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Original Article

Impact of climate change implies the northward shift in distribution of the Irano-Turanian subalpine species complex *Acanthophyllum squarrosum*

Masoumeh Mahmoudi Shamsabad [a,*], Mostafa Assadi [b], Laura Parducci [c]

[a] Department of Plant Biology, Tarbiat Modares University, Tehran, Iran
[b] Research Institute of Forests and Rangelands, Agricultural Research Education and Extension Organization (AREEO), Tehran, Iran
[c] Department of Ecology and Genetics, Evolutionary Biology Centre, Uppsala University, Uppsala, Sweden

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ABSTRACT

In this study, we used maximum entropy modeling to predict the climate change effects on the distribution range of a subalpine steppe flora species complex, *Acanthophyllum squarrosum* (Caryophyllaceae). We used data from four different models, with two representative concentration pathways of climate scenarios in modern time, 2030, 2070 and 2080. Our results showed that *A. squarrosum* has a suitable habitat in ca. 1 million km^2 (33% of our study area) and will likely experience a northward shift, gaining new habitat in Azerbaijan, Armenia and North of Afghanistan in the near decades. Maxent model predicts *A. squarrosum* complex populations from southern Iran to be under treat of extinction, especially at lower altitudes regions and this prediction may concern other subalpine species found in the same region. Among the climatic variables investigated, annual mean temperature, and precipitation of warmest and coldest quarter were those that mostly affected *A. squarrosum* complex distribution.

Introduction

Climate is one of the most important environmental factors influencing species range (Kreft and Jetz 2007). The Intergovernmental Panel on Climate Change estimated that the average global temperature will increase by about 1.4–5.8°C from 1990 to 2100 (IPCC et al 2014). Rates at which climate change is currently occurring are too fast for many species to shift their range or adapt to new climatic conditions. Therefore, it is important to understand how changes will affect biodiversity at all levels of organization (Razgour et al 2013; Wiens et al 2010). In recent years, species distribution modeling analyses have contributed significantly to the prediction of current and future distribution of species (Elith and Leathwick 2009; Razgour et al 2013). These predictions play a crucial role in decisions taken by policymakers in predicting future risks on biodiversity loss and promoting strategies to reduce such risks (Bellard et al 2012; Dawson et al 2011; Gilman et al 2010; McMahon et al 2011; Pereira et al 2010).

Because nearly half of Iran is composed of arid and semi-arid mountain regions, climate change projections suggest warmer and drier conditions, which will intensify the already existing water stress situation across the region with strong impact on the level of biodiversity and on human societies (Abbaspour et al 2009; Babaeiana et al 2015; Karimi et al 2018; Noroozi et al 2008). Consequently, in Iran, many areas are likely to lose species via local extinctions and migrations, while desert and semi-desert areas are expected to increase their range at the expense of previous forest steppe areas.

In recent years, the importance of predicting the consensus of climate changes on biodiversity and species distribution range has been discussed with high concern. The review of literature shows that distribution ranges of many plant and animal species will be changed in response to global warming and human activities in Iran. Various studies indicated that suitable habitat area will probably decrease for many species from diverse taxonomic groups in the next several decades in Iran (Esmaeili et al 2018; Yousefi et al 2015; Yousefkhani et al 2017), while also there is evidence of potential suitable habitat areas expansion in some cases (Erfanfar et al 2014; Kafash et al 2016; Solhjouy-Fard and Sarafrazi 2014; Yousefi

