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CURRENT GEOGRAPHICAL DISTRIBUTION OF SALVIA ARISTATA (LAMIACEAE), PREDICTION OF ITS FUTURE DISTRIBUTION BASED ON CLIMATICAL DATA; A GUIDE FOR ITS CONSERVATION

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The current global climate change is a big challenge for biodiversity. Efforts on monitoring biodiversity and conservation is more effective by having information about species spatial distribution. Development in computational model provide new opportunity for botanist to integrate herbarium specimen's records with evolutionary and ecological data which are so crucial for biodiversity. *Salvia aristata* Auch. ex Benth (Lamiaceae) is an Irano-Turanian endemic species restricted to western, northwest and center of Iran along with few records from eastern parts of Turkey. In this study, we applied ecological niche modeling with emphasizing on climate data to infer *S. aristata* distribution in the past, present and future. Our niche model produced good results with high performance based on Area Under Curve (AUC>0.9). Altitude was the most important variable contributing in niche models of *S. aristata*. The last glacial model showed that *S. aristata* had more restricted niches during Last Glacial Maximum than its current distributions. Also, our future niche model showed that the suitable area of *S. aristata* will be decreased in 60 years.

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Key words: *Salvia; herbarium; ecological niche modeling*; conservation; climate change; Iran

انتشار کنونی گونه S. aristata (Lamiaceae)، پیش‌بینی کنام‌های اکولوژیک در زمان آینده براساس داده‌های هواشناسی؛ راهنمایی برای حفاظت گونه

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امروزه تغییرات اقلیم در سطح جهان چالشی بزرگ برای تنوع زیستی است. داشتن اطلاعات از داده‌های مکانی گونه به مراتب برای نشان دادن تنوع زیستی و حفاظت مؤثر است. پیشرفت‌های اخیر در شبیه‌سازی مدل‌های رایانه‌ای فرصت مناسبی را برای محققین علوم گیاهی در تلفیق داده‌های هرباریومی با اطلاعات تکاملی و اکولوژیکی گونه که برای حفظ تنوع زیستی نیز با اهمیت است فراهم آورده است. گونه Salvia aristata Auch. ex Benth (Lamiaceae) گیاهی انحصاری ناحیه ایرانو–تورانی است که پراکنش آن به مناطق شمال، شمال‌غرب و مرکز ایران محدود می‌شود.

اخیرا چندین گزارش برای S. aristata از بخش شرقی ترکیه ذکر شده است. دراین مطالعه از شبیه‌سازی کنام‌های اکولوژیک با تأکید بر داده‌های اقلیمی برای تخمین توزیع گونه در زمان حاضر، گذشته و آینده استفاده کردیم براساس نتایج Area Under the Curve (AUC>0.9)، مدل شبیه‌سازی شده کارایی بالا دارد. ارتفاع مهمترین عامل تعیین کننده در پراکندگی جغرافیایی گونه S. aristata است. براساس مدل‌های شبیه سازی شده، در آخرین عصر یخبندان نقاط جغرافیای مناسب برای پراکندگی S. aristata نسبت به پراکندگی گونه‌ی کنونی کمتر بوده است. همچنین، مدل شبیه‌سازی شده برای آینده نشان داد که نقاط جغرافیایی احتمالی مناسب برای حضور S. aristata در ۶۰ سال پیش رو کاهش خواهد یافت.

INTRODUCTION

Over the past decades, more than 38,700,000 specimens were collected in 3001 herbaria across the world (Thiers 2017; James & al., 2017). Herbarium specimens are not just a good source for taxonomic classification, floristic studies or molecular studies, but also, they provide invaluable information record of present and past distribution (Soltis & Soltis 2016, Ferrara & al., 2014). By emerging the cyberinfrastructure and development in computational technology, the immense collections becoming more available by increasing of natural history museum digitization activities (Soltis 2017; Vollmar & al., 2010). These digital repositories provide easy, fast and cheap access to thousands of museum collections. In addition, easy access to herbarium data facilitate applying integrative model of herbarium specimen's data to phylogeny, ecology and biodiversity (Soltis & Soltis 2016; Soltis 2017). These novel methods provide opportunity for researchers to address evolutionary, conservation and ecological question in biology and conservations.

