An ecological niche modelling approach to assess present and future suitability areas of *Quercus coccifera* L. in the Levant under climate change scenarios

AUTHORS

Al-Qaddi Nisreen[1], Vessella Federico[1*], Stephan Jean[2], Dawud Al-Eisawi[3], SchironeBartolomeo[1]

AFFILIATIONS

[1] *Dipartimento Agricoltura, Foreste, Natura ed Energia (D.A.F.N.E.), Università degli Studi della Tuscia, Via S. Camillo de Lellis, snc, 01100 - Viterbo, Italy*

[2] *Faculty of Science II- Department of Earth and Life Science, Lebanese University, Fanar, Lebanon*

[3] *Department of Biological Sciences, University of Jordan, Amman 11942, Jordan*

* Corresponding Author

Vessella Federico
Dipartimento Agricoltura, Foreste, Natura ed Energia (D.A.F.N.E.)
Università degli Studi della Tuscia
Via S. Camillo de Lellis, snc, 01100 - Viterbo, Italy
email: vessella@unitus.it

Abstract

Quercus coccifera L. (Kermes oak) is an evergreen oak, typical of the maquis in the eastern and south eastern part of the Mediterranean. It occurs almost continuously along the Syrian-Lebanese coast up to 1500 m, and more scattered inland, until the southernmost arid area of Petra in Jordan. Coupled human impacts and global warming are strongly affecting the species natural distribution leading to a widespread forest fragmentation in the whole region. In this study, we aim at investigating the current bioclimatic range of Kermes oak, and forecast the potential suitability area to the 21st century. Ecological niche modelling was used to retrieve the environmental envelope of the species according to 23 topographic and climate variables. Five algorithms and three General Circulation Models were applied to provide the potential distribution of Kermes oak at present time and project it to future. Results pointed out a current suitability area in the Middle East extending from NW of Syria, rather continuously along the Lebanese coasts and inland until the Mediterranean western slopes of Palestine and the Golan area (Israel), encompassing the Jordan Valley toward Dana and Wadi Rum (Jordan), with an isolated patch in Jabal Al-Arab (South Syria). Future scenarios depict a significant fragmentation and restriction of Kermes oak range, especially in the north of Syria and Golan, with a general shifting in altitude. These information might facilitate the foresters to cope with the challenge of climate changes by identifying the most suitable areas climatically effective for successful ecosystem restoration, including reforestation programmes.

Keywords: *Quercus coccifera,* Ecological Niche Modelling, Climate change, Forest conservation and reforestation, Middle East.

Introduction

The portion of the Mediterranean biome of the Old World spans the coastal and the inland of the homonymous Basin, and it is recognized as one of the most threatened hotspot of biodiversity worldwide (Underwood et al., 2009). The richness and the composition of the vegetation assemblages are also the result of millennia of human interactions with the environment, especially, in the eastern part of the Basin. The most typical form of vegetation increasingly affected by anthropogenic impacts is the Mediterranean maquis, which hosts a considerable number of tree species, including deciduous and evergreen oaks as key elements (Tomaselli, 1977). The genus *Quercus* L. (Fagaceae) comprises around 30 species in the Euro-Mediterranean region(Govaerts and Frodin, 1998, Denk and Grimm, 2010, Simeone et al., 2013), one of them being a prominent evergreen component of the Levantine maquis: the Kermes oak (*Quercus coccifera* L.). Its global distribution encompasses the Mediterranean Basin and it is the only one evergreen oak with such a range (Blondel et al., 2010, Toumi and Lumaret, 2010). Moreover, it defines the easternmost limit of the Mediterranean maquis in the Middle East (Al-Eisawi, 1996), together with other few shrubs and trees (e.g. *Ceratonia siliqua* L., *Cercis siliquastrum* L., *Laurus nobilis* L., *Olea europaea* L., *Phillyrea latifolia* L., *Pinus halepensis* Mill., *Pistacia palaestina* Boiss., *Quercus ithaburensis* Decne., *Rhamnus alaternus* L., and *Styrax officinalis* L.). Although oaks are deeply investigated from decades, their taxonomy is still a matter of debate producing a long list of subspecies, varieties, ecotypes and synonyms. Kermes oak is not excluded from this contest and the two latest reviews of its nomenclature lead to the following main classifications: one single species, namely *Quercus coccifera* L., with a plethora of synonyms (e.g. *Q. calliprinos* Webb, *Q. palaestina* Kotschy) (Govaerts and Frodin, 1998), and one species with two distinct subspecies, i.e. *Quercus coccifera* subsp. *coccifera* (distributed in Europe and North Africa), and *Quercus coccifera* subsp. c*alliprinos* (distributed in Cyprus, Anatolia, Middle East) (Tutin et al., 2001, Menitsky, 2005). In this paper we will refer to Kermes oak as *Quercus coccifera* L. according to the currently accepted species list in Govaerts and Frodin (1998). A further reason to consider the species as a single entity relies on the genetic results by Toumi and Lumaret (2010) who identify some differences only to distinguish two morphotypes.

Focusing on the Middle East, *Q. coccifera* can be found in pure stands or mixed with other eastern entities, for example *Arbutus andrachne* L., *Pinus brutia* Ten., *Pistacia palaestina* Boiss., *Quercus infectoria* subsp. *boissieri* (Reuter) O. Schwarz, *Quercus ithaburensis* Decne., *Styrax officinialis* L. (Whyte, 1950, Danin, 1992, Danin, 2001, Ghattas et al., 2005, Jomaa et al., 2009, Al-Eisawi, 2012). It occurs on poor and rocky areas on different parent rocks marl, limestone, basalt and green rocks, on terra rossa, rendzina, sandy loam, and even on some podzolic soils (Nahal et al., 1989, Nahal and Zahoueh, 2005), from the Thermo-mediterranean (coastal) to the Presteppic Supra-mediterranean zone (up to 1800 m a.s.l.) (Zohary, 1960, Abi-Saleh et al., 1976, Al-Eisawi, 1996, UNDP, 2011). Despite its widespread distribution from the northwest Syria to the Ma'an Governorate in the Petra area (Jordan), and from the Mediterranean coast to the surrounding of As Suwayda (southern inland of Syria), the Kermes oak forests are suffering from degradation by human impacts: population growth, the creeping of urban areas and cultivated lands, overgrazing, forest fires, coal production and pollution are some of the threats affecting the natural occurrence of the species, with consequences also on the phytosociological structure, as most of the climax vegetation has disappeared (ARIJ, 2007, Jomaa et al., 2008).

