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Predicted Changes in Climatic Niche of *Alburnus* Species (Teleostei: Cyprinidae) in Iran Until 2050

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Abstract

Distribution ranges of many organisms are changing in response to global climate change and human activities. To test the impact of climatic change on distribution range of cyprinid fish species, Species Distribution Modeling (SDM) was used to predict the current climatically suitable habitats and to identify key variables shaping the potential distribution for the genus *Alburnus* in Iran, an excellent example of high diversity and endemism in the western Palearctic region. Then, future changes in potential suitable areas of the genus *Alburnus* were evaluated with one future global climatic model (GCM) based on 2050 climatic projection. Results show as a general pattern, basins along the Elburz and Zagros Mountains had highest climatic suitability for the genus in Iran. According to the results of jackknife test and percent contribution of each variable to construct the models, precipitation plays the important role on the distribution of *Alburnus* species in Iran than temperature. Model outputs show all species likely to be negatively affected by the climate change in future and the currently potential suitable areas were predicted to decrease in the coming decades, suggesting a comprehensive management plan for conservation of this cyprinid fish need to be conducted in the country.

Key words: Cyprinidae, Niche modeling, Freshwater fishes, Global warming

Introduction

The geographic distribution of a species is a function of biotic, abiotic and movement factors that of which climate is a major factor delimiting species' distribution (Fei et al., 2012; Engler, Rödder, Elle, Hochkirch, & Secondi, 2013). Climate change is known to affect range contractions and expansions of numerous plants, animals and other organisms (see Walls, 2009) including freshwater fishes throughout the world especially in the Middle East. Anthropogenic treats (e.g. changes in land use, habitat destruction, fish introductions, dam construction, pollution and drought) have played a significant role in changing distribution pattern of Iranian freshwater fishes especially in the past few decades (Esmaeili et al., 2015). With the frequency of droughts in many parts of Iran in recent years (Teimori, Mostafavi, & Esmaeili, 2016), its impact on freshwater fishes will likely increase in coming years and will have effects on their phenology, productivity and distribution.

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The genus *Alburnus* Rafinesque, 1820 belongs to the largest teleost family, Cyprinidae, comprising 45 valid described species distributed from Europe to northern parts of southwest Asia including Iran (Freyhof & Kottelat, 2007a,b; Özuluğ & Freyhof, 2007; Elp, Sen, & Özuluğ, 2015). The genus *Alburnus* is an excellent example of high diversity and endemism in the western Palearctic freshwater fishes particularly in Turkey with 24 species, of which 15 are endemic (Elp et al., 2015; Gülle, Küçük, & Güçlü, 2017). Eight species of bleaks of the genus *Alburnus* are recorded from Iran including *Alburnus doriae* De Filippi, 1865 from the Namak Lake basin; *A. chalcoides* (Güldenstädt, 1772) from the Caspian Sea basin (Freyhof, & Kottelat, 2008; Esmaeili, Coad, Gholamifard, Nazari, & Teimory, 2010; Esmaeili et al., 2014); *A. filippii* Kessler, 1877 from the Kura-Aras basin and Sefid-Rud River (see Freyhof, 2014 for more details); *A. hohenackeri* Kessler, 1877 from the Aras River to the Atrek River along the Caspian coast of Iran (Esmaeili et al., 2010, 2014); *A. atropatenae* Berg, 1925 from the Lake Urmia (=Lake Orumiyeh) basin; *A. caeruleus* Heckel, 1843 from Qweik, Euphrates and Tigris drainages from southern Anatolia to Iraq and Iran; *A. sellal* Heckel, 1843 from Tigris Euphrates system, and some other freshwater systems of the Persian Gulf basin; *A. zagrosensis* Coad, 2009 from the upper Karun River basin. As the *Alburnus* spp. are distributed in many drainage basins of Iran at different latitudes; therefore, study on effects of climate change on the species of this genus is interesting and our findings can be generalized to other cyprinid fish with same ecological requirements and same geographic distribution.

