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Response to Global Warming of Eichwald's Toad, *Bufo eichwaldi* Litvinchuk, Borkin, Skorinov and Rosanov, 2008 (Anura; Amphibia) in Iran and Azerbaijan

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Original article

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Global warming is considered to be a major threat to biodiversity and to have an erosive effect on the survival of endangered species. Amphibians are known as a vulnerable group of vertebrates that live and reproduce in both terrestrial and aquatic habitats. The subtropical regions of the world are among the land areas where amphibians will suffer the most from climate change. In the present study, the effect of climate change on *Bufo eichwaldi* inhabiting Hyrcanian forests was investigated. According to our results, the lowest temperature in the coldest season is the most important variable for the presence of this species. Due to the beginning of reproductive activity and mating taking place in late January until the end of February, this variable will have a direct effect on the rate of breeding and thus on the conservation of this species, because the species can find a new suitable area outside of high humanisation and increase its chance of successful breeding. Of course, climate change will cause the average annual temperature to rise by 2070, and this will favour the early onset of reproduction. Therefore, according to the analysis and scenarios considered in this study, global warming cannot have a negative effect on the toad species. However, a careful assessment of the status of other competing species in conjunction with the Talysh toad could provide a better explanation of the impact of climate change.

Key words: amphibian, species distribution modelling Caspian Sea, ecological niche, maximum entropy.

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Climate and landscape characteristics play an important role in the distribution of species, as well as in inter-population relations (VELO-ANTON *et al.* 2013; EARLY & SAX 2014; KUSZA *et al.* 2019; ARCHIS *et al.* 2018; ASHRAFZADEH *et al.* 2019). In particular, climate change can cause changes in the distribution of organisms in terms of the altitude, latitude and longitude, which affects their geographic distribution (PEARSON & DAWSON 2003; RAXWORTHY *et al.* 2008; SUTTON *et al.* 2015; DUAN *et al*. 2016). Geographic distribution changes do not occur without an impact on the ecosystem functions and on biodiversity (RAXWORTHY *et al*. 2008). Furthermore, if the populations of a given species cannot adapt to the new environment conditions resulting from climate change, it may lead to the extinction of the species in the wild, which poses a serious threat to biodiversity.

The problem of biodiversity loss is currently a serious concern worldwide (STUART *et al*. 2004; BEEBEE & GRIFFITHS 2005; MANDAL 2011; MFUNDA &

ROSKAFT 2011; QAZI & ASHOK 2012). Although the exact number of endangered species is unknown, it is estimated that the extinction of the species is occurring faster than in the last 100,000 years (HOULAHAN *et al*. 2000). The decline and extinction of amphibian populations has been observed in many parts of the world in the last decade (ALFORD & RICHARDS 1999; HOULAHAN *et al*. 2000; ARAÚJO *et al*. 2006).

Because amphibians are an indicator of environmental stress, their declining numbers are a matter of concern (BLAUSTEIN & WAKE 1995). These animals feel the stress factors which occur in both aquatic and terrestrial environments, because they live in water during the larval stage and in terrestrial habitats during the adult stage. Amphibians have moist, highly permeable skin and spawn without a special coat, so they are directly exposed to soil, water and sunlight and can easily absorb toxins (ADLASSNIG *et al*. 2022). Amphibians live in both water and land feeding in both environments, but also play an important role in the food chain by being sustenance for a number of living things. Due to these reasons, the extinction of amphibians is likely to affect many other organisms (BLAUSTEIN *et al*. 1994; BLAUSTEIN & KIESECKER 2002). The study of the relationships between the distribution of animal species and climatic variables is critical for improving our ability to predict the future ecological responses to climate change (PIHA *et al*. 2007; GIRARDELLO *et al*. 2010). Because of their great vulnerability to environmental stressors, amphibians are of special importance in the context of global climate change (RON *et al*. 2003; D'AMEN & BOMBI 2009). Climate change has been shown to affect amphibian population dynamics (BLAUSTEIN *et al*. 2010). Specifically, long periods of unusually low rainfall and high temperatures may raise mortality rates and limit reproductive success (BLAUSTEIN *et al.* 2010).

A number of factors are thought to have caused a decline in amphibian populations, one of which is a climate change. Seasonal and annual changes in temperature and precipitation, as two of the key climate factors, can affect amphibian populations (DERVO *et al.* 2016) as well as the productivity of each individual (CLUSELLA-TRULLAS *et al*. 2011; ARCHIS *et al*. 2018).