* Corresponding author. Tel.: +98 021 44787282 5.
E-mail addresses: m.mahmoudishamsabad@modares.ac.ir (M. Mahmoudi Shamsabad), assadi1950@yahoo.com (M. Assadi).
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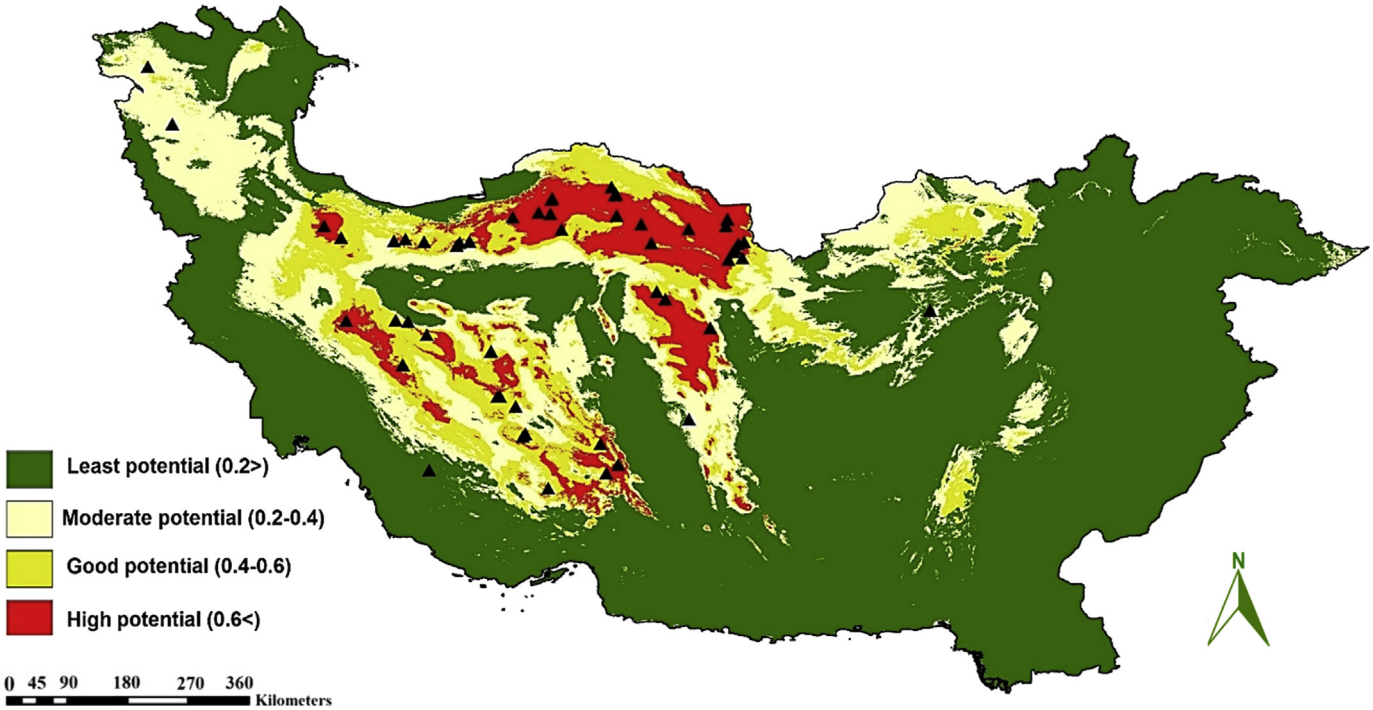

Figure 1. Habitat suitability map of *A. squarrosum* species complex. Sampling point localities (black triangles), least suitable habitats (green); moderate habitat suitability (white); suitable habitats (yellow); highly suitable habitats (red).

et al 2017). However, it is difficult to make general predictions on the consequences of such habitat modifications on biodiversity in the Iranian plateau, which has a broad spectrum of climatic conditions across the region.

Acanthophyllum C.A. Meyer species are small, shrub perennial plants with spiny leaves that adapted to deserts, mountains, and temperate areas and are found in sandy or stony hills and rocky slopes. They are important components of the steppe and mountain vegetation in central and southwest Asia (Mahmoudi Shamsabad et al 2012; Pirani et al 2014; Zohary 1973). *Acanthophyllum* genus is of medical interest due to the cytotoxic properties of many saponins present in its roots. Because *A. squarrosum* Boiss., *A. laxiusculum* Schiman-Czeika, and *A. heratense* Schiman-Czeika are all morphologically similar and difficult to differentiate (Basiri-Esfahani et al 2011; Ghazanfar and Nasir 1986; Mahmoudi Shamsabad et al 2013; Schiman–Czeika 1998), the three species here are considered as a species complex group (*A. squarrosum* species complex group).