Whilst species distribution modeling (SDM) have received increasing attention in many biological fields in recent years especially to predict potential impacts of climatic change on the species distribution and range losses under future climate scenarios, to the best of our knowledge it has not been published for Iranian freshwater species from this perspective and this contribution represents a first attempt. Our study objectives included, (1) providing update distribution maps for all species that belong to the genus *Alburnus* within Iran territory, (2) identifying current climatically suitable habitats for each species and comparing the predicted habitat suitability maps with the distribution maps and finally (3) evaluating likely changes in climactically suitable habitats of each species based on 2050 climatic projections using SDM.

Materials and Methods

In this study, contemporary distribution pattern of Iranian species of the genus *Alburnus* from entire drainage basins of Iran was mapped. Materials for this study are resulted from (I) Available published data (Abbasi, 2009; Coad, 2009, 2016; Esmaeili et al., 2010; Esmaeili, Gholamifard, & Freyhof, 2011; Esmaeili et al., 2014; Zareian, Esmaeili, Gholamhosseini, & Sayyadzadeh, 2013; Mehraban, Sayyadzadeh, Malekzehi, & Ahmadi, 2014), (II) Extensive fieldworks that provided the geographic coordinate datasets for *Alburnus* distribution during 2006 - 2016 (deposited in the Zoological Museum-Collection of Biology Department, Shiraz University, ZM-CBSU).

Species Distribution Modeling (SDM) was used to predict the climatically suitable habitats for five *Alburnus* species of Iran, because *A. doriae* and *A. zagrosensis* is only known from the type locality and *A. caeruleus* only from three localities close to each other, SDMs were not generated for these species.

Once current climatic models were developed, we compared them with future potential distributions for each species. To construct the models, 19 current climatic variables including temperature and precipitation layers obtained from the WordClim data set (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005) with 30-second spatial resolution were combined to georeferenced occurrence locations for each species including 23 points for *A. atropatenae*, 74 points for *A. chalcoides*, 26 points for *A. filippii*, 71 points for *A. hohenackeri* and 161 points for

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A. sellal. Only natural distributions of each species were considered and introduced occurrence points were ignored except in well-established cases; although, translocated populations have been only reported for *A. hohenackeri* so far (Zareian et al., 2013). Models were constructed using the maximum entropy algorithm implemented in MaxEnt 3.3.3 software. MaxEnt is a presence-background method that combines occurrence data with environmental variables and provides a measure of habitat suitability in a given cell. It has generally been accepted as an appropriate tool for modeling species distributions when presence-only data are available (Elith et al., 2006).

At first, we run the models with all climatic variables to diagnose the more informative variables. Environmental information from 1000 randomly generated geographic points across the study area was extracted in order to establish a set of uncorrelated climatic layers to minimize the impact of multi-collinearity and over-fitting of the models. The more biologically informative variables (based on ecological requirements, a pairwise Pearson correlation matrix and variables with percent contribution up to 5% to construct the models recognized from initially run with all layers) were retained in this step including seven variables with $R^2 < 0.90$ as following; Bio 2: mean diurnal range, Bio 3: isothermality, Bio 4: temperature seasonality, Bio 9: mean temperature of driest quarter, Bio 15: precipitation seasonality, Bio 18: precipitation of warmest quarter and Bio 19: precipitation of coldest quarter. For correlated pairs, we removed the variable that captured less information.