Temperature also affects water availability for amphibians, because heat causes evaporative water loss through the skin and dries the temporal small ponds within the habitats of these species (GREENBERG & PALEN 2021). Over the next century, the Earth's climate is expected to alter even more radically. By 2100, the global average yearly temperatures are expected to climb between 1.1 to 6.4 degrees Celsius (IPCC 2007). Precipitation, humidity and soil moisture all have the potential to alter the water availability for amphibians, and as a result, could have an impact on their survival and behaviour. Therefore, the physiology, behaviour and ecology of many amphibian species will be influenced by changes in temperature and precipitation (KIM *et al*. 2021).

There are 'hotspots' with many endemic or endangered species that are especially sensitive to climate change (MALCOLM *et al*. 2006). One such place is the Caucasus Ecoregion in the Western Palearctic. This ecoregion includes the territories of the North Caucasus in Russia, Georgia, Azerbaijan, Turkey, Iran and Armenia (CEPF 2003). The genus *Bufo* is represented by four species (LITVINCHUK *et al*. 2008; KIDOV *et al*. 2020). *Bufo eichwaldi* is one of the species, which has geographic distribution in the southeastern part of Azerbaijan and the northern part of Iran (Gilan, Mazandaran and Golestan Provinces) that is part of the Caucasus Ecoregion.

The aims of this research are: (i) to predict the impact of climate change on the distribution range of *B. eichwaldi* (Talysh toad), a vulnerable species according to the IUCN Red List, in the northern part of Iran and in southern Azerbaijan in current and future periods; and (ii) to also find the most important variable for the presence and distribution pattern of the species.

Materials and Methods

Database and occurrence records

In this study, we used two sets of datasets: one with occurrence records and one with bioclimatic variables. The species occurrence records were gathered from the literature and directly through fieldwork in northern Iran and southeastern Azerbaijan, and were sorted by country (105 unique records) (Supplementary Material; Figure 1). Nineteen bioclimatic layers for the current period of time (1950±2010) were downloaded from www.worldclim.org. In addition, 19 future bioclimatic layers were downloaded from recent IPCC reports for 2070 as four scenarios (2.6, 4.5, 6.0 and 8.5) from www.ccafs-climate.org (Table 1). All the bioclimatic layers were downloaded in 30 arc-sec resolution and cropped using ArcGIS 10.3 (ESRI) for the southern Caspian Sea and Azerbaijan regions. To avoid the effect of a high correlation among the layers, we examined all 19 of them using ENMTools 1.3 (WARREN *et al*. 2010) and removed the highly-correlated ones (Pearson Coefficient index >0.7). The low correlative layers were selected to run the models. Altitude and slope layers were used to run the models for the current period of time.

Species distribution modelling

The maps for the species distribution range in the current and future periods of time were predicted using Maxent 3.3.3e (PHILLIPS *et al*. 2006). The suitable predicted regions for the current period were calculated

