Climate change produces winners and losers: Differential responses of amphibians in mountain forests of the Near East

Kafash, Anooshe; Ashrafi, Sohrab; Ohler, Annemarie; Yousefi, Masoud; Malakoutikhah, Shima; Koehler, Gunther; Schmidt, B R

Abstract: Climate change is now considered as a serious threat to the viability of many species and consequently as one of the major drivers of global biodiversity loss. Amphibians serve critical roles in forest ecosystems and are one of the most sensitive groups to environmental change. Despite the importance of amphibians in forest ecosystems and their sensitivity to environmental changes, little is known about potential impacts of future climate change on forest-dwelling amphibians. We projected the impact of climate change on the geographic distribution of three typical species of forest-dwelling amphibians, the Balkan Crested Newt (Triturus ivanbureschi), the Anatolian Crested Newt (T. anatolicus) and the Southern Crested Newt (T. karelinii). We also evaluated the representation of suitable habitats of the three crested newts in protected areas under the current and future climatic condition. We found that the Balkan Crested Newt and the Anatolian Crested Newt are likely to lose considerable proportions of their currently suitable habitats in the future as climate changes, while the Southern Crested Newt is likely to gain new habitats. Results showed that the future coverage of the most suitable habitats inside protected areas would drop by 22% and 49.2% for the Balkan Crested Newt and for the Anatolian Crested Newt, respectively. However, results showed a 15.7% increase in the suitable habitats of the Southern Crested Newt inside protected areas. Our study suggests that forest biodiversity will be negatively affected by future climatic change. Our findings also highlight the importance of integrating the impacts of climate change into designation of new protected areas in mountain forests of the Near East.

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Original Research Article

Climate change produces winners and losers: Differential responses of amphibians in mountain forests of the Near East

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A B S T R A C T

Climate change is now considered as a serious threat to the viability of many species and consequently as one of the major drivers of global biodiversity loss. Amphibians serve critical roles in forest ecosystems and are one of the most sensitive groups to environmental change. Despite the importance of amphibians in forest ecosystems and their sensitivity to environmental changes, little is known about potential impacts of future climate change on forest-dwelling amphibians. We projected the impact of climate change on the geographic distribution of three typical species of forest-dwelling amphibians, the Balkan Crested Newt (*Triturus ivanbureschi*), the Anatolian Crested Newt (*T. anatolicus*) and the Southern Crested Newt (*T. karelinii*). We also evaluated the representation of suitable habitats of the three crested newts in protected areas under the current and future climatic condition. We found that the Balkan Crested Newt and the Anatolian Crested Newt are likely to lose considerable proportions of their currently suitable habitats in the future as climate changes, while the Southern Crested Newt is likely to gain new habitats. Results showed that the future coverage of the most suitable habitats inside protected areas would drop by 22% and 49.2% for the Balkan Crested Newt and for the Anatolian Crested Newt, respectively. However, results showed a 15.7% increase in the suitable habitats of the Southern Crested Newt inside protected areas. Our study suggests that forest biodiversity will be negatively affected by future climatic change. Our findings also highlight the importance of integrating the impacts of climate change into designation of new protected areas in mountain forests of the Near East.

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1. Introduction

Climate change is now considered as a serious threat to the persistence of many species (Thomas et al., 2004; Sinervo et al., 2010) and consequently as one of the major drivers of global biodiversity loss (Dawson et al., 2011; Urban, 2015). The IUCN Red List of Threatened Species has recorded 1610 species as being threatened by climate change of which 19 species are now considered extinct (Monzón et al., 2011). Climate change has been shown to have a variety of effects on species (Meynecke, 2004). In a changing climate, the ranges of some species may expand while the ranges of many other species are likely to shrink. Yet other species may have to shift their ranges in order to track suitable climate niches elsewhere (Monzón et al., 2011). In this respect, species distribution models (SDMs) have been recommended as helpful and informative tools (Araújo et al., 2011; Rodriguez-Castaneda et al., 2012) to predict species future range changes under climate change (Lotter and Maitre, 2014; Yousefi et al., 2017a; Duan et al., 2016).

Ectotherms have high extinction risk from climate change (Stuart et al., 2004; Lawler et al., 2010; Urban, 2015) because they are less likely to track their climate niches compared to endotherms (Aragón et al., 2010). As ectotherms, amphibians depend on environmental temperature to regulate their body temperature, and therefore, climate is a key factor influencing their geographic distribution and local abundance (Hairston, 1949; Pough et al., 2001). Thus, increasing temperature is a major factor that will most likely alter the distribution of amphibians (Bickford et al., 2010). Research has shown that response to climate change could be species-specific (Muths et al., 2017; Kolanowska et al., 2017; Prugh et al., 2018; Miller et al., 2018). While many species are expected to lose suitable habitats, others are predicted to gain new habitats and will expand their current distribution ranges (Urban, 2015).