We evaluated the changes in climatic niche of each species with one future global climatic model (GCM), the general circulation model CCSM4 along with the representative concentration pathway (RCP) 4.5 from the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 5 (AR5) and based on 2050 climatic projection with 30-second spatial resolution. The Community Climate System Model (CCSM) is one of the most respected and recent GCM climate projections that is used in the Fifth Assessment IPCC report and is a coupled climate model composed of four separate models simultaneously simulating different components (atmosphere, Ocean, land surface and sea/ice) and one central coupler component (Gent et al., 2011; Domșa, Sándor & Mihalca, 2016). CCSM4 used previously to assess the possible bio-geographical changes in the climatic niche of *Montivipera raddei* species complex limited to Iran, Turkey and Armenia over the Last Glacial Maximum (LGM) and over the future by Yousefi et al. (2015), then to study of effects of future climate changes on the distribution of the Houbara, *Chlamydotis macqueenii*, in Iran by Yousefi et al. (2017) and also to make inferences about the evolutionary history of the Persian Jird, *Meriones persicus* distributed from eastern Anatolia to Afghanistan and western Pakistan for the LGM by Dianat, Darvish, Cornette, Aliabadian, & Nicolas (2016). The CCSM4 model was chosen for the *Alburnus* as apparently most utilized and better simulated the past and future distribution patterns of some vertebrates in this geographical area. RCP 4.5 can be considered as a relatively moderate warming scenario (Turner, Fiore, Horrowitz, Naik, & Bauer, 2013). For consistency, we used the same seven bioclimatic variables that we used for modeling current potential distribution for each species to predict future distributions.

Predictive models were evaluated by splitting localities into 75% training and 25% testing data and 10 replicates run (cross-validation method) were performed for each species. All MaxEnt runs were adjusted with a convergence threshold of 1.0E-5 with 1000 iterations, application of a random seed, logistic probabilities and other settings were left at default levels. The models were tested using the AUC (area under the receiver operating curve) approach of Phillips, Anderson, and Schapire (2006) and mean value ≥ 0.7 as evidence that the model had sufficient discriminatory ability (Swets, 1988). AUC values across the 10 replicates were reported.

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Relative importance of the variables was recognized based on the Jackknife test and percent contribution of each variable was used to construct the models. Results of ASCII files were imported into the DIVA-GIS (available at http://www.diva-gis.org/) to visualize the models and reclassified into five equal classes of habitat suitability: 0.00-0.20, 0.20-0.40, 0.40-0.60, 0.60-0.80 and 0.80-1.0 in which red color (habitat suitability up to 0.80) shows areas with the highest suitability. Since the area with red color was very limited for almost species, decrease or increase in the climatic potential suitability areas until 2050 were estimated for the two last classes (suitability up to 0.60) by calculating the number of 'colored' grid cells (orange for habitat suitability between 0.60-0.80 and red for 0.80 -1.0).

Results

The distribution of *Alburnus* species in Iran can be summarized as follows (see Figure 1): *A. atropatenae* is found in the Urmia basin, northwestern Iran and it is known only from a few localities in the south, east and west of lake Urmia; *A. caeruleus* is known from a few localities in Tigris River basin, Gamasiab and Doab that are tributaries of Karkheh River; *A. chalcoides* is recorded from the entire southern coast of the Caspian Sea and its rivers, including Aras, Sefidrud, Lisar, Gazafrud, Shirud, Haraz, Gharasu, Tajan, Atrak, Anzali Lagoon and Gorgan Bay. *A. filippii* is also known only from Aras and Sefidrud in southern Caspian Sea and Anzali Lagoon. *A. hohenackeri* is widely distributed in the Caspian Sea basin and adjacent basins particularly, occurs along the Caspian coast from Aras River in west to Atrak River in east of this basin. *A. hohenackeri* is also reported from Urmia (Mahabad River, Ghodarchay and Shahrchay), and also is widely introduced to some other basins including Tigris (Karkhe River, Chaghakhor lagoon and Zarivar Lake), Zayandeh River of the Esfahan basin, Dasht-e Kavir basin, and Sistan basin. *A. sellal* is recorded from the Tigris River (Karun, Karkhe, Sirvan, Jarahi, Zohre, Gamasiab Rivers), Persis (Mond and Helleh River drainages), Lake Maharlu, Kor River (Kor and Pulvar (Sivand), and a few Qanats in this basin) and upper parts of the Hormuz basins. *A. zagrosensis* was described from a stream in Chahar Mahall va Bakhtiari west of Boldaji. This stream is dried up now, but according to our data, it is now restricted to the Gandoman Lagoon in the upper Karun River triburary.