In addition, the increasing frequency of climate extremes, augments the stress on those ecosystems and consequently aggravate the effects of the abovementioned impacts. In fact, climate changes are widely acknowledged as the major drivers for adverse consequences on terrestrial and marine ecosystems (Bellard et al., 2012, Alberto et al., 2013), thus understanding the framework of climate-species interactions is of paramount importance to assess the vegetation dynamics and its related feedbacks on biotic and abiotic factors (Diaz et al., 2007, Thuiller et al., 2011, Bellard et al., 2012).

The eastern part of the Mediterranean Basin is already experiencing a strong increase in temperature and drought, with ongoing effects on forests and ecosystem services (Kelley et al., 2015), high risk of massive species extinction, landscape modifications (Kitoh et al., 2008), habitat fragmentation, over-exploitation and invasive alien species diffusion (UNDP, 2011). The latest projections for the 21st century are not encouraging, especially for the Levant, which is predicted to undergo a severe surface reduction of the Mediterranean vegetation (Klausmeyer and Shaw, 2009). The situation is even more exacerbate by human exploitation of the natural resources (ARIJ, 2007, Jomaa et al., 2008), civil disorders and geopolitical instability (Schoenfeld, 2010, Hens, 2012).

In view of this, novel prosing approaches helpful to provide information for decision-makers are welcomed. The Ecological Niche Modelling (ENM) might be considered an effective method to create maps of predicted suitable areas of a target vegetation unit (e.g. species, coenoses, ecosystems), dealing with responses to present climate features and future global warming scenarios. Several positive feedbacks might outcome from the application of ENM for conservation, reforestation and management purposes (Parmesan, 2006, Hidalgo et al., 2008, Vessella and Schirone, 2013, Vessella et al., 2015).

The present study is the first application of different ENM algorithms targeting the occurrence of *Quercus coccifera* in the east Mediterranean Basin to its easternmost extent. More specifically, it aims at (i) predicting the species current potential distribution, (ii) forecasting its suitability areas in the 21st century under different greenhouses emissions scenarios, and (iii) evaluating the effects of climate change on species bioclimatic range stability, contraction or extension of its area of occupancy, and (iv) identify accordingly proper sites for in situ conservation and ecosystem restoration activities.

Materials and Methods

Study area and data collection

In this paper, we focused on the Levant countries facing the easternmost part of the Mediterranean Basin where a Csa/Csb climate rules (Peel et al., 2007), namely: Syria, Lebanon, Israel, State of Palestine, Jordan (the same area is also known as Bilād al-Shām, بلاد الشام in Arabic).

The actual distribution of Kermes oak in the study area was puzzled out using heterogeneous data from different but mostly updated sources: Lebanon Reforestation Initiative (LRI)and Forest Map of Lebanon (FAO and MoA, 2005)for Lebanon, Reinforcing Capacity Building for Defending Biodiversity in the Palestinian Territories (DEBPAL2 EU Project) for Palestine, Israel Biodiversity Information System (BioGIS) for Israel and Palestine, bibliographic research and field surveys for Jordan, Syria, Palestine (Zohary, 1960, Al-Eisawi, 1996, ARIJ, 2007, Ghazal, 2008, Jomaa et al., 2009, Al-Eisawi, 2012, Jawarneh et al., 2012). The retrieved distribution was standardized into a presence point dataset 30 arc-seconds resolution to match the ENMs requirements employed hereafter and to avoid pseudo-replications or to lessen the effect of variation in sampling effort. A total of 7,739 spatially unique points represent the actual distribution of *Q. coccifera* in the study area (Figure 1a).

Environmental variables and modelling algorithms

Twenty-three environmental variables were chosen as main determinants to model the niche of *Q. coccifera* based on its present distribution. In details, 19 climatic raster layers were retrieved from WorldClim 1.4 (release 3) at 30 arc-seconds resolution to represent the actual climatic envelope (Hijmans et al., 2005). Elevation was obtained from ASTER Global Digital Elevation Model (http://gdem.ersdac.jspacesystems.or.jp) and re-scaled to30 arc-seconds resolution to correspond with WorldClim data; slope and aspect were handled from elevation using ArcMap 9.3.1. In addition, the Emberger Quotient was calculated and employed to summarized the evapotranspiration and draughtiness in a single user-friendly parameter (Emberger, 1930, Daget, 1977). The full list of the environmental layers is shown in Table 1. Additional biotic and abiotic factors (e.g. soil nutritional factors, species competition, regeneration patterns) were excluded mainly because of lack of data at broad scale (Pearson and Dawson, 2003).

A selection of 5 ENM algorithms commonly employed in modelling studies were applied to define the potential suitability range for *Q. coccifera* based on its present distribution and the current climate conditions. The list of models includes ‘machine learning techniques’ (Genetic Algorithm for Rule set Prediction – GARP; Maximum Entropy – MaxEnt), ‘multivariate analysis’ (Climate Space Model – CSM) and ‘profile methods’ (BIOCLIM; Envelope Score). All algorithms were run using openModeller 1.5.0 with default options and only presence-data with pseudo-absence points randomly generated from the background (Muñoz et al., 2011). Each algorithm produced a raster map 30 arc-seconds resolution as output, showing the suitability areas for the study species in terms of probability of occurrence ranging from 0 (no suitability) to 100% (optimal conditions). The goodness-of-fit of the results was evaluated toward the generated confusion matrix, which counts for the observed and predicted presence/absence events. The Receiver Operating Characteristic (ROC) curve approach was followed, and the Area Under the Curve AUC was calculated to estimate the prediction success (Fielding and Bell, 1997). Correlation and similarity among the models outputs were also assessed by Principal Component Analysis (PCA) and UPGMA Clustering (Diniz-Filho et al., 2010). Once the statistical robustness was assessed, the level of agreement among the models was computed by calculating the weighted average of the raster value per grid cell, taking into account the AUC value of each model (Vessella et al., 2015).

Forecasting projections under multiple scenarios

Predictive modelling is becoming an important tool in ecology, biogeography, conservation and management of tree species, and an increase number of studies is focusing on prominent hotspots of biodiversity, such as the Mediterranean Basin (Thuiller et al., 2005, Benito Garzon et al., 2008, Hidalgo et al., 2008, Casazza et al., 2014, López-Tirado and Hidalgo, 2014).

The consensus map pointed out at the current time from the five models was used to assess and extract the potential climatic niche of *Q. coccifera* to be later projected under future climate scenarios in the 21st century.

