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Mediterranean habitat loss under future climate conditions: Assessing impacts on the Natura 2000 protected area network

José I. Barredo [a,*], Giovanni Caudullo [a], Alessandro Dosio [b]

[a] European Commission, Joint Research Centre, Bio-Economy Unit, TP 261, I-21027, Ispra, Italy
[b] European Commission, Joint Research Centre, Disaster Risk Management Unit, TP 1001, I-21027, Ispra, Italy

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ABSTRACT

The Mediterranean basin is a global hotspot of biological diversity and the most rich biodiversity region in Europe. Nevertheless, climate-driven habitat loss is one of the most serious concerns for biodiversity conservation in this region. We assess Mediterranean habitat loss and conversion into arid habitat under scenarios of climate change and evaluate protected areas, including Natura 2000 sites, which will be affected by these changes. We mapped shifts of Mediterranean and arid domains using four bias-corrected simulations from Regional Climate Models for two emission scenarios over this century, disaggregated to a 1 km grid size. Our results indicate that by the end of the century the Euro-Mediterranean domain is projected to shift into other climatic domains by an area equivalent to 53–121% of its current size. However it is projected to lose 11–25% of its current extent, which represents an area close to the size of Greece and Portugal combined. The loss is entirely due to shifts of the arid domain. Additionally, our results indicate that the extent of the arid domain is projected to increase by 228–450% of its current size in the European region. The shrinking of the current Euro-Mediterranean domain is projected to affect 15–23% of the Mediterranean Natura 2000 sites, and the loss in these sites is projected at 13–30% of its current area. Loss is projected to occur in central and southern areas of the Iberian Peninsula, southern Italy and the island of Sicily, south-eastern Greece, Cyprus, Malta and central Turkey. Computed changes in projected climatic parameters indicate that current areas of the Euro-Mediterranean domain will be hotter and drier. Temperature increase and precipitation decrease are projected to be more marked in the summer half of the year. As early as in the 2020s annual temperature is projected to increase by 0.9–1.4 °C with respect to the present reference climate, reaching an increase of 2.2–3.6 °C by the end of the century. By this period, summer precipitation is projected to decrease by 24–46% and annual precipitation by 14–23%. We provide insight into several aspects of adaptation and management of Mediterranean protected areas. A proactive approach taking into consideration landscape connectivity and the concomitant threats triggered by climate change is a priority. Proactive adaptation and management promoting investments in Green Infrastructure and a denser network of interconnected protected areas are necessary instruments for preserving Mediterranean biodiversity from the threats of habitat loss.

1. Introduction

The Mediterranean basin is a global hotspot of biological diversity and the most rich biodiversity region in Europe where 25,000 flowering plants, or around 10% of all known plants on earth, are found in an area representing only 1.6% the global land surface (Médail & Quézel, 1997; Olson & Dinerstein, 2002). Almost half of the plants and animals and more than half of the habitats listed in the European Union (EU) Habitats Directive (Council of the European Communities, 1992) occur in the Mediterranean region. Mediterranean climate is characterised by hot dry summers and cool wet winters. These climatic conditions have had a deep influence on the evolution of communities of animal and plant species. In this region the threat posed by anthropogenic climate change is one of the most serious concerns for biodiversity conservation (IPCC, 2014). Habitat loss, which is the focus of this paper, is one of the effects of climate change for Mediterranean species

* Corresponding author.
E-mail address: jose.barredo@jrc.ec.europa.eu (J.I. Barredo).

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(Klausmeyer & Shaw, 2009). In turn, shifts in the distribution of climatic conditions can affect the availability and distribution of suitable areas for species in space and time (Garcia, Cabeza, Rahbek, & Araújo, 2014). Additionally, other current threats to the Mediterranean region such as destruction of habitats by urban growth, the development of transport and tourism infrastructures, and the evolving consumption patterns (Benoit & Comeau, 2005), could restrict migration of species further exacerbating the effects of habitat loss. Increased drought is another concern in the Mediterranean basin (Hoerling et al., 2011). The concomitant effects of the contraction of the Mediterranean domain, and the expansion of the arid domain occurring in a fragmented landscape, may aggravate the impacts on plant and animal species in the Mediterranean region.

Klausmeyer and Shaw (2009) pointed out that the Mediterranean biome will likely shift as a consequence of future climate change. They used an ensemble of atmosphere-ocean general circulation models (AOGCMs) and the conservative definition of Mediterranean climate given by Aschmann (1973). Although the definition of Aschmann seems to faithfully represent the Mediterranean biome in other regions of the world, in the Mediterranean basin it is too restrictive when compared with the area traditionally considered Mediterranean (e.g. Bohn et al., 2004; Médail & Quézel, 1997, 1999; Olson et al., 2001). The study of Klausmeyer and Shaw (2009) provides relevant insight into the impacts of climate change in the Mediterranean biome. In this paper, a closer assessment of habitat loss in the Euro-Mediterranean basin is provided, additionally addressing shifts of the arid climate. Results of the assessment will provide new evidence on the potential threats to biodiversity. In addition, using a more comprehensive definition of the Mediterranean climate and high-resolution and bias-corrected climate simulations from Regional Climate Models (RCMs) provides a more detailed assessment for this region. Therefore, the aim of this paper is twofold. First, to assess changes in the spatial range of the Mediterranean climate domain in Europe and conversion into arid domain under scenarios of climate change using data from RCMs; and second, to assess protected areas, including Natura 2000 sites, that will be affected by these changes. The Natura 2000 network of protected areas is the cornerstone of EU Nature and Biodiversity policy. The aim of the network is to preserve the most valuable and threatened species and habitats. The terrestrial network consists of over 26,000 sites covering about 18% of the EU territory. The sites cover approximately 30% of forested land in the EU and are areas of high biodiversity value (European Commission, 2014c).

2. Methods and data

The objective of the first part of the method is to map the European Mediterranean and arid climate domains (hereafter MCD and ACD respectively) under historical climate (1960–1990) and future emission scenarios A1B (Nakicenovic & Swart, 2000) and E1 (Lowe et al., 2009), and to map the four possible combinations of change derived from the presence or absence of the MCD and ACD in historical climate and future scenarios. A1B is a moderate emissions scenario with a balance across all sources of emissions, not relying too heavily on one particular energy source. E1 represents a stabilisation scenario and simulates matching the EU target of keeping anthropogenic global warming below 2 °C above pre-industrial levels in 2100. This target is coherent with the UNFCCC COP 21 agreement that stipulates holding the increase in the global average temperature below 2 °C above pre-industrial levels (United Nations, 2015).