The predicted climatically suitable areas based on current bioclimatic variables and known occurrences for five species of *Alburnus* are visualized in Figure 2. The AUC value for all species supported the discriminative power of the models (*A. atropatenae*: 0.96 ± 0.03, A. *filippii*: 0.96 ± 0.02, *A. sellal*: 0.87 ± 0.03, *A. hohenackeri*: 0.97 ± 0.02 and *A. chalcoides*: 0.99 ± 0.00).

Areas of potential distribution under the current climatic scenario (Figure 2) along with the MaxEnt model internal jackknife test of variable importance and percent contribution for each variables showed that habitat suitability for *A. hohenackeri* and *A. chalcoides* were highest in the Caspian Sea basin and Bio18 (precipitation of warmest quarter) had the highest value with 55.4 and 51 percent contribution respectively, for *A. atropatenae* was highest in the Urmia Lake basin and Bio 3 (isothermality) and Bio18 (precipitation of warmest quarter) had the highest values with 60 and 22.1 percent contribution respectively, for *A. filippii* and *A. sellal* were highest in the Caspian Sea basin and basins located in the west and southwest Iran respectively and Bio 15 (precipitation seasonality) had the highest value with 59.2 and 44.5 percent contribution respectively. Some potentially climatic areas were predicted for *A. filippii* along the coast at the eastern shores of the Caspian Sea, *A. atropatenae* in the north east Iran and *A. sellal* in the eastern half of Iran that not occupied by the species so far (Figure 2) and have not removed these non-distribution areas when we calculated the number of 'colored' grid

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cells for the decrease or increase in the potential suitability areas until 2050. Indeed, changes in areas are calculated for the potential suitable habitats. *A. sellal* is the most distributed species with high suitability habitats in west and southwestern Iran (Figure 2).

Within the future climatic scenario, the AUC value for all species supported the discriminative power of the models (*A. atropatenae*: 0.96 ± 0.03, A. *filippii*: 0.97 ± 0.01, *A. sellal*: 0.92 ± 0.01, *A. hohenackeri*: 0.98 ± 0.01 and *A. chalcoides*: 0.99 ± 0.00). To estimate the potential impact of climate change on the distribution range of each species, the predicted potential areas in the future climate scenario (Figure 3) compared with the current climatic potential areas (Figure 2). According to the results, all species belongs to *Alburnus* are likely to be negatively affected by the climate change and their climatically suitable areas (areas suitability up to 0.60) were predicted to decrease (Figure 4). Future climatic models predicted lower habitat suitability for *Alburnus* species in a moderate warming scenario and great declines in the potential area of suitable climatic conditions (suitability up to 0.60) for all species including 13.65% for *A. hohenackeri*, 37% for *A. atropatenae*, 48.64% for *A. chalcoides*, 55.90% for A. *filippii* and 63.14% for *A. sellal*, with the greatest reduction in the area for *A. sellal* and least reduction for *A. hohenackeri*. Most importantly, our results demonstrate that reduction in the suitability of potential niches will occur especially in the eastern part of Iran for some species (e.g. *A. sellal* and *A. atropatenae*) that is not occupied by the species (Figure 3). Effect of climate change on contemporary range of each species can be seen in the Figure 3 that mainly is in the form of decrease in habitat suitability rather than habitat loss.

Discussion

This study provides the first results on the climatic potential distribution for five, out of eight species of *Alburnus* in Iran. Applying the selected climatic variables resulted in well-defined potential distribution for each species. As a general pattern, basins along Elburz and Zagros mountains had the highest suitability areas for these species in Iran.

Representative concentration pathways (RCPs) named RCP 8.5, RCP 6.0, RCP 4.5 and RCP 2.6 with the numbers indicating the estimated global radiative forcing at the end of the twenty-first century due to human activities, present a range of plausible emissions trajectories that the planet would be experience from each pathway at the end of this century. RCPs depict a wide range of possible futures from relatively modest climatic changes to very sever climatic change (Pittock, Hussey, & Dovers, 2015). Our exported models for the future potential distribution of the genus *Alburnus* based on RCP 4.5 (represents a moderate emission mitigation trajectory) predicted decrease in the potential suitable habitats (climatically) for all species of *Alburnus* until 2050. Apparently this decrease in climatically potential habitats is severe for some species (e.g., *A. sellal* in comparison to *A. hohenackeri*) and some regions (eastern Iran in comparison to north and western parts). In other words, certain species and regions appear to be affected more than others from climate change in future.

