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Modeling the species distribution of Caucasian pit viper (*Gloydius halys caucasicus*) (Viperidae: Crotalinae) under the influence of climate change

Aijamal Ghelichy Salakh[1], Haji Gholi Kami[1*], Mehdi Rajabizadeh[2]

1. Department of Biology, Faculty of Sciences, Golestan University, Gorgan, Iran
2. Department of Biodiversity, Institute of Science and High Technology and Environmental Sciences, Graduate University of Advanced Technology, Kerman, Iran

**Corresponding author's email: hgkami2000@yahoo.com*

ABSTRACT

During recent years, the effects of climate change on various biological and ecological aspects of the species have been discussed in several litterateurs. The aim of this study was to reveal the effect of climate change on the extent and suitability of the *Gloydius halys caucasicus* habitats at present time and future. So that, 50 presence points and 19 bioclimatic variables were used. To compare the effects of global warming and climate change over the extent andsuitability of habitats, future bioclimatic variables were used in two mild climate change (PCR2.6) and severe (PCR8.5) scenarios in species distribution modeling. The results show that due to warming process of the planet and its growing trend in the future, the extent of suitable habitats of Caucasian pit viper is declining. Due to the fact that most of the suitable habitats of Caucasian pit viper are outside the protected areas, comprehensive studies are needed to plan and introduce new protected areasin future.

Keyword: Modeling, *Gloydius halys caucasicus*, Maxent, Climate change.

INTRODUCTION

Increasing the temperature of the world is considered as a major concern for conservation biologists (Brooks *et al*. 2006) because for example, increased temperature has affected the distribution of species (Parmesan &Yohe 2003). One of the most important threats to the management and protection of the biodiversity is climate change which has an impact on living communities, causing many animal species to migrate (Root *et al*. 2003; Yousefi *et al.* 2015). So one of the challenges for conservation biologists is to understand how the climate change affects different plant and animal species (Root & Schneider 2006).

Today, modeling the distribution of speciesis used to identify the habitats, predicting the presence of unknown and rare populations, as well as predicting the effects of climate change on different taxonomic groups (Kumar & Stohlgren 2009; Williams *et al*. 2009; Kafash *et al.* Sarhangzadeh *et al*. 2013, 2014; Yazarloo *et al.* 2017, 2019; Hosseinian Yousefkhani 2019). Therefore, the area evaluated by the model are regions with potential for the presence of the species (Anderson *et al*. 2003; Lorena *et al.* 2008) and the potential effect of climate change on the distribution of the species could be evaluated according to different global warming scenarios (Kafash *et al*. 2014). Maximum entropy (Maxent) is one of the popular methods for modeling the species distribution that uses only presence data. Because of the high predictive powerof Maxent, despite the low number of points of presence, also because of time saving and cost reduction, the researchers widely use it (Hoffman *et al*. 2008; Baasch *et al*. 2010; Witing *et al*. 2010; Warren *et al.* 2011; Adjaye 2011; Bassi *et al*. 2015).

Caucasian pit viper (*Gloydius halys caucasicus*) is distributed in south-eastern Azerbaijan (Talysh Mountains), southern Turkmenistan (Kopet Dagh Mountains), northern Iran and north-western Afghanistan (Nikolsky 1916; Chernov 1934; Terentjev & Chernov 1949; Ataev 1985; Ananjeva *et al.* 1998). It inhabits a variety of habitats, but often is found in forests and in mountain steppe (Russel & Campbell 2015). The population of these species

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is declining for several reasons, including habitat destruction and uncontrolled hunting for the production of antivenom serum (Kian *et al.* 2011).

Considering that so far no comprehensive research has been performed about the effect of global warming over the distribution of Caucasian pit viper, this study try to assess the current and future distribution of Caucasian pit viper and to study the effects of global warming on the conservation status of *Gloydius halys caucasicus*.

MATERIALS AND METHODS

In this study, Maxent software (Version 3.3.3k) (Phillips, Anderson & Schapire 2006) was used to provide habitatsuitability model and also predict the effects of climate change on future distribution of Caucasian pit viper.