This study is a post-hoc assessment in the framework of the PESETA II project (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis) (Ciscar et al., 2014). The main objective of this project was to analyse the impacts of climate change in several sectors in Europe. Therefore, despite the availability of more recent simulations i.e. CMIP5 (Taylor, Stouffer, & Meehl, 2012) from CORDEX (Giorgi, Jones, & Asrar, 2009), in this study the emission scenarios and the climate simulations were selected in agreement with PESETA II for ensuring comparability of results with the other sectors of this project. At the moment of implementing PESETA II only simulations for SRES scenarios (Nakicenovic & Swart, 2000) were available from the European Union 6th Framework Program ENSEMBLES project (van der Linden & Mitchell, 2009). ENSEMBLES climate simulations from four RCMs were used for mapping the future MCD and ACD (Table 1). Simulations for scenario A1B and E1 covering the period 1961–2100 at a resolution of ~25 km (A1B) and ~50 km (E1) were provided from four RCMs. The future scenarios represent three periods centred on the 2020s (2010–2039), 2050s (2040–2069) and 2080s (2070–2099).

Bias correction of climate simulations is deemed necessary for climate impact studies (Dosio, Paruolo, & Rojas, 2012; Ekström, Grose, & Whetton, 2015; Glotter et al., 2014). Climate model outputs may present bias when compared with observed data. Therefore, their use for impact assessment may lead to unrealistic results unless the biases are corrected (Dosio et al., 2012; Glotter et al., 2014). Consequently, the climate simulations sourced from ENSEMBLES, 12 A1B and three E1, were corrected for biases in temperature and precipitation by Dosio and Paruolo (2011) and Dosio et al. (2012). A statistical bias correction technique by Piani, Haerter, and Coppola (2010) was applied to the RCMs simulations. The technique is based on a transfer function, estimated on historical climate, and applied to the whole probability density function (PDF) of variables. The function is assumed constant between the historical and future climate (Dosio et al., 2012).

We followed Dosio et al. (2012) and Ciscar et al. (2014) for selecting three A1B simulations from the 12 bias-corrected simulations according to PESETA II project (Table 1). The chosen simulations were meant to provide a common set for all the sectors assessed in PESETA II. Although the selection may be not optimal for each individual sector, it is consistent across all the sectors

Table 1
Description of climate simulations, variants and regional climate models.

Climate simulations	Description of climate simulations	Institute: RCM (driving GCM)	Spatial resolution
A1B - reference	Represents the central of 12 A1B bias corrected simulations sourced from the ENSEMBLES project (van der Linden & Mitchell, 2009)	KNMI: RACMO2 (ECHAM5) (van Meijgaard et al., 2008)	~25 km
A1B - variant 1	Warmer and drier than the reference A1B	METO-HC: HadRM3Q0 (HadCM3Q0) (Collins et al., 2011)	~25 km
A1B - variant 2	Colder and wetter than the reference A1B	DMI: HIRHAM5 (ECHAM5) (Christensen et al., 2006)	~25 km
E1	This run represents a stabilisation scenario keeping anthropogenic global warming below 2 °C above pre-industrial levels in 2100	MPI: REMO (ECHAM5 BC r1) (Jacob, 2001)	~50 km

assessed. The A1B reference simulation represents the central (closest to ensemble) of the 12 A1B bias-corrected simulations. The two additional A1B simulations show the most extreme deviations from the reference, being usually warmer and drier (variant 1) and colder and wetter (variant 2) than the reference (Ciscar et al., 2014; Dosio et al., 2012). By using these three simulations of the scenario A1B, the range of variability of the 12 bias corrected simulations of scenario A1B is well represented (Ciscar et al., 2014). We used the three A1B simulations for mapping future MCD and ACD in the A1B scenario. Using the entire ensemble of 12 A1B simulations was not feasible for computational reasons, although using more simulations increase performance of regional climate change impact studies (Pierce, Barnett, Santer, & Gleckler, 2009). The E1 simulation is used to illustrate the future impacts in case of global mitigation efforts. However using one simulation of E1 scenario captures less uncertainty in future climate than in the case of the A1B simulations. Results from the three A1B simulations were used for computing ensemble metrics in a sensitivity analysis. Datasets of monthly average temperature and accumulated monthly precipitation were extracted from the bias corrected RCMs datasets for four periods: the control period 1961–1990, and the three future periods 2020s, 2050s and 2080s. The datasets represent 30-year means centred on the midpoint of each period. The spatial domain covered by the bias corrected datasets is shown in Fig. 1. The domain is smaller than the area often considered Mediterranean (e.g. Olson & Dinerstein, 2002), nevertheless the datasets cover the European Mediterranean domain which is the focus of this paper.

The second part of the method aims at identifying protected areas that will be affected by changes in the MCD. We used two indicators for assessing the change. First, the number of protected areas facing either total or partial MCD loss; second the extent of MCD loss in protected areas. The mapping of the MCD and ACD was implemented at the 1 km grid size using the WorldClim database (version 1.4, release 3) (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005) as the source for the historical climate. WorldClim is a global database of climate monthly data with a spatial resolution of 30 arc second (~1 km) representing the average of the period 1960–1990. WorldClim was implemented by interpolating monthly climate surfaces for global land areas. The interpolation used precipitation from 47,554 locations, mean temperature from 24,542 locations, and minimum and maximum temperature for 14,835 locations. The uncertainty of this database is higher for precipitation in mountainous regions and areas with few stations. Nevertheless, Europe is one of the regions with the highest density of stations used in WorldClim. Maps of average monthly temperature and accumulated monthly precipitation were produced for the Mediterranean basin.