According to the results of jackknife test and percent contribution of each variable to construct the models, precipitation plays more important role on the distribution of *Alburnus* species in Iran than temperature which contributed most to the models especially for species restricted to the Caspian Sea basin, the localities with more precipitation than the rest of Iran. Annual precipitation is lower in the eastern half of Iran compared with the western half (Nazemosadat, Samani, Barry, & Mollaii Niko, 2006). In consistent to this precipitation pattern, all species of the genus *Alburnus* are also restricted to north and western Iran. According to the Intergovernmental

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Panel on Climate Change (IPCC), global warming will result a number of impacts on the hydrological cycle, including change in precipitation that are expected to differ from region to region. It is predicted that precipitation will decrease in most subtropical areas including Iran. Decrease in average winter rainfall has been observed in northern districts of Iran (as a core area for *Alburnus*) throughout the last two decades. Climate change projections of precipitation for the Middle East and Northern Africa until 2050 also showed that the annual precipitation sum will decrease for the majority of countries especially predicted for central and eastern Iran (Terink, Immerzeel, & Droogers, 2013). Application of Maxent modelling for Iranian freshwater fishes is restricted to a few studies (e.g. Esmaeili et al., 2015; Teimori, Esmaeili, Sayyadzadeh, Zarei, & Gholamhosseini, 2015; Masoudi et al., 2016; Amiri, Shabanipour, & Eagderi, 2017) that none has modeled the effects of future climate changes on the suitable habitats. However, considering the results of Terink et al. (2013) (mentioned above), decrease in predicted areas through the years that have been reported for some non-fish organisms in Iran or adjacent countries (e.g. Ashraf Vaghefi, Mousavi, Abbaspour, Srinivasan, & Yang 2013; Yousefi et al., 2015; Tok, Koyun, & Çiçek, 2016), it seems decrease in potential predicted areas due to future climate changes maybe the most common pattern for freshwater fishes in the Middle East.

According to our results, *A. sellal* and *A. atropatenae* will loss potential climatic areas in the eastern half of Iran in coming decades. The MaxEnt model identified climatically potential suitable areas outside the known distribution range of these species eastern half of Iran but the species has not been recorded from those areas so far (Figure 2). Why those areas are currently not occupied can be explained by dispersal limitations and disconnection of basins. Lake Orumiyeh (Urmia) was formed during the late Pliocene-Pleistocene and may well have had a Pleistocene connection to the Caspian Sea basin; although, this is in dispute (Scharlau, 1968). The fundamental niche consists of the total potential area that meets all the physical and biological requirements of a species; whereas, the realized niche describes the actual distribution of a species that is influenced by factors such as dispersal, history and physical barriers (Mak, Morshed, & Henry, 2010). Therefore, it seems that a species can't occupies the large areas with potentially distribution climatic conditions in its life history. In contrast, model output showed suitability habitats for A. *hohenackeri* only in the Caspian Sea basin but introduced to other basins in Iran (Figure 1), likely the species have been imported from the Caspian Sea basin to other localities with commercial fish species (Zareian et al., 2013). Model outputs obtained from natural distribution of the species indicated that introduced localities have low habitat suitability for the species.