Amphibians serve critical roles in forest ecosystems (Davic and Welsh, 2004; Hocking and Babbitt, 2014). In some forests, amphibians contribute more to vertebrate biomass than birds and mammals combined (Burton and Likens, 1975; Peterman et al., 2008). Despite the importance of amphibians in forest ecosystems and their sensitivity to environmental change (Collins and Storfer, 2003; Stuart et al., 2004), little is known about potential impacts of future climate change on forest-dwelling amphibians. Thus, in this study we investigated the impacts of climate change on the distribution of the Balkan Crested Newt (*Triturus ivanbureschi* Wielstra et al., 2013a), the Anatolian Crested Newt (*T. anatolicus* Wielstra and Arntzen, 2016), and the Southern Crested Newt (*T. karelinii* (Strauch, 1870)), three typical forest-dwelling (Temperate broadleaf and mixed forest (Olson et al., 2001)) amphibians in mountain forests of the Eastern Europe and the Near East (Wielstra et al. 2014a, 2014b). These three species have a similar natural history (Sparreboom, 2014) and are closely related and comprise a monophyletic group (Wielstra and Arntzen, 2011; Wielstra et al., 2014c). We aimed to assess potential impacts of future climate change on these forest-dwelling species, and evaluated if current protected areas will be able to maintain their conservation role for these species. Since amphibians are sensitive to environmental change, we hypothesized that future climate conditions will affect these forest dwelling newts in a negative manner, as they share similar natural histories and ecological requirements.

2. Material and methods

2.1. Species occurrence data and climate variables

To predict the impact of climate change on the distributions of species using niche modeling approaches, two types of data are required: 1) data specifying geographic occurrence of species, and 2) climate variables under present and future conditions. Data on the occurrence of the crested newts (Fig. 1) were obtained from published papers (Wielstra et al. 2013b,

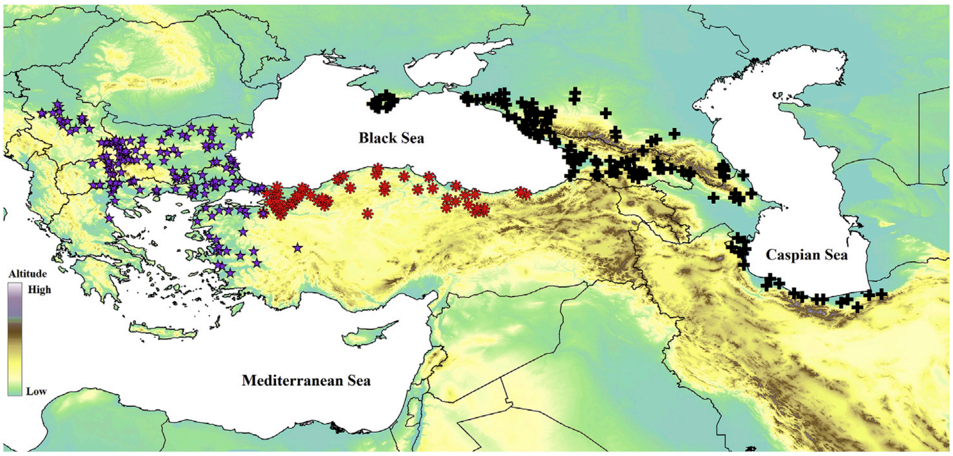

Fig. 1. Presence records of Balkan Crested Newt *Triturus ivanbureschi* (purple stars), Anatolian Crested Newt *Triturus anatolicus* (red asterisks) and Southern Crested Newt *Triturus karelinii* (black crosses) in a topographic overview of the study area. Colours indicate altitude. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2014a, 2014b). Duplicate records were deleted using ENMtools (Warren et al., 2010). The spatial resolution of environmental variables was 30 s (~1 km^2) so to avoid pseudo-replication (having more than one distribution record within 1 km^2), we only used the distribution records of the species that were at least 1 km apart. Overall 366 occurrence locations were collected for the three species (Balkan Crested Newt: $n = 151$, Southern Crested Newt: $n = 133$ and Anatolian Crested Newt: $n = 55$).