The change-factor approach (Baker, Diaz, Hargrove, & Hoffman, 2010; Ekström et al., 2015; Klausmeyer & Shaw, 2009; Tabor & Williams, 2010) was used for disaggregating the coarse spatial resolution of the RCMs simulations to the fine resolution of the WorldClim data. Anomalies (differences) of monthly mean temperature and ratios (scenario/control) of monthly precipitation were computed from the RCMs future simulations (2020s, 2050s and 2080s) and control period (1961–1990). Then the temperature anomalies and precipitation ratios were interpolated using the spline method (Franke, 1982; Mitas & Mitasova, 1988) to the spatial resolution of the WorldClim data (1 km). Temperature anomalies were added, and precipitation ratios multiplied, to the corresponding variable of the WorldClim data for producing high resolution maps of future monthly mean temperature and monthly precipitation. We implemented a test for the selection of the three

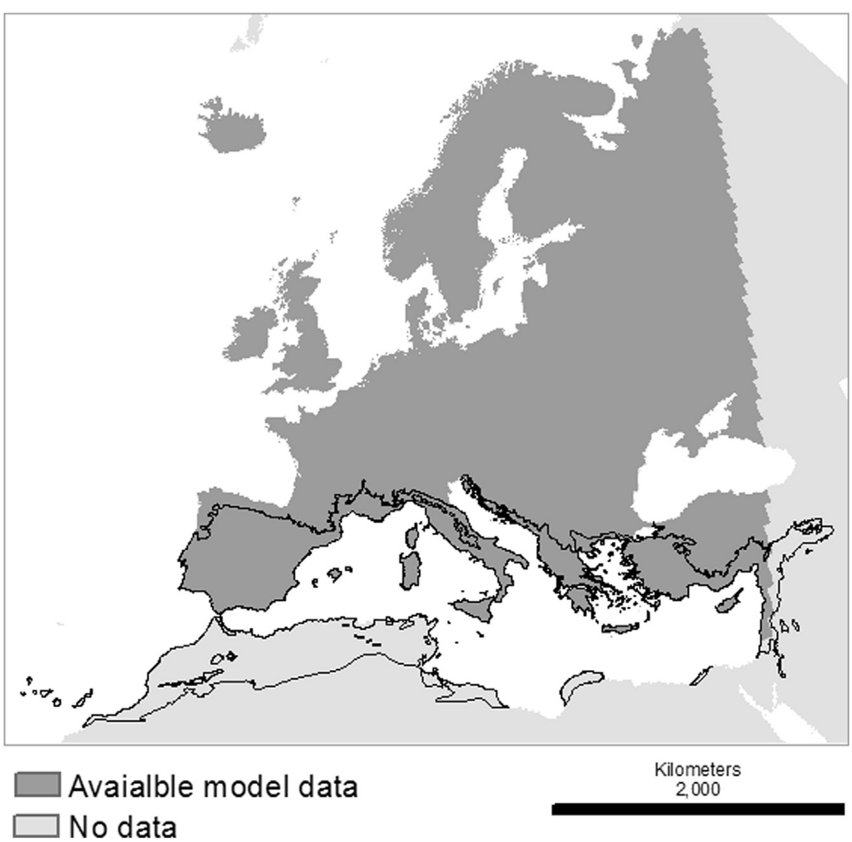

Fig. 1. Spatial domain of the climate simulations used in this study (dark grey) and Mediterranean habitat according to Olson and Dinerstein (2002) (black line).

input parameters of the spline method (available as online Supplementary material, Appendix A – S1).

The MCD and ACD were mapped for the different combinations of periods and simulations using the Köppen-Geiger climate classification (Hantel, 1989). The Mediterranean and arid climates are often described using respectively the Cs and B climate types of the Köppen-Geiger classification (Klausmeyer & Shaw, 2009; Kottek, Grieser, Beck, Rudolf, & Rubel, 2006; Peel, Finlayson, & McMahon, 2007; Rubel & Kottek, 2010). In this study we used the criteria for Cs and B climate types according to Peel et al. (2007) and Garcia et al. (2014) (see online Supplementary material, Appendix A – S2). In the Köppen-Geiger classification the winter half of the year is from October to March and the summer half of the year from April to September. Un-projected latitude and longitude climate data were used for mapping the MCD and ACD (WGS 84) and projected (ETRS 89 LAEA) maps were used for area change computation taking into consideration the curvature of the earth.

Changes of MCD in protected areas were identified using the database of Natura 2000 sites (EEA, 2013: version of end 2012) for EU countries and the IUCN and UNEP-WCMC (2013) World Database on Protected Areas (WDPA; version of July 2013) for other European countries (Turkey, Croatia, Albania, Bosnia and Herzegovina, Montenegro, Serbia and The former Yugoslav Republic of Macedonia). At the moment of accessing the Natura 2000 database data for Croatia (recent EU Member State) was not available. Both databases, Natura 2000 and IUCN, are useful tools for assessing habitat loss in areas of high biodiversity value. We used all IUCN database categories (I to VI) in our assessment.

Sensitivity analysis was used to assess the degree of agreement and disagreement between the three A1B simulations in mapping MCD and ACD in the three future periods. To this end, ensemble maps of MCD and ACD were computed following the approach by Klausmeyer and Shaw (2009). Areas of agreement (where the three simulations match) and uncertain areas (where at least one simulation differ in the projected change: stability, loss, increase) were mapped accordingly.

3. Results

The current MCD is projected to loss around 151,000–225,000 km^2 under A1B scenario by 2080s, an area close to the size of Greece and Portugal combined, and 143,000 km^2 under E1 scenario. The loss in A1B (and E1) represents 17–25% (and 16%) of the current 898,631 km^2 of MCD (Fig. 2A). Our results