The depiction of the mechanistic links of variables affecting by the global change was attempted and climate projections from three downscaled and bias corrected GCMs (Global Circulation

Models, CCSM4, HADGEM2-ES and MIROC5) were retrieved from WorldClim website (original data from CMIP Phase 5 home page, http://cmip-pcmdi.llnl.gov/cmip5). Two greenhouse gas emission scenarios based on Representative Concentration Pathways (RCP) were considered for each GCM, namely: RCP 4.5 (intermediate emission scenarios achieving an impact of 4.5 watts per square metre by 2100) and RCP 8.5 (hard emission scenario accomplishing an increase of 8.5 watts per square metre by 2100) (van Vuuren et al., 2011, IPCC, 2014). Changes were investigated separately for two temporal frameworks representing the 21st century: 2041-2060 (average on 2050) and 2061-2080 (average on 2070). Topographic variables were excluded from the forecasting procedure because future changes are expected in the bioclimatic features linked to topography and not topography per se. Undeniably, those variables would contribute to a robust current distribution, but they would alter future projections (Kumar, 2012).

Results

Quercus coccifera present potential distribution

The five algorithms employed gave back potential distribution maps with discriminatory capacity far from random results, as stated by high AUC values over 0.88. MaxEnt provided the most robust prediction at present, with the smallest suitability area, while CSM and Envelope Score yielded lager areas but weaker goodness-of-fit (Table 2). The Spearman matrix pointed out strong positive correlation among the cell probability values calculated by MaxEnt, GARP and BIOCLIM, while Envelope Score and CSM slightly diverge (Table 3). This pattern is reinforced by the dendrogram of similarity, which showed an asymmetric clustered tree with two subgroups (Figure 2). The uncertainties related to the intrinsic structures of the differences among models were also assessed by PCA (Figure 2). The first principal component explains 73.78% of the correlation structure, and the factors values mapped in Figure 2 depict the level of agreement among the models in the same areas where they match with the highest probabilities. In addition, the plot of loadings shows that the five models are similarly oriented along the first axes, thus tending to be almost analogous.

Thus, the majority of discrepancy pointed out is related to the relative position of 'MaxEnt - GARP - BIOCLIM' and 'Envelope Score - CSM' groups along the second axes, which explains only 12.99% of the correlation (Figure 2). Despite such a divergence among the models about the extent of the predicted habitable surface and the probability magnitude associated to each cell (Figure S1), the majority consensus map mostly disentangles those sources of variation by producing a more conservative prediction map. This solution also reinforces the high suitability for *Q. coccifera* in the coastal part of the study area, further inland in Syria (Aleppo and Idlib District), in the Golan region and around the Jordan Valley slopes (Figure 1b; cf. the physical map in Figure S2). The present predicted habitable surface is about 38,300 km^2 mostly distributed within Csa/Csb climates extent, and representing the theoretical continuous species range, part of which is occupied by the actual distribution.

Quercus coccifera distribution in the 21st century

The three-tested General Circulation Models project a future potential distribution of *Q. coccifera* progressively reduced in extent across the 21st century (Figure 3). Such a contraction is also different in magnitude, depending on the GCM and the considered emission scenario. Overall, two areas seem to undergo a strong change in *Q. coccifera* occurrence: the inland part of northern Syria and the Golan region. The intermediate emissions (RCP 4.5) would affect the species suitability in the lowlands, on the coasts and in the eastern slopes of the Jordan Valley. If we focus on the surface with probability values over 50%, Table 3 shows a global reduction ranging from about 4,000 to 24,000 km^2, geographically displayed in Figure 3. Among the GCMs, HADGEM2-ES resulted to be the most severe, CCSM4 the most lenient. This pattern is confirmed both in 2050 and in 2070. Where the species is still predicted to occur, the associated probability values are generally lower; this is true especially around the Jordan Valley and the Western Mediterranean slopes. The high emissions scenario (RCP 8.5) confirms the abovementioned trend, projecting a more marked reduction and range fragmentation. For example, the southern part of the species potential distribution is predicted to mostly disappear according to HADGEM2-ES (Israel, State of Palestine and Jordan), as well as in Syria where the Aleouite Mts (Jabal An Nusayriyah reliefs)would host the last remnants of the largest habitable area predicted at the present time. The estimated loss of potential area under the most pessimistic scenario would range from about 18,000 to 30,000 km^2. Nevertheless, a core area placed around the Mt Lebanon, Mt Hermon and Anti-Lebanon Mts resulted to survive to every future scenario here investigated.

Notably, the bioclimatic envelope retrieved from the niche modelling at the present condition would not be altered in time. Most of the variables used in this study would nearly keep constant their values ranges with the exception of the Emberger Quotient and Annual Precipitation - Bio12 (upper limit), Maximum Temperature of the Warmest Month - Bio5 and Temperature Annual Range - Bio7 (lower limit). The major change in those ranges is observed in elevation, resulted in an upward shift of a minimum value of 350 (CCSM4, RCP4.5 in 2050) up to a maximum of 700 m (HADGEM2-ES, RCP 8.5 in 2070) (Table 3).

In view of this, the range dynamics of *Q. coccifera* affected by climate change would lead to an unbalanced variation when projected to the 21st century (Figure 4 and Table 5). The analysis focused on the probability values over 50% reveals as the gained surface concentrated around the Lebanon and Anti-Lebanon Mts, Hermon Mt, Damascus and As Suwayda Districts, Petra region, scarcely replaces the large loss of suitable area observed in the remaining parts of the potential species range. This pattern is reflected into a stable surface, with respect to the present area, of about 39.9 - 67.9% in 2050, reduced up to 11.7 - 23.8% in 2070 (RCP4.5); as expected, under the RCP 8.5 the stable surface is further reduced up to 10.9 - 17.6% in 2050, and 3 - 11.9% in 2070. Globally, every scenario depicts a negative variation of *Q. coccifera* future potential distribution with extreme values from -47.6% to -83.6% (HADGEM2-ES in 2050 under RCP4.5, and in 2070 under RCP8.5, respectively).

Discussion

The output map of the potential distribution of *Q. coccifera* at the present climate conditions confirms as the species could encompass the whole Levant defined by a Mediterranean climate, with the exception of the highest reliefs where deciduous broadleaves and conifers dominate (e.g. the upper part of Lebanon Mts. and Anti-Lebanon) (Abi-Saleh et al., 1976, Blondel et al., 2010).