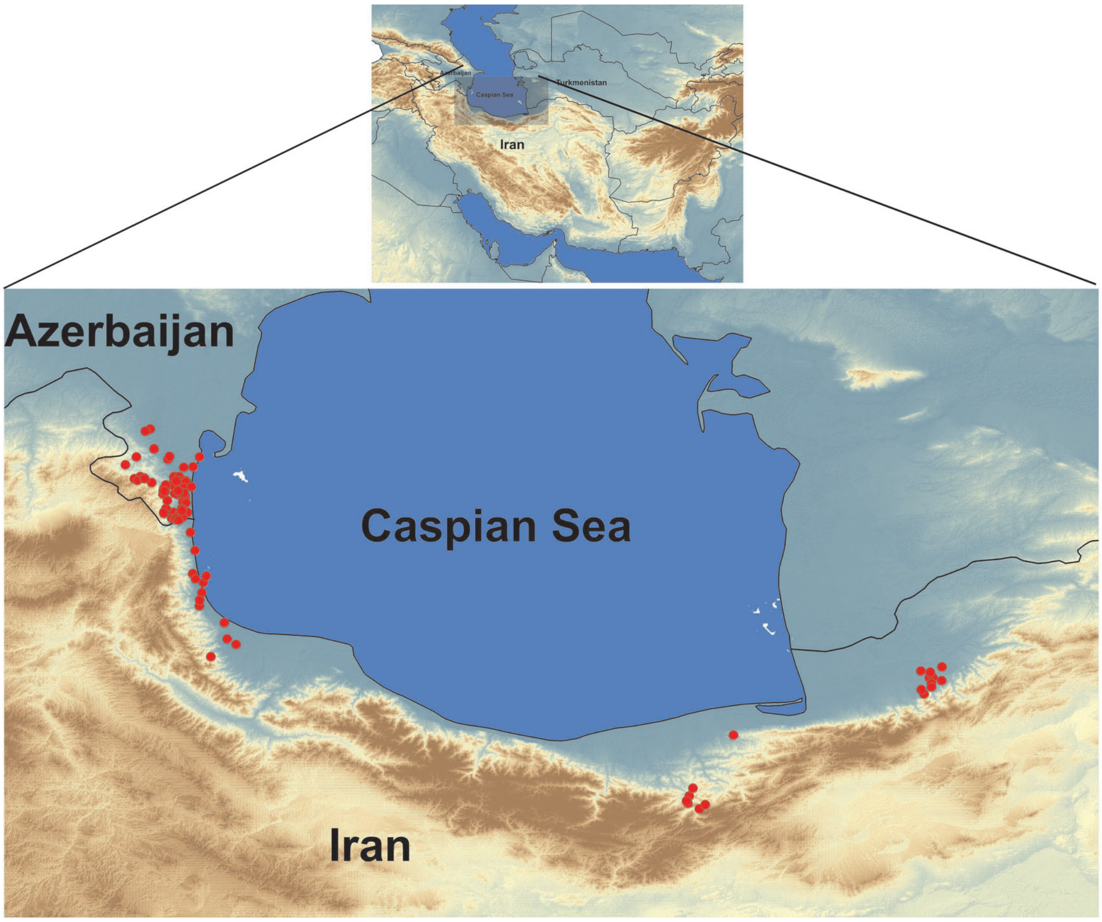

Fig. 1. Map of Iran and the study area in northern Iran and southeastern Azerbaijan. Red circles indicate the presence of *Bufo eichwaldi* as recorded from the literature and fieldwork.

Table 1

Bioclimatic variables used to run the species distribution modelling. Variables that were used in this study are marked by an asterisk (*)

Variable	Definition
*BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range [monthly mean (max temp - min temp)]
BIO3	Isothermality [(var2 / var7) * 100]
BIO4	Temperature Seasonality (standard deviation * 100)
BIO5	Maximum Temperature of the Warmest Month
*BIO6	Minimum Temperature of the Coldest Month
BIO7	Annual Temperature Range (var5 - var6)
*BIO8	Mean Temperature of the Wettest Quarter
*BIO9	Mean Temperature of the Driest Quarter
*BIO10	Mean Temperature of the Warmest Quarter
*BIO11	Mean Temperature of the Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation in the Wettest Month
BIO14	Precipitation in the Driest Month
BIO15	Precipitation Seasonality (standard deviation / mean)
BIO16	Precipitation in the Wettest Quarter
BIO17	Precipitation in the Driest Quarter
BIO18	Precipitation in the Warmest Quarter
BIO19	Precipitation in the Coldest Quarter

and then projected onto the future 2070 period scenarios. The software was set to run the models as follows: regularisation multiplier = 1; max number of background points = 10,000; cross validate type; 25% of all the data was set as test and the rest (75%) was considered as training data; and the models were run for 10 replicates. The accuracy of the models was calculated based on the area under the curve (AUC). This area is categorised between the number 0.5 (random mode) and 1 (most appropriate mode), where the closer this number is to 1, the higher the accuracy of the model and the more reliable the prediction areas are. Also, the ecological niche overlap between the suitable present and future maps was calculated using ENMTools 1.3 software, which is based on two niche overlap indices: Schoener's *D* and Hellinger's-based *I* (Schoener 1968).

Results

All the models were run in ten replicates and the highest area under the curve (>0.9) was obtained for them, which indicates the high accuracy of the models in predicting suitable areas for the presence of the Talysh toad in Iran and Azerbaijan. Each layer contribu-

Table 2

Percentage contribution of bioclimate layers for the current and 4 future scenarios. The AUC values for each model are provided. Bold numbers refer to the layers with the highest contribution to the models