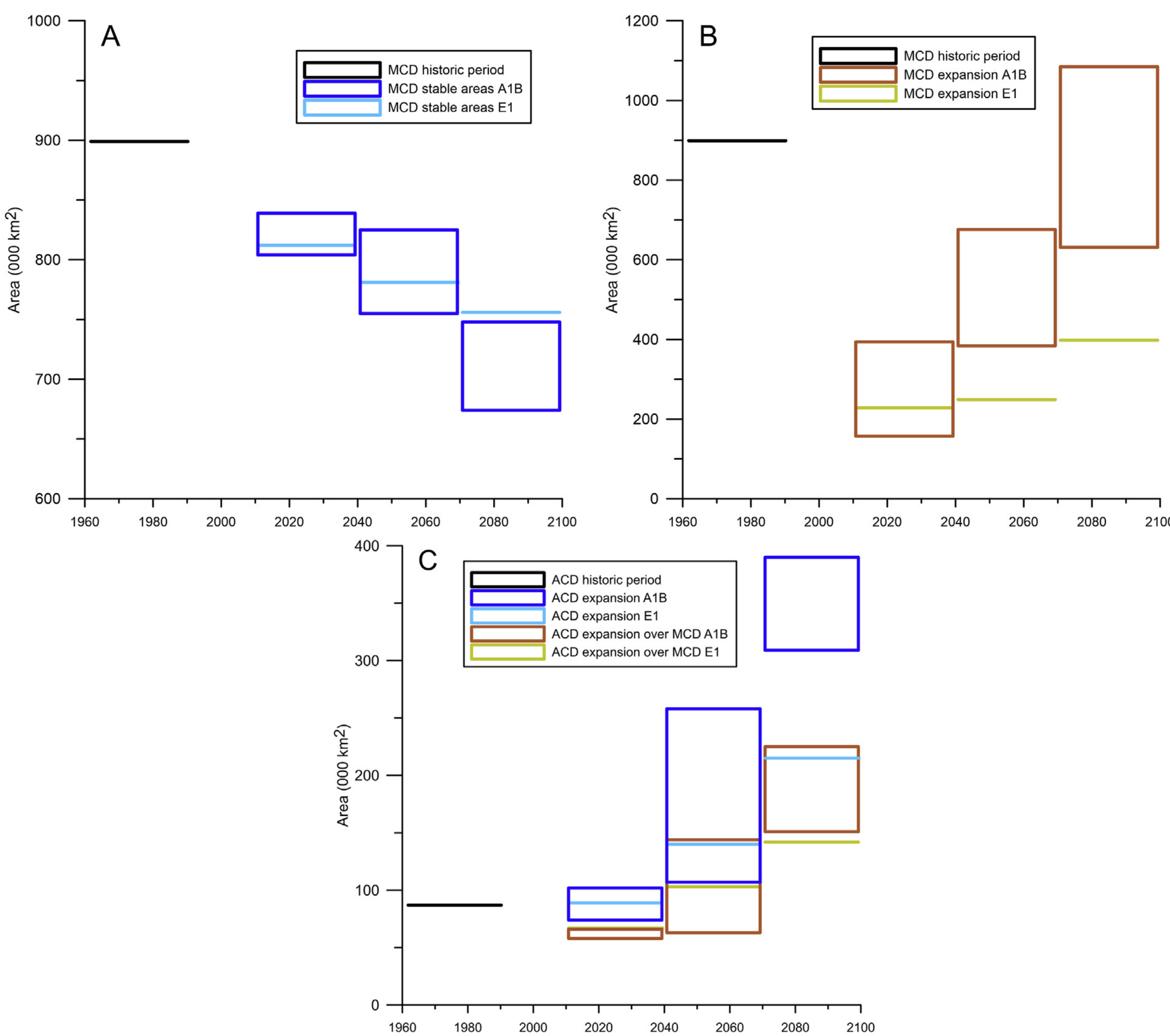

Fig. 2. Changes of the Euro-Mediterranean climate domain (MCD) and arid climate domain (ACD) under scenario A1B (range of KNMI-RACMO2, METO-HC and DMI-HIRHAM5) and E1 (MPI-REMO) in three future periods (2020s, 2050s and 2080s). No range was computed for E1 because only one simulation was used. A) Stable areas of the MCD. The loss is the difference with the historic period. B) Expansion (new areas) of the MCD into other climatic domains; C) Expansion (new areas) of the ACD.

indicate that as early as in the 2020s the MCD is projected to lose between 60,000 km^2 (7%) and 95,000 km^2 (11%) under scenario A1B, and 86,000 km^2 (10%) in E1. This declining trend is projected to continue in the other two future periods assessed producing a contraction of the stable areas of MCD. Despite the projected loss of the current MCD, the area projected to remain stable is 75–83% (84%) under scenario A1B (E1) by the end of the century.

Our results indicate that the MCD is projected to shift over other climatic domains. As result of the shift the MCD is projected to increase by 631,000–1,085,000 km^2 in scenario A1B, and 398,000 km^2 in scenario E1, an expansion equalling 70–121% (44%) of its current extent in A1B (E1). Therefore, by the end of the century the total area of the MCD is projected to be between 1.5 and two times its current extent in A1B, and 128% in E1 (Fig. 2B).

In both scenarios the spatial pattern of MCD loss, stability and increase is comparable though more marked in the medium emission scenario (A1B) than in the stabilisation scenario (E1). According to the three A1B simulations, projected MCD loss is evident in central and southern areas of the Iberian Peninsula, southern Italy and Sicily, south-eastern Greece, Cyprus, Malta and central Turkey (Fig. 3). Stable areas of MCD are mostly located in western areas of the Iberian Peninsula and western parts of Italy, Greece and Turkey. Finally, the MCD is projected to expand over Northern Spain, western and southern areas of France, eastern Italy, the Balkans, and central and northern zones of Turkey.

The ACD is projected to increase by more than 330% of its current extent by the end of the century in the European region (Fig. 2C). In the 2080s the ACD is projected to increase by 446–550% (337%) of its current extent in scenario A1B (E1), passing from its current 87,000 km^2 to 388,000–477,000 km^2 (292,000 km^2) in A1B (E1) scenario. The projected expansion equals 309,000–390,000 km^2 (215,000 km^2) in the 2080s under A1B (E1) scenario, an area close to three times the size of Greece. This increase in projected to occur at the expenses of the MCD, for instance in all periods and in the four simulations the almost totality of projected MCD loss is explained by ACD expansion.

Projected spatial changes of the ACD are shown in Fig. 4. Both scenarios show a comparable pattern of increasing ACD. Central and southern zones of the Iberian Peninsula are projected to face the largest increase of arid zones. Other areas that are projected to be affected are Southern Italy including the island of Sicily, eastern and southern parts of Greece, Cyprus, Malta and central areas of Turkey. Areas of expansion of the ACD are in agreement with the losses of the MCD shown in Fig. 3 (B to M).