SDM is an important tool for understanding the climatic factors may be responsible for species range limitation and alteration. However, majority of studies were carried out in terrestrial environments and only a few investigated aquatic systems (Barbosa, Schneck, & Melo, 2012). Probably limitation of SDM for freshwater taxa is related to lack of sufficiently ecological data layers (e.g. water quality variables) for aquatic habitats, which is also the case for Iranian aquatic habitats and for our study that only take climatic variables into account. Although SDMs can be useful in conservation planning and frequently used to examine effects of climate change on distribution ranges of organisms, projections of models through time with different climate scenarios may lead to different results. There is no agreement on which models are the most appropriate for predicting future species distribution. Care should be taken when interpreting of our results, because a potential caveat might be that our results based on only the general circulation model CCSM4 that previously used by some authors in this geographic area. Despite these limitations, the study based on available climatic variables provided information on the decreasing of habitat suitability for *Alburnus* species in Iran in the coming decades and likely for other cyprinid species with same ecological requirements in the moderate future emissions scenario (RCP 4.5), suggesting that a comprehensive management plan for aquatic systems is need. We suggested modelling the potential distribution of other Iranian freshwater fishes especially key or/and endangered species and effects of climatic changes on their distribution especially with more general circulation models to access better conservation management strategies by identifying critical habitats with high diversity or with endangered/endemic species. These habitats can be targeted by conservation biologists to define conservation priorities. However, the overall consequences of global warming are still difficult to predict because genetic adaptation, behavior, habitat dependency and the impacts of fishing on species, is a complex response that may be only partially explained by simple climate envelope predictions.

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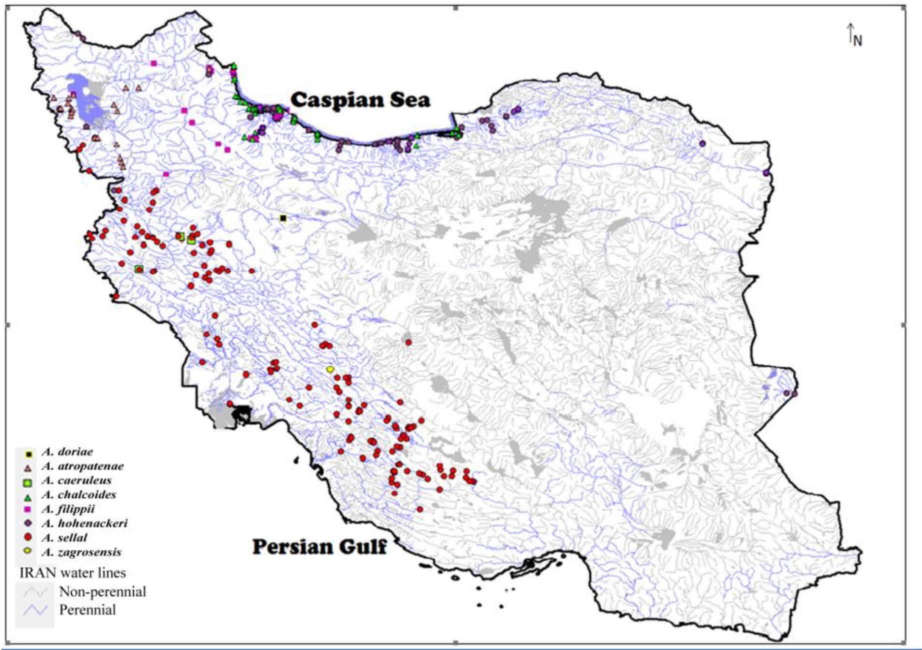

Figure 1. Distribution map of eight species of *Alburnus* in Iranian basins.