Data preparation

All Caucasian pit viper presence points were collected from thefield researches, published papers and books (Wagner *et al*. 2016; Rajabizadeh 2018) and databases (www.gbif.org) and documented in Zoology Museum of the Department of Biology, Golestan University (ZMGU). Totally, fifty obtained presence points in Iran, Turkmenistan, Afghanistan and the Republic of Azerbaijan were georeferenced and mapped in GIS (Fig. 1). In this study, 19 climate variables (resolution 30 arc-seconds, ~1 km) were obtained from World Clim database (Hijman *et al.* 2005) (Table 1). Climate variables were converted to ASCII format using the GIS software.

Fig. 1. The distribution points of *Gloydius halys caucasicus* used in this study.

Table 1. Variables used in modelling *Gloydius halys caucasicus* habitat suitability

Unit	Description	Variable
°C	Annual Mean Temperature	BIO1
adimensional	Isothermality	BIO3
°C	Mean Temperature of Wettest Quarter	BIO8
adimensional	Precipitation Seasonality (CV)	BIO15
mm	Precipitation of Warmest Quarter	BIO18

The bioclimatic data used to reconstruction the effect of climate change on the extent and suitability of habitats

The suitability of the Caucasian pit viper habitat was evaluated under the effect of climate change from present to future (2070). In order to evaluate the current climatechange of theworld, the interpolation of the geographic location of all the earth’s meteorological stations between 1950 and 2000 was used. Also, a prediction of the earth’s climate in 2070 (average 2060-2080), (resolution 30 arc-seconds, ~1 km) was used to model the extent of variation and suitability of the Caucasian pit viper habitats in two mild [Representative Concentration Pathways (RCP) 2.6] and severe (RCP8.5) scenarios under the Community Climate System Model (CCSM)4 (Moss *et al.* 2010).

Data analysis

Maxent software compares the maximum presence data with the data of the environment variables using the entropy approach (Philips *et al.* 2006).Pearson correlation coefficient analysis was used to find variables that are highly correlated using SPSS software (version 15). Then, each of the predicted variables was evaluated using the Jackknife assay and the degree of importance of the variable was determined.

To evaluate the performance of Maxent model, the Receiver Operating Characteristic (ROC) and Area Under the Curve (AUC) curves were used. ROC is one of the most commonly used methods for estimating predictive models widely used in modelling distribution of species (Elith *et al.* 2011). The area under curve (AUC) is a quantitative indicator for demonstrating the efficiency and predictive accuracy of the model (Philips *et al*. 2004).

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The AUC index that indicates to the area under ROC curve is between 0 and 1. AUC = 0.5 indicates that the performance of the model is equivalent to random whereas AUCs closer to 1.0 indicate more accurate performances (Philips *et al.* 2006).

Response curve: the average response of the species to environmental variables is shown. Using the Maxent model, there is an answer for each of the environmental variables in the curve. In the graph, the x axis is the value of each variable, while the y axis represents the probability of presence or suitability.

Overlapping with protected area network

The effectiveness of the conservation zones in each area is determined by considering the number of species available (Araújo *et al.* 2007; Bergl *et al.* 2007; Parra-Quijano *et al.* 2012) or by comparing them with distribution models of species (Drummond *et al*. 2005; Maiorano *et al.* 2006). In order to determine the efficiency of the network of protected areas, a map of the suitability of the Caucasian pit viper habitat was intersected with the map of the protected area network. In this study, only the protected areas of Iran were shown due to the unavailability of protected areas of Azerbaijan, Turkmenistan and Afghanistan.

RESULTS

Habitatsuitability and distribution of Caucasian pit viper

In this study, the value of the AUC is 0.99, which indicates the high ability of the model to predict the Caucasian pit viper distribution (Fig. 2).