Climatic variables for current conditions and future predictions were obtained from WorldClim (Fick and Hijmans, 2017). To forecast future potential distributions of crested newts, we used climatic data layers from general circulation model (GCM): CCSM4 for 2050 (average for 2041–2060) and 2070 (average for 2061–2080). Two representative concentration pathways (RCP 2.6, RCP 8.5) were used from each model. To prevent inputting climate variables with high correlation, we used ENMtools (Warren et al., 2010) to calculate correlation among the 19 bioclimatic variables (Fick and Hijmans, 2017). For the modeling, we used seven of the original variables with correlations less than 0.75 (Table 1).

2.2. Developing species distribution models

We used MaxEnt 3.4.1 (Phillips et al., 2017) to build distribution models for crested newts under present climate conditions and projected them into the future. The study area is the entire known distribution range (Fig. 1) of the three species (Longitude: left 18.8509 – right 57.1009 E, Latitude: top 47.0941- bottom 32.9274 N).

Maxent was run with maximum iterations of 1000, convergence threshold of 0.0001 and 10000 background points. Using the default setting of regularization multiplier in Maxent can lead to unrealistic contractions in future projections (Warren and Seifert, 2011). Regularization is a mechanism that can be used to optimize predictive accuracy (Phillips and Dudik, 2008) and to avoid fitting too complex models (Elith et al., 2011). Thus, in this study, we used different values for the regularization multiplier for setting an appropriate level of regularization (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15) and produced 15 Maxent models for each species. We used the corrected Akaike information criterion (AICc) in ENMtools (Warren et al., 2010) to select the best value for the regularization multiplier. The results suggested that the best value for regularization multiplier was 3, 5 and 3 for Balkan Crested Newt Southern, Southern Crested Newt and Anatolian Crested Newt, respectively (Appendix I). We used the cross-validation method in Maxent and distribution points were randomly split into 10 folds containing equal number of occurrences, and training models were created by eliminating each fold in turn (Merow et al., 2013).

2.3. Evaluation performance of the models

The performance of the model was assessed using the Area under the Curve (AUC) metric of Receiving Operator Characteristic (ROC) curve (Phillips et al., 2006). AUC ranges between 0 and 1; 0.5 means no predictive ability or randomness and 1.0 shows perfect predictive ability (Fielding and Bell, 1997). AUC is a threshold-independent measure of model prediction accuracy and one of the most commonly used metric in SDM studies to date (Yang et al. 2013; West et al., 2016; Qin et al., 2017; Kafash et al., 2018; Fourcade et al., 2018; Xu et al., 2018; Moradi et al., 2019).

2.4. Protected areas coverage under present and future climate conditions

To estimate the representation level of present and future suitable habitats of the crested newt inside protected areas, we firstly used the “10 percentile training presence logistic” threshold (averaged values of the all ten models) to convert the continuous predictions into binary suitable-unsuitable maps (values of 0.35, 0.32 and 0.3, for Balkan Crested Newt Anatolian Crested Newt and Southern Crested Newt, respectively). This threshold was used because it is one of the most commonly used thresholds for creating binary suitability maps for species distribution with Maxent (Liu et al., 2005; Vale et al., 2014; Yousefi et al., 2017b). Secondly, SDMs developed for the present and future (RCP 8.5, 2050 and 2070) were overlaid on the protected areas layer (obtained from www.protectedplanet.net). By protected areas we mean permanent national and international protected areas such as IUCN (I-VI), UNESCO-MAB Biosphere Reserve and forest parks in the study areas. Finally, the area of current and future suitable habitats inside protected areas calculated using the raster package in R (Hijmans, 2017).

Table 1
List of the bioclimatic variables which were used for modeling in the present study. All pairwise correlations were smaller than 0.75.

Variable	Abbreviation	Units
Annual mean temperature	Bio1	Degrees Celsius
Temperature annual range	Bio7	Degrees Celsius
Mean temperature of wettest quarter	Bio8	Degrees Celsius
Annual precipitation	Bio12	Millimeters
Precipitation of driest month	Bio14	Millimeters
Precipitation seasonality	Bio15	Fraction
Precipitation of coldest quarter	Bio19	Millimeters

3. Results

3.1. Performance of the models

All Maxent models in this study reached an AUC value of greater than 0.8 (Balkan Crested Newt: AUC = 0.885 (SD = 0.026), Anatolian Crested Newt: AUC = 0.943 (SD = 0.040), Southern Crested Newt: AUC = 0.908 (SD = 0.029), indicating a good performance of the models.