Our results indicate that 12% of the MCD area is within the Natura 2000 network. By the end of the century projected MCD loss will include 13–30% (18%) of the area protected by Natura 2000 sites under scenario A1B (E1). This is equivalent to 18,000–41,000 km^2 (and 25,000 km^2) in scenario A1B (and E1) (Table 2). Furthermore, our results indicate that 15–23% of Natura 2000 sites (362–567 sites out of 2475) that are located within the MCD are projected to face total or partial MCD loss under scenario A1B by the 2080s. In scenario E1 the proportion is of 15% (371 sites) by the same period.

Results regarding all protected areas (Natura 2000 in EU countries and WDPA sites in European non-EU countries) are

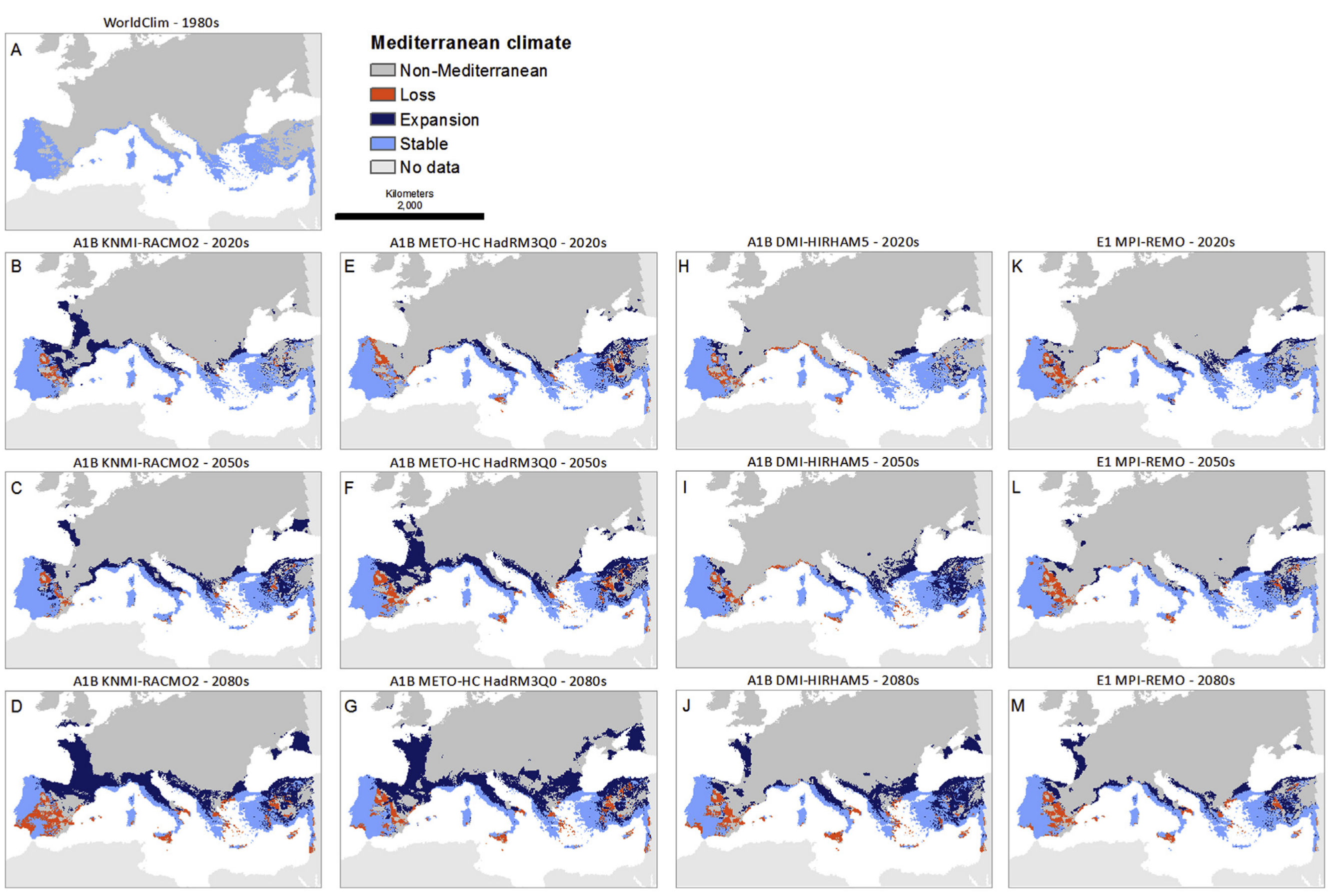

Fig. 3. Euro-Mediterranean climate domain under current climate (1980s) (light blue in A), and changes under scenario A1B in 2020s, 2050s and 2080s (KNMI-RACMO2: B, C and D; METO-HC HadRM3Q0: E, F and G; DMI-HIRHAM5: H, I and J); and under scenario E1 (MPI-REMO) in 2020s, 2050s and 2080s (K, L and M). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