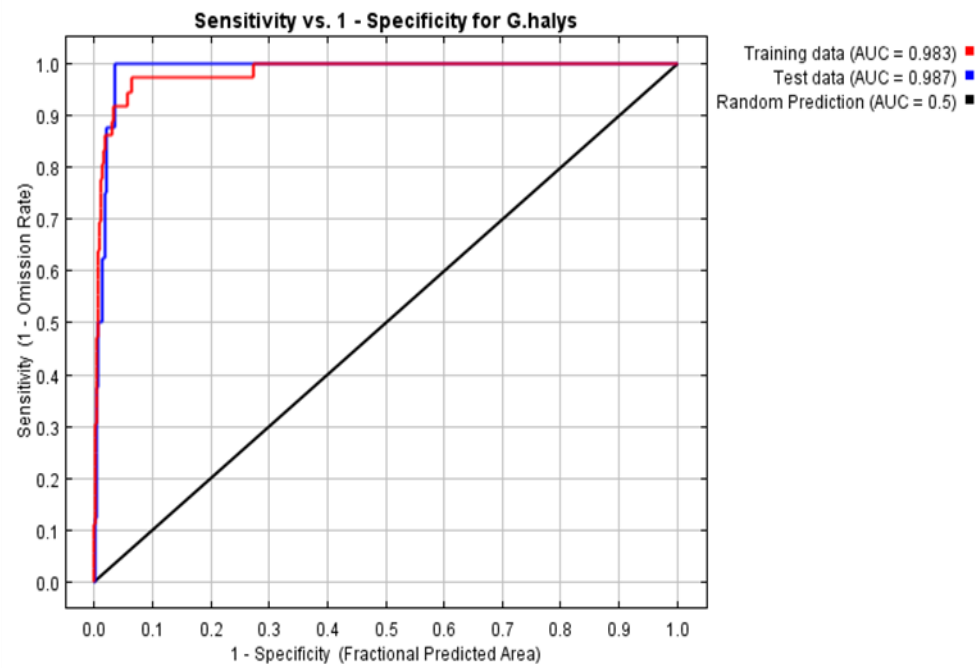

Fig. 2. ROC curve. The red (training) line shows the “fit” of the model to the training data. The blue (testing) line indicates the fit of the model to the testing data.

Using Pearson c orrelation coefficients analysis, climatic variables that are less correlated than 0.75 were identified as Bio1 (bioclimatic variables 1), Bio3, Bio8, Bio15, Bio18 (Figs. 3 and 4). Variables isothermality with 38.3% and the variable annual mean temperature with 31.7% exhibited the most influences on the selection of suitable habitat (Table 2), which therefore appears to have the most meaningful information by itself.
Furthermore, the environmental variable thathighly decreases the gainof the model when it is omitted is Bio3, henceseems to have the most information which is not present in the other variables.

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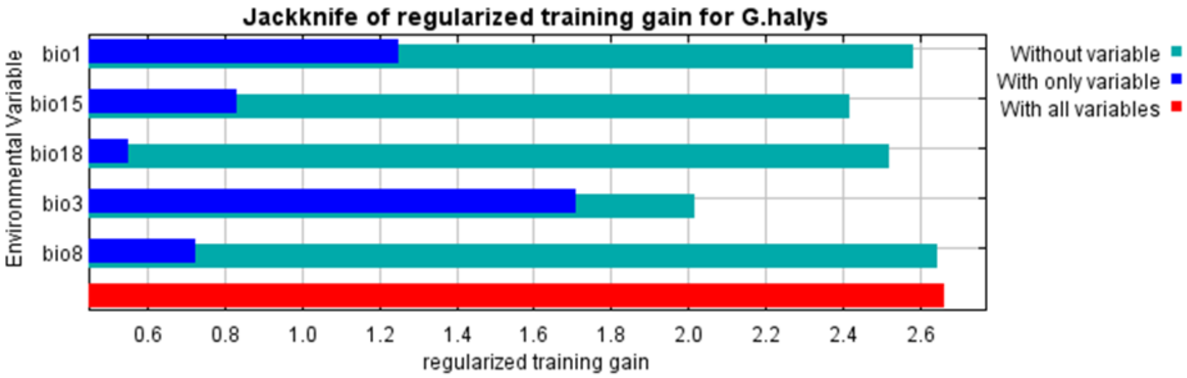

Fig. 3. The importance of variables for the *Gloydius halys caucasicus* on Jackknife.