Online database and data aggregator

The data aggregators such as GBIF (Global Biodiversity Information Facility), (https://www.gbif.org/) is an online open source tool gathering species data and information of species distribution derive from many natural history museums digital collections. GBIF currently serve (980,000,000) specimens. "iDigBio" (Integrated Digitized Biocollections), (https://www.idigbio.org/) is founded in 2011 and serves over 115,000,000 specimens records from US and international natural history museums.

Hart et al (2014) used 14,295 herbarium specimens records to study the effect of climate change and rapid warming on flowering time over the past 45 years. Phylodiversity refers to combining phylogenetic tree information with spatial distribution identify biodiversity hotspots which is important for conservation (Faith and Baker 2006). Integrating spatial data of specimens with environmental variables can predict the past, present and future distribution (Guisan & Thuiller 2005; Peterson 2012). Ecological niche modeling or species distribution modeling becoming a considerable tool in study of biodiversity (Illoldi-Rangel 2004; Sen & al., 2016). This method is well documented for species delimitation and conservation studies (Wiens 2006; Raxworthy & al., 2007; Zhang & al., 2014).

Integrating spatial data of specimens with environmental variables can predict the species distribution. This paper will focus on applying this method in predicting *Salvia aristata* distribution in past, present and future.

Ecological Niche Modeling

Ecological Niche Modeling or "Species Distribution model" applying occurrence record (geographic coordinates) in combination with climate data (precipitation, temperature) or geospatial variables (slope & soils) to estimate species niches or geographical area (Guisian & Thuilller 2005; Phillipes & al., 2006; Merchant & al., 2016). In this method Geographical species occurrences are derived from observations, reported species occurrence in data aggregators or preserved herbarium sheets records. The environmental variables can be extracted from Worldclim database which is a common source of climate data (http://www.Worldclim.org). Worldclim also provides the data for past (Middle Holocene & Last Glacial Maxiumum). Different computational methods have been developed to predict the species distributions (Different approaches and algorithms have been developed to predict species distributions (BIOCLIM: Busby 1991; GARP: Stockwell and Peters 1999; MAXENT: Phillips *& al.* 2006; BIOMOD: Thuiller 2009). These tools are different in implemented method, treating occurrence records (presence-only or presence/absence) and the ability to generating continuous or discrete predictions of habitat suitability. Specific research aims, and the domain of any given study determines which methods are most appropriate (Alvarado-Serrano and Knowles 2014).

Iran Biodiversity

Because of the diverse climates, soils and geographical formations, Iran is known as a country rich in biodiversity with about 7500 vascular plant species and 1168 species of mainland vertebrates. Farashi & Shariati (2017) showed that large parts of Iran have potential to be regarded as biodiversity hotspots.

Ongoing climate changes lead to doubling of CO_2 concentration by the year 2100. In Iran, the average temperature will increase by 1.5-4.5. Consequently, precipitations, water sources and drought frequency will be changed (Amiri & Eslamian 2010). Thus, studying biodiversity in these areas and determining the threatened species is so crucial for conservation.

Salvia L. is the largest genus in Lamiaceae (Mentheae-Salviinae) encompassing approximately 1000 species distributed across the world: Central and South America (500 spp.), Western Asia (200 spp.) and Eastern Asia (100 species) (Walker & al., 2004). Iran is regarded as one of the important regions for *Salvia* diversity by having 61 species in which 19 of them are endemics (Jamzad 2012). Species are more threatened with climate change due to restricted habitat areas. Therefore, understanding the effects of climate change on endemic species distribution is essential to prevent them from extinction. In this study, we applied ecological niche modeling with considering climatic aspect to study the changes on *S. aristata* distribution, involved with climate changes in Last Glacial Maximum, present and in around 60 years.

MATERIALS AND METHODS

Two types of data are essential for ecological niches modeling. 1) The coordinate points of localities. 2) GIS -maps of the environmental variables (Seasonality, temperature and precipitation) and geophysical data (altitude, slope, soil and other aspect) that are likely to affect the suitability for our objective species (Kozak & al., 2008). These maps are obtained from monthly values gathered from thousands of weather stations around the world (~50,000 locations for precipitation and ~25,000 locations for temperature). In this study, we used MAXENT program to model the potential distribution of *S. aristata*. Maxent integrate occurrence records (coordinate points of species) with environmental variables to provide gridded map of potential distribution of studied species.