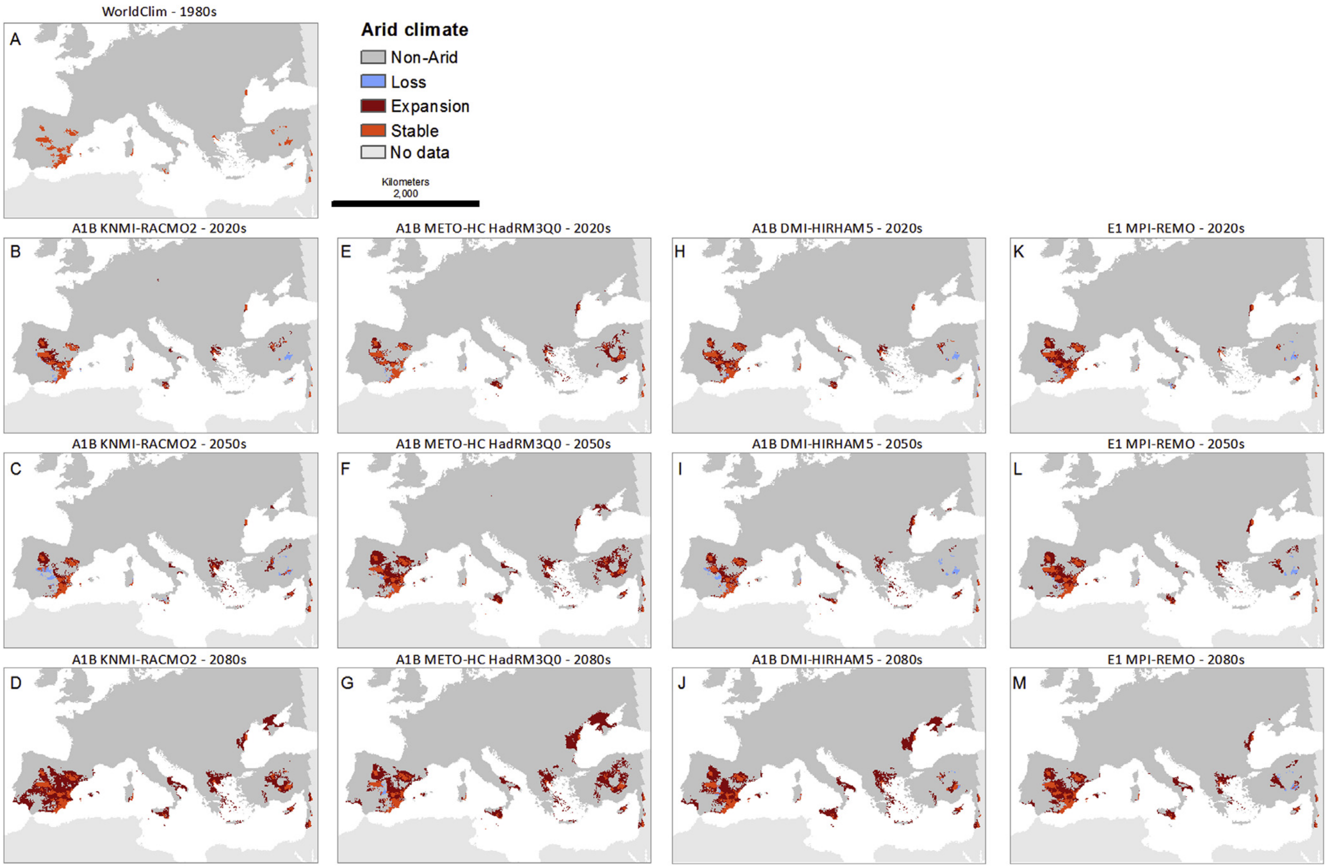

Fig. 4. European arid climate domain under current climate (1980s) (red in A), and changes under scenario A1B in 2020s, 2050s and 2080s (KNMI-RACMO2: B, C and D; METO-HC HadRM3Q0: E, F and G; DMI-HIRHAM5: H, I and J); and under scenario E1 (MPI-REMO) in 2020s, 2050s and 2080s (K, L and M). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Area and number of Natura 2000 sites in the current Euro-Mediterranean climate domain (MCD) and in areas where the MCD persist under scenario A1B (range of KNMI-RACMO2, METO-HC and DMI-HIRHAM5) and E1 (MPI-REMO) (area: 000 km^2). In parenthesis: percentage loss in relation to the historical climate (1980s).

Scenario	Natura 2000 sites	1980s	2020s	2050s	2080s
A1B	Area	137	120–127 (−13to−7)	119–127 (−13to−8)	96–119 (−30to−13)
	Number of sites	2475	2213–2393 (−11to−3)	2171–2301 (−12to−7)	1908–2113 (−23to−15)
E1	Area	137	121 (−12)	116 (−15)	112 (−18)
	Number of sites	2475	2177 (−12)	2172 (−12)	2104 (−15)

comparable to the results using Natura 2000 sites alone. The assessment is available as online Supplementary material (Appendix A – S3).

In addition to mapping shifts of the MCD and ACD, we computed changes in climate parameters over the current MCD. The current MCD is projected to be hotter and drier in both scenarios. The complete assessment is available as online Supplementary material (Appendix A – S4).

Results of the sensitivity analysis are consistent with the overall pattern of change of the MCD and ACD under scenario A1B (sensitivity analysis available as online Supplementary material, Appendix A – S5). Nevertheless, figures of stability, loss and expansion are less pronounced than those from the individual simulations. For example, in the ensemble A1B mapping computed in the sensitivity analysis the MCD loss projected by the end of the century is 11%, in contrast with the 17–25% computed from the three A1B simulations. Similarly, in the ensemble map, the stable MCD is projected to be only 70%, i.e. lesser than that computed from the three A1B simulations (75–83%). In a similar way, ensemble figures regarding changes of the ACD are less pronounced than the figures from the individual simulations. Still, the ensemble map indicates that the ACD is projected to increase by 228%, and the total extent is projected to be 315% of the current extent by the end of the century under A1B (Tables S4 and S5 of Supplementary material). Finally, the degree of uncertain changes between the simulations was 42–44% in MCD and 53–67% in ACD in the three future periods.

4. Discussion

This study aimed to assess MCD loss and conversion into ACD under scenarios of climate change, and to assess the number and extent of Natura 2000 sites that will be affected. The most salient result is the projected loss of 17–25% (16%) of the current MCD under scenario A1B (E1) by the end of the century. A projected increasing trend of MCD loss is evidenced in the three future periods in both scenarios. An important finding is that almost all the projected MCD loss is due to shifts of the ACD, a climate type with higher temperatures and drier conditions, into current MCD. The shifts of the ACD into MCD areas possess a threat of range contraction for Mediterranean species, the effect could be greater for species with specialised climatic requirements.

Despite the fact that the area occupied currently by the MCD is projected to shrink, shifts into other climatic domains project an increase of its total extent by the end of the century under both scenarios. These new MCD areas could provide opportunities for range expansion of Mediterranean species if habitat quality and biotic interactions allow establishment (Garcia et al., 2014). Nevertheless, the effect of these shifts on current biota in those areas remains uncertain (Moritz & Agudo, 2013; Urban, Tewksbury, & Sheldon, 2012).

Results using scenario E1 are comparable with the range obtained in A1B regarding MCD stable areas and contraction across the three periods. In contrast, E1 projects smaller shifts of the MCD into other climatic domains and a minor total extent. Regarding ACD, E1 projects smaller expansion and total area in comparison with A1B. Therefore, even in the stabilisation scenario (E1) some impacts remain close to the moderate emissions scenario (A1B). Nevertheless, the overall impacts are projected to be less marked in E1.