Since isothermality (Bio3) is the most contributed variable, the habitat suitability will be optimum when isothermality is ranging between 30 and 40. The response of the species distribution to the bioclimatic variable of annual mean temperature (Bio1) indicated that there is an optimum condition in a short range of temperatures (between 12 and 18°C). According to this graph, *G. h. caucasicus* prefers the habitats with an average annual temperature of 12-18°C, and in high mountains area with an average annual temperature of lower than 10°C, as well as in areas above 20°C, the suitability of its habitat decreases. The response curve to bioclimatic variable of mean temperature of wettest quarter (Bio8) reveals that there is an optimum condition in about 10°C. Finally, response curve of precipitation seasonality (Bio15) exhibits that the most appropriate seasonal precipitation range is about 5 mm.Also, the precipitation of warmest quarter (Bio18) in 1 mm is the optimum habitat condition for the species.

Table 2. Analysis of variables contributions used in habitat suitability *Gloydius halys caucasicus.*

Variable	Percent contribution
Bio3	38.3
Bio1	31.7
Bio15	12.7
Bio18	12.1
Bio8	5.3

The suitability map of the *G. h. caucasicus* habitat for the present and future, developed employing theclimatic variablesare presented in Figs. 5 and 7. The above maps were classified according to the threshold into four classes of unsuitable (white), low(green), medium (yellow) and highly suitable (red) (Fig. 5).

The effects of climate change on the extend and suitability of habitats

The results of suitability evaluation based on the climate changemild scenario (PCR 2.6) (Fig. 7), and the scenario of severe climate change (PCR 8.5) (Fig. 8) in 2070 exhibited that the distribution of the Caucasian pit viper will decline. Fig. 9 illustrated that the current protected area of Iran does not cover the future distribution of Caucasian pit viper properly.

DISCUSSION

In this study, an optimal model for the *G. h. caucasicus* habitat suitability in Asia was prepared using Maxent. Most of the identified and recorded points of *G. h. caucasicus* were in the Southern Caspian Sea coastal areas. Bombi *et al.* (2009) in modeling the species of *Archaeolacerta bedriagae* concluded that bioclimatic variables such as maximum temperature of warmest month (Bio5), isothermality (Bio3) and precipitation seasonality (Bio15) are the most important variables in predicting habitat suitability. Additionally, Fadakar *et al.* (2016) in the modelling of the *Phrynocephalus mystaceus*, observed that the most important variables for predicting the its distribution with the Maxent model are variables including minimum temperature of coldest month (Bio6), mean

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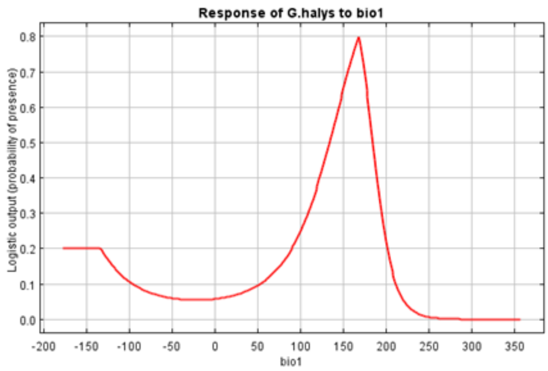
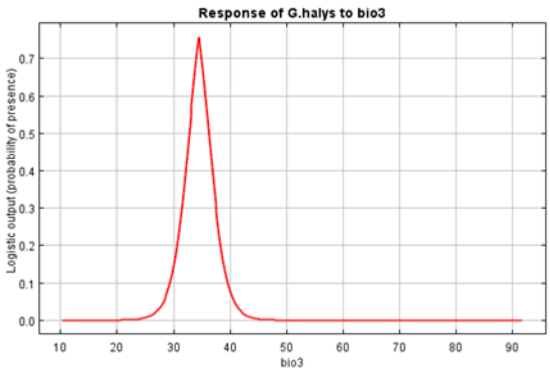
temperature of coldest quarter (Bio11) and precipitation of driest quarter (Bio17). Zanganeh *et al.* (2017) also observed that the optimal *Neurergus kaiseri* habitat is modeled mainly by annual precipitation (Bio12), Bio15 and annual mean temperature (Bio1).