A total of 37 coordinate points for *S aristata* were georeferenced from herbarium data and GBIF database (http://www.gbif.org) to cover as complete as possible the distributional range of *S. aristata* (table 1, fig. 1). 19 bioclimatic variables (2.5 arc- minute) for present (1970-2015) were downloaded and extracted from World Clime database (http://www.worldclim.org, Hijmans & al., 2015). Extracted variables were masked into Iran and Turkey maps (areas of *S. aristata* distribution). All variables were stacked and converted into “ascii” formats using the packages raster (Hijmans & Van Etten, 2015) and rgdal (Bivand & al. 2006) in R (R CoreTeam, 2015). Including all 19 variables in models may lead to misinterpretation of the potential species distribution. Therefore, we performed Pearson Correlation and variables higher than 0.8 overlap were removed. Also, we did clustering of bioclimatic variables to reduce the correlated variables. Six Bioclim variables along with altitude were retained for *S. aristata* niche modeling including: Bio3 (isothermality), Bio4 (temperature seasonality), Bio7 (temperature annual range), Bio8 (mean temperature of wettest quarter), Bio12 (annual precipitation), and Bio18 (precipitation of warmest quarter).

To achieve the effect of bio-geographic changes on *S. aristata* distribution, we also modeled Last Glacial Maximum (LGM) (~22000 years BP) and Future (~ 2050-2080) as well.

Niche models are often calibrated or projected to past and future from global climate models (GCMs). GCMs provides statistical of physical processes operating in oceans, cryosphere, atmosphere, and land surface for statistical model of the historical events (including LGM) and forecasting of the global climate change through time. GCMs has nine general circulation models (Varela & al., 2015). In this study, we used the Community Climate System Model (CCSM) of GCMs. CCSM is part of coupled climate model for simulating the earth's climate system. This model composes of four separate models simultaneously simulating the earth's atmosphere, ocean, land surface and sea-ice, and one central coupler component, the CCSM allows researchers to conduct fundamental research into the earth's past and future climate states.

For future model, we obtained the future bioclimatic variables CCSM4 of GCM projection for the year 2070 considering the climate change scenario rcp8.5 from Worldclim database. Based on this scenario, the atmospheric CO2 concentration will rise to 677.1 ppm (mg/L).

For the past model of the Last Glacial Maximum (around 22000 years ago), we used paleoenvironmental conditions as provided by global circulation models (GCM) with applying CCSM. The original data was made available by (CMIP5, https://cmip. llnl.gov/cmip5/). These data were downscaled and calibrated as described by Peterson and Nyari (2007). Bioclimatic variables for Last Glacial Maximum (LGM) were obtained from the WorldClim database. We applied all procedure for extracting all the variables in past and future like present as discussed.

We estimated habitat aspects and potential areas of distribution of *S. aristata*, using maximum entropy algorithm implemented in MAXENT v.3.3 (Phillips & al. 2006). MAXENT is a machine learning method that estimates the probability of species occurrence using group of environmental variables and presence data. The previous studies showed that MAXENT is useful method for small sample size (Baldwin 2009; Vroh &

al., 2016). To simulate the model, we used 75% of occurrence point for testing and 25% for training with 5000 iterations. Default settings were used for convergence threshold and regularizations parameter. To evaluate the model, the Area Under the Curve (AUC) of Receiver Operating Characteristic curve (ROC) was estimated. AUC is a statistic parameter which measures the ability of a model to discriminate between the present size and absent size by taking the random sample from the population (Phillips *& al.* 2006). We performed Jackknife test to assess the importance of each environmental variable in our modeling. The output models of MAXENT were created using QGIS 2.18.0.