The shrinking of the current MCD will affect (totally or partially) between 15% and 23% of the Mediterranean Natura 2000 sites in both scenarios by the end of the century. In addition, the projected loss of MCD in Natura 2000 sites, 13–30% of their current area in both scenarios, represents a threat to these areas. Specific adaptive management strategies are deemed necessary in the affected areas (European Commission, 2015; Vos et al., 2008). Results assessing protected areas in non-EU European countries combined with Natura 2000 in EU countries are fairly in line with the figures computed for Natura 2000 sites only.

The sensitivity analysis revealed areas of agreement and disagreement between the A1B simulations used for mapping the MCD and ACD. Results of the sensitivity analysis indicate that the ensemble mapping is consistent with the overall pattern of projected MCD stability, loss and expansion computed from the individual simulations in the three future periods. In general, MCD tendency to shift to northern latitudes and higher elevations holds true in the ensemble mapping. Similarly, projected expansion of ACD in areas of current MCD is indicated in the ensemble mapping. However, the extent of changes of the MCD and ACD derived from the ensemble mapping is less pronounced. This is because areas where there is no spatial agreement between the three simulations cover more than 40% in the MCD, and 50% in the ACD, in the three future periods. These are considered uncertain changes in the sensitivity analysis. Therefore, the ensemble mapping provides a more conservative projection of changes (loss and expansion). However, also the projected stable areas are lesser than that computed from the three A1B simulations.

In addition to the projected changes in the MCD and ACD, computed changes in climatic parameters project that the current MCD will be hotter and drier. Increases in temperature will be more marked in the summer half of the year in both scenarios, likewise percentage changes in precipitation. Projected hotter and drier conditions in the MCD support the hypothesis of an increase of other concomitant effects of climate change. Among the possible negative effects there is evidence of increasing forest fire danger (Camia & Amatulli, 2009; Migliavacca et al., 2013; Migliavacca et al., 2013; Moriondo et al., 2006), more frequent and longer drought (Allen et al., 2010; Hoerling et al., 2011; Lindner et al., 2010), establishment and spread of invasive alien species (Hellmann, Byers, Bierwagen, & Dukes, 2008) and newly introduced forest pests and diseases (Lindner et al., 2010; Netherer & Schopf, 2010). The changing climate of Mediterranean habitats poses a threat to species composition and interactions and may cause transient and novel communities of plants and animals (Blois, Zarnetske, Fitzpatrick, & Finnegan, 2013; Urban et al., 2012). These changes suggest a decrease of biodiversity due to migration or local extinction of Mediterranean species unable to cope with the magnitude of habitat change, however the extent of the impacts remain uncertain (Moritz & Agudo, 2013). Additionally, the fragmented character of the Mediterranean landscape restricts mobility of vagile species, but in contrast offers topographically complex areas that could provide climate refugia. Finally, caution is needed regarding the potential future impact of these threats, either individually or concomitantly, because the magnitude of their impact is still unclear (Garcia et al., 2014).

A number of recent studies indicate relevant climate-driven changes in the Mediterranean region. Hoerling et al. (2011) suggest that a change towards drier conditions has likely occurred with increased winter drought frequency after 1970, a change that cannot be reconciled with internal variability alone. Winter precipitation is an important climatic parameter in the Mediterranean due to the fact that in average 72% of the annual precipitation falls in the winter half of the year (Table S3 in online Supplementary material). The results of Hoerling et al. (2011) are consistent with our finding of a projected decrease of precipitation and an expansion of the ACD into MCD areas during this century. Hoerling and co-authors computed a drop in winter (November–April) precipitation of 6.8% after comparing the periods 1902–1970 versus 1971–2010, a result that seems consistent with the projected decreasing winter (October–March) precipitation of 10.3–14.1% (10.9%) in the 2080s under scenario A1B (E1). Another study indicated that the current habitat of Mediterranean tree species in the Iberian Peninsula will likely shrink as a consequence of anthropogenic climate change (Benito Garzón, Sánchez de Dios, & Sainz Ollero, 2008). This could result in local extinction of species with limited migration capabilities or in the absence of adaptation measures. These results are consistent with the fact that the Iberian Peninsula is one of the areas projected to have MCD loss and expansion of ACD in this study.

Klausmeyer and Shaw (2009) assessed habitat loss in the Mediterranean ecosystem at global level. Nevertheless, methodological and input data differences with our study make any comparison challenging. Both studies differ in many aspects. First, Klausmeyer and Shaw (2009) used the conservative Mediterranean climate definition of Aschmann (1973) for mapping the MCD, although they also used Köppen-Geiger for sensitivity analysis. A relevant difference in our study is that we followed Peel et al. (2007) and Garcia et al. (2014) using the temperature of the coldest month greater than 0 °C, instead of −3 °C, as originally defined in the Köppen-Geiger classification (Hantel, 1989) and used by Klausmeyer and Shaw (2009) in their sensitivity analysis. Using the temperature of the coldest month greater than 0 °C generates a mapping of the MCD which is in agreement with areas traditionally considered part of the Mediterranean biome (e.g. Bohn et al., 2004; Médail & Quézel, 1997, 1999; Olson et al., 2001).

Despite these differences, when comparing the maps of both studies implemented using the Köppen-Geiger classification, the overall pattern of the MCD appears to be in accordance. The second cause of differences is the climate simulations used. Klausmeyer and Shaw (2009) used simulations of future climate from atmosphere-ocean general circulation models (AOGCMs). These models range from 125 to 550 km horizontal resolution at the equator, therefore AOGCMs are well suited for global assessments but lack detail in coastal zones or in areas of complex topography. In their study these datasets were disaggregated to a 5 km spatial resolution. In our study we used high resolution bias corrected simulations from RCMs (Dosio & Paruolo, 2011; Dosio et al., 2012) at a resolution ranging from 25 to 50 km (Table 1), disaggregated to a 1 km grid size.