Results of assessing the effects of climate changes on the distributions of the three newts showed that the area of suitable habitats for Balkan Crested Newt (Fig. 2) and Anatolian Crested Newt (Fig. 3) would decrease. However, the area of suitable habitats for the Southern Crested Newt would (Fig. 4) increase in the future. Table 2 shows percentage cover of predicted suitable habitats of the three species in the study area. Loss of suitable habitat would be more pronounced for the Balkan Crested Newt than for the Anatolian Crested Newt. Based on RCP 8.5 until 2070, Balkan Crested Newt will lose 74% of its current suitable range (current: 22.5%, predicted (RCP 8.5, 2070): 5.8%, relative change = 5.8/22.5−1 = −74%) and Anatolian crested newt will lose 54% (relative change). In contrast, there will be 46% increase in suitable habitats of the Southern Crested Newt (Based on RCP 8.5, 2070).

3.2. Variable importance

The result of estimating variable importance showed that precipitation of driest month was the most important environmental predictor of distribution of Balkan Crested Newt and Southern Crested Newt with 25.9 and 53.3 percent contribution, respectively, to the Maxent model. For the Anatolian Crested Newt, precipitation of coldest quarter (with 32.8 percent contribution) was determined to be the most important environmental variable affecting the distribution. Precipitation seasonality (29.7%) and precipitation of the driest month (24.1%) also made substantial contributions to the model for the Anatolian Crested Newt (Table 3). The responses of the Anatolian Crested Newt and Balkan Crested Newt to climatic variables were similar but differed from the shape of the response curves of the Southern Crested Newt. The latter showed sigmoid