RESULTS

Our model predicted a patchily potential suitable area for *S. aristata* accessions. The results suggest that Kopet Dagh Mountains and a narrow part of Alborz Mountains in northeast of Iran are potentially suitable areas for *S. aristata* occurrence (fig. 2A). Notably no specimen is recorded form Kopet Dagh Mountains so far. The area under the curve (AUC) for the current model is 0.94, both past and future projection models had an AUC higher than 0.9. Taking 0 to 1 as the range for AUC, the amount < 0.5 shows random model, between 0.7 - 0.9 indicates good model fit and the AUC > 0.9 shows that the model performance is excellent. The Jackknife test showed that altitude and annual precipitation are the most contributing factors in Maxent model (table 2). The Last Glacial model showed that *S. aristata* had more unsuitable areas during Pleistocene. Also, the future projected model indicated that *S. aristata* may not be affected dramatically by climate change, however, the suitable niches for *S. aristata* will be reduced (fig.2C & fig.3). In addition, statistical changes in niche suitability of *S. aristata* distribution for present and future niche are shown in fig. 4.

DISCUSSION

In this study, we attempted to model the current, future and past condition of *S. aristata* to evaluate the effect of climate and biogeographic changes. Our current model (fig. 2B) showed that there are some potentially suitable areas for *S. aristata* from where no specimen was reported so far in northeastern part of Iran. The AUC score for all the models were above 0.9, which shows that the model of prediction performance based on occurrence point is accurate.

Biogeographic Changes and Climate Change effect

The Last Glacial Model predicted smaller suitable area than the current distributions. Based on several lines of evidence, Northern Iran and Zagros (fig. 2A) experienced dry and cold climate conditions (up to 5◦c) during the Last Glacial. Also, precipitation (highly contributed factor *in S. aristata* distributions) was low throughout this period

It is projected that the future climatic changes such as global warming and increasing in CO2 emission will affect the distribution of plants and animal, from species to community levels (Walther *& al.* 2002). Our projected model for future (fig. 2C) indicated that changes in *S. aristata* distribution is not striking, however, suitable area habitat will be reduced and a niche shift to higher elevation will be expected (fig. 2c & fig. 3). Since *S. aristata* has fragmented populations, limited areas of occupancy and insufficient seed setting, this species is recognized as an endangered species according to IUCN red list categories (Jamzad & Moein 2017). Therefore, a conservation program is essential to preserve their narrow and fragmented populations. According to a recent study (Jamzad & Moein, 2017) and based on IUCN red list categories *S. aristata* is recognized as a least concerned (LC) taxon based on Extent of Occurrence (EOO), but as an endangered (EN) regarding to Area Of Occupancy (AOO). Therefore, applying a more conservation program is recommended to prevent *S. aristata*'s populations from extinction. Also, this study can be considered as model for the other Iranian *Salvia* species and other flowering plants in the future.

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Table 1. Localities and geographical coordinates used in this study for climate niche modeling of *S. aristata*.

