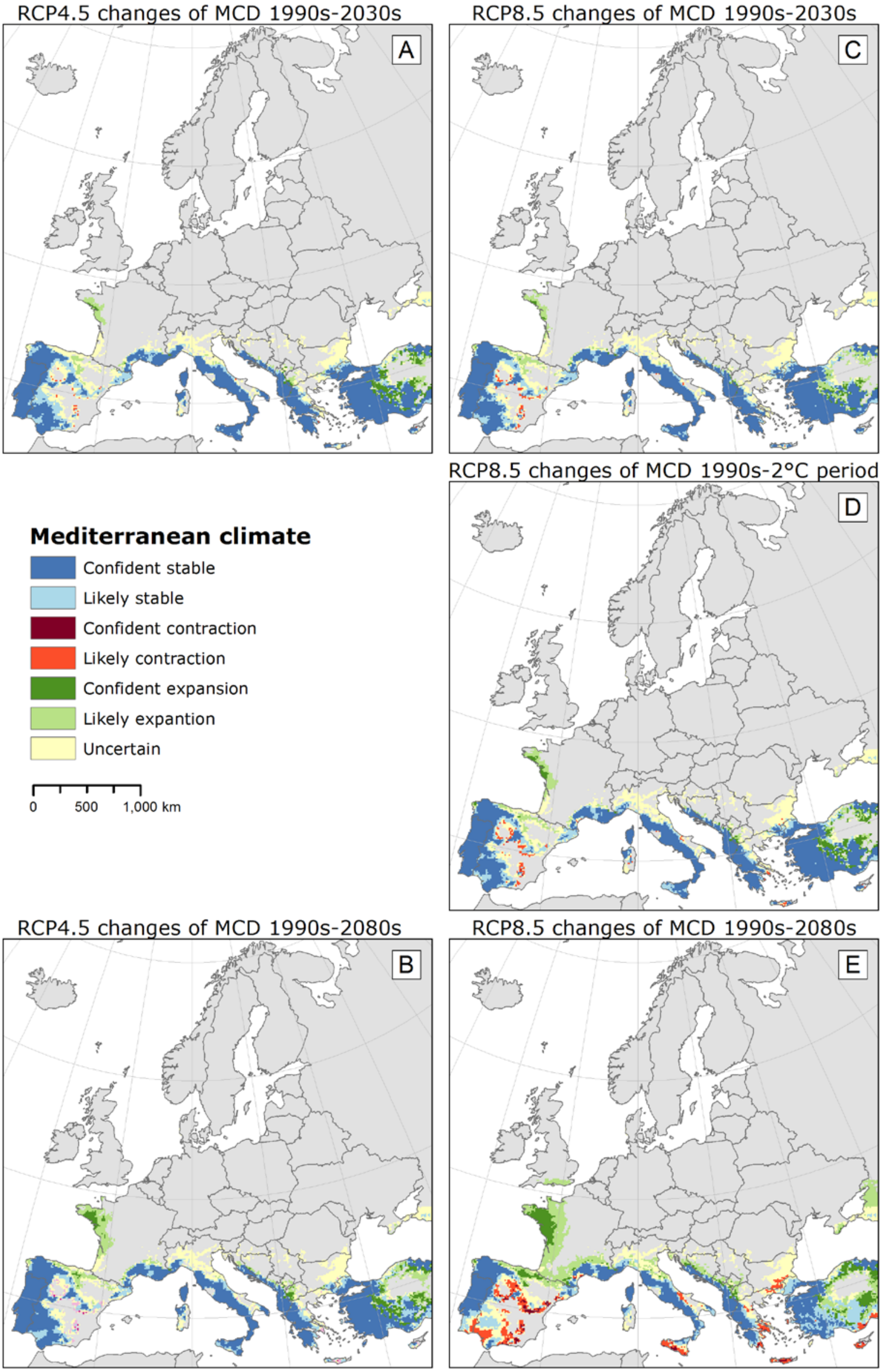
Figure 3. Projected relative changes of the arid climate domain (ACD) under scenario RCP4.5 and RCP8.5 in three future periods (2030s, 2080s and 2 °C warming period) in relation to the current ACD (1990s). Box-and-whisker plots show minimum, maximum, median (number), lower quartile (25%) and upper quartile (75%) of the 11 RCM simulations. A) ACD stable areas; B) Shifts of the ACD in other climatic domains.



4.1. Mediterranean climate domain summary

Summary maps of changes show areas where the MCD is projected to remain stable, contract or expand using different levels of confidence (Figure 4). In the 2030s both scenarios projected similar patterns of stable areas (likely and confident), totalling around 91% of the current extent of the MCD in either scenario (Figure 5). Projected expansion areas also show a comparable pattern in both scenarios. In the 2030s both scenarios projected a limited contraction of around 1%. By this period stable areas are projected in the Iberian Peninsula; southern areas of France including Corsica; western parts of Italy, Sardinia and Sicily; the Balkans; western, southern and north-west areas of Greece; Cyprus; and western zones of Turkey. Projected expansion areas are in north-western and southern parts of France, northern Spain, areas of northern Greece and central zones of Turkey. Under RCP8.5, the magnitude of projected change in the 2 °C warming period is comparable to the 2030s period (Figure 5).

Figure 4 (next page). Projected changes of the Mediterranean climate domain (MCD) under scenario RCP4.5 and RCP8.5 in three future periods (2030s, 2080s and 2 °C warming period) in relation to the current MCD. A) and B) Changes under scenario RCP4.5 in the 2030s and 2080s, respectively; C), D) and E) Changes under scenario RCP8.5 in the 2030s, 2 °C warming period and 2080s, respectively.


RCP4.5 changes of MCD 1990s-2030s
A
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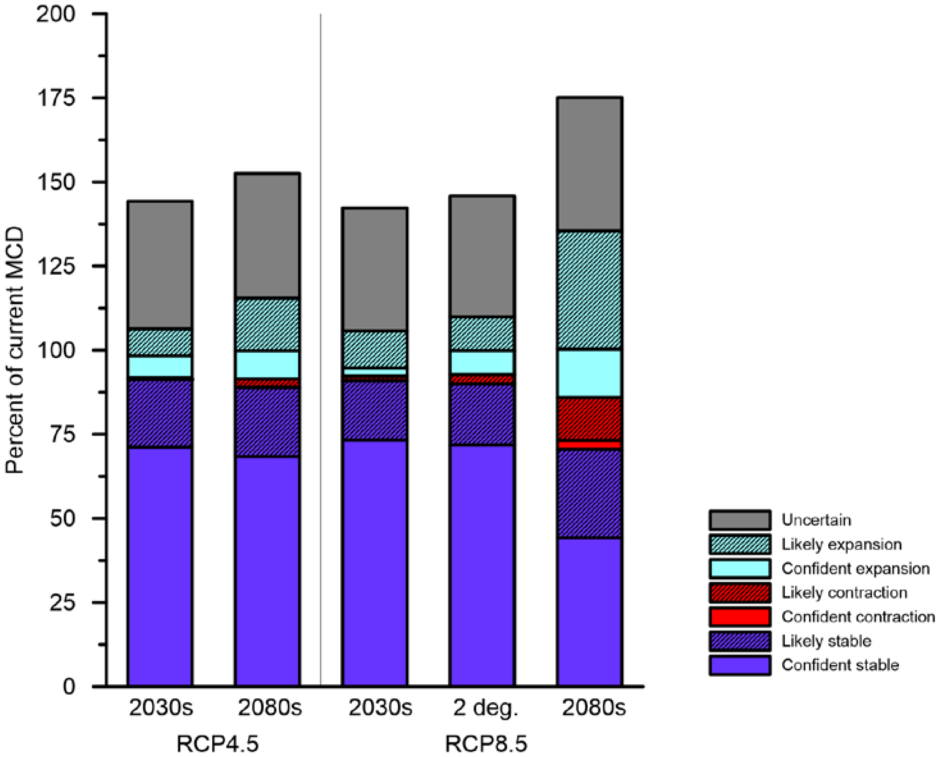
C
RCP8.5 changes of MCD 1990s-2°C period
D
Mediterranean climate
Confident stable
Likely stable
Confident contraction
Likely contraction
Confident expansion
Likely expantion
Uncertain
0
500
1,000 km
RCP4.5 changes of MCD 1990s-2080s
B
RCP8.5 changes of MCD 1990s-2080s
E

Figure 5. Projected relative changes of the Mediterranean climate domain (MCD) under scenario RCP4.5 and RCP8.5 in three future periods (2030s, 2080s and 2 °C warming period).