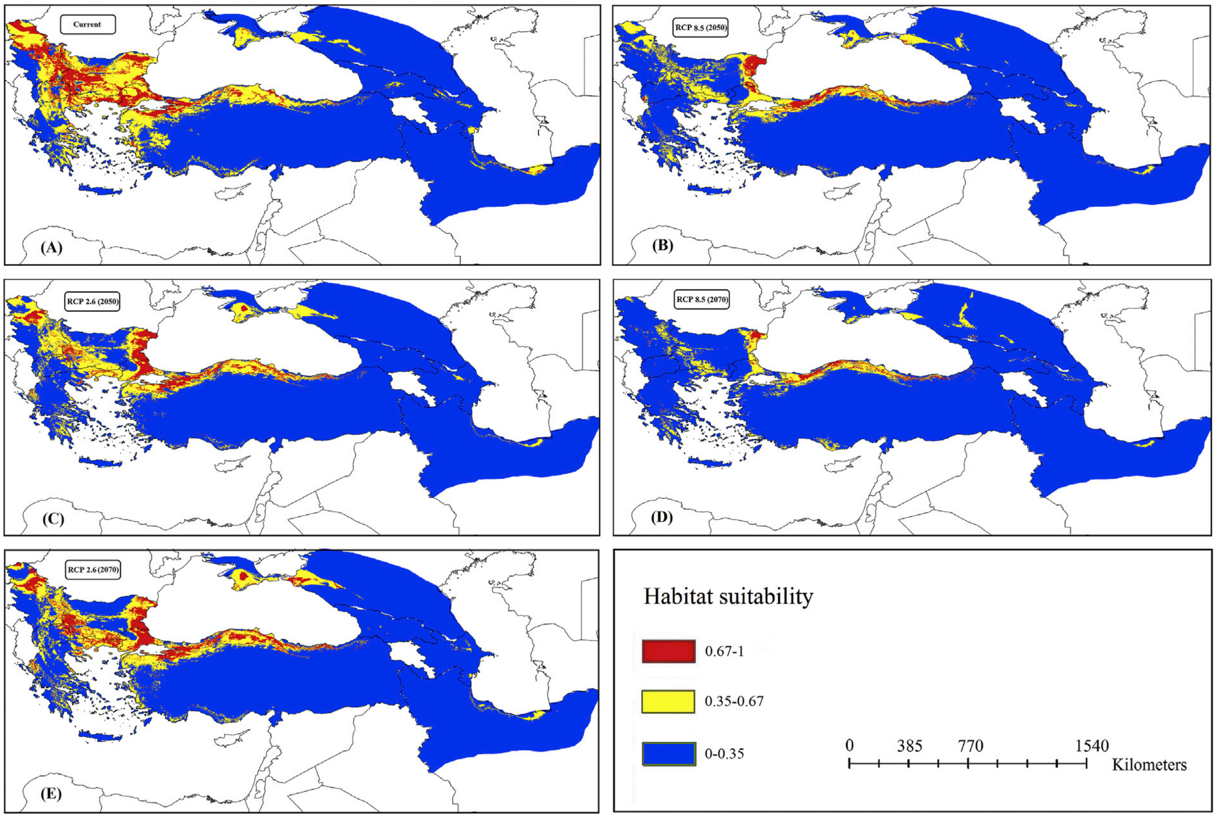

Fig. 2. Habitat suitability maps for the Balkan Crested Newt (*Triturus ivanbureschi*) under current (A) and future climate, 2050 under RCP 8.5 (B) and RCP 2.6 (C) and 2070 under RCP 8.5 (D) and RCP 2.6 (E). Red, yellow and blue describe high, medium and low habitat suitability. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

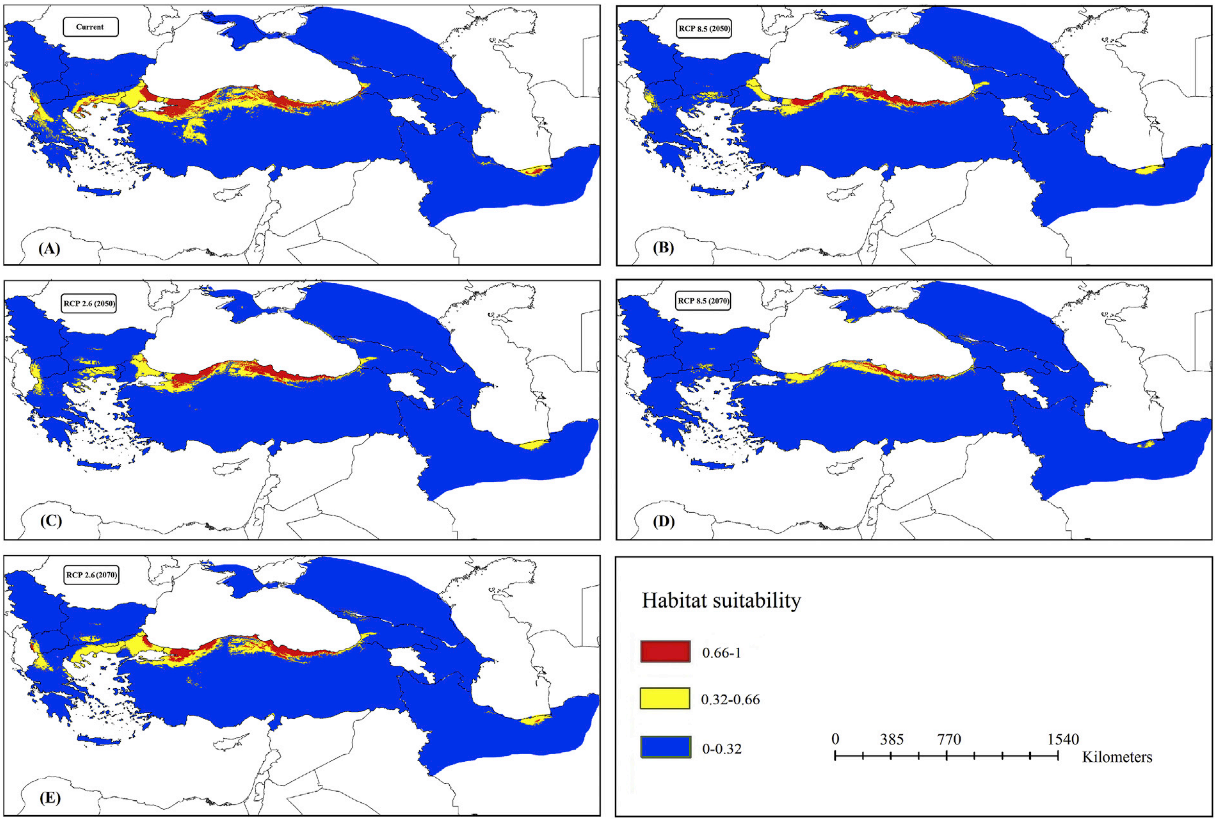

Fig. 3. Habitat suitability maps for the Anatolian Crested Newt (*Triturus anatolicus*) under current (A) and future climate, 2050 under RCP 8.5 (B) and RCP 2.6 (C) and 2070 under RCP 8.5 (D) and RCP 2.6 (E). Red, yellow and blue describe high, medium and low habitat suitability. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

response curves whereas the response curves of the Anatolian Crested Newt and the Balkan Crested Newt were mostly unimodal and showed optima. Response curves are shown in the appendix (Fig. 4).