Accession numbers	**Localities**		
		Longitude	Latitude
1	Azerbaijan: 14 km from Khalkhal to Kivi, Anavis, village, 1680m, 34149 TARI.	48.47°	37.67°
2	Azerbaijan: 35 Km from Kivi, Firouzabad, 1180-1350m 34230 TARI.	48.22°	37.59°
3	Azerbaijan: 78 km from Mianeh to Khalkhal, 1500m, 56889 TARI.	48.47°	37.68°
4	Azerbaijan: Darreh Ghasemlou, TARI s. n.	45.15°	37.35°
5	Azerbaijan: From Tabriz to Marand after Soufian, 1500m, 29804 TARI.	45.47°	38.37°
6	Azerbaijan: Inter Naqadeh et Mahabad, 1600m, Siami 2640.	45.52°	36.89°
7	Azerbaijan: Supra Heydar Abad, 1520 m, Archibald 2212.	37.42	46.63°
8	Esfahan: Faridan, Daran, Tarrar, 2450m, 13266 TARI.	50.21	33.21°
9	Esfahan: Fereydunshahr, 12691/23, 2500m TARI.	50.09°	32.94°
10	Esfahan: Fereydunshahr, near the village Sibak, 2900m, 76486 TARI.	50.07°	32.89°
11	Esfahan: Fereydunshahr, Sibak, 2670m, 90331. TARI.	50.07°	32.89
12	Esfahan: Ghameshlou protected area, 2350m, 1118 TARI.	51.47°	32.05°
13	Esfahan: Ghameshlou, 2200m, 5239 TARI.	51.47°	32.05°
14	Esfahan: Ghameshlou, protected area, Tange darposht, 2200m, 1203 TARI.	51.47°	32.05°
15	Esfahan: Ghameshlou, Sanjab pass (Halaj), 2230m, 90369 TARI.	51.47°	32.05°
16	Esfahan: Ghameshlou, Sanjab, 2200m, 90328 TARI.	51.47°	32.05°
17	Esfahan: Ghameshlou, Sanjab, 90336 TARI.	51.47°	32.05°
18	Esfahan: Khansar: Darre bid, 2700M, 13607 TARI.	50.45°	33.07°
19	Esfahan: Tiran to Damaneh, Tange kolang, 2500m, 12495 TARI.	50.18°	33.17°
20	Ghazvin to Hamedan just after Avaj, 2100m, 36689m TARI.	49.21°	35.57°
21	Ghazvin: Aloak to Esbzad, 2120m, 90329 TARI	50.03°	36.42°
22	Hamedan: Avaj, 1800-2000, Mozaffarian, 64432 TARI.	49.22°	35.58°
23	Kurdistan: 25 km from Sanandaj, mountain above Narran village, 1850-2600m, 60235 TARI.	47.10°	35.14°
24	Kurdistan: Saghez, Zanbill village, 1300-1360m, 5103 (TARI).	46.04°	36.38°
25	Kurdistan: Sanandaj, Abidar mountain, 1700-1760, 7226 TARI.	35.31◦	46.97
26	Kurdistan: Sanandaj, Narran village, 1850m, 72 TARI.	47.10°	35.14°
27	Kurdistan: SW of Sanandaj, 38 KMm Sanandaj to Kamyaran, 1850 m, 72 TARI	35.07°	46.94°
28	Kurdistan: Saghez to Marivan, Shipanju village, 1710m, 4234 TARI	46.26°	35.96°

Table 1. Continued.

Accession numbers	**Localities**		
		Longitude	Latitude
29	Lorestan: Oshtorankuh, above Tihun village, 37072/24 2000-2500m TARI**.**	49.29°	33.42°
30	Lorestan: Dorud, 1670 m, Koelz 15622.	49.05°	33.46°
31	Tehran: Between Arak and Khomein Vartche mountain, 2600m, 48029 TARI.	49.92°	33.79°
32	Tehran: Komayjan, Pass of Chehregan village, the margin road, 2350m, 501 TARI	49.26°	34.89°
33	Turkey: Caldiran, Van, 2000-2200m, VANF 955771.	39.14°	43.91°