In this study, we used ecological niche modeling simulations to predict range shifts and extension of suitable habitats for *Acanthophyllum* species complex in the Irano-Turanian (IT) region under different climate scenarios and to identify populations under threat of extinction. Results of this study can be useful in conservation and biodiversity management in the IT region.

Material and methods

Study area

Our study area in southwest Asia includes part of Afghanistan, Armenia, Iran, and Pakistan (23.702915-41.907482 N and 43.456450-72.117800 E). Zohary (1973) characterized Iran as "outstanding in its rich halophytic flora and vegetation due to the abundance of saline habitats". In Iran, there are a large variety of climates, soils, and topographies and a high degree of fragmentation and isolation in mountain ranges and glacial refugia, which caused a high level of endemism (Djamali et al 2012). The dominant vegetation type in the IT region is cushion-like xerophytes and dwarf shrubs (Manafzadeh et al 2016; Takhtajan 1986)

Occurrence and distribution of A. squarrosum in the IT region

To obtain general information on the occurrence of *A. squarrosum* across its whole range in the IT region, we first accessed distribution reported in Flora Iranica, FUMH (Ferdowsi University of Mashhad Herbarium) and TARI (Herbarium of Research institute of Forests & Rangelands) and also recent taxonomic studies on the genus (Basiri-Esfahani et al 2011). In total, we collected 70 spatially separated occurrence data and specimens stored in TARI (Figure 1, Appendix 1).

Environmental data

Nineteen bioclimatic variables with 30-second spatial resolution (ca. 1 km) (Hijmans et al 2005) were downloaded from WorldClim (http://www.worldclim.org) database. Future climate scenario data for 2030 and 2080 (A2 emission scenario) were obtained from Research Program on Climate Change, Agriculture and Food Security (CCAFS) climate data archive (http://ccafs-climate.org), while for modern time and 2070, data were downloaded from WorldClim database. To reduce the uncertainty in single global circulation model (GCM) predictions, we used data from four different global climate models: Canadian Centre for Climate Modeling and Analysis (CCCMA), Model for Interdisciplinary Research on Climate-ESM (MIROC-ESM), Commonwealth Scientific and Industrial Research Organisation (CSIRO), and Community Climate System Model (CCSM). We used two representative concentration pathways of climate scenarios: RCP2.6 and RCP8.5. The layers were cropped using ArcGIS 10.3 (ESRI group) to construct the current distribution of this species complex.

We select Maxent software v3.3.3 (Phillips et al 2006) for current and future climate simulations because it performs better with small sample sizes than other modeling methods (Elith and Leathwick 2009; Phillips et al 2006; Porretta et al 2013). Maxent uses presence data only (geo-referenced occurrence data) coupled with environmental variable information for the whole study area and generates an estimate of habitat suitability for the species with values ranging from 0 (lowest suitability) to 1 (highest suitability). Maxent also provides a Jackknife option to test training gain of each climatic variable used alone or in combination with the others, which is useful to identify how the variables contribute individually.

ENMTools ver 1.4.4 (Warren et al 2010) http://enmtools.blogspot.ca/ was used to exclude highly correlated (Pearson's $r \geq 0.70$) (Asuero et al 2006) variables, and we select variables based on their importance (Table 1). We used 75% of the occurrence points to construct the model and the remaining 25% to test it (Nenzén and Araújo 2011; Pearson et al 2007; Pedersen et al 2014). Maxent model output was logistic; therefore, to evaluate accuracy, we measured the area under the curve (AUC) (Pearson et al 2007; Porretta et al 2013). An AUC value of 1.0 indicates perfect discrimination, whereas AUC = 0.50 indicates that the model does not perform better than randomly (Swets 1988).

Finally, species distribution models were classified in ArcGIS 10.3 by running the ArcMap Spatial Analyst tools. We classified the potential species distribution values from 0 to 1, with probability values <0.2 indicating the least potential, 0.2–0.4 moderate potential, 0.4–0.6 good potential, and >0.6 high potential.