3.3. Protected areas coverage

Results showed that the percentage of suitable habitat for the Balkan crested newt within protected areas varied from 33.5% at the present to 25.8% in 2070 (according to the scenario RCP 8.5), which equals a 22% decrease. The percentage of suitable habitat for the Anatolian Crested Newt within protected areas varied from 25% at the present to 12.7% in 2070 according to the scenario RCP 8.5, which equals a 49.2% decrease. However, the percentage of suitable habitat for the Southern Crested Newt within protected areas varied from 18.4% at the present to 21.3% in 2070 according to the scenario RCP 8.5, which equals a 15.7% increase (see results for 2050 in Table 4).

4. Discussion

Geographic distributions of amphibians are determined to a large extent by rainfall and temperature. Consequently, climate change is likely to have negative impacts on their geographic distribution (Hof et al., 2011; Bickford et al., 2010; Popescu et al., 2013). The results from the projections in this study suggest that crested newts may lose a considerable proportion of their current suitable habitats in forests of the Near East and southeastern Europe under the future climatic change but, importantly, there will be winners and losers. From the three studied species, the Balkan Crested Newt and the Anatolian Crested Newt will lose suitable habitat; loss of suitable habitat would be more pronounced for the Balkan Crested Newt compared to the Anatolian Crested Newt. Surprisingly, our model predicted that the suitable habitats for the Southern Crested Newt are likely to increase in the future.

The species-specific response to climate may explain why two species are climate change losers with shrinking ranges whereas the third is a winner because the amount of suitable habitat is predicted to increase. If a species has a climatic niche with optimal environmental conditions, then any change in their optimal environmental conditions can affect their performances and lead to a shrinking range (Chase and Leibold, 2003). Indeed, we found that there was a small optimal