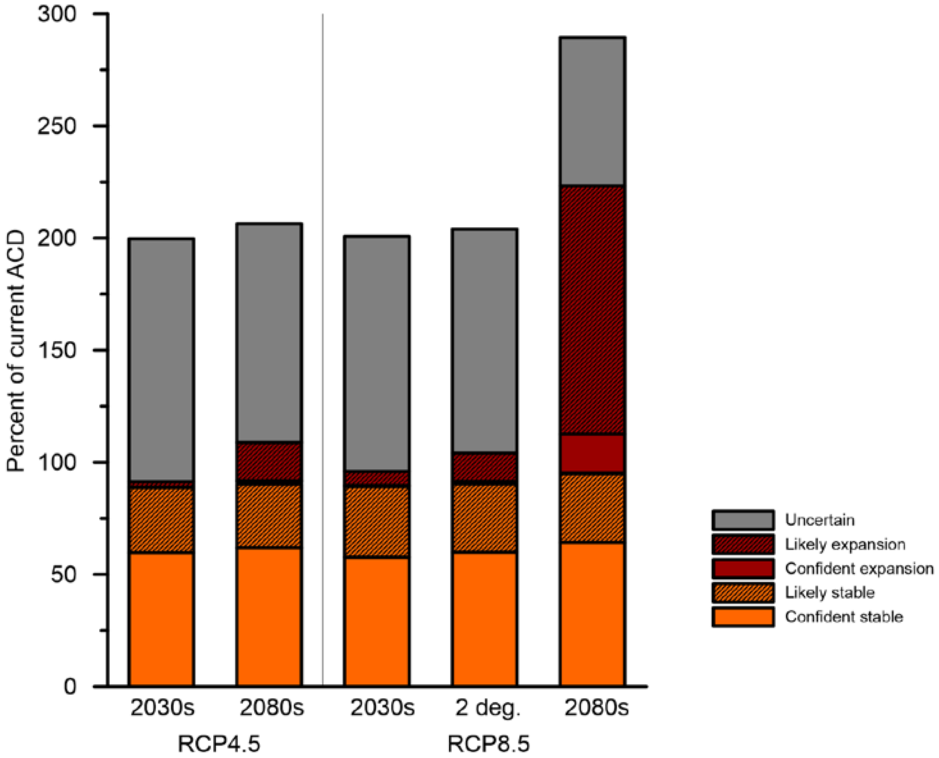
Projected expansion of the MCD is evident in the 2030s and more pronounced in the 2080s, in both scenarios, but more marked in RCP8.5. In addition, in the 2080s under RCP4.5, confident and likely contraction of the MCD totals 3% of the current extent. In contrast, under RCP8.5 the projected likely contraction is 13% and the confident contraction 3% of the current MCD (Figure 4E), which is an area (~157 000 km^2) equivalent to half the size of Italy. As a consequence, the projected confident stable area of the current MCD is projected to contract to 44% and the likely stable area to 26%. Contraction areas are projected in central and southern zones of the Iberian Peninsula; southern Italy and Sicily; southern and north-eastern Greece and Crete; Cyprus; and parts of southern Turkey. Contraction areas geographically distant from stable or expansion areas will require adaptation measures, e.g. those oriented to facilitate the migration of species of plants and animals. These areas are projected to face the more severe impacts. In the 2080s, projected expansion areas are more marked than in the previous period in either scenario (Figure 5). Under RCP4.5, projected confident and likely expansion of the MCD totals an area equivalent to 24% of the current extent. Under RCP8.5, the expansion in both categories is more pronounced, projected at 50%. The geographical distribution of expansion areas follows the pattern projected in the 2030s, but with an evident increase in extent (Figure 4B and 4E), e.g. in western and southern France.

4.2. Arid climate domain summary

Contraction areas of ACD are marginal (< 1%) in both scenarios and across all periods (Figure 6). By the 2030s, projected stable areas of the ACD under RCP4.5 and RCP8.5 are in the Iberian Peninsula; parts of Italy and Sardinia; eastern Greece and south-eastern Turkey (Figure 7A and C). By this period, both scenarios project a likely expansion of 2% and 6%, respectively, while no confident expansion is projected in any scenario (Figure 6). Under RCP8.5, changes of the ACD in the 2 °C warming period are comparable with those of the 2030s period, though the likely expansion of the ACD is projected at 13% and the confident expansion at 1%.

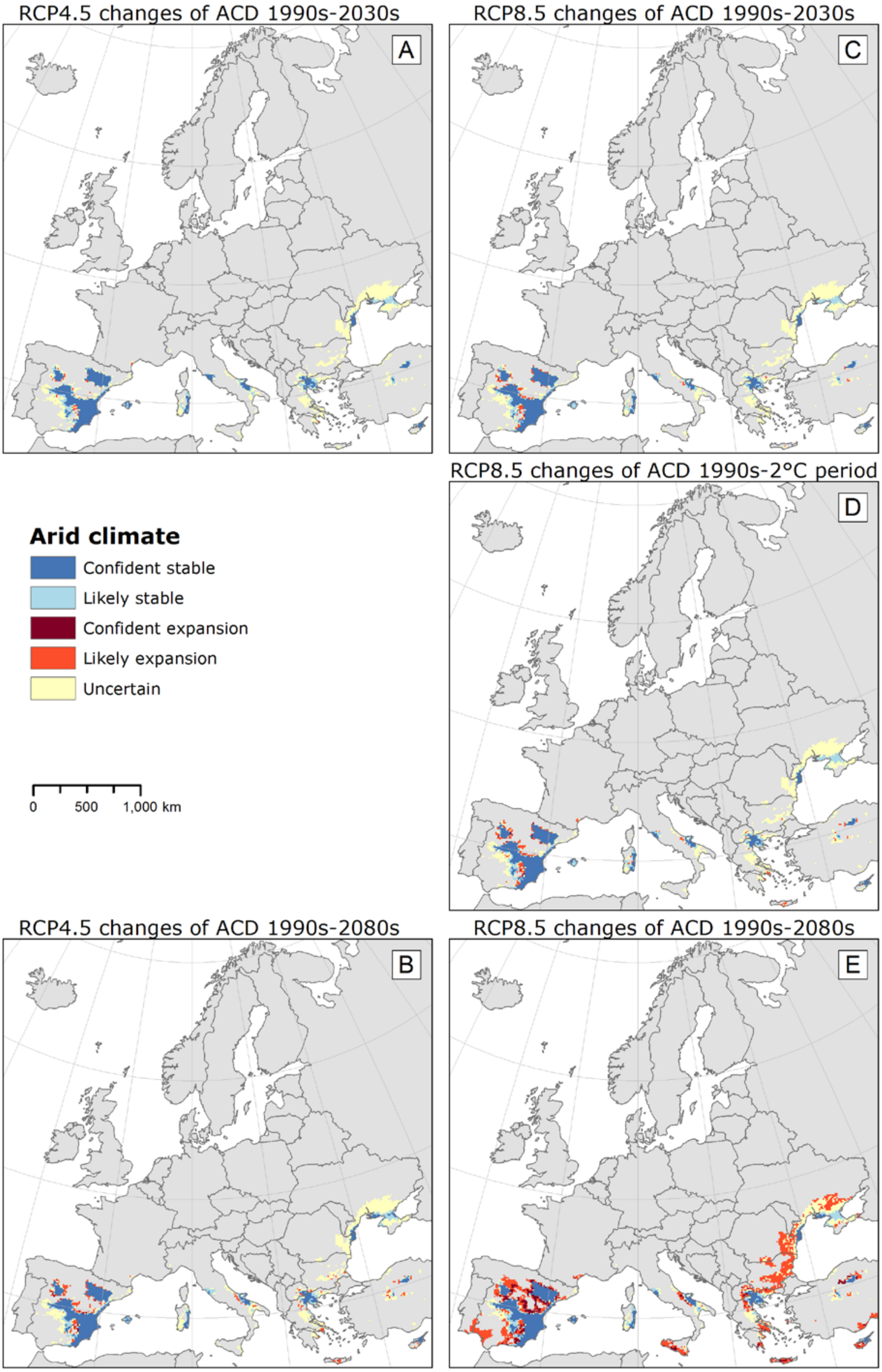
The pattern of projected stable areas in 2080s follows that of the 2030s. However, in the 2080s the likely expansion of the ACD under RCP4.5 is projected at 17% and the confident expansion is projected at 1%. By this period, the projected changes under RCP8.5 are more marked, where the likely expansion is projected at 111% and the confident expansion is projected at 17% (Figure 6), meaning that under this scenario the ACD is projected to increase by more than twice its current extent, an increase equivalent to three times the size of Greece. The increase is projected in the Iberian Peninsula; southern Italy and Sicily; parts of Greece; parts of Turkey; eastern parts of Bulgaria and Romania; and eastern zones (not shown) of the spatial domain of the climate simulations (Figure 7E).

Figure 6. Projected relative changes of the arid climate domain (ACD) under scenario RCP4.5 and RCP8.5 in three future periods (2030s, 2080s and 2 °C warming period).



The expansion of the ACD is projected to occur at the expense of the MCD; for instance, under RCP8.5 in the 2080s, 99% of the MCD loss is explained by ACD expansion. The conversion of MCD into ACD suggests a decrease of biodiversity due to migration or local extinction of Mediterranean species unable to cope with the magnitude of habitat change; however, the magnitude of the impact remains uncertain.

Figure 7 (next page). Projected changes of the arid climate domain (ACD) under scenario RCP4.5 and RCP8.5 in three future periods (2030s, 2080s and 2 °C warming period) in relation to the current ACD. A) and B) Changes under scenario RCP4.5 in the 2030s and 2080s, respectively; C), D) and E) Changes under scenario RCP8.5 in the 2030s, 2 °C warming period and 2080s, respectively.