Moreover, our findings are consistent with recent updates on vegetation decline by global warming in the Middle East (Kitoh et al., 2008, Klausmeyer and Shaw, 2009). A general reduction of the Mediterranean environment, threaten by desertification and expansion of arid and semi-arid regions has been stated (IPCC, 2014) and striking contractions with no suitable expansion areas nearby might further limit the species capacity to persist in the Levant. The GCMs and the emissions scenarios considered in this study evidence a coherent response of the species in terms of suitable area that would be reduced especially in the lowlands, with a consequent constraint and upward shift at higher elevations (Figure 4, 5; Table 4). This phenomenon has been already assessed for other species with recent climate change (Parmesan, 2006, Kelly and Goulden, 2008, Lenoir et al., 2008) and rather stressed under future global warming (Hayhoe et al., 2004, Gonzalez et al., 2010). According to our results, higher temperatures, drought and evapotranspiration (synthesized by the Emberger Quotient) are the main drivers for such an upward shift by *Q. coccifera* and they would affect the species adaptability as well (Reyer et al., 2013, Bussotti et al., 2014).

Water deficits and heat stress resulted from prolonged drought period might be predicted to induce extensive tree mortality (Allen et al., 2010, Sarris et al., 2011), produce ecophysiological and phenological shifts (Gordo and Sanz, 2010), alter the seasonal cycles of insects and pathogens (Rafferty et al., 2015), modify soil thermal cycles and soil moisture (Petroselli et al., 2013), limit seed production (Connolly and Orrock, 2015). Since the induced spatiotemporal modification by climate mainly strikes the southernmost part of the species range (Alberto et al., 2013, Bussotti et al., 2014), the vegetation composition, the inter- and intraspecific competition and the biogeography of forests in the Levant might be drastically undergoing a radical change (Kelly and Goulden, 2008). Under another perspective, the upward shift of *Q. coccifera* and related species in response to warming may induce a progressive isolation and degradation of Montane Mediterranean and Oro-Mediterranean forest ecosystems up to replacement. This phenomenon has been already observed in many parts of the world pointing out cascading effects leading to habitat and biome reassessment even at broad scale (Parmesan and Yohe, 2003, Peñuelas and Boada, 2003, Jump et al., 2009). In view of this, the future distribution of Mediterranean and montane/temperate ecosystems is strictly interlinked, and the results of modelling projections applied to a Mediterranean species might be the starting point for evaluating the dynamics of the montane environments as well (Beniston, 2003, Sanz-Elorza et al., 2003, Xu et al., 2009, Sarris et al., 2011, Ruiz-Labourdette et al., 2013).

The results achieved could be also informative to detect priority areas and future putative refuge for *Q. coccifera* forests conservation, highlighting where to intervene and plan strategies to restrain the effects of global change. However, the results from the models might be mitigated and less pessimistic for the future, due to some ecophysiological features of the species. Among them, the plasticity of the reproductive phenology with recurrent flowerings and cycles of acorns maturation from less than one year up to two years (Bianco and Schirone, 1985), coupled with the high resprouting capacity (e.g. Trabaud, 1991). The effectiveness of ENM approach to rethink the network of protected areas and readdress the forest management has been already discussed (Hannah et al., 2007, Hannah, 2008, Klausmeyer and Shaw, 2009, Loarie et al., 2009, Araújo et al., 2011), but this study represents the first attempt to Levant using several ENMs and GCMs.

All the scenarios considered depict a marked reduction in species suitability area, close to 50% in the most optimistic one (Table 5). The geographical location of such a contraction mainly interests the northern and southern limits of the potential range (Syria, Israel, State of Palestine and Jordan). In those areas, the species would seem to face a severe fragmentation or even run an extinction risk. Efforts to face forest fragmentation, to protect, recover and extend the species occurrence in those areas would seem a hard challenge, mainly due to geopolitical reasons, while species translocation and *ex situ* strategies might ensure at least an extreme conservation measure for those provenances, although it is essential to assess the risks beyond those actions and when the benefits outweigh the costs (Hunter, 2007, Thomas, 2011). On the other hand, *Q. coccifera* would persist and extend around the mountainous regions of Lebanon and Anti-Lebanon Mts (Figure 4). This area represents the present core of the species distribution in the Levant, and it could be considered as future putative refugia where to focus the *in situ* conservation programmes.

Overall, a multidisciplinary approach is welcomed, coupling for example ENMs, ecophysiological and genetic studies to better understand the processes behind *Q. coccifera* adaptation, survival, seed dispersion capacity, gene flow, local phenology, etc. This might help to evaluate the repercussions of a changing climate for the species, and to secure its future persistence in the Levant by means of appropriate guidelines and recommendations for the decision-makers.

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Table 1. Environmental variables used in this study to model present potential distribution of *Q. coccifera*. All of them are raster data at 30 arc-seconds of resolution. Asterisks indicate those layers not used in forecasting modelling (see Materials and Methods).

Variable	*Label*	*Source*
Annual Mean Temperature (°C)	Bio1	WorldClim
Mean Diurnal Range (°C)	Bio2	WorldClim
Isothermality (Bio2/Bio7) x 100	Bio3	WorldClim
Temperature Seasonality (SDx100) (°C)	Bio4	WorldClim
Max Temperature of Warmest Month (°C)	Bio5	WorldClim
Min Temperature of Coldest Month (°C)	Bio6	WorldClim
Temperature Annual Range (°C)	Bio7	WorldClim
Mean Temperature of Wettest Quarter (°C)	Bio8	WorldClim
Mean Temperature of Driest Quarter (°C)	Bio9	WorldClim
Mean Temperature of Warmest Quarter (°C)	Bio10	WorldClim
Mean Temperature of Coldest Quarter (°C)	Bio11	WorldClim
Annual Precipitation (mm)	Bio12	WorldClim
Precipitation of Wettest Month (mm)	Bio13	WorldClim
Precipitation of Driest Month (mm)	Bio14	WorldClim
Precipitation Seasonality (Coeff. of variation)	Bio15	WorldClim
Precipitation of Wettest Quarter (mm)	Bio16	WorldClim
Precipitation of Driest Quarter (mm)	Bio17	WorldClim
Precipitation of Warmest Quarter (mm)	Bio18	WorldClim
Precipitation of Coldest Quarter (mm)	Bio19	WorldClim
Emberger Quotient	Emb	This work
Elevation (m) *	DEM	ASTERGDEM
Slope (%) *	SL	Derived from DEM
Aspect (degrees) *	AS	Derived from DEM

Table 2. Statistical scores for the goodness-of-fit of the algorithms used in this paper. Values of predicted surfaces refer to the full range of suitability (1-100%).

	AUC	**Surface predicted presence (km^2)**	**Accuracy (%)**	**Commission error**
Bioclim	0.92	71,913	100.00	2.1×10^{-3}
Climate Space Model	0.88	137,449	59.74	0.056
Envelope Score	0.89	332,794	100.00	1.54×10^{-3}
GARP – Best Subsets	0.93	52,238	96.54	0.017
Maximum Entropy	0.97	34,297	81.82	0.035

Table 3. Spearman correlation matrix resulted from PCA analysis among the algorithms.