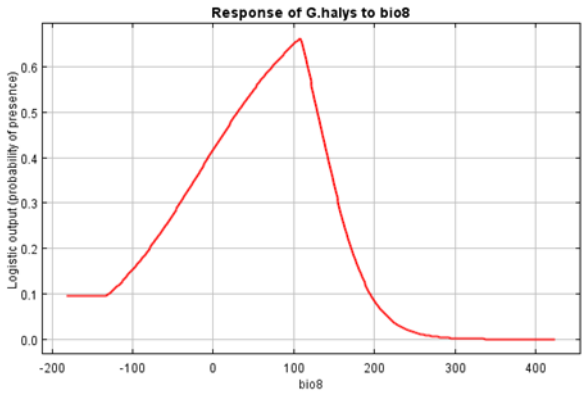
Bio1



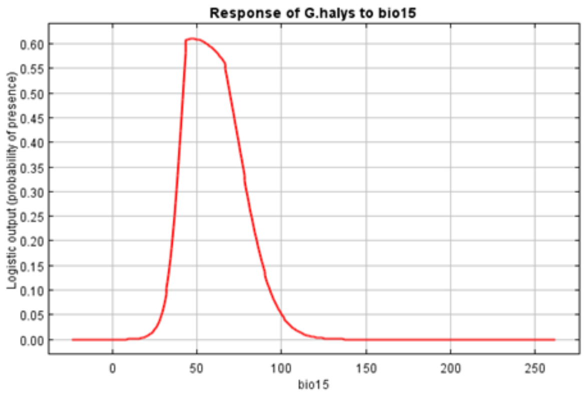
Bio3

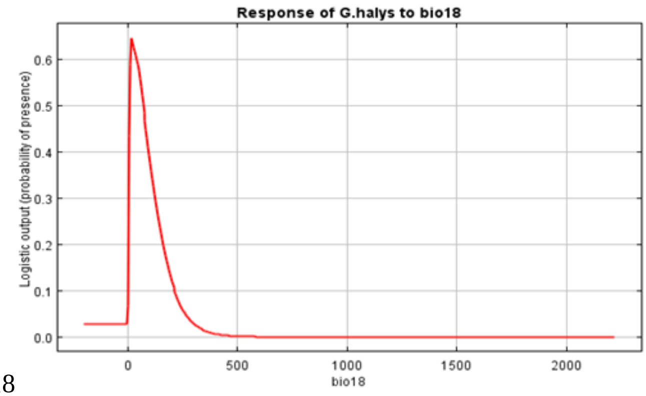


Bio8



Bio15





Bio18

Fig. 4. Curve response to variables Bio1, Bio3, Bio8, Bio15 and Bio18.