Dynamical downscaling conducted by RCMs, and driven by Global Climate Models (GCMs), serves to inform on change of the climate on a finer spatial resolution than the provided by GCMs (Giorgi, 2008). Finer resolution data able to resolve environmental or topographic features is useful for impact, adaptation, and vulnerability (IAV) applications. Therefore, RCMs are conceived for regional assessments of the impacts of climate change at better resolution (Feser, Rockel, von Storch, Winterfeldt, & Zahn, 2011; van der Linden & Mitchell, 2009). Projections from RCMs are more valuable in regions with heterogeneous topography (Gutmann et al., 2012), zones of land-ocean contrast, regions at the margins of seas and large water bodies, and areas of heterogeneous landscape (Ekström et al., 2015; Rummukainen, 2016). For instance, features that may produce important effects in the delineation of the MCD and ACD.

The presented study offers a transparent methodology and an easy to communicate assessment. Nevertheless our results are subject to a number of constraints. First, the spatial domain of the RCM simulations (van der Linden & Mitchell, 2009) does not cover the totality of the Mediterranean region, for instance the Canary Islands and Madeira are not included. Additionally, other extra European regions such as some areas in North Africa, including the Atlas in Morocco, and a few zones of the Middle East are also outside the study area. A map of the current MCD (not shown) with an extended spatial domain implemented using WorldClim comprises most of the Canary Islands and Madeira and some zones of the Middle East and North Africa. Second is the use of SRES scenarios. However, despite SRES A1B and E1 scenarios have been superseded by the most recent CMIP5, there are some similarities between them. A comparison between simulations from EURO-CORDEX (http://www.euro-cordex.net/) RCP4.5 and RCP8.5, and ENSEMBLES A1B, indicates that the overall spatial patterns for temperature and precipitation changes and related indices are similar in the three scenarios in Europe, with some differences in regional details partly due to the higher resolution in EURO-CORDEX. The projected warming under RCP8.5 in the range of 2.5–5.5 °C encompass the warming range of A1B scenario (3–4.5 °C). The pattern of changes in annual precipitation is very similar between RCP4.5 and RCP8.5 but less pronounced in the former, and the pattern for A1B agrees with both RCP and mostly lies between the two RCP (Jacob et al., 2014). Similarly, the E1 scenario equivalent to the 2 °C target is close to the RCP2.6 scenario that projects a warming lower than 2 °C (Arora et al., 2011; Vautard et al., 2014).

Third is that only three simulations were available for scenario A1B and one for E1. In the case of A1B this issue is alleviated because, as indicated by Ciscar et al. (2014), the three simulations used represent both the mean climate change signal and the most extreme deviations of the 12 bias corrected simulations implemented by Dosio and Paruolo (2011) and Dosio et al. (2012). Therefore, we assume that the main statistical properties of the whole ensemble of 12 simulations are conserved. Although, using only three simulations may capture less uncertainty of the future climate than using a larger suite of simulations, ideally five or more according to Pierce et al. (2009). Results using only one simulation for E1 capture much less uncertainty. For instance, some results of the E1 simulation should be interpreted with caution. An example is given by some areas in south of France that, after exhibiting MCD loss in 2020s, recover the MCD in the 2050s and 2080s. Whether these effects are due to internal variability of the climate simulation, or to other factors, remains unknown. However, they are confirmed by the climate parameters shown in Tables S2 and S3 in online Supplementary material (Appendix A – S4), where the changes in 2020s are in some cases more marked in the stabilisation emissions scenario E1 than in the moderate emissions scenario A1B, such as the drop in winter and annual precipitation or the increase of winter temperature.

Finally, measuring the impacts of climate change is difficult, yet their dimensions can be captured by different metrics. In this study we implemented one type of metrics that accounts for change in area of analogous climates. Results using more types of metrics could convey complementary information regarding the potential impacts of climate change on species and biodiversity (Garcia et al., 2014).

Even if we consider the mapping results a faithful projection of the MCD and ACD, our results are subject to uncertainties due to two principal sources. Firstly, from the uncertainties of the dataset representing the baseline climate (Bedia, Herrera, & Gutiérrez, 2013) and the future climate simulations (Dosio et al., 2012), and secondly, from using only four simulations as mentioned above. Nevertheless, using bias corrected simulations, as we did, present advantages because original RCM outputs contain significant bias that restricts its applicability in impact studies (Ekström et al., 2015; Glotter et al., 2014).

4.1. Options for adaptation

The results of this study provide insight into several aspects of adaptation and management of Mediterranean protected areas. Around 75–83% (84%) of the current MCD and 70–87% (82%) of the Mediterranean Natura 2000 area is projected to remain stable during this century under A1B (E1) scenario. These stable areas are projected to host most of the Mediterranean biodiversity and should be considered priority areas for long-term conservation. A proactive approach taking into consideration landscape connectivity and the concomitant threats triggered by climate change is a priority (Vos et al., 2008). EU initiatives such as Green Infrastructure (European Commission, 2014b) investments and the Natura 2000 network of protected sites are among the cornerstones of the European biodiversity conservation policy (European Commission, 2014a).

While some Mediterranean areas are projected to face severe changes due to conversion into arid and semi-arid habitats, stable areas not included in the network of protected areas could become refugia for plant and animal species, specially forest and shrubland areas. Therefore, promoting increased connectivity and a denser network of protected sites is a reasonable option in this case. Green Infrastructure projects could play a major role connecting areas where the MCD persist, thus facilitating and promoting natural migration of species. New protected sites in zones of persisting MCD could serve as both corridors between isolated areas and home for migrating species from degraded or transient Mediterranean habitats.

There is no univocal management strategy for protected areas in the current MCD projected to shift to arid climatic conditions. In this case the magnitude of the habitat change could overpass migration capabilities and resilience of plants and animals, e.g. Mediterranean tree species, likely leading to decline. Proactive adaptation management on a site by site basis is suggested in this case (European Commission, 2015). Adaptation options include for instance assisted migration of species, although this is an aspect that has produced controversy because balancing extinction risk again the potential negative impact of assisted relocation requires information that is usually not available or is too uncertain to support management decisions at local level (Iverson, Peters, Matthews, & Prasad, 2013).

Proactive adaptation and effective landscape management promoting investments in Green Infrastructure and a denser network of interconnected protected areas are necessary instruments for preserving Mediterranean biodiversity from the threats of habitat loss.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.apgeog.2016.08.003.

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