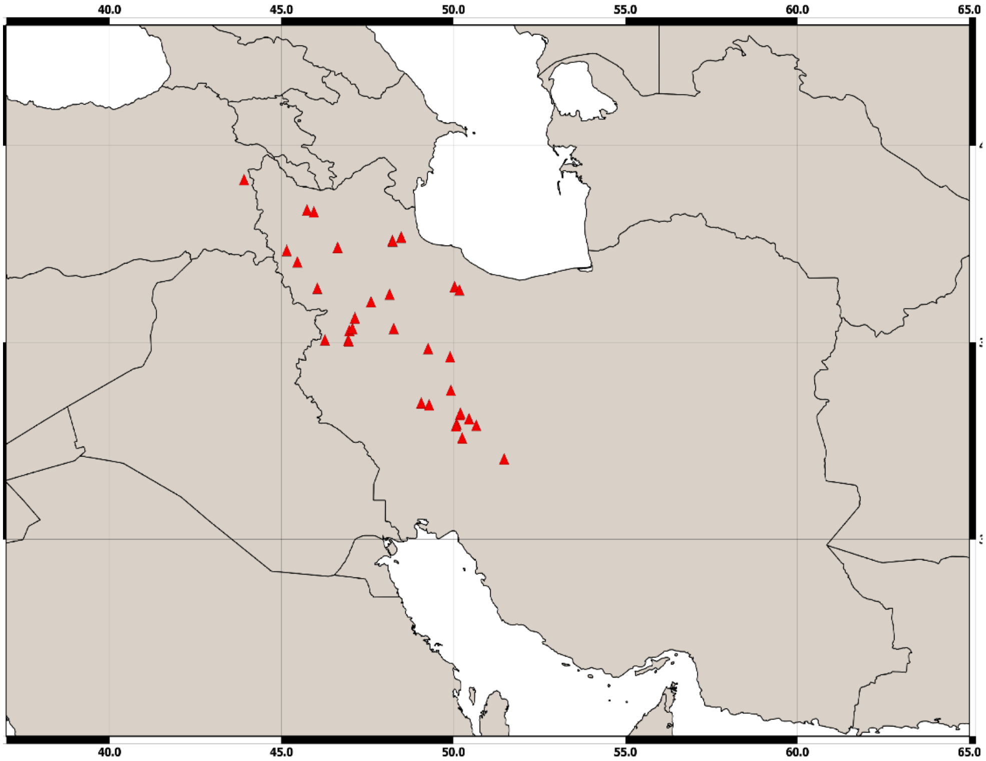


Fig. 1. Distribution map of *S. aristata*.