RCP4.5 changes of ACD 1990s-2030s
A
RCP8.5 changes of ACD 1990s-2030s
C
RCP8.5 changes of ACD 1990s-2°C period
D
Arid climate
Confident stable
Likely stable
Confident expansion
Likely expansion
Uncertain
0
500
1,000 km
RCP4.5 changes of ACD 1990s-2080s
B
RCP8.5 changes of ACD 1990s-2080s
E

4.3. Natura 2000 protected area network summary

The current extent of the MCD includes 2 599 Natura 2000 sites totalling an area of around 168 000 km^2, which represents 16% of the MCD. The summary maps of projected changes of the MCD of Figure 4 were used for computing changes in Natura 2000 sites (Figure 8).

Figure 8. Projected changes of the Mediterranean climate domain (MCD) in Natura 2000 sites under scenario RCP4.5 (A) and RCP8.5 (B) in the 2080s in relation to the current MCD.

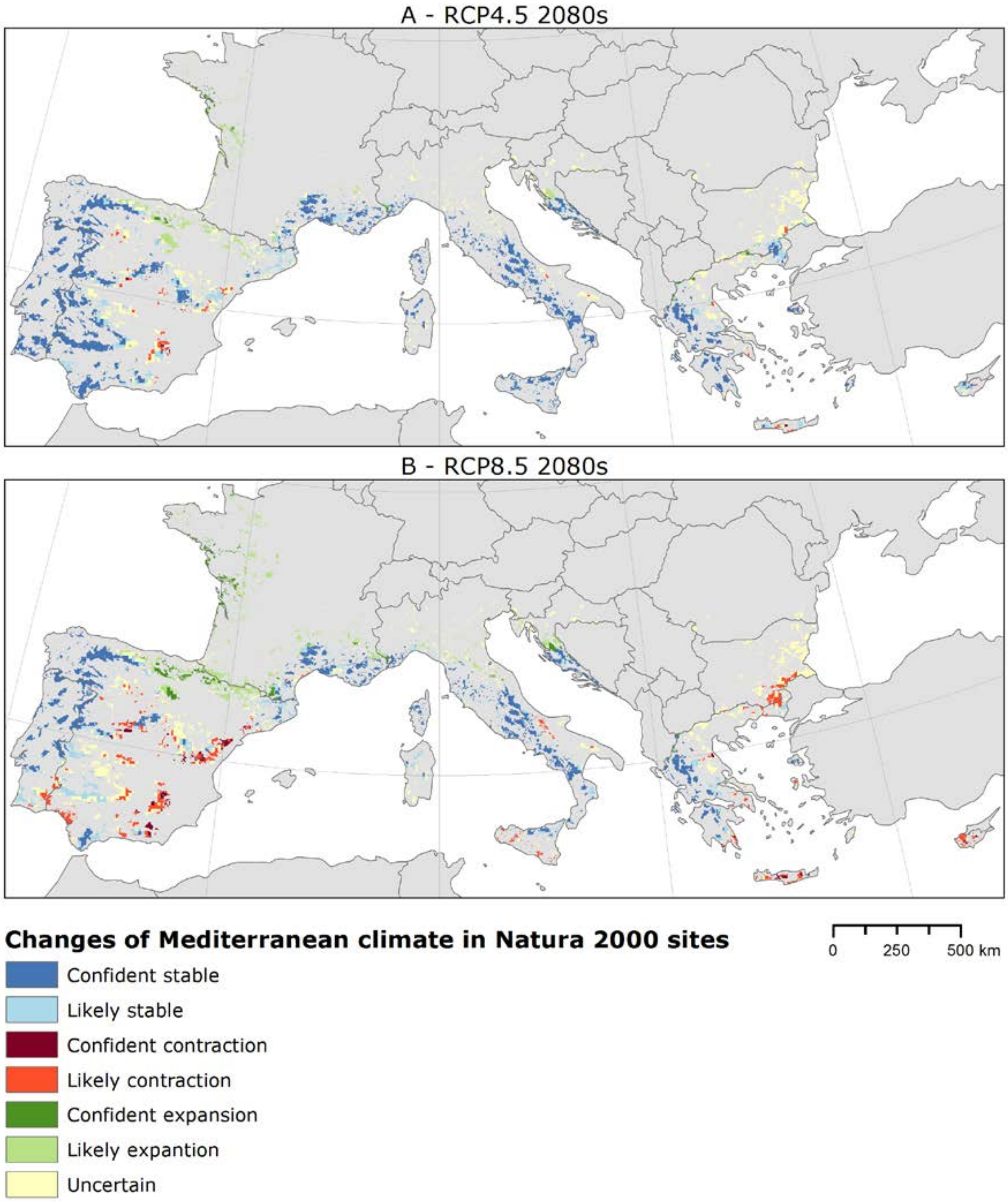


Table 4 shows the projected relative area of Natura 2000 sites affected by changes of the MCD (Table A1 in the annex shows the projected changes in km^2). Projected area changes are more marked in scenario RCP8.5 than in scenario RCP4.5, particularly in the 2080s. By the 2030s, both scenarios projected comparable changes. First, the projected stable (confident + likely) area of MCD within Natura 2000 sites were 88% in RCP4.5 and 87% in RCP8.5, in relation to the area in the historical reference climate. Second, MCD contraction (confident + likely) within Natura 2000 sites was projected at 1% and 2% in RCP4.5 and RCP8.5, equivalent to 986 km^2 and 3 310 km^2, respectively. Finally, MCD expansion (confident + likely) in Natura 2000 sites was projected at 5% and 7% in RCP4.5 and RCP8.5, respectively. Projected changes in the 2 °C warming period under RCP8.5 are comparable to the changes projected by 2030s in the same scenario. Uncertain changes were projected in the range of 35% to 39% across scenarios and periods, which represents and area between 59 483 km^2 and 66 021 km^2, respectively.

By the 2080s, projected stable (confident + likely) areas of MCD within Natura 2000 sites decrease to 86% in RCP4.5 and to 63% in RCP8.5, thus leading to a reduced extent of 143 814 km^2 and 106 025 km^2 in both scenarios, respectively. Accordingly, contraction areas (confident + likely) were projected to 3% and 20% in RCP4.5 and RCP8.5, representing an area of 6 010 km^2 and 32 412 km^2, respectively. In addition, the projected expansion (confident + likely) is more marked in RCP8.5, exhibiting 23%, in contrast with the 12% projected in RCP4.5.

Table 4. Projected relative area of Natura 2000 sites by category of change of the Mediterranean climate domain (MCD) under scenario RCP4.5 and RCP8.5 in three future periods (2030s, 2080s and a 2 °C warming period). Changes are represented as percentages in relation to the area of Natura 2000 sites in the MCD in the historical reference period.

Historical reference period (km^2)	Changes (percentage)	RCP4.5		RCP8.5		
		2030s	2080s	2030s	2 °C period	2080s
167 682	Confident stable	63	66	67	65	43
	Likely stable	25	20	20	20	20
	Uncertain	38	35	36	36	39
	Likely contraction	1	3	2	3	16
	Confident contraction	0	0	0	0	4
	Likely expansion	5	10	6	7	17
	Confident expansion	0	2	1	1	6

Results regarding the number of Natura 2000 sites affected (totally or partially) by changes of the MCD are shown in Table 5. The number of sites affected by contraction and expansion of the MCD is higher in RCP8.5 than in RCP4.5, and the difference is more marked towards the end of the century. By the 2030s, the sites projected to be affected by likely contraction were 46 (0 in confident contraction) in RCP4.5. By this period in RCP8.5, 67 sites were projected to be affected by likely contraction and four by confident contraction. In the 2 °C warming period 148 sites were projected to face likely contraction and four were projected to face confident contraction. By the 2080s, the sites projected in contraction areas were 130 in likely and 12 in confident changes under RCP4.5. In contrast, the number of sites increases to 517 and to 142, respectively, under RCP8.5. Consequently, the number of sites in stable areas decreases from the 2030s to the 2080s in both scenarios, though more markedly in RCP8.5.

Table 5. Projected number of Natura 2000 sites by category of change of the Mediterranean climate domain (MCD) under scenario RCP4.5 and RCP8.5 in three future periods (2030s, 2080s and a 2 °C warming period). Changes are represented as absolute number of sites in each category of change. Note that one site can be represented in more than one category of change, e.g. one site can be partially in stable and partially in contraction areas.