Results

Maxent model with *A. squarrosum* species complex performed better than randomly with a statistically significant AUC value (Current: 0.899; 2070 CCSM 2.6: 0.894; 2070 CCSM 8.5: 0.9; 2080 CCCMA 2.6: 0.862; 2030 CCCMA 8.5: 0.868; 2080 CCCMA 8.5: 0.926; 2030 MIROC-ESM 2.6: 0.859; 2080 CSIRO 8.5: 0.880; 2030 CSIRO 8.5: 0.862; 2080 MIROC-ESM 8.5: 0.846; 2080 MIROC-ESM 2.6: 0.864; 2030 MIROC-ESM 8.5: 0.853).

Maxent model results show that currently circa 6% of the IT region (203276 km^2) has high potential for the distribution of *A. squarrosum* species complex, and this area mostly occurred in northeast and part of middle of Iran on the Zagros and Alborz mountains. Approximately 10% of the IT region (325128 km^2) shows a good potential, 17% (569632 km^2) moderate potential, whereas circa 65% of the region (2115460 km^2) was covered by Lut and Kavir deserts, coastal areas, and north forest showing the least potential with unsuitable habitats for this species complex.

Variable contributions

Analyses of relative predictive power of environmental variables indicated that bio 1 (annual mean temperature), bio 18 (precipitation of the warmest quarter), and Bio 19 (precipitation of the coldest quarter) were the main factors influencing *A. squarrosum* distribution in the IT region, with 57.7%, 15.6%, and 13% contributions, respectively (Table 1, Figure 2). The relationship between these environmental variables and the logistic probability of presence are illustrated in Figure 3. According to the response curves, the distribution of *A. squarrosum* is highly controlled by both temperature and precipitation. With respect to Bio1, the habitat suitability increases as temperature increases from 10 to 20°C and rapidly decreases when the temperature was greater than 20°C. A similar pattern is shown by the response curves for precipitation. The habitat suitability was decreased as the precipitation of the warmest and coldest quarter (Bio 18 and Bio 19) exceeded 20 mm in the warmest quarter and 80 mm in the coldest quarter.

Table 1. Percent contributions of the bioclimatic variables used in the final model reconstruction in this study.

Variable	Layer name	Percent contribution
Bio 1	Annual mean temperature	57.7
Bio 2	Mean diurnal range	−2.8
Bio 4	Temperature seasonality	7.8
Bio 15	Precipitation seasonality (standard deviation/mean)	3.1
Bio 18	Precipitation of warmest quarter	15.6
Bio 19	Precipitation of coldest quarter	13

A. squarrosum distribution under future scenarios

Results of assessing the effects of climate changes on the distribution of *A. squarrosum* in Iran showed that the distribution range of this species complex will increase until 2080 (Table 2) and will likely experience a northward shift, gaining new habitat in northwest of Iran, Azerbaijan, Armenia, and north of Afghanistan in the near decades (Figure 4).

Discussion

The best method for biodiversity conservation and for protecting the ecosystem performance is the potential distribution modeling of endemic species. Endemic species with narrow niches are more vulnerable to climate changes, and they are generally at higher risk of extinction. Therefore, it is important to understand how climate change will impact on the distribution range of this species (Rosenzweig et al 2008).

Our case study predictions illustrate the spatial distribution of the IT species complex *Acanthophyllum squarrosum* at four time periods. The habitat suitability areas for *A. squarrosum* were grouped into four categories: 0–0.2 indicating areas with least suitable habitats (green); 0.2–0.4 areas with moderate habitat suitability (white); 0.4–0.6 suitable areas (yellow); and 0.6–1 highly suitable areas (red) (Figure 1). Habitat suitability modeling indicated that a vast area in the plains of the Zagros Mountains in the southwest of Iran, plains in the north and northeast of the country in the Alborz and Kopet Dagh mountains, and a vast area in the plains of the Hindu Kush Mountains in Afghanistan are highly suitable areas for this species complex. Our model also indicates other dispersed patches of suitable habitats in the southeast country in Taftan Mountain, although it seems there was a continuous distribution range of this species complex from southeast to northeast of Iran in the past decades. Based on our simulations, these isolated populations in the southeast of Iran are in threat of extinction. Moreover, based on our result, additional *A. squarrosum* populations from southern Iran (south of Khorasan, Kerman, and Yazd province) are under treat of extinction, especially at lower altitude regions. However, such prediction may concern also other subalpine species occurring in the same region; we therefore urge to consider restoration plans in this region.