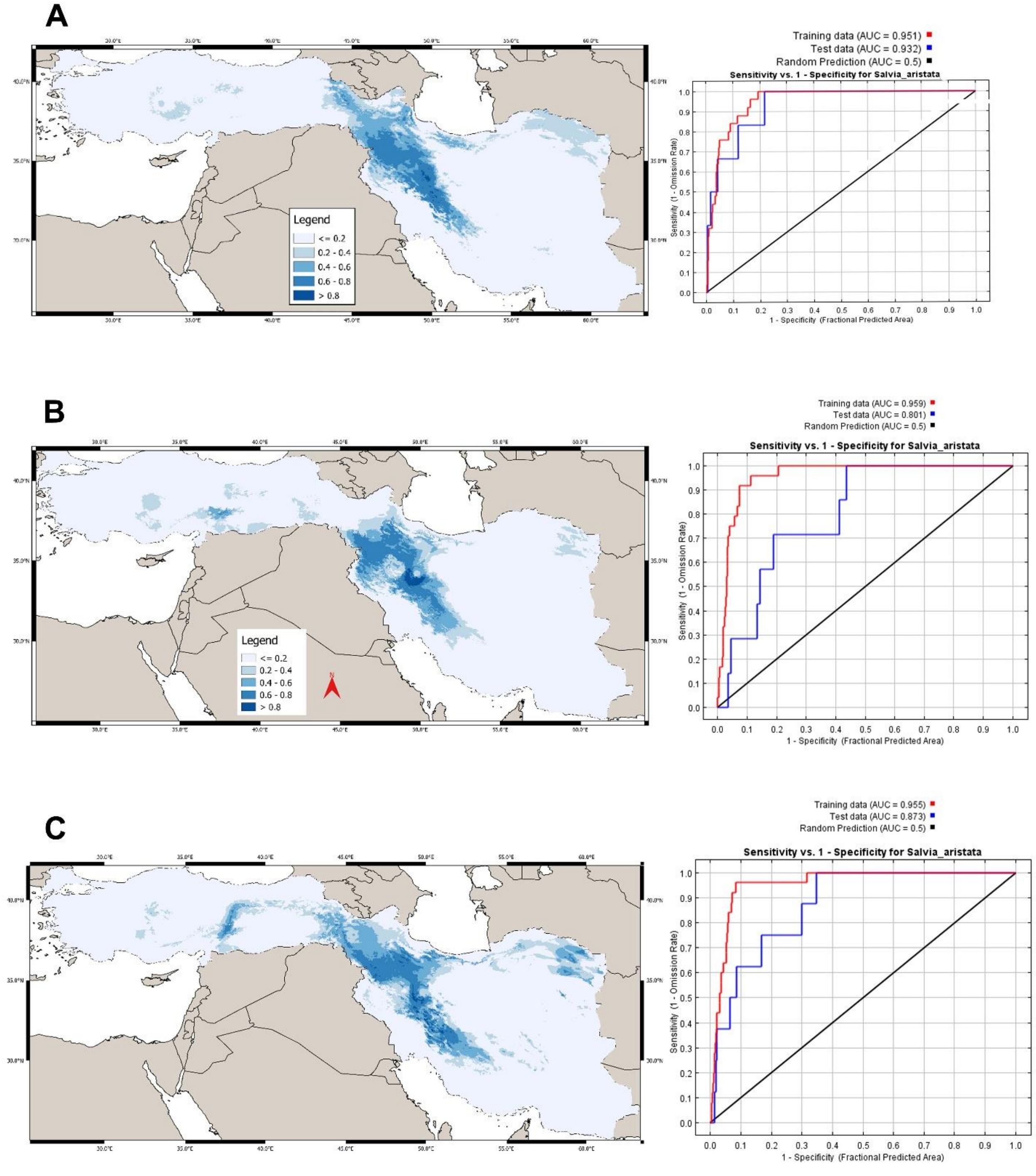


Fig. 2. Niche model projected by Maxent for all *S. aristata* populations. A, last glacial maximum projected niche model. B, Current niche model. C, Future niche model. Area under the curve (AUC) which shows the performance of constructed model are shown as well.

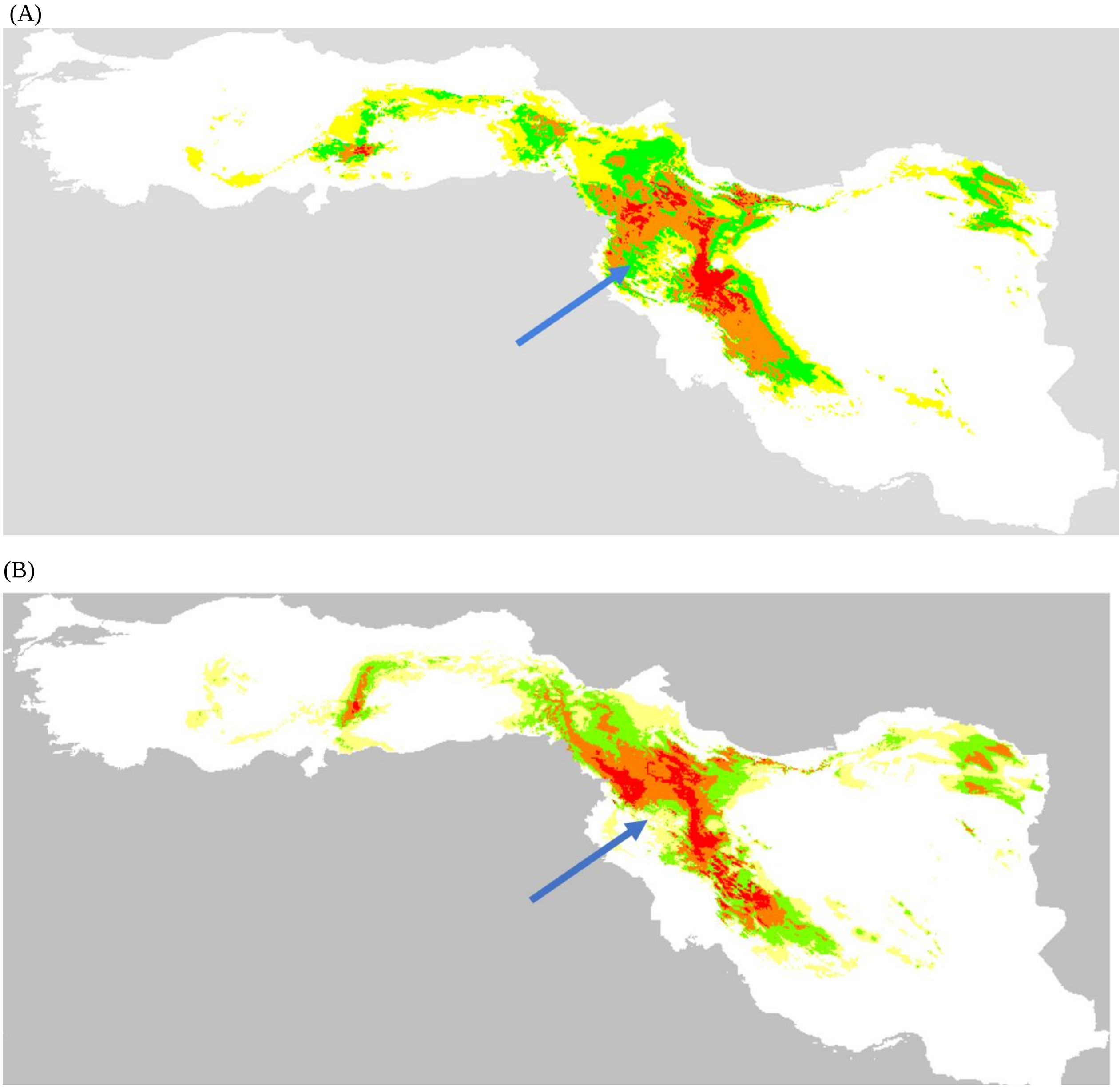
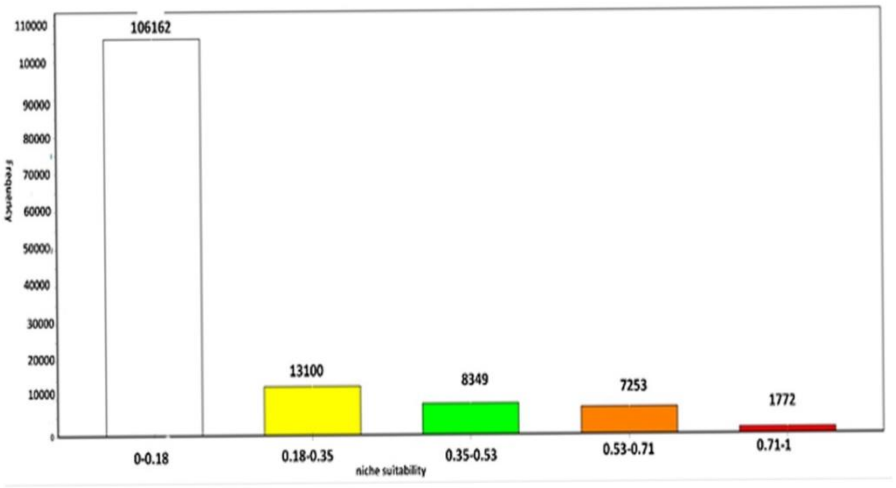