Historical reference period	Changes	RCP4.5		RCP8.5		
		2030s	2080s	2030s	2 °C period	2080s
2 599	Confident stable	1 897	1 905	1 949	1 888	1 357
	Likely stable	859	771	797	812	822
	Uncertain	1 676	1 677	1 637	1 648	1 698
	Likely contraction	46	130	67	148	517
	Confident contraction	0	12	4	4	142
	Likely expansion	202	440	309	341	857
	Confident expansion	27	91	36	54	295

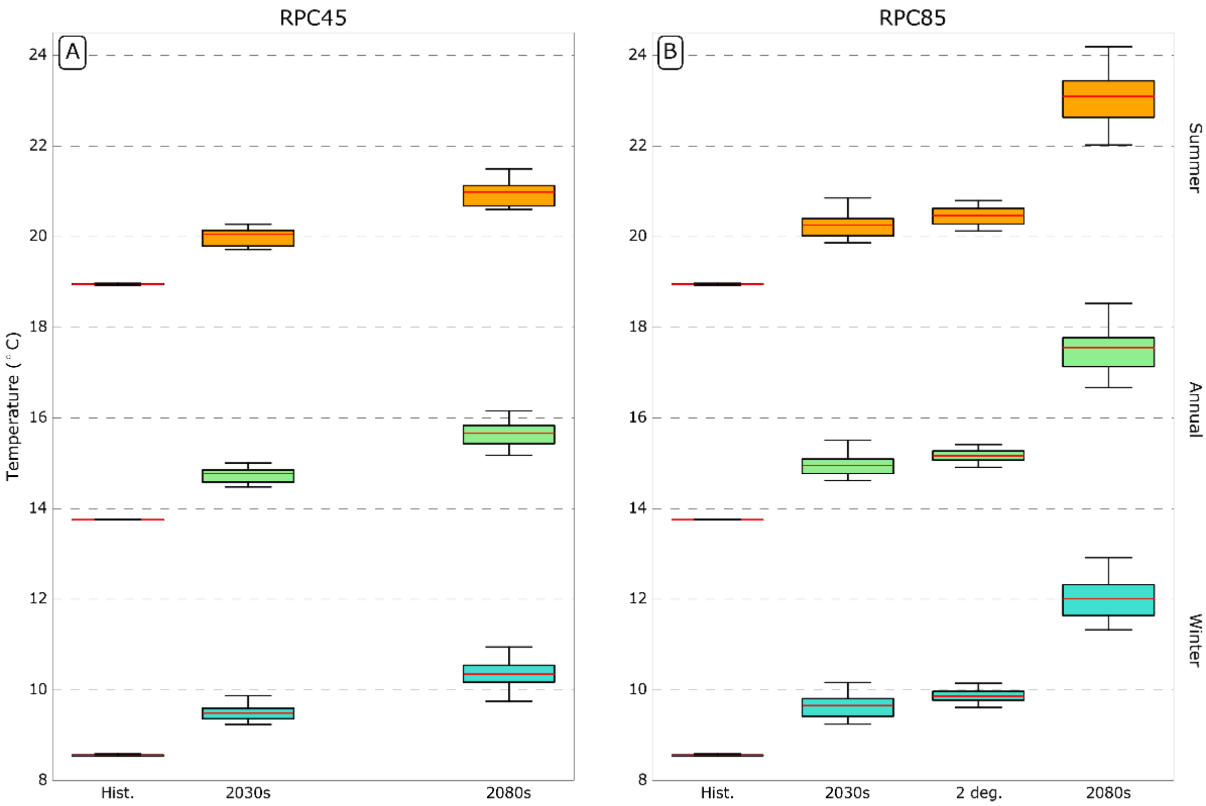
The number of sites in expansion areas is also more marked under RCP8.5 in both periods. In this scenario, by the end of the century, 857 sites are projected in likely expansions areas and 295 in confident expansion, whereas under RCP4.5 the number of sites is 440 and 91, respectively.

4.4. Climatic parameters

In addition to assessing shifts of the MCD and the ACD, we computed projected changes in climate parameters over the current MCD, which is projected to be hotter and drier in both scenarios. The annual mean temperature is projected to increase by 1.9 °C and 3.8 °C under RCP4.5 and RCP8.5, respectively, from the 13.8 °C of the historical reference climate by the 2080s (Figure 9). The increase is already evident in the 2030s period in both scenarios.

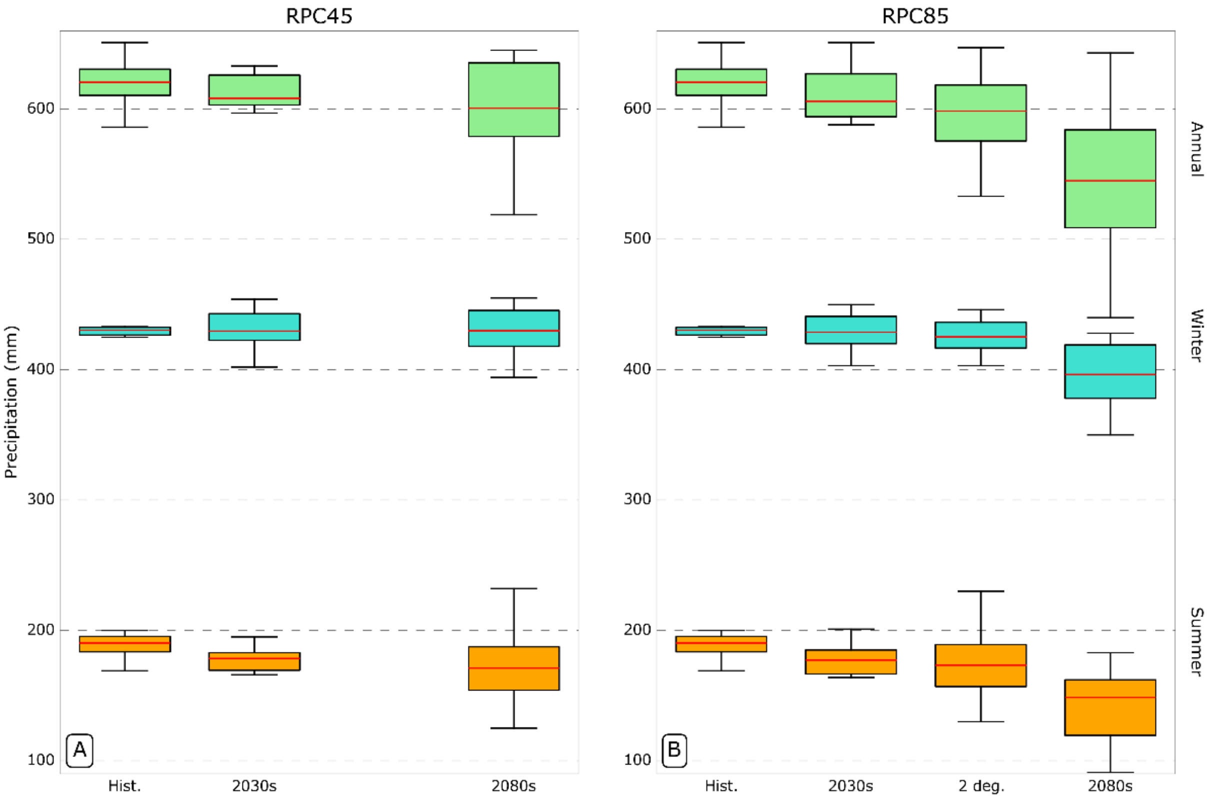
Changes in temperature are expected to be more marked in the summer half of the year. The mean temperature of the summer half of the year is projected to increase by 2.1 °C under RPC4.5 and by 4.2 °C under RPC8.5, whilst in the winter half of the year the projected increase is 1.7 °C and 3.4 °C, under RCP4.5 and RCP8.5, respectively.

Figure 9. Temperature parameters in the Mediterranean climate domain (MCD) under historical reference climate conditions and future scenarios RCP4.5 (A on the left) and RCP8.5 (B on the right) in 2030s and 2080s. The 2 °C warming period (2 deg.) is shown only for RCP8.5. Summer: mean temperature of the summer half of the year; annual: mean annual temperature; winter: mean temperature of the winter half of the year. Box-and-whisker plots show minimum, maximum, mean, lower quartile (25%) and upper quartile (75%) of the 11 RCM simulations.



In the MCD, annual precipitation is projected to decrease in both scenarios, but more markedly under RCP8.5 (Figure 10). In the 2030s period a reduction of 2% is projected in both scenarios. Then, by the 2080s, annual precipitation is projected to decrease by 3% and 12% under RCP4.5 and RCP8.5 scenarios, respectively, from the 620 mm in the historical reference climate. As for temperature increase, larger drops in precipitation are projected in the summer half of the year. By the end of the century, summer precipitation is projected to decrease by 10% under RCP4.5 and by 22% under RCP8.5. By this period, winter precipitation is projected to remain stable under RCP4.5; however, a decrease of 8% is projected under RCP8.5.

Figure 10. Precipitation parameters in the Mediterranean climate domain (MCD) under historical reference climate conditions and future scenario RCP4.5 (A on the left) and RCP8.5 (B on the right) in 2030s and 2080s. The 2 °C warming period (2 deg.) is shown only for RCP8.5. Summer: mean precipitation of the summer half of the year; annual: mean annual precipitation; winter: mean precipitation of the winter half of the year. Box-and-whisker plots show minimum, maximum, mean, lower quartile (25%) and upper quartile (75%) of the 11 RCM simulations.



5. Adaptation measures

Without external intervention and in response to a changing environment, the adjustments made by ecosystems and species are known as autonomous adaptation (intrinsic adaptation). In this report we assess human-assisted adaptation (extrinsic adaptation), which means deliberate interventions oriented to increase the capacity of organisms and ecosystems to survive and function at an acceptable level in the presence of climate change [3]. Human-assisted adaptation options include an array of strategies and measures for addressing adaptation needs.