Increasing future global temperatures will likely force many alpine plants migrate to higher altitudes. According to climatic data from meteorological stations, in the Alborz Mountain range, we have already seen an increase in temperatures during the recent decades (Noroozi et al 2008). Therefore, we expect many alpine ranges of the IT region, which host a large number of endemic species, will likely suffer from critical species loss. In central Iran, *Acanthophyllum* species populations are mainly concentrated at high altitudes around the Zagros Mountain, and here, we expect that low-altitude populations will be lost due to drought and higher temperature. In the similar study, distribution of *Daphne mucronata* in Isfahan Province would shift to higher

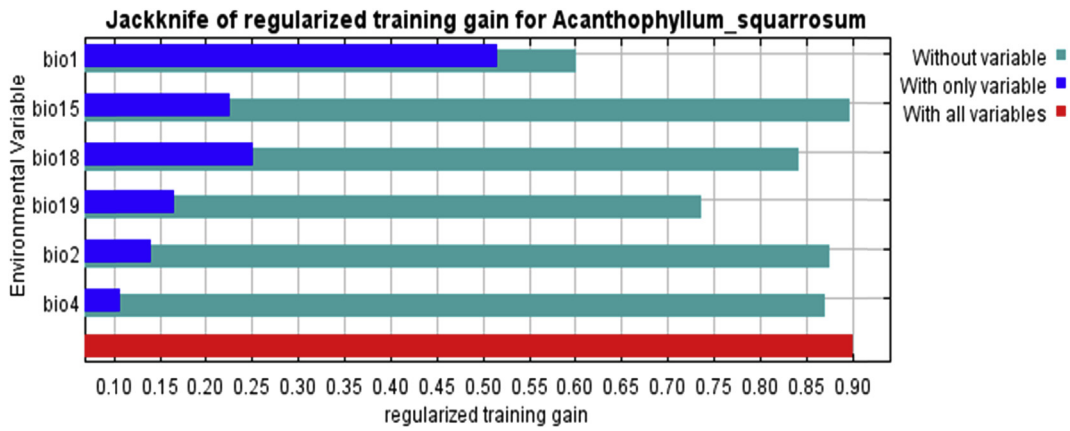

Figure 2. The Jackknife test for evaluating the relative importance of environmental factors for *A. squarrosum* species complex.

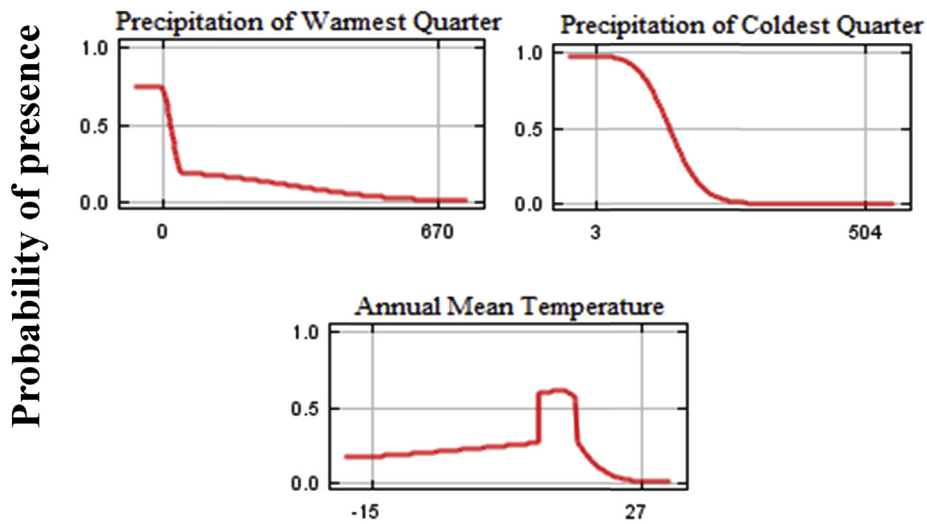

Figure 3. Response curves showing how the presence of *A. squarrosum* species complex is affected by the most important variables.

elevation ranges, whereas its habitat in areas lower than 2000 meter above the sea level will become totally inappropriate, and the species will disappear under future climate scenarios (Abolmaali et al 2018).