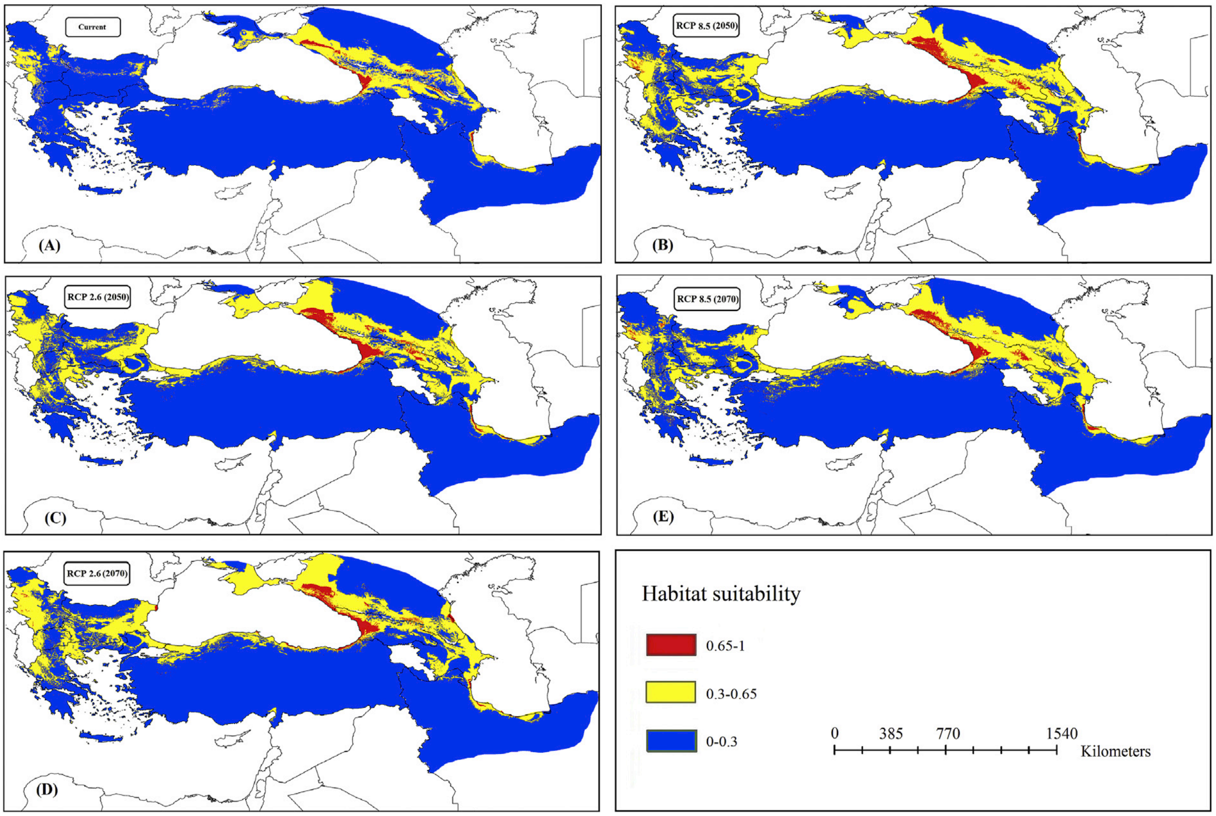

Fig. 4. Habitat suitability maps for the Southern Crested Newt (*Triturus karelinii*) under current (A) and future climate, 2050 under RCP 8.5 (B) and RCP 2.6 (C) and 2070 under RCP 8.5 (D) and RCP 2.6 (E). Red, yellow and blue describe high, medium and low habitat suitability. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Suitable habitats under current and future climatic conditions for the distribution of Balkan Crested Newt (*Triturus ivanbureschi*), Anatolian Crested Newt (*Triturus anatolicus*) and Southern Crested Newt (*Triturus karelinii*) in the Near East.

Species	Current	RCP 8.5 (2050)	RCP 2.6 (2050)	RCP 8.5 (2070)	RCP 2.6 (2070)
Balkan Crested Newt	22.5	6.9	15	5.8	17.9
Anatolian Crested Newt	11.2	6.9	8.7	5.1	8.6
Southern Crested Newt	19.6	25.1	24.9	28.7	27.3

Table 3
Contribution of each environmental variable in Maxent models.

Variables	Balkan Crested Newt	Anatolian Crested Newt	Southern Crested Newt
Annual mean temperature	2.2	2.5	3
Temperature annual range	24.1	7.8	9.8
Mean temperature of wettest quarter	15.2	0.4	8.7
Annual precipitation	13.9	2.7	10.5
Precipitation of driest month	**25.9**	24.1	**53.3**
Precipitation seasonality	1.6	29.7	7.2
Precipitation of coldest quarter	17	**32.8**	7.5

Table 4
Percentage cover of suitable habitats of Balkan Crested Newt (*Triturus ivanbureschi*), Anatolian Crested Newt (*Triturus anatolicus*) and Southern Crested Newt (*Triturus karelinii*) within protected areas.

Species	Current	RCP 8.5 (2050)	RCP 8.5 (2070)
Balkan Crested Newt	33.5	26.4	25.8
Anatolian Crested Newt	25	20.8	12.7
Southern Crested Newt	18.4	19.8	21.3