Algorithm	**BIOCLIM**	**CSM**	**ENVSCORE**	**GARP**	**MAXENT**
BIOCLIM	**1**	0.603	0.714	0.843	0.821
CSM	0.603	**1**	0.596	0.545	0.476
ENVSCORE	0.714	0.596	**1**	0.587	0.599
GARP	0.843	0.545	0.587	**1**	0.879
MAXENT	0.821	0.476	0.599	0.879	**1**

Table 4. Ranges of the environmental layers (minimum-maximum) of *Q. coccifera* over the threshold (50%) for each studied scenario in the present and future. Topographic variables are also included to quantify the species shifting in altitude, orientation and slope. Surfaces refer to the global predicted areas with suitability values over 50%.

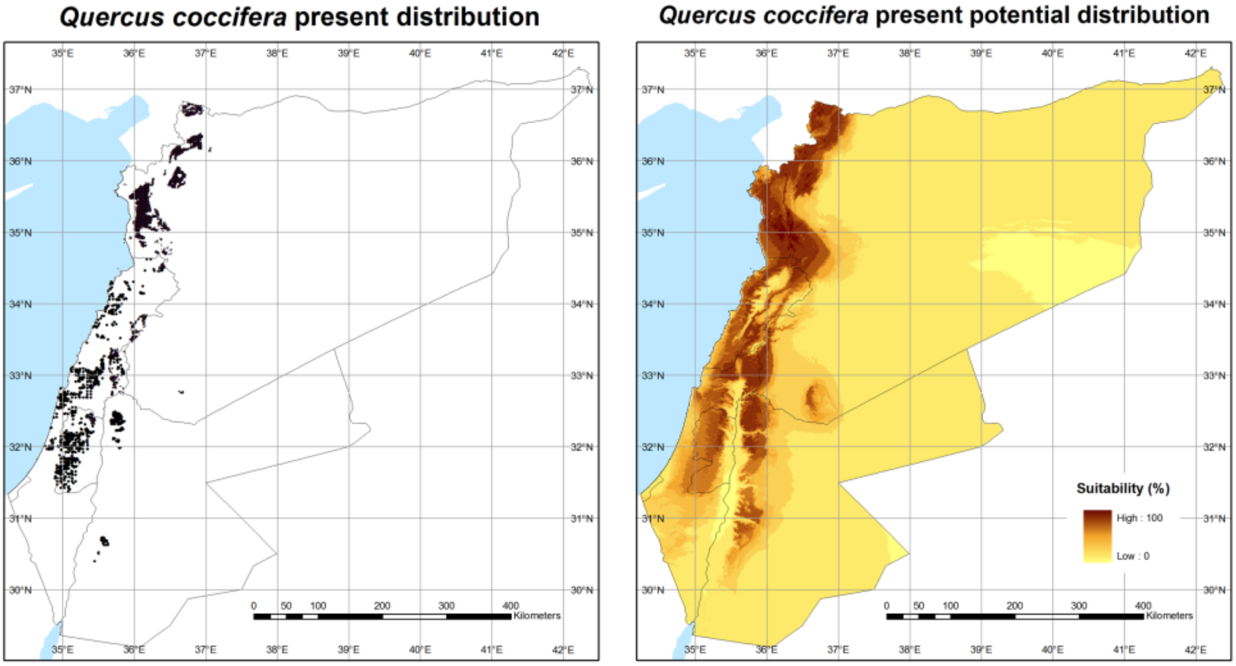
		RCP 4.5 (moderate emissions)						**RCP 8.5 (hard emissions)**					
		2050			**2070**			**2050**			**2070**		
	Present	CCSM4	HADGEM2-ES	MIROC5	CCSM4	HADGEM2-ES	MIROC5	CCSM4	HADGEM2-ES	MIROC5	CCSM4	HADGEM2-ES	MIROC5
Bio1	10.8/21.3	10.8/21.3	11.1/21.3	11.2/21.3	10.9/21.4	11.2/21.4	11.4/21.3	10.9/21.4	11.3/21.3	11.4/21.3	10.9/21.5	11.9/21.4	11.7/21.3
Bio2	7.7/13.4	7.7/13.4	7.8/13.4	7.7/13.4	7.8/13.5	7.9/13.5	7.8/13.4	7.7/13.6	7.9/13.4	7.8/13.5	7.7/13.7	8/13.5	7.9/13.5
Bio3	31/48	31/46	31/43	31/45	31/47	31/43	31/44	31/45	31/43	31/44	31/44	31/41	31/42
Bio4	4782/8139	5070/8138	5421/8103	5479/8137	5106/8138	5444/8038	5538/8017	5214/8058	5521/7860	5446/8122	5176/7886	5694/7692	5659/7860
Bio5	24.7/35.8	24.8/35.8	25.7/35.8	25.5/35.8	24.7/35.9	26.3/35.8	26.4/35.8	24.9/35.9	26.3/35.8	25.7/35.8	24.9/36	27.5/35.9	26.2/35.8
Bio6	-2.1/9.1	-2.1/9.1	-2.1/9.1	-2.1/9.1	-2/9.2	-2/9.1	-2.1/9.2	-1.9/9.2	-2/9.1	-2/9.2	-1.9/9.3	-1.9/9.1	-1.9/9.2
Bio7	21.8/34.3	22.7/34.3	23.6/34.3	23.1/34.3	22.6/34.5	23.7/34.4	23.6/34.4	23/34.3	24/34.5	23.2/33.8	23/33.9	24.4/34.4	23.6/33.8
Bio8	2.5/13.9	2.6/13.9	2.5/13.9	2.5/13.8	2.5/14	2.5/14	2.5/13.9	2.6/14	2.5/14	2.5/13.9	2.7/14	2.8/14	2.6/13.9
Bio9	18.4/28.2	18.4/28.2	19.4/28.2	19.5/28.2	18.6/28.2	19.6/28.2	19.9/28.2	18.4/28.3	19.8/28.2	19.6/28.3	18.6/28.5	20.6/28.2	20.1/28.3
Bio10	18.6/28.3	18.6/28.3	18.4/28.3	19.5/28.3	18.7/28.5	19.6/28.3	19.9/28.3	19/28.5	19.8/28.3	19.5/28.4	19/28.6	20.7/28.6	20.2/28.2
Bio11	2.5/13.8	2.5/13.8	2.5/13.8	2.5/13.8	2.5/13.8	2.5/13.8	2.5/13.8	2.5/13.8	2.5/13.8	2.5/13.8	2.5/13.8	2.7/13.8	2.6/13.8
Bio12	205/1389	205/1312	221/1217	221/1306	205/1223	226/1187	219/1267	210/1108	221/1165	219/1296	223/1107	244/1083	234/1198
Bio13	45/299	45/291	45/285	45/299	45/284	45/297	48/293	45/245	45/292	46/284	47/259	52/272	52/299
Bio14	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/4	0/5	0/5	0/3	0/5	0/5
Bio15	73/114	74/113	75/115	74/115	76/110	77/109	75/111	82/108	81/115	80/110	82/110	82/117	81/109
Bio16	119/793	119/759	120/745	120/777	119/714	123/740	119/723	119/626	123/737	119/725	119/615	135/686	124/699
Bio17	0/32	0/32	0/29	0/31	0/32	0/31	0/30	0/24	0/30	0/31	0/32	0/26	0/31
Bio18	0/38	0/38	0/29	0/32	0/38	0/33	0/30	0/38	0/30	0/31	0/38	0/26	0/31
Bio19	117/791	119/759	120/745	120/777	120/714	123/740	119/723	117/626	123/737	120/725	119/614	135/686	124/694
Emb	23/202	23/182	23/146	23/155	23/161	23/133	23/136	23/137	23/129	23/144	23/132	23/107	23/130
DEM	2/1678	7/2019	178/2053	139/2001	7/2082	411/2202	377/2068	113/2068	457/2207	364/2131	405/2236	725/2384	581/2266
SL	0/22.4	0/22.3	0/22.3	0/22.3	0/22.3	0/22.3	0.22.4	0/22.3	0.22.3	0/22.3	0/22.4	0.22.3	0/22.3
AS	0/360	0/360	0./360	0/360	0/360	0/360	0/360	0/360	0/360	0/360	0/360	0/360	0/360
Surface (km^{2}x10^3)	38.3	34.4	20.1	23.4	28.9	14.4	16.4	20.7	13.8	18.1	15.1	6.2	8.5