Table 2. The potential variation of the climatically suitable distribution area for *A. squarrosum* complex.

Models	High potential (km^2)	Good potential (km^2)	Moderate potential (km^2)	Total range distribution (km^2)
Present distribution	569632.8	325128	203276	1098037
2070, CCSM, 2.6	460439.8	267909	175222.9	903571.9
2070, CCSM, 8.5	564378.7	336366	216963.8	1117708.9
2030, MIROC-ESM, 8.5	451245.8	265220	180126.7	896592.7
2080, MIROC-ESM, 8.5	571675.6	323060.5	222890	1117626
2030, MIROC-ESM, 2.6	551219	281418	219235.6	1051872.9
2080, MIROC-ESM 2.6	523936.4	253021.6	190600	967558
2030, CCCMA, 8.5	472674.4	254809.8	182597	910081.4
2080, CCCMA, 8.5	696268.7	415345.7	228491.9	1340106
2030, CCCMA, 2.6	542115.2	294677.4	201339.7	1038132
2080, CCCMA, 2.6	633419	381753	212132.8	1227305
2030, CSIRO, 8.5	454761	302777	186890	944428
2080, CSIRO, 8.5	506292.8	340971.6	196754.9	1044019

CCCMA, Canadian Centre for Climate Modeling and Analysis; CCSM, Community Climate System Model; CSIRO, CommonWealth Scientific and Industrial Research Organisation; MIROC-ESM, Model for Interdisciplinary Research on Climate-ESM.

Rapid and extensive distribution shifts in response to climate change have been observed for several plant taxa and likely will continue in the coming decades (Burrows et al 2014; Chen et al 2011; Hill et al 2016; Parmesan and Yohe 2003; Pinsky et al 2013). However, there is evidence of suitable habitat range shift due to climate change in Iran (Yousefi et al 2015) Asynchronous migrations will likely have major impacts on community composition, creating new combinations of species, with new neighbors and new competitors (Blois et al 2013; Williams et al 2013). Our result showed that the suitable habitat area for this species complex will considerably shift to the northwest of Iran and north of Afghanistan under future climate conditions. The northwest of Iran covered by cold mountain and Mediterranean climate is climatically different from south of Iran with dry and hot climate. This region will likely experience the warmer climate in the next decades and will be a suitable habitat for migration of this complex and similar species.

Among the climatic variables investigated, annual mean temperature and precipitation of the coldest and warmest quarter were those that mostly affected *A. squarrosum* complex distribution. Suitability decreased more rapidly for this species complex, with increasing annual mean temperature maximum greater than 20°C. These results are in concordance with Maxent distribution map and occurrences reported (Flora Iranica, FUMH, and TARI), which