Bioclimate layer	Current	Future 2070/2_6	Future 2070/4_5	Future 2070/6_0	Future 2070/8_5
BIO1	13.0	0.2	0.7	0.1	0.3
BIO6	**31.4**	28.4	**40.3**	**39.3**	26.4
BIO8	15.6	**40.5**	20.3	18.0	**40.9**
BIO9	22.7	18.7	16.3	34.5	18.6
BIO10	2.0	6.9	13.7	0.1	9.4
BIO11	5.4	5.3	8.6	8.1	4.5
Altitude	3.6	–	–	–	–
Slope	6.3	–	–	–	–
AUC	0.954 ±0.024	0.912 ±0.070	0.921 ±0.066	0.919 ±0.067	0.916 ±0.071

tion performance for the present and future periods and scenarios is provided in Table 2. According to the results, BIO6 and BIO9 (Table 1) are the most important variables for the current distribution range of *Bufo eichwaldi.* In the future model predictions, the most layers that contributed the most to each scenario were distinguished as follows: for 2.6, BIO8; for 4.5, BIO6; for 6.0, BIO6; and for 8.5, BIO8 (Table 1). As is presented, all the effective bioclimatic layers related to the temperature and directly changed the presence location of the species. A comparison of the current and future predicted maps (Figure 2) indicated that the distribution range of the species is mainly focused in the west and southwestern Caspian Sea, but there are also some suitable areas in the southern and southeastern Caspian Sea. The future predicted maps show more suitable regions than the current period, but with a disconnection between suitable regions, especially in the southeastern Caspian Sea. The niche overlap between the current and future predictions showed that only an 18% overlap can be distinguished, and this indicates that *Bufo eichwaldi* may disperse to the east.

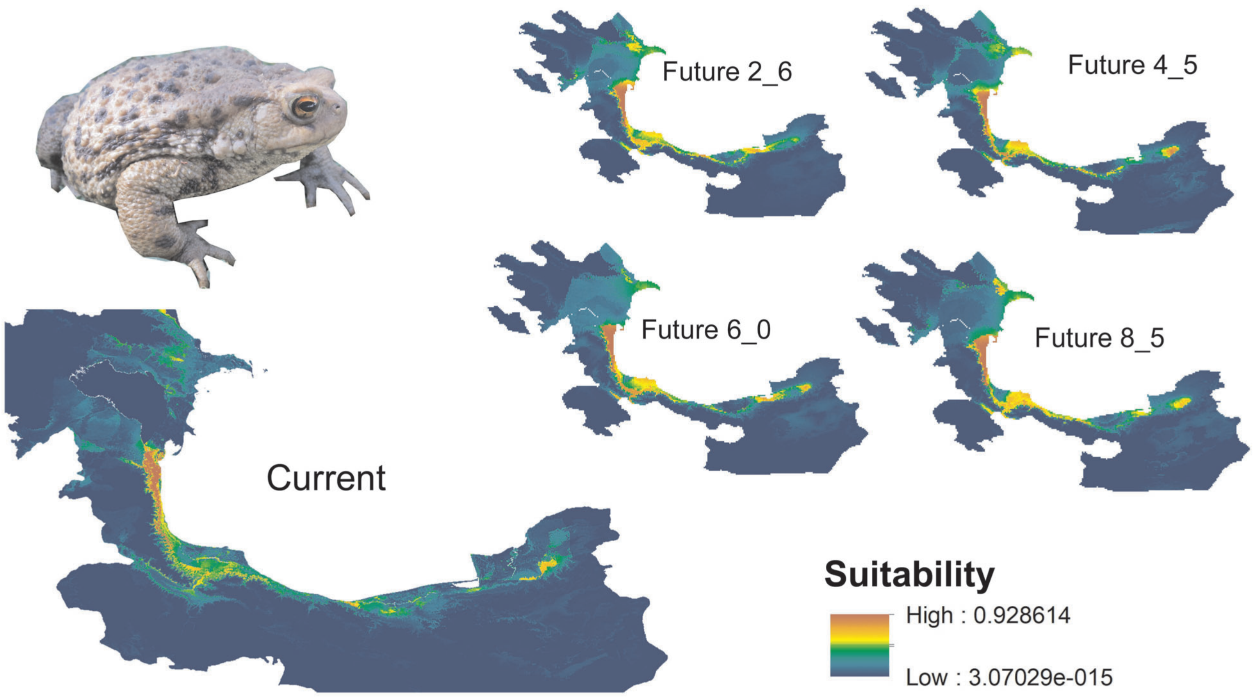

Fig. 2. Habitat suitability map and predicted distribution range for *Bufo eichwaldi* in the current and future periods.