Adaptation of Natura 2000 sites in the Mediterranean region encompasses a series of nature-based measures oriented to reduce non-climate stressors and to restore degraded habitats (e.g. using Green Infrastructure [36]), protective actions (within protected and non-protected areas projected to remain stable), additions/reconfiguration of the protected area network, and integration of protected areas with biodiversity-hospitable landscape outside the protected network (corridors and stepping stones) [3][7][35].

In 2013, the European Commission issued a set of guidelines on climate change and Natura 2000 [37]. The guidelines are in line with the actions proposed by the IPCC in its Fifth Assessment Report regarding human-assisted adaptation of terrestrial ecosystems [3]. The guidelines include the following six main categories of adaptation measures.

1. Reduce existing pressures:
   - restoration measures
   - buffer zone development
   - increase reserve size
   - site and landscape management.
2. Enhance ecosystem heterogeneity:
   - site management.
3. Increase connectivity:
   - additions to, or reconfigurations of, the protected area estate
   - corridors/stepping stones
   - wider landscape management/spatial planning.
4. Ensure required abiotic conditions:
   - site management.
5. Management of disturbances and extreme events:
   - forest fire management.
6. Other measures:
   - relocation of species
   - control of invasive alien species (management)
   - increase size of protected area/creation of new sites.

In Table 6 we present a series of adaptation measures oriented to the Natura 2000 network according to changes of the MCD, i.e. stable, contraction and expansion. First, Natura 2000 sites in projected stable areas of the MCD are priority areas for long-term conservation because they are expected to host most of the Mediterranean biodiversity [5][7]. In addition, natural and semi-natural areas projected to remain stable outside the Natura 2000 network could become refugia and stepping stones for plant and animal species.

Table 6. Adaptation measures in Natura 2000 sites according to climate-driven changes of the Mediterranean climate domain (MCD). Source of measures: European Commission [37].

MCD change: stable (S) contraction (C) expansion (E)	**Adaptation measures**	**On site**	**Around site**	**Network level**
S, E	1) Restoration of degraded habitats	x	x	
S, E	2) Protective actions: improved land management and spatial planning		x	x
S, E	3) Establishing new protected areas; reconfiguration of the protected area state		x	x
S	4) Integration of protected areas with biodiversity-hospitable landscape outside protected areas, e.g. buffer zones or through conservation schemes [38]		x	
S, C, E	5) Creating corridors/stepping stones facilitating migration of species			x
S	6) Stricter implementation of Natura 2000 and protection [38]	x		
S	7) Increase in reserve size		x	
S, C, E	8) Adaptive management (reducing pressures/disturbances, enhancing ecosystem heterogeneity, ensure abiotic conditions and control of invasive alien species)	x	x	

More species are likely to have a greater chance of surviving if larger areas of suitable habitat are protected [39]. Therefore, increased connectivity and a denser network of protected sites are a reasonable option in natural and semi-natural stable areas of the MCD. Figure 11 shows Natura 2000 sites and natural and semi-natural (3) areas projected to remain stable across the future periods assessed in this study (hereafter 'persistent areas') by the end of the century. The maps in the figure exhibit numerous natural and semi-natural areas around Natura 2000 sites in persistent areas of the MCD. Natural and semi-natural areas, not included in the Natura 2000 network, are important features that can contribute to autonomous adaptation because of their potential role as corridors and stepping stones. In addition, these areas could facilitate some of the adaptation measures indicated in Table 6, such as the establishment of new protected areas for increasing network coherence, the implementation of buffer zones around Natura 2000 sites or the creation of corridors between Natura 2000 sites in projected contraction areas of the MCD and projected persistent areas of the MCD.

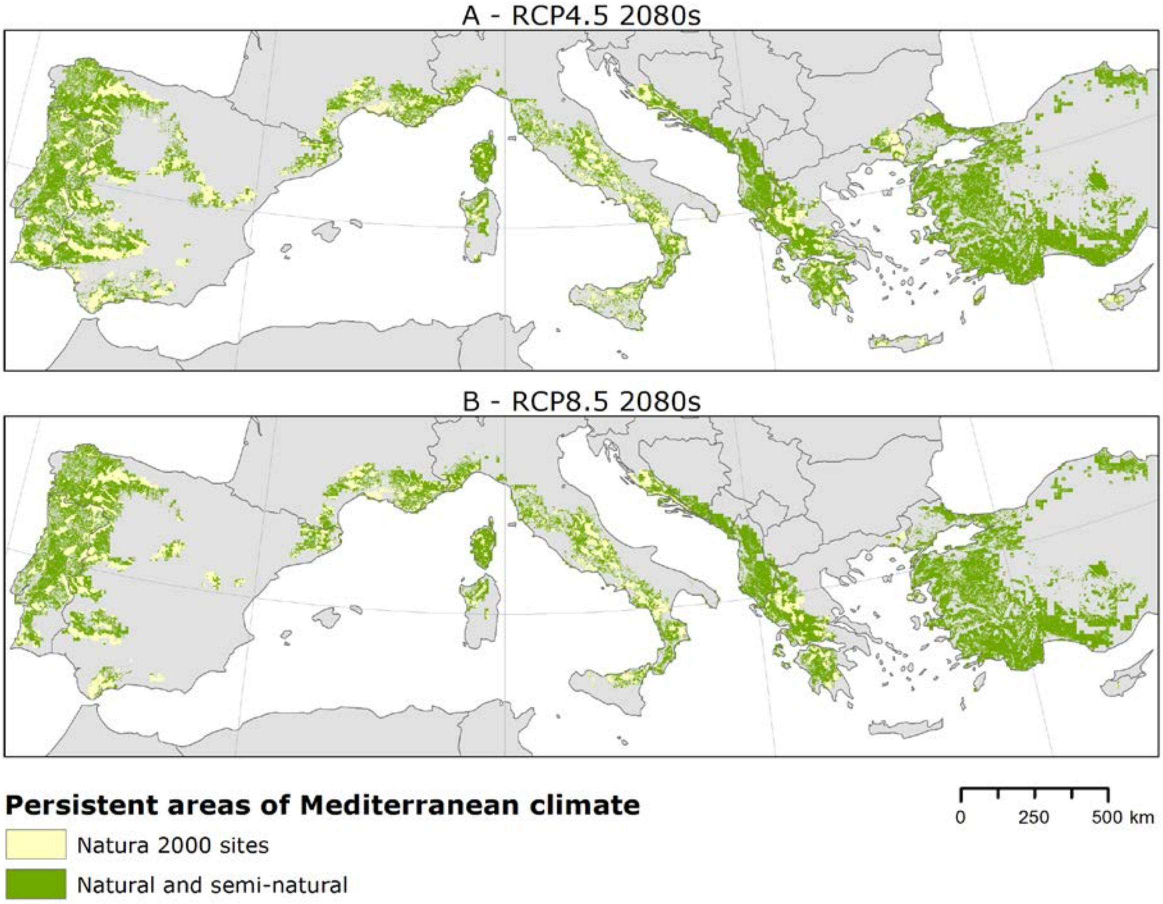
Adaption measures can be supported by Green Infrastructure projects for increasing connectivity to areas where the MCD persist, thus facilitating natural migration of species from MCD contraction areas. A proactive approach that takes into consideration on-site measures and network connectivity is a priority. Projected persistent areas of the MCD in Figure 11 account for around 139 000 km^2 and 103 000 km^2 of Natura 2000 sites under RCP4.5 and RCP8.5, respectively; and 430 000 km^2 and 372 000 km^2 of natural and semi-natural areas under RCP4.5 and RCP8.5, respectively, by the end of the century.

Second, climate change effects in Natura 2000 sites in contraction areas of the MCD are expected to be severe [5][7]. Nevertheless, adaptation should be oriented to facilitating natural changes in species and ecosystems (autonomous adaptation) and to protecting individual species and habitats of particular relevance. Migration of species is expected to occur from contraction areas to persistent and expansion areas of the MCD. Therefore,

(3) Natural and semi-natural areas were mapped using Corine 2012 (V18.5) land cover data. Corine classes considered in natural and semi-natural were: Class 3 — Forest and semi-natural areas; Class 4 — Wetlands; Class 5 — Terrestrial water bodies; Category 243 — Land principally occupied by agriculture with significant areas of natural vegetation; and Category 244 — Agro-forestry areas.

landscape corridors and stepping stones facilitating migration are reasonable conservation measures [35]. Contraction areas of the MCD resulting from expansion of the ACD are projected to face major changes regarding disturbances such as increased forest fires, invasive species, longer drought periods and major habitat changes. In this case, the magnitude of habitat change could overpass the natural migration and autonomous adaptation capacity of plants and animals, such as shown for the Mediterranean tree species cork oak (*Quercus suber*) [40], likely leading to the local decline and extinction with unknown effects at the ecosystem level [41].

Figure 11. Projected persistent areas of the Mediterranean climate domain (MCD) by the 2080s in Natura 2000 sites and natural and semi-natural areas under scenario RCP4.5 (A) and RCP8.5 (B).