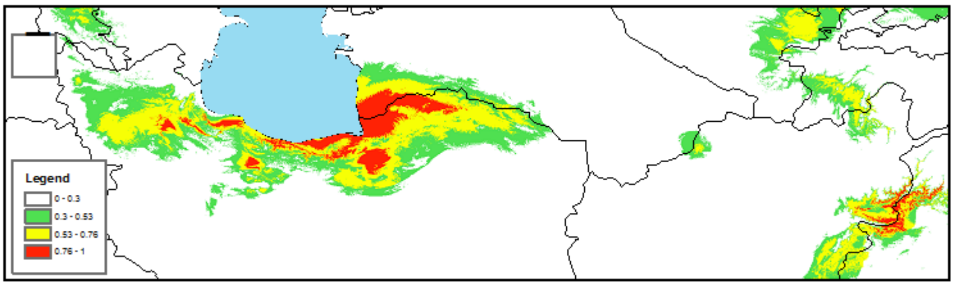


Fig. 5. Predictedcurrent suitable habitat for *Gloydius halys caucasicus.*

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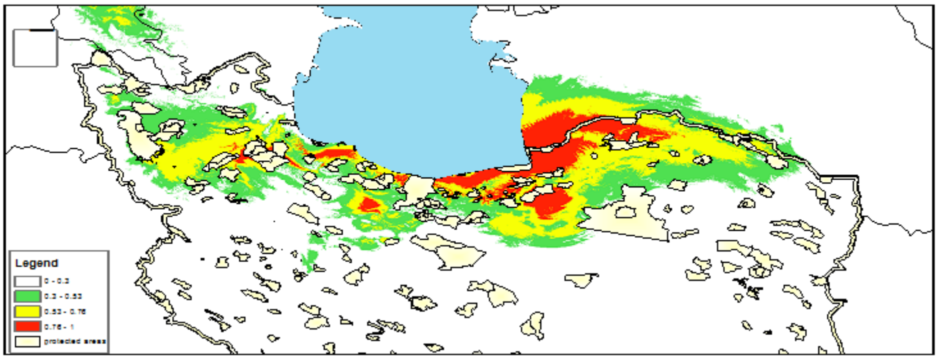

Fig. 6. Interconnection of Iranian protected areas withcurrentsuitability habitats of Caucasian pit viper.

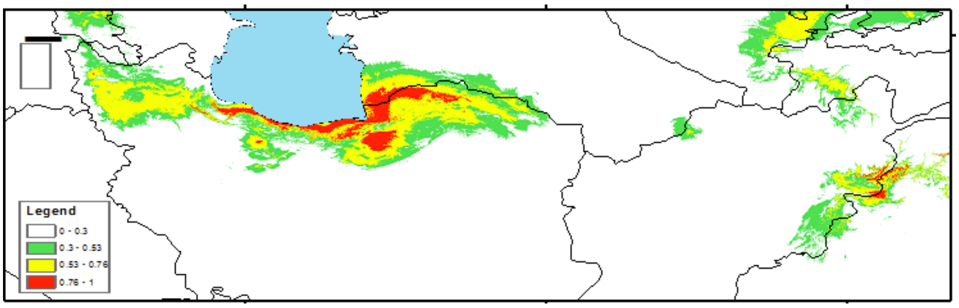

Fig. 7. The Caucasian pit viper suitability habitats map in mild (PCR 2.6) climate change scenario under the CCSM model.

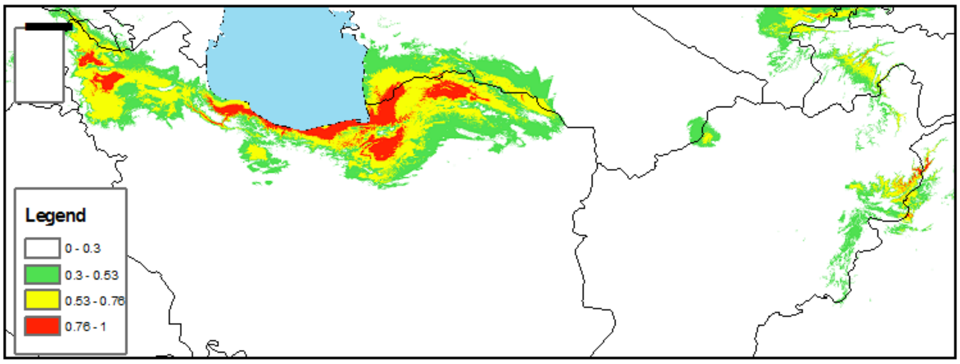

Fig. 8. The Caucasian pit viper suitability habitats map in severe (PCR 8.5) climate change scenario under the CCSM model.

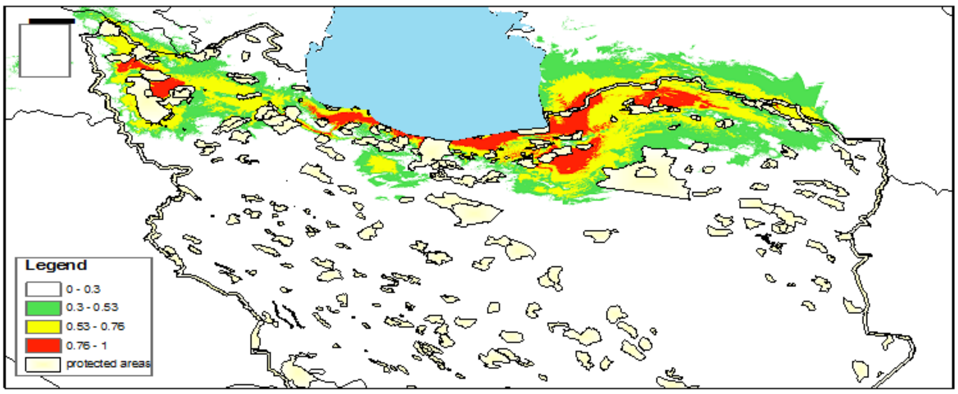

Fig. 9. Interconnection of Iranian protected areas with current suitability habitats of Caucasian pit viper under severe climate change scenarios.