Table 5. Comparison among suitable surfaces with probability class over 50% at the present time and future scenarios. Values are given in km^2 x 10^3 and in percentage (brackets) when referred to the forecasted portion of stable, gain, loss and net variation surfaces with respect to the present time. Bold values refer to the major expected variations, all of them belonging to HADGEM2-ES scenario.

		2050				**2070**			
		Stable	**Gain**	**Loss**	**Variation**	**Stable**	**Gain**	**Loss**	**Variation**
RCP 4.5	CCSM4	26.02	8.39	-12.26	-3.87	23.85	5.08	-14.43	-9.35
		(67.9)	(21.9)	(-32.0)	(*-10.1*)	(62.3)	(13.3)	(-37.3)	(*-24.4*)
	HADGEM2-ES	17.14	2.93	-21.14	-18.21	11.70	2.7	-26.58	-23.88
		(36.9)	(7.6)	(-55.2)	(**-47.6**)	(30.5)	(7.0)	(-69.4)	(**-62.3**)
	MIROC5	19.31	4.09	-18.96	-14.87	13.65	2.71	-24.63	-21.92
		(50.4)	(10.7)	(-49.5)	(-38.8)	(35.6)	(7.1)	(-64.3)	(-57.2)
RCP 8.5	CCSM4	17.66	3.0	-20.62	-17.62	11.97	3.11	-26.31	-23.20
		(46.1)	(7.8)	(-53.8)	(*-46.0*)	(31.2)	(8.1)	(-68.7)	(*-60.6*)
	HADGEM2-ES	10.96	2.83	-27.32	-24.49	3.64	2.61	-34.64	-32.03
		(28.6)	(7.4)	(-71.3)	(**-63.9**)	(9.5)	(6.8)	(-90.4)	(**-83.6**)
	MIROC5	14.73	3.35	-23.55	-20.20	5.69	2.82	-32.59	-29.77
		(38.9)	(8.7)	(-61.5)	(-52.7)	(14.9)	(7.4)	(-85.1)	(-77.7)