Third, adaptation of Natura 2000 sites in expansion areas of the MCD should be oriented to restore degraded habitats contributing to accommodate migrant species from contraction MCD zones, where present biota and interactions permit relocation. In this case, increased connectivity will ease migration of species; nevertheless, the distance from contraction areas to expansion zones could represent an unsurmountable obstacle for natural migration of species. There is great uncertainty regarding habitat changes in expansion areas of the MCD. In relation to the current situation, expansion areas are projected to be hotter and drier, i.e. a Mediterranean climate, and hence be more exposed to increased forest fires and other disturbances such as invasive alien species and pests [42].

An estimation of the extent and nature of adaptation measures potentially required can be computed by assessing the extent of Natura 2000 sites located in the three categories of change of MCD in Table A1 in the annex and the information provided in Table 6. Nevertheless, there is a large array of local adaptation measures that can be implemented in Natural 2000 sites [43], therefore a closer look at the specific local characteristics of the sites and the surrounding habitats would be needed for proper design and implementation. This is evidenced by the diversity of local measures implemented by the LIFE+ Nature & Biodiversity projects that contribute to climate adaptation in natural zones [43].

5.1. Costs of adaptation

There are some gaps in the adaptation literature regarding cost and benefit estimates for the biodiversity/ecosystem services adaptation measures [44]. It is reasonable to suggest at least three probable reasons for these gaps: first, the multiplicity of adaptation actions that can be implemented at local/site level; second, the difficulties for measuring benefits in the short to medium term; and finally, the diversity of habitats in Natura 2000 sites requiring different and specific adaptation measures that are in most cases related with local habitat features.

Despite the limited available information on the cost of adaptation measures in Natura 2000 sites, in this study we provide some figures that can be used as guidelines (Table 7). We collected costs of adaptation, restoration and management of Natura 2000 sites and natural and semi-natural areas from two sources: first, a literature review of reports that have collected information on management and restoration costs; and second by collecting information directly from LIFE projects that fund climate change adaptation with a focus on forests and biodiversity [43].

Information on the cost of management of Natura 2000 sites was estimated by Gantioler et al. [45] based on data provided by EU Member States. We collected only recurrent costs, i.e. those related with management and monitoring on a regular basis in terrestrial sites, thus excluding one-off costs that are related with a designation of new Natura 2000 sites. Despite wide variations in the adaptation costs per hectare between Members States, Gantioler et al. [45] provide average values for all Member States, of 46 €/ha/year, and for geographic regions. Additionally, Tucker et al. [46] assessed costs of habitat restoration and sustainable management of natural and semi-natural areas within the framework of Target 2 of the EU Biodiversity Strategy. The information collected from these two sources is relevant for estimating the cost of adaptation because some adaptation measures can be seen as management activities at site level. Indeed, as shown in Table 6, some adaptation measures are closely related with management, e.g. the restoration of degraded habitats, improved land management, stricter protection and adaptive management.

We assessed information on adaptation measures from 49 projects sourced from the projects database of the LIFE portal [47]. The collected information includes project title, total budget, project area, area of the adaptation measures, type of adaptation measures, country (or countries) of the project, cost of adaptation measures and project duration. With this information, we computed some estimates of the cost of adaptation measures per hectare and per year for different types of adaptation measures (Table 7). Only 14 LIFE projects provided the necessary information for computing economic cost and listing the adaptation measures implemented. Therefore, the figures included in the table are considered a first estimate of the cost of adaptation measures. There are local socioeconomic factors that can produce differences in the cost; similarly, local factors regarding habitat typology and status can influence the cost of specific adaptation measures.

Table 7. Cost of management and adaptation measures in Natura 2000 sites and natural and semi-natural areas.

Management/adaptation measures	Cost in €/ha/year unless otherwise indicated	Source
Managing semi-natural forests (Natura 2000 sites)	37	[46]
Soil organic management practices	44-384	[46]
Sustainable forest management practices (compensation payments)	116	[46]
Restoration of native pine forests	1 450 €/ha	LIFE project LIFE03 NAT/E/000054 [46]
Forest conservation and restoration	133 €/ha	Rural development programmes [46]
Forest combined restoration measures	4 300 €/ha	Rural development programmes [46]
Planting native forest tree species	1 000 €/ha	Rural development programmes [46]
Removal of invasive alien plant species in forest	2 265 €/ha	LIFE projects in Ireland, Spain, France, [46]
Combined maintenance cost of sclerophyllous vegetation	200	[46]
Combined restoration cost of sclerophyllous vegetation	2 000 €/ha	LIFE projects in Spain, France, Italy [46]
Habitat re-creation of sclerophyllous scrub	2 000 €/ha	[46]
Management of Natura 2000 sites (southern Europe average)	54	[45]
Management of Natura 2000 sites (EU average)	46	[45]
Restoration of degraded habitats and improved management (forest)	2 558	LIFE project Resilformed, Italy, 2012 [47]
Monitoring tools, not specific adaptation measures (forest fires)	44	LIFE project FLIRE, Greece, 2012 [47]
Protective actions: improved land management and restoration of degraded habitats (forest)	320	LIFE project Montserrad, Spain, 2014 [47]
Adaptation measures: sustainable forestry, combatting forest fires and pests	2 541	LIFE+ project SUBER, Spain, 2014 [47]
Restoration of degraded habitats and sustainable forest management	1 000	LIFE+ project Pinassa, Spain, 2014 [47]
Sustainable forest management	699	LIFE+ project Boscos, Spain, 2014 [47]
Restoration of degraded habitats and creation of corridors	487	LIFE project OZON, Belgium, 2013 [47]
Creation of corridors and integration of protected areas with biodiversity-hospitable landscape outside protected areas	2 904	LIFE project BEAR Defragmentation, Spain, 2013 [47]
Restoration of degraded habitats and improved land management	1 466	LIFE project EcoCo, United Kingdom, 2014 [47]
Creation of corridors/stepping stones	2 387	LIFE project EstepÁrias, Portugal, 2009 [47]
Creation of corridors and improved land management	3 332	LIFE project Alde-Ore, United Kingdom, 2010 [47]
Restoration of degraded habitats and creation of corridors	2 171	LIFE project Mansalt, Slovenia, 2010 [47]
Adaptive management and restoration of degraded habitats	1 482	LIFE project Saimaa Seal, Finland, 2013 [47]
Protective actions: improved land management and restoration of degraded habitats	2 217	LIFE project MixForChange, Spain, 2016 [47]

6. Discussion

This study aimed to assess changes in the Mediterranean climate using an approach that accounts for change in the area of analogous climates, specifically the MCD and the ACD. Results of this study show projected contraction of the current area of the MCD under both RCP4.5 and RCP8.5 scenarios. The contraction process is evident in the 2030s and continues towards the end of the century. By this period, the contraction is notably more marked in RCP8.5 than in RCP4.5. Projected contraction of the MCD supports the hypothesis of changes in species composition and interactions and may drive transient and new assemblages of plant and animal species [4]. However, the extent of the impacts remains uncertain [21][48][41]. Our results also suggest a projected expansion of the MCD in other climate domains under both scenarios. These 'new' MCD areas could provide a suitable habitat for Mediterranean species if habitat quality and biotic interactions allow the establishment [21].

A relevant finding of this study is the mapping of the persistent areas of the MCD under RCP4.5 and RCP8.5. Natura 2000 sites and natural and semi-natural areas in persistent areas of the MCD are considered critical zones for biodiversity conservation. For instance, these areas could contribute to the autonomous adaptation of vagile species serving as corridors and refugia. In fact, persistent areas should be considered target zones for human-assisted adaptation.

In addition to the effects of shifts of the MCD, computed changes in climatic parameters project a transition towards hotter and drier conditions in the MCD. A hotter and drier Mediterranean region is projected to occur in the 2030s under both scenarios and in the 2 °C warming period under RCP8.5. These warming and drying trends are projected to worsen in the 2080s in both scenarios. This result supports the hypothesis of an increase of other concomitant effects of climate change such as forest fires [49][50][51][52], more frequent and longer drought [53][6][54], the establishment and spread of invasive alien species [55] and changes in temporal and spatial patterns of forest pests and diseases [54][56]. The concomitant effects of these projected changes indicate decreasing levels of biodiversity due to the migration or local extinction of Mediterranean species.

Results of this study are consistent with previous evidence assessing projected climatic changes in the Mediterranean region (e.g. [5][7][57]). In a study using an ecosystem model, Guiot and Cramer [58] suggest a series of climatic impacts in the Mediterranean region under RCP scenarios. Among the impacts with a likely effect on biodiversity, they indicate regression of alpine forest, extension of Mediterranean sclerophyllous vegetation, expansion of the desert biome in the Iberian Peninsula and a general shift of the Mediterranean biome towards norther latitudes and higher elevations.