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This is consistent with the results of the present study, exhibiting that variables such as Bio3, Bio1 and Bio11 are the most important variables for determining the distribution of the *G. h. caucasicus* habitat.According to the results of the present study, the suitable habitat of Caucasian pit viper was more expanded in coastal area than mountainous, which is consistent with those of Russel & Campbell 2015. The prediction of the *G. h. caucasicus* distribution and the status of their occupied habitats are important in defining conservation issues.It seems that the results of this modelling would make conservation more effective for wildlife managers. Regarding Figs. 7 and 8 and assessing the effect of future climate change on the suitability of the Caucasian pit viper habitats, it can be predicted that climate change under the relevant scenarios has led to the loss of much of the suitability of its habitat in coastal areas. Shrink of the habitat of reptiles of Iran because of global warming has also been reported in other studies (Yousefi *et al.* 2015; Yousefi *et al.* 2019). Furthermore, the continuation of this trend in the future will cause disconnection between large suitable habitat spots of the species, while other threats, including destruction of habitats, will be added to the destructive effects of climate change (Nagelkerke & Alkemade 2003). Based on the mapping of the network of protected areas with suitable habitats for the Caucasian pit viper (Fig. 6), it was revealed that a large part of the habitats of this species in 2070 will be outside the protected areas. Therefore, in order to plan and introduce new protected areas, to protect the species populations against global warming effects, it is important to protect higher mountain suitable habitat of the species predicted in models of 2070 in this study. These results can be considered as a serious warning to global climate change and its impact on biodiversity, especially endangered species.

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مدل‌سازی پراکنش گونه افعی قفقازی (*Gloydius halys caucasicus*) (Viperidae: Crotalinae) تحت تاثیر تغییرات اقلیمی

آیجمال قلیچی سلخ[1]، حاجی قلی کمی[1*]، مهدی رجبی زاده[2]

۱- گروه زیست‌شناسی، دانشکده علوم، دانشگاه گلستان، گرگان، ایران
۲- گروه تنوع زیستی، پژوهشگاه علوم و تکنولوژی پیشرفته و علوم محیطی، دانشگاه تحصیلات تکمیلی صنعتی و فناوری پیشرفته، کرمان، ایران

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چکیده

در طی سال‌های اخیر، تأثیر تغییرات اقلیمی بر جنبه‌های مختلف بیولوژیکی و اکولوژیکی گونه‌ها در چندین بستر مورد بحث قرار گرفته است. هدف از این مطالعه، تأثیر تغییرات اقلیمی بر وسعت و مطلوبیت زیستگاه‌های *Gloydius halys caucasicus* در زمان حال و آینده است. بدین ترتیب، از ۵۰ نقطه حضور و ۱۹ متغیر اقلیمی استفاده شد. برای مقایسه اثرات گرم شدن کره زمین و تغییرات اقلیمی بر وسعت و مطلوبیت زیستگاه‌ها، از متغیرهای اقلیمی آینده از دو سناریوی تغییر اقلیمی خفیف (PCR2.6) و شدید (PCR8.5) در مدل‌سازی پراکنش گونه استفاده شد. نتایج نشان می‌دهد که با توجه به روند گرم شدن کره زمین و روند رو به رشد آن در آینده، میزان مطلوبیت زیستگاه افعی قفقازی رو به کاهش است. با توجه به اینکه اکثر زیستگاه‌های مطلوب افعی قفقازی در خارج از مناطق حفاظت شده قرار دارند، نیاز به مطالعات جامعی به منظور برنامه‌ریزی و معرفی مناطق حفاظت شده جدید برای این مناطق است.

*مولف مسئول

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