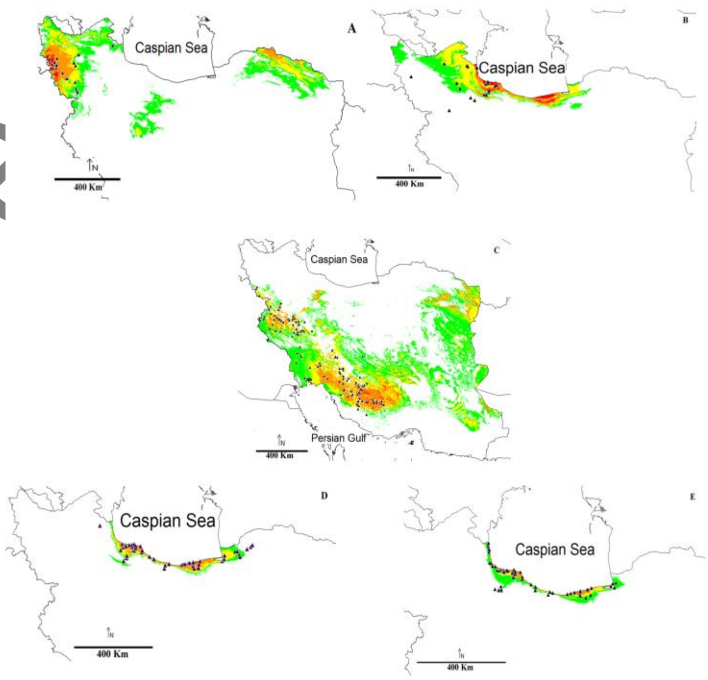

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Figure 2. Current climatically suitable areas for *Alburnus* species in Iran. Sampling point localities for A) *Alburnus atropatenae*, B) *Alburnus filippii*, C) *Alburnus sellal*, D) *Alburnus hohenackeri* and E) *Alburnus chalcoides* are indicated with dark triangular. All potential distributions were estimated using SDM in MaxEnt. Warmer colors indicate more suitable areas for each species. White color represents habitat suitability between 0.00-0.20, green between 0.20-0.40, yellow between 0.40-0.60, orange between 0.60-0.80 and red between 0.80-1.0.

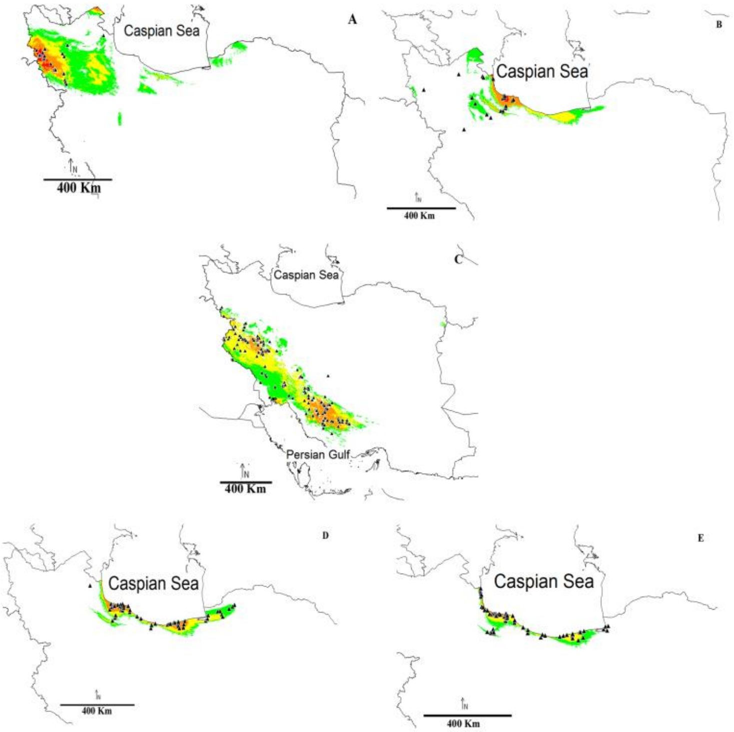

Figure 3. Climatically suitable areas for *Alburnus* species in Iran based on 2050 climatic projection. Sampling point localities for A) *Alburnus atropatenae*, B) *Alburnus filliipi*, C) *Alburnus sellal*, D) *Alburnus hohenackeri* and E) *Alburnus chalcoides* are indicated with dark triangular. All potential distributions were estimated using SDM in MaxEnt. Warmer colors indicate more suitable habitats for each species. White color represents habitat suitability between 0.00-0.20, green between 0.20-0.40, yellow between 0.40-0.60, orange between 0.60-0.80 and red between 0.80-1.0.