Discussion

One of the important effects of climate change and global warming is the reduction of suitable habitats. In some areas it has caused the complete extinction of fauna and flora, and in some areas the main and continuous habitat of a species has been fragmented and the relationship between the population disrupted (FUNK *et al*. 2005). Currently, conservation biologists are trying to identify endangered species from such agents and to come up with a practical plan to prevent an event that could eventually lead to their extinction (FUNK *et al*. 2005).

Amphibians, as the most endangered terrestrial vertebrates, are resisting climate change and trying to counter the effects of global warming by developing various strategies such as shifting their distribution area, as well as changing their pattern of daily activity or seasonal reproduction activities (ROHR *et al.* 2008; BICKFORD *et al*. 2010). Some amphibians have a limited distribution and need human help. Through climate change studies, we are trying to identify the important climatic factors in the distribution of amphibians and to develop a conservation programme for their future protection.

The Talysh toad (*Bufo eichwaldi*) is an amphibian species that inhabits forest habitats and wetlands in northern Iran and southeastern Azerbaijan (GANIEV & GASIMOVA 2013). According to studies on the distribution and habitats of this species, several regions with a high population density have been identified, including the following regions: the south east of Azerbaijan on the border with Astara; Gilan Province from the Astara area to the Asalem area; around Sari in Mazandaran Province; and around Aliabad Katoul in Golestan Province in the south and southeastern part of the Caspian Sea (DARVISHNIA *et al*. 2018; KAMI & BASHIRICHELKASARI 2018).

In the present study, the effect of climate change on this species was evaluated and the most suitable distribution areas were predicted. The current distribution range indicates that this species is mainly distributed in the west of the Caspian Sea, with a number of scattered spots on the southern and southeastern coast of the Caspian Sea (Figure 2). However, there are no suitable areas between these spots or, in other words, strong habitat connections. The prediction of the distribution maps in 2070 shows that the suitable habitats of this species will be wider than they are now. On the other hand, the extent of the distribution will continue to the north east in Azerbaijan and to the east in Iran, so that it includes all the areas of Gilan Province. An important point in the distribution for the next 50 years shows that suitable habitats in the east of the distribution range, i.e. in Golestan Province and east of Mazandaran, may connect weakly to the areas in the west. The minimum temperature during the coldest month of the year (January) is the most important factor in the presence of the species at the present time, because the mating time and sexual activity of this species have been identified as occurring between 20 January and 1 March (KAMI & BASHIRICHELKASARI 2018). According to the response diagrams of the climatic layers, if the ambient temperature is below zero the probability of the presence of the species decreases, although this species is also not very interested in environments with high temperatures. In other words, an increase in the temperature will reduce the presence of this species. Furthermore, the sexual activity and mating will occur in winter, which is the most important factor for the presence of the species in the habitats south and west of the Caspian Sea.

The same climate layer with the lowest temperature in January has been identified as the most important effective layer in 2070, showing its importance for the presence of populations of this species in relation to mating and reproduction. In general, according to the climate change that is predicted by the existing scenarios, the climate change does not have a negative effect on the distribution and presence of this species, and incidentally increases the range of distribution (in the current period 23,344 km^2 has been distinguished as suitable area, while in the future it could increase to 45,471 km^2) and the favourable areas for the presence of this species. However, other factors such as road accidents (KAMI & BASHIRICHELKASARI 2018) and the release of municipal wastewater into wetlands are among the most important reasons why measures should be taken for the protection of this endangered species. We hope that the status of such species will be prevented from becoming endangered by publishing important data on biodiversity conservation, as well as raising local awareness of the importance of biodiversity conservation.

Finally, a genetic evaluation of the different populations of Talysh toads from Golestan Province in Iran to the south east of Azerbaijan could further help in developing the action plan and preparing the necessary conservation instructions for this species. Determining the amount of gene flow, as well as the isolation of populations from each other, are considered as the most important indicators of biodiversity protection and by considering the effects of climate change on the different distribution spots of this species, the right decisions can be made to protect it.

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Author Contributions

Research concept and design: S.S.H.Y.; Collection and/or assembly of data: S.S.H.Y, F.Y., G.G.; Data analysis and interpretation: S.S.H.Y, A.Y., M.N., F.Y., G.G.; Writing the article: S.S.H.Y, M.N.; Critical revision of the article: A.Y., M.N.; Final approval of article: S.S.H.Y, M.N., G.G.

Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary Material to this article can be found online at:
http://www.isez.pan.krakow.pl/en/folia-biologica.html

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