The present study used a transparent methodology that facilitates mapping of Mediterranean habitat loss. Nevertheless, despite known uncertainties in climate models, our results are subject to a few constraints. First, assessing projected impacts of climate change on biodiversity is a complex task that could be approached from different perspectives. In fact, different metrics of change may account for various dimensions of change, each with different implications for biodiversity conservation [21]. In this study we followed an approach using one type of metric that provides an assessment of changes of analogous climates. This approach has been used by Klausmeyer and Shaw [7] at global level and by Barredo et al. [5] at European level, offering valuable results regarding biodiversity conservation. Nevertheless, using more types of metrics could provide additional information regarding projected impacts on biodiversity. Secondly, the spatial resolution of the RCM simulations, although state of the art [59], is notably larger than the optimal resolution required for assessing local-level features such as Natura 2000 sites. This aspect can be alleviated by using downscaling methods, e.g. change factor [60]. However, downscaling methods would require increased computing resources.

The Mediterranean region is projected to face shifts of its climatic domain and changes in climate parameters. Therefore, appropriate and timely climate adaptation in the Mediterranean region should be seen as a priority. Proactive adaptation and landscape management, facilitating a denser network of interconnected protected areas, are necessary instruments for protecting Mediterranean biodiversity from the threats posed by changing climatic conditions.

References

[1] Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. and Kent, J., 'Biodiversity hotspots for conservation priorities', *Nature*, Vol. 403, 2000, pp. 853-858. doi:10.1038/35002501.

[2] Council of the European Communities, 'Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora', *Official Journal of the European Communities*, 1992.

[3] IPCC, 'Part A: Global and sectoral aspects', in *Climate change 2014: impacts, adaptation, and vulnerability*, contribution of Working Group II to the *Fifth assessment report* of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, New York, 2014.

[4] Blois, J.L., Zarnetske, P.L., Fitzpatrick, M.C. and Finnegan, S., 'Climate change and the past, present, and future of biotic interactions', *Science*, Vol. 341, 2013, pp. 499-504. doi:10.1126/science.1237184.

[5] Barredo, J. I., Caudullo, G. and Dosio, A., 'Mediterranean habitat loss under future climate conditions: assessing impacts on the Natura 2000 protected area network', *Applied Geography*, Vol. 75, 2016, pp. 83-92. doi:10.1016/j.apgeog.2016.08.003.

[6] Hoerling, M., Eischeid, J., Perlwitz, J., Quan, X., Zhang, T. and Pegion, P., (2011) 'On the increased frequency of Mediterranean drought', *Journal of Climate*, Vol. 25, 2011, pp. 2 146-2 161. doi:10.1175/jcli-d-11-00296.1.

[7] Klausmeyer, K.R. and Shaw, M. R., 'Climate change, habitat loss, protected areas and the climate adaptation potential of species in Mediterranean ecosystems worldwide', *PLoS ONE*, Vol. 4, 2009, p. e6392.

[8] Benoit, G., Comeau, A., *A sustainable future for the Mediterranean: the Blue Plan's environment and development outlook*, Earthscan, London, 2005, p. 464.

[9] European Commission, *Natura 2000 network*, 2016b; http://ec.europa.eu/environment/nature/natura2000, accessed 10.5.2016.

[10] European Commission, *Green Infrastructure*, 2016a; http://ec.europa.eu/environment/nature/ecosystems, accessed 11.5.2016.

[11] Moss, R. H. et al., 'The next generation of scenarios for climate change research and assessment', *Nature*, Vol. 463, 2010, pp. 747-756. doi:10.1038/nature08823.

[12] van Vuuren, D. P. et al., 'The representative concentration pathways: an overview', *Climatic Change*, Vol. 109, No 5, 2011. doi:10.1007/s10584-011-0148-z.

[13] IMPACT2C, *Project final report*, IMPACT2C, 2015, p. 42.

[14] Taylor, K. E., Stouffer, R. J. and Meehl, G. A., 'An overview of CMIP5 and the experiment design', *Bulletin of the American Meteorological Society*, Vol. 93, 2012, pp. 485-498. doi:10.1175/BAMS-D-11-00094.1.

[15] Dosio, A., 'Projections of climate change indices of temperature and precipitation from an ensemble of bias-adjusted high-resolution EURO-Cordex regional climate models', *Journal of Geophysical Research: Atmospheres*, Vol. 121, No 10, 2016, pp. 5 488-5 511. doi:10.1002/2015jd024411.

[16] Dosio, A. and Paruolo, P., 'Bias correction of the Ensembles high-resolution climate change projections for use by impact models: evaluation on the present climate', *Journal of Geophysical Research: Atmospheres*, Vol. 116, 2011, p. D16106. doi:10.1029/2011jd015934.

[17] Dosio, A., Paruolo, P. and Rojas, R., 'Bias correction of the Ensembles high-resolution climate change projections for use by impact models: Analysis of the climate change signal', *Journal of Geophysical Research: Atmospheres*, Vol. 116, No D16, 2012, p. D17110. doi:10.1029/2012jd017968.

[18] Hantel, M., '13.4.2 The Köppen climate classification', in Fischer, G. (ed.), *Climatology. Part 2*, Landolt-Börnstein — Group V Geophysics, Springer, Berlin Heidelberg, Vol. 4C2, 1989, pp. 462-465. doi:10.1007/10367682_59.

[19] Kottek, M., Grieser, J., Beck, C., Rudolf, B. and Rubel, F., ‘World map of the Köppen-Geiger climate classification updated’, *Meteorologische Zeitschrift*, Vol. 15, 2006, pp. 259-263. doi:10.1127/0941-2948/2006/0130.

[20] Peel, M. C., Finlayson, B. L. and McMahon, T. A., ‘Updated world map of the Köppen-Geiger climate classification’, *Hydrology and Earth System Sciences*, Vol. 4, 2007, pp. 439-473. doi:10.5194/hessd-4-439-2007.

[21] Garcia, R. A., Cabeza, M., Rahbek, C. and Araújo, M. B., ‘Multiple dimensions of climate change and their implications for biodiversity’, *Science*, Vol. 344, 2014, No 6 183, doi:10.1126/science.1247579.

[22] Russell, R. J., ‘Dry climates of the United States: I. Climatic map’, *University of California Publications in Geography*, Vol. 5, 1931, pp. 1-41.

[23] Mastrandrea, M. D., Field, C. B., Stocker, T. F., Edenhofer, O., Ebi, K. L., Frame, D. J., Held, H., Kriegler, E., Mach, K. J., Matschoss, P. R., Plattner, G-K., Yohe, G. W. and Zwiers, F. W., *Guidance note for lead authors of the IPCC Fifth assessment report on consistent treatment of uncertainties*, Intergovernmental Panel on Climate Change, 2010; available at http://www.ipcc.ch.

[24] Aschmann, H. ‘Distribution and peculiarity of Mediterranean ecosystems’, in di Castri, F. and Mooney, H. A. (eds.), ‘Mediterranean type ecosystems’, *Ecological Studies*, Vol. 7, Springer, Berlin Heidelberg, 1973, pp. 11-19. doi:10.1007/978-3-642-65520-3_2.

[25] Bohn, U., Gollub, G., Hettwer, C., Neuhäuslová, Z., Raus, T., Schlüter, H. and Weber, H., *Map of the natural vegetation of Europe, Scale 1:2.500.000, interactive CD-ROM*, Landwirtschaftsverlag, Münster, 2004.

[26] Médail, F. and Quézel, P., ‘Hot-spots analysis for conservation of plant biodiversity in the Mediterranean Basin’, *Annals of the Missouri Botanical Garden*, Vol. 84, 1997, pp. 112-127. doi:10.1046/j.1523-1739.1999.98467.x.

[27] Médail, F. and Quézel, P., ‘Biodiversity hotspots in the Mediterranean Basin: setting global conservation priorities’, *Conservation Biology*, Vol. 13, 1999, pp. 1 510-1 513. doi:10.1046/j.1523-1739.1999.98467.x.

[28] Olson, D. M. et al., ‘Terrestrial ecoregions of the world: a new map of life on Earth: a new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity’, *BioScience*, Vol. 51, 2001, pp. 933-938. doi:10.1641/0006-3568(2001)051[0933:teotwa]2.0.co;2.

[29] FAO, *Global ecological zones for FAO forest reporting: 2010 update*, Food and Agriculture Organization of the United Nations, Rome, 2010, p. 42.

[30] EEA, *Europe’s biodiversity — Biogeographical regions in Europe*, EEA report No 1/2002, European Environment Agency, Copenhagen, 2002.

[31] Cohen, J., ‘A coefficient of agreement for nominal scales’, *Educational and Psychological Measurement*, Vol. 20, 1960, pp. 37-46. doi:10.1177/001316446002000104.

[32] Hudson, W. D. and Ramm, C. V., ‘Correct formulation of the Kappa coefficient of agreement, *Photogrammetric Engineering and Remote Sensing*, Vol. 53, 1987, pp. 421-422.

[33] Congalton, R. G., ‘A review of assessing the accuracy of classifications of remotely sensed data’, *Remote Sensing of Environment*, Vol. 37, 1991, pp. 35-46. doi:10.1016/0034-4257(91)90048-B.

[34] Landis, J. R. and Koch, G. G., ‘The measurement of observer agreement for categorical data’, *Biometrics*, Vol. 33, 1977, pp. 159-174.