Present Time (reference surface value) = **38.30 km^2 x 10^3**

FIGURE 1



Quercus coccifera present distribution

Quercus coccifera present potential distribution

FIGURE 2

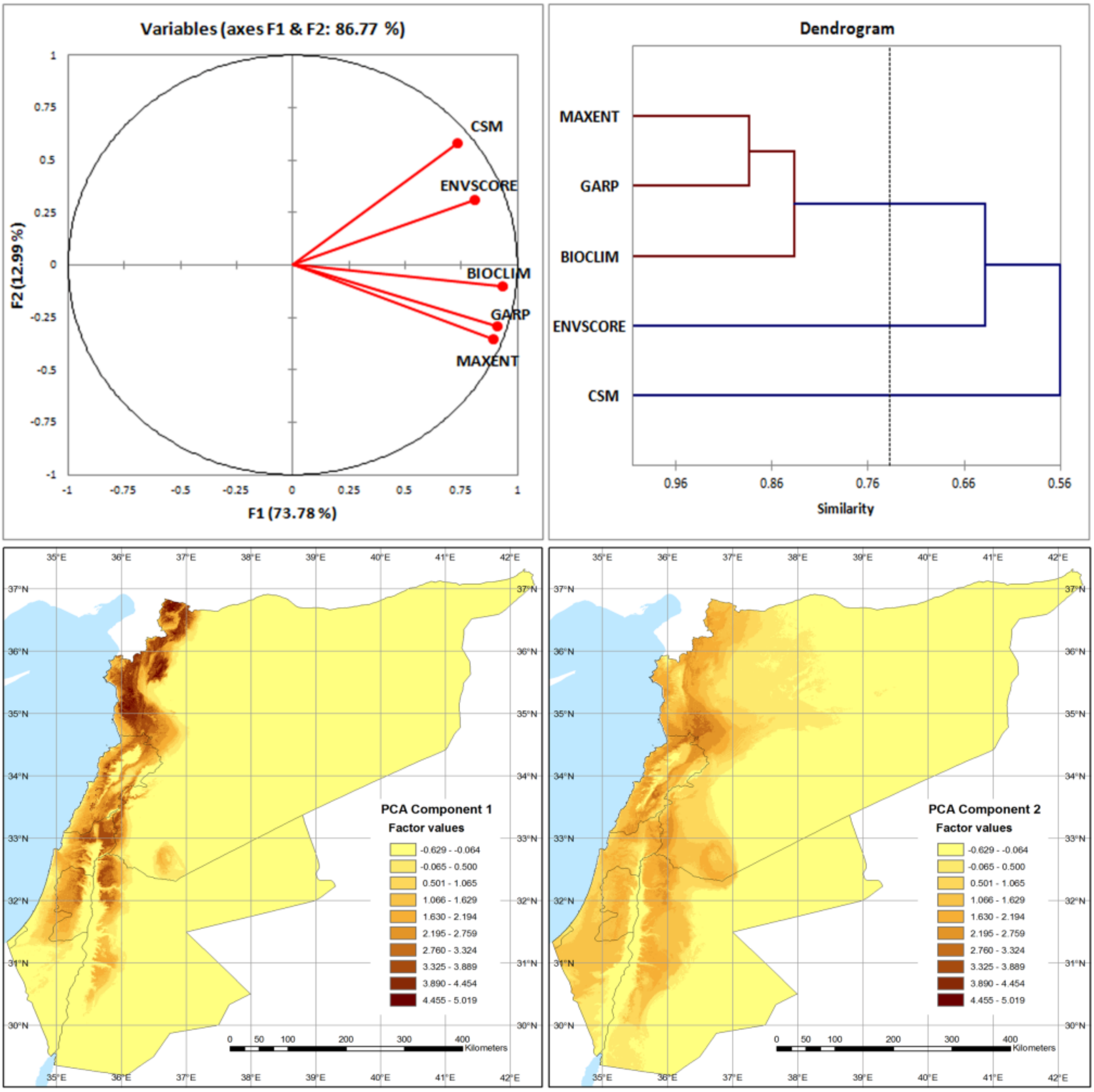

Variables (axes F1 & F2: 86.77 %)
F2 (12.99 %)
F1 (73.78 %)
CSM
ENVSCORE
BIOCLIM
GARP
MAXENT
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
Dendrogram
MAXENT
GARP
BIOCLIM
ENVSCORE
CSM
0.96
0.86
0.76
0.66
0.56
Similarity
PCA Component 1
Factor values
-0.629 - -0.064
-0.065 - 0.500
0.501 - 1.065
1.066 - 1.629
1.630 - 2.194
2.195 - 2.759
2.760 - 3.324
3.325 - 3.889
3.890 - 4.454
4.455 - 5.019
PCA Component 2
Factor values
0
50
100
200
300
400
Kilometers
35°E
36°E
37°E
38°E
39°E
40°E
41°E
42°E
37°N
36°N
35°N
34°N
33°N
32°N
31°N
30°N