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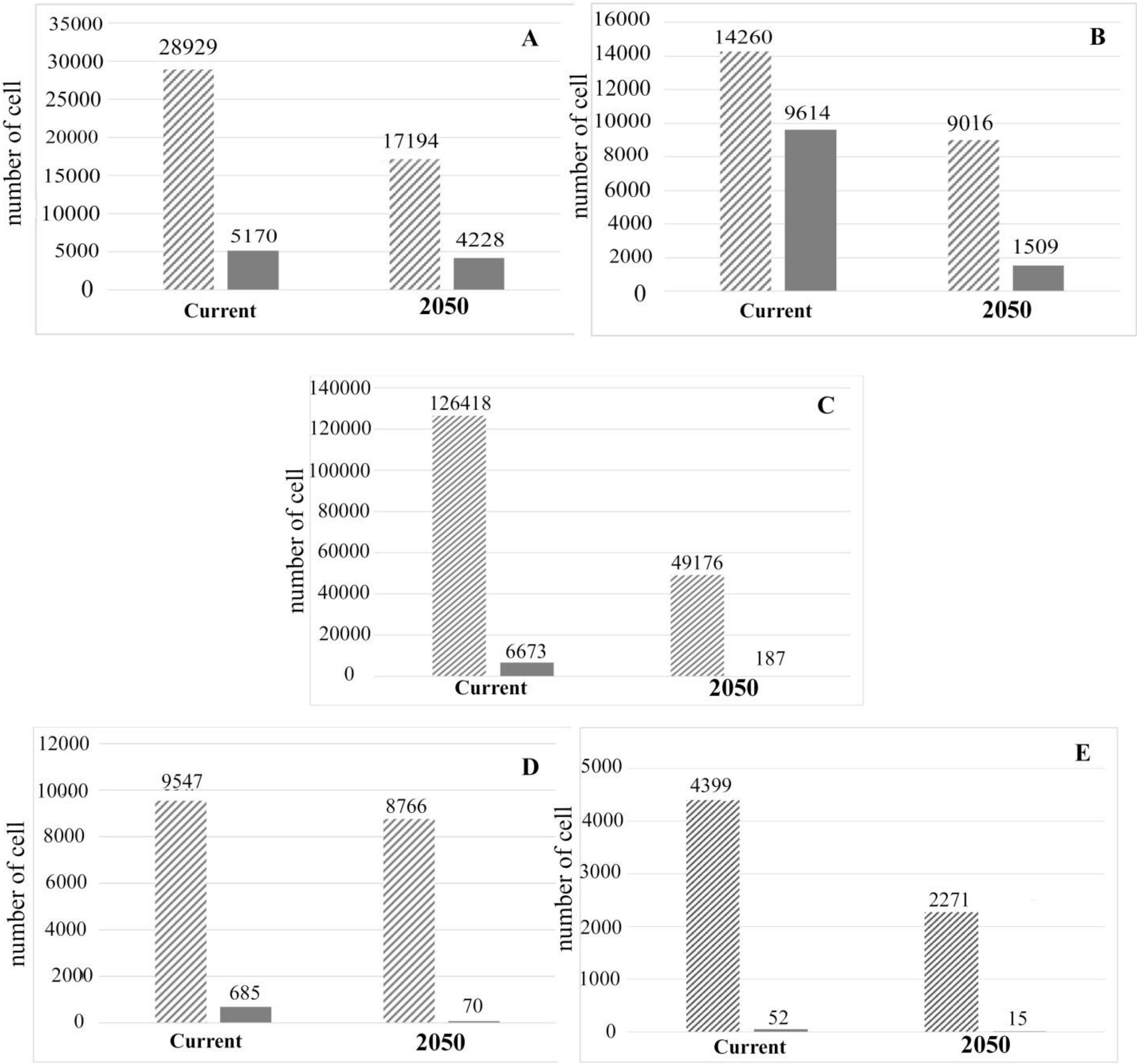

Figure 4. The estimated decrease of the predicted potential areas of five *Alburnus* species in Iran until 2050 including A) *Alburnus atropatenae*, B) *Alburnus filliipi*, C) *Alburnus sellal*, D) *Alburnus hohenackeri* and E) *Alburnus chalcoides* based on RCP 4.5. The hatched histograms show area with habitat suitability between 0.60-0.80 and the solid one habitat suitability between 0.80-1.0.