[35] Vos, C. C., Berry, P., Opdam, P., Baveco, H., Nijhof, B., O’Hanley, J., Bell, C. and Kuipers, H., ‘Adapting landscapes to climate change: examples of climate-proof ecosystem networks and priority adaptation zones’, *Journal of Applied Ecology*, Vol. 45, No 6, 2008, pp. 1 722-1 731. doi:10.1111/j.1365-2664.2008.01569.x.

[36] Estreguil, C., Caudullo, G., Rega, C. and Paracchini, M. L., *Enhancing connectivity improving green infrastructure*, EUR 28142 EN, 2016. doi:10.2788/170924.

[37] European Commission, *Guidelines on climate change and Natura 2000 — Dealing with the impact of climate change on the management of the Natura 2000 network of areas of high biodiversity value*, Publications Office of the European Union, Luxembourg, 2013, p. 104.

[38] de Koning, J., Winkel, G., Sotirov, M., Blondet, M., Borras, L., Ferranti, F. and Geitzenauer, M., 'Natura 2000 and climate change — Polarisation, uncertainty and pragmatism in discourses on forest conservation and management in Europe', *Environmental Science & Policy*, Vol. 39, 2014, pp. 129-138. doi:10.1016/j.envsci.2013.08.010.

[39] Dunlop, M. and Brown, P. R., *Implications of climate change for Australia's national reserve system: a preliminary assessment*, Department of Climate Change, Canberra, Australia, 2008, p. 147.

[40] Benito Garzón, M., Sánchez de Dios, R. and Sainz Ollero, H., 'Effects of climate change on the distribution of Iberian tree species', *Applied Vegetation Science*, Vol. 11, 2008, pp. 169-178.

[41] Urban, M., Tewksbury, J. and Sheldon, K., 'On a collision course: competition and dispersal differences create no-analogue communities and cause extinctions during climate change', *Proceedings of the Royal Society B: Biological Sciences*, pp. 1-9, 2012. doi:10.1098/rspb.2011.2367.

[42] Barredo, J. I., Strona, G., de Rigo, D., Caudullo, G., Stancanelli, G., and San-Miguel-Ayanz, J. 'Assessing the potential distribution of insect pests: case studies on large pine weevil (Hylobius abietis L) and horse-chestnut leaf miner (Cameraria ohridella) under present and future climate conditions in European forests', *EPPO Bulletin*, Vol. 45, No. 2, 2015, pp. 273-281.

[43] European Commission, *LIFE and climate change adaptation, European Commission, LIFE Environment,* Publications Office of the European Union, Luxembourg, 2015, p. 113.

[44] Econadapt, 'Results of the Econadapt project', *Econadapt consortium*, Vol. 15, 2016.

[45] Gantioler, S. et al., *Costs and socioeconomic benefits associated with the Natura 2000 network*, final report to the European Commission, DG Environment on Contract ENV.B.2/SER/2008/0038, Institute for European Environmental Policy, GHK, Ecologic, Brussels, pp. 122, 2010.

[46] Tucker, G., Underwood, E., Farmer, A., Scalera, R., Dickie, I., McConville, A. and van Vliet, W., *Estimation of the financing needs to implement Target 2 of the EU Biodiversity Strategy*, report to the European Commission, Institute for European Environmental Policy, London, pp. 507, 2013.

[47] European Commission, *LIFE programme*, 2017; http://ec.europa.eu/environment/life accessed 10.1.2017.

[48] Moritz, C. and Agudo, R., 'The future of species under climate change: resilience or decline?', *Science*, Vol. 341, 2013, pp. 504-508. doi:10.1126/science.1237190.

[49] Camia, A. and Amatulli, G., 'Weather factors and fire danger in the Mediterranean', in Chuvieco, E. (ed.), *Earth observation of wildland fires in mediterranean ecosystems*, Springer-Berlag, Berlin Heidelberg, 2009, pp. 71-82.

[50] Migliavacca, M., Dosio, A., Camia, A., Hobourg, R., Houston Durrant, T., Kaiser, J. W., Khabarov, N., Krasovskii, A. A., Marcolla, B., San-Miguel-Ayanz, J., Ward, D. S. and Cescatti, A., 'Modeling biomass burning and related carbon emissions during the 21st century in Europe', *Journal of Geophysical Research: Biogeosciences*, Vol. 118, 2013, 2013JG002444. doi:10.1002/2013jg002444.

[51] Migliavacca, M., Dosio, A., Kloster, S., Ward, D. S., Camia, A., Houborg, R., Houston Durrant, T., Khabarov, N., Krasovskii, A. A., San-Miguel-Ayanz, J. and

Cescatti, A., ‘Modeling burned area in Europe with the Community Land Model’, *Journal of Geophysical Research: Biogeosciences*, Vol. 118, 2013, pp. 265-279. doi:10.1002/jgrg.20026.

[52] Moriondo, M., Good, P., Durao, R., Bindi, M., Giannakopoulos, C. and Corte-Real, J., ‘Potential impact of climate change on fire risk in the Mediterranean area’, *Climate Research*, Vol. 31, 2006, pp. 85-95. doi:10.3354/cr031085.

[53] Allen, C. D., Macalady, A. K, Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Kitzberger, T., Rigling, A., Breshears, D. D., Hogg, E. H. T., Gonzalez, P., Fensham, R., Zhang, Z., Castro, J., Demidova, N., Lim, J-H., Allard, G., Running, S. W., Semerci, A. and Cobb, N., ‘A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests’, *Forest Ecology and Management*, Vol. 259, No 4, 2010, pp. 660-684. doi:10.1016/j.foreco.2009.09.001.

[54] Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., Seidl, R., Delzon, S., Corona, P., Kolström, M., Lexer, M. J. and Marchetti, M., ‘Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems’, *Forest Ecology and Management*, Vol. 259, 2010, pp. 698-709. doi:10.1016/j.foreco.2009.09.023.

[55] Hellmann, J. J., Byers, J. E., Bierwagen, B. G. and Dukes, J. S., ‘Five potential consequences of climate change for invasive species’, *Conservation Biology*, Vol. 22, 2008, pp. 534-543. doi:10.1111/j.1523-1739.2008.00951.x.

[56] Netherer, S. and Schopf, A., ‘Potential effects of climate change on insect herbivores in European forests — General aspects and the pine processionary moth as specific example’, *Forest Ecology and Management*, Vol. 259, 2010, pp. 831-838. doi:10.1016/j.foreco.2009.07.034.

[57] Giorgi, F. and Lionello, P., ‘Climate change projections for the Mediterranean region’, *Global and Planetary Change*, Vol. 63, Nos 2-3, 2008, pp. 90-104. doi:10.1016/j.gloplacha.2007.09.005.

[58] Guiot, J. and Cramer, W., ‘Climate change: the 2015 Paris Agreement thresholds and Mediterranean basin ecosystems’, *Science*, Vol. 354, 2016, pp. 465-468. doi:10.1126/science.aah5015.

[59] Jacob, D., Petersen, J., Eggert, B., Alias, A., Christensen, O. B., Bouwer, L. M., Braun, A., Colette, A., Déqué, M., Georgievski, G., Georgopoulou, E., Gobiet, A., Menut, L., Nikulin, G., Haensler, A., Hempelmann, N., Jones, C., Keuler, K., Kovats, S., Kröner, N., Kotlarski, S., Kriegsmann, A., Martin, E., van Meijgaard, E., Moseley, C., Pfeifer, S., Preuschmann, S., Radermacher, C., Radtke, K., Rechid, D., Rounsevell, M., Samuelsson, P., Somot, S., Soussana, J-F., Teichmann, C., Valentini, R., Vautard, R., Weber, B. and Yiou, P., ‘EURO-Cordex: new high-resolution climate change projections for European impact research’, *Regional Environmental Change*, Vol. 14, 2014, pp. 563-578. doi:10.1007/s10113-013-0499-2.

[60] Ekström, M., Grose, M. R. and Whetton, P. H., ‘An appraisal of downscaling methods used in climate change research’, *Wiley Interdisciplinary Reviews: Climate Change*, Vol. 6, 2015, pp. 301-319. doi:10.1002/wcc.339.

List of abbreviations and definitions

ACD	arid climate domain
EEA	European Environment Agency
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
IPCC	Intergovernmental Panel on Climate Change
MCD	Mediterranean climate domain
RCM	regional climate model
RCP	representative concentration pathway
RCP4.5	representative concentration pathway with a future scenario at +4.5 W/m^2
RCP8.5	representative concentration pathway with a future scenario at +8.5 W/m^2

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Table A1. Projected area of Natura 2000 sites by category of change of the Mediterranean climate domain (MCD) under scenario RCP4.5 and RCP8.5 in three future periods (2030s, 2080s and a 2 °C warming period).

MCD historical reference period (km^2)	Changes (km^2)	RCP4.5		RCP8.5		
		2030s	2080s	2030s	2 °C period	2080s
167 682	Confident stable	106 308	111 053	112 372	109 612	71 872
	Likely stable	41 152	32 761	34 036	34 208	34 153
	Uncertain	63 602	59 483	60 659	60 469	66 021
	Likely contraction	986	5 420	3 253	5 749	26 505
	Confident contraction	0	590	57	295	5 912
	Likely expansion	8 272	16 550	10 148	12 398	29 001
	Confident expansion	837	2 764	969	2 275	10 738

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