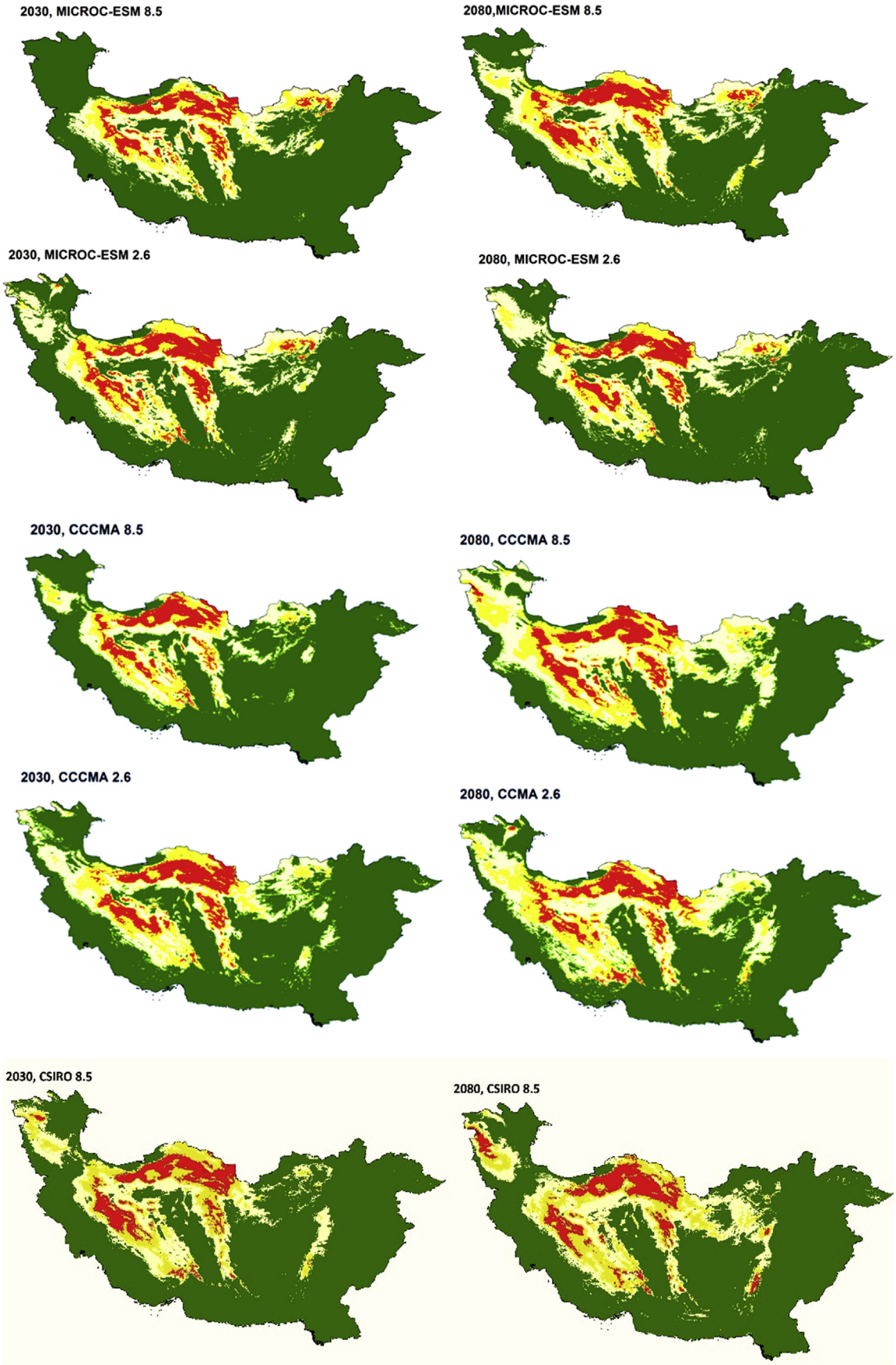

Figure 4. Maps of potential distribution of *A. squarrosum* species complex in the IT region under climate change scenarios, in modern time, 2030 and 2080. IT, Irano-Turanian.

showed that this species complex is absent in the hyper arid areas of central Iran with higher temperature. Moreover, the distribution of *A. squarrosum* is also highly controlled by precipitation, so that probability of presence decreases with increasing precipitation exceeding 20 mm in the warm quarter and 80 mm in the cold quarter. These results are consistent with geographical occurrences of this species complex that is absent in the forested regions of northern Iran and in the coastal areas.

Conclusion

The results of this study indicated that the distribution range of this species complex will be increased until 2080. It should be considered that we expect a range shift to the northwest of Iran, Azerbaijan, and Armenia and north of Afghanistan, while south and some parts of central Iran populations are under threat of extinction. Improving conservation management strategies can decrease the climate changes effects in the south of Iran. Germplasm preparation and storage from south populations and increase of protected area in west of Iran can be considered in biodiversity protection programs.

Conflicts of interest

The authors declare that there is no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.japb.2018.08.009.