Fig. 3. Niche projections for *S. aristata* species using herbarium records and niche models. A, potential distributions in present. B, projected distributions of *S. aristata* in 2070. Based on the resulted maps, the areas showing with blue arrow will not be suitable area for S. *aristata* distribution in 2070.

A) Present model



B) Future model

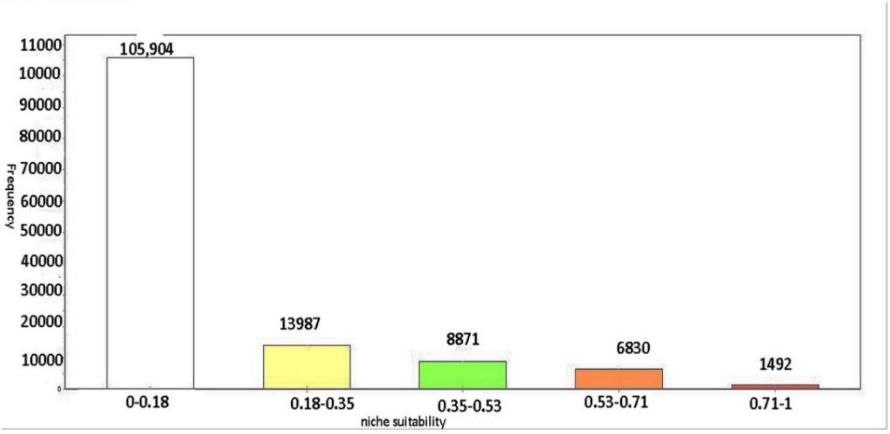


Fig. 4. The frequency of suitable area of *S. aristata* for present niche model and future niche model in 2070 are shown as histograms. Suitable area ranges from 0 (Not suitable) to 1 (highly suitable). Based on the histograms the frequency of moderate suitable area (0.53-0.71) and highly suitable (0.71-1) will be decreased for future model.

Table 2. Levels of contribution of each bioclim variable in present niche model generated by Maxent based on Jacknife test.

Variables	**Description of Variable**	**Percent of contribution**
Bio3	Isothermality	13.3
Bio4	Temperature seasonality	0.3
Bio7	Temperature annual range	14.5
Bio8	Mean temperature of wettest quarter	56.7
Bio12	Annual precipitation	3.4
Bio18	Precipitation of warmest quarter test	13.3

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