FIGURE 3

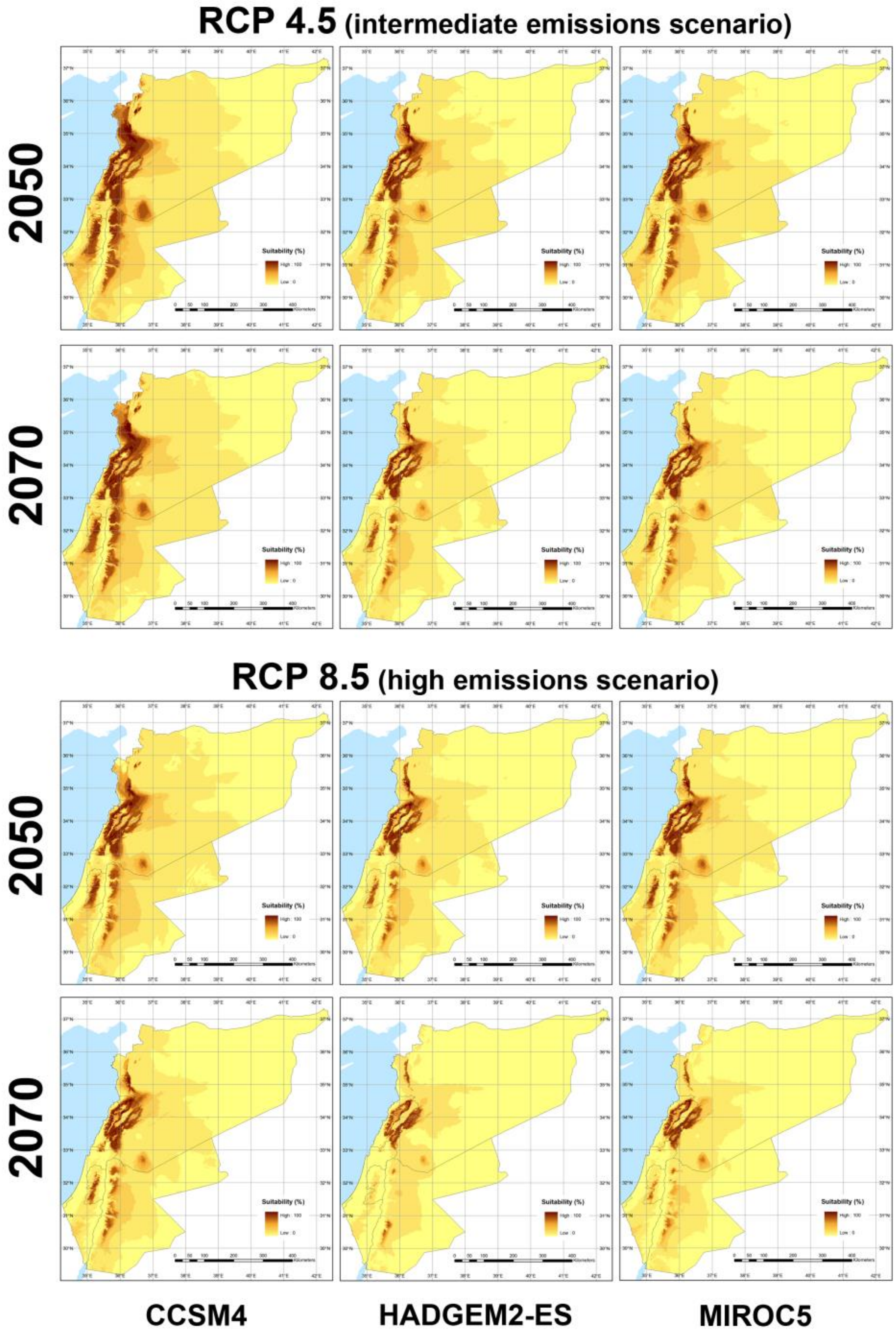
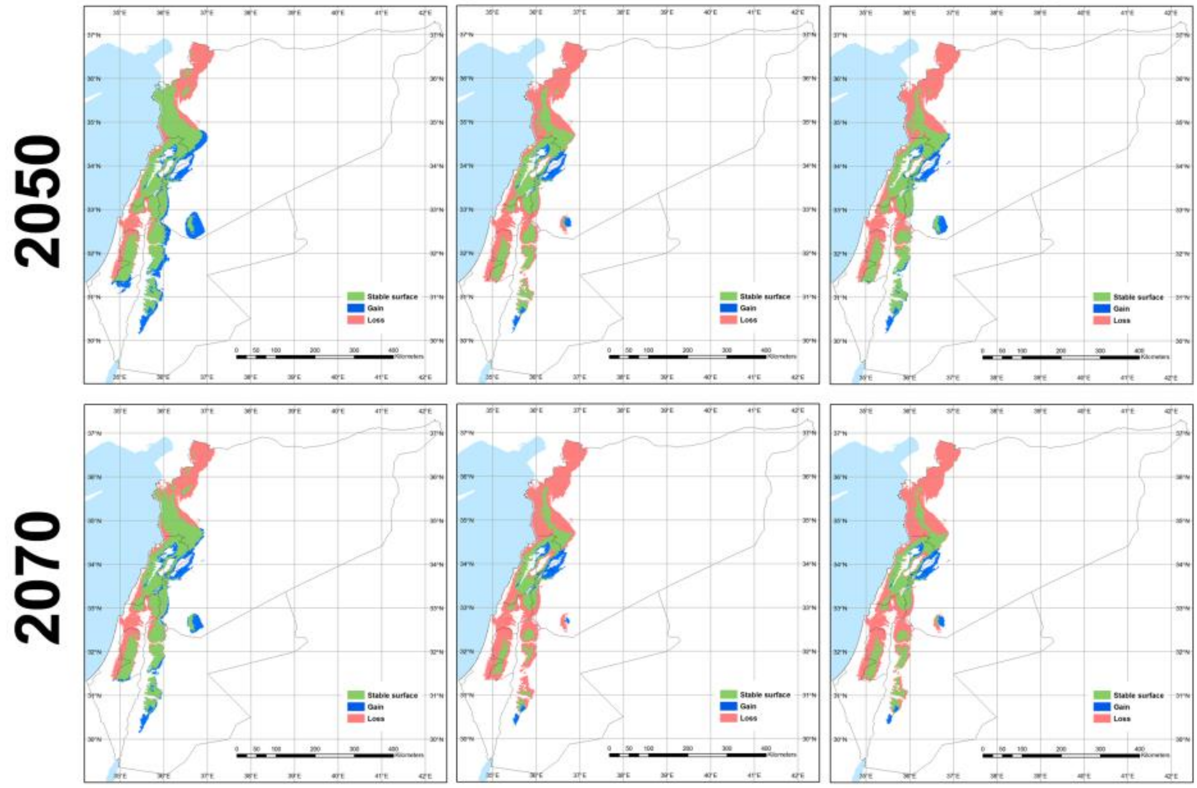
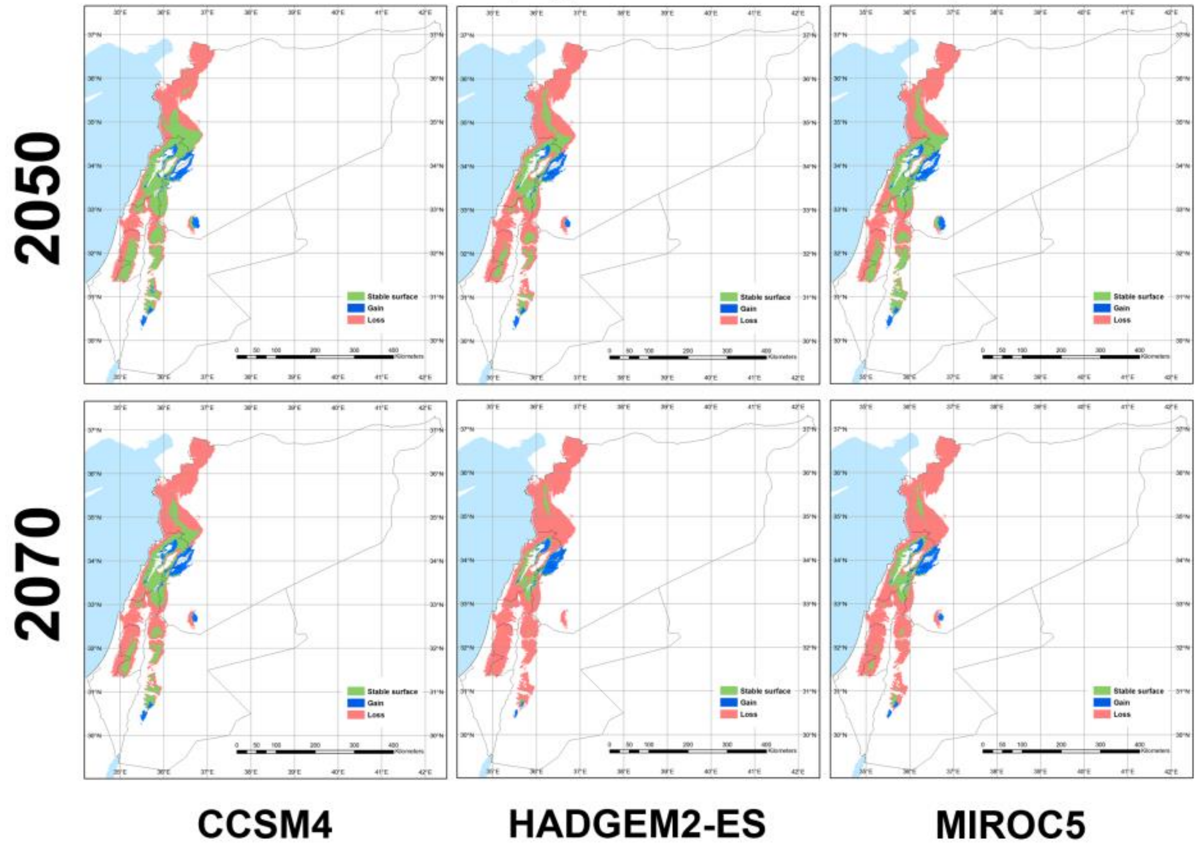

RCP 4.5 (intermediate emissions scenario)
2050
2070
RCP 8.5 (high emissions scenario)
2050
2070
Suitability (%)
High : 100
Low : 0
0 50 100 200 300 400
Kilometers
CCSM4
HADGEM2-ES
MIROC5

FIGURE 4

RCP 4.5 (intermediate emissions scenario)



RCP 8.5 (high emissions scenario)



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