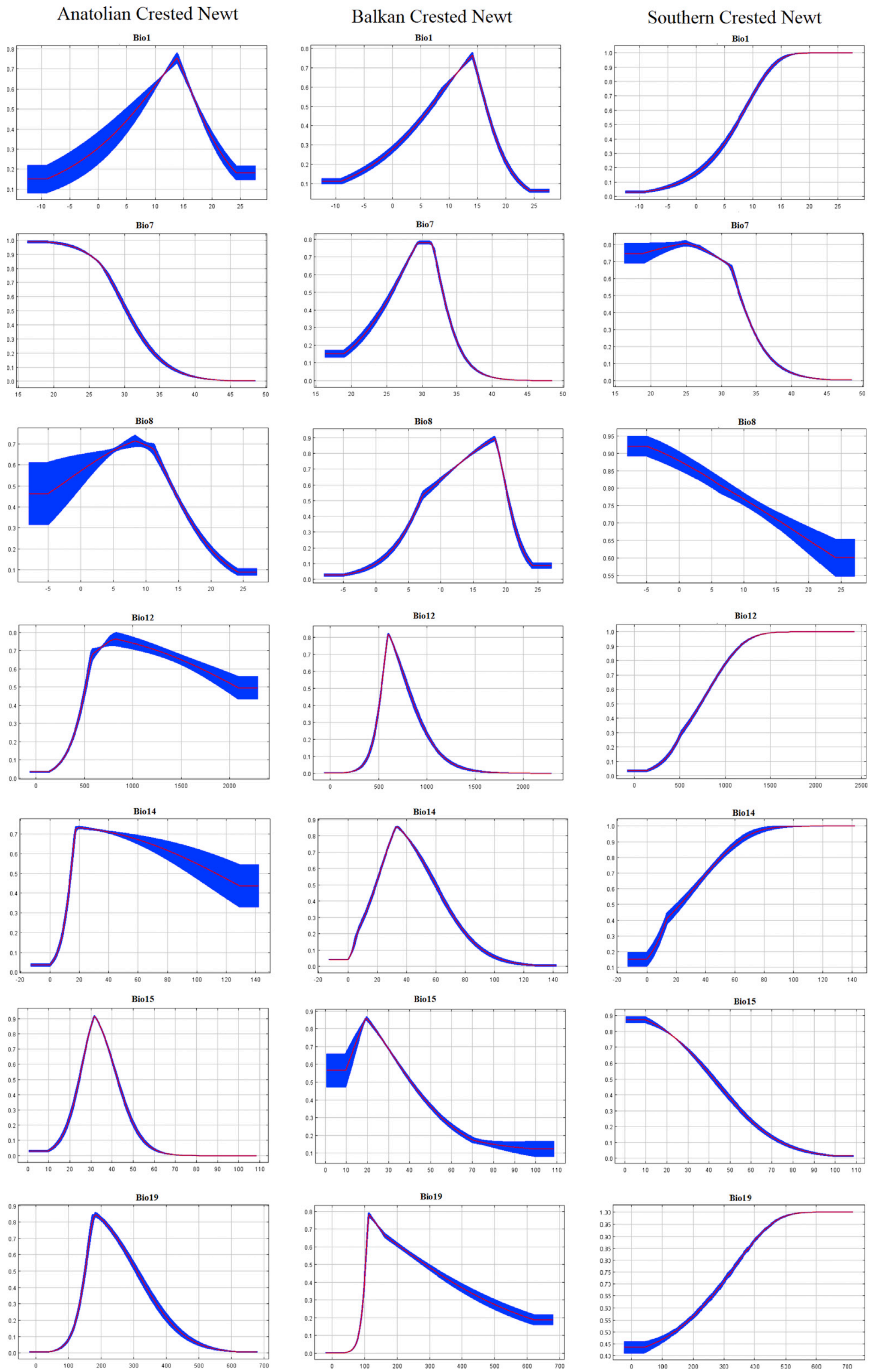

Fig. 5. Response curves showing how the presence of Anatolian Crested Newt (*Triturus anatolicus*), Balkan Crested Newt (*Triturus ivanbureschi*) and Southern Crested Newt (*Triturus karelinii*) is related to the climatic variables.

range of climatic conditions for the two species with reduced habitat suitability, so any change in climate may mean that they no longer encounter optimal conditions in their current ranges which means that future climatic conditions will be unsuitable. In contrast, the winner had sigmoid responses to climate. This type of response may lead to either more or less suitable conditions in a future climate. Here, future climate is apparently such that conditions improve for the species. Another reason for increasing the suitable habitats of the Southern Crested Newt is that precipitation amount predicted to increase by 50% (from 3000 to 6000 mm) in some parts of its distribution range (e.g., Georgia), this will strengthen humidity of those areas (Elizbarashvili et al., 2017). Thus, due to increased humidity future climate is likely to become more suitable for the species which prefers habitats with more precipitation and less seasonality (Fig. 5). One of the most important applications of species distribution models is evaluating the efficiency of protected areas in terms of their coverage for suitable habitats of species (Araújo et al., 2004; Kafash et al., 2016; Yousefi et al., 2015; Hu et al., 2017) and their efficiency under future climate change (Hannah et al., 2007; Coetzee et al., 2009; Araújo et al., 2011; Velásquez-Tibatá et al., 2013). In this study, results of assessing protected areas coverage indicated a 22% and 49.2% reduction in representation of the suitable habitats of the Balkan Crested Newt and Anatolian Crested Newt, respectively, within the protected areas in the future (based on RCP 8.5, year 2070). However, results revealed 15.7% increase in representation of the suitable habitats of the Southern Crested Newt within the protected areas in the future (based on RCP 8.5, 2070). These reductions of the representation of crested newts within protected areas will expose them to threats outside the protected networks (Popescu et al., 2013). This suggests the necessity of incorporating climate change impacts on the process of selecting new protected areas for conservation of biodiversity (Thomas and Gillingham, 2015). Large scale human-induced land use changes for instance, land conversion for agriculture can be an additional threat for these forest-dwelling amphibians across their distribution range. Land use changes have greatly affected the distribution of amphibians through fragmentation and destruction of their terrestrial and aquatic habitats (Nori et al., 2015). Fragmentation can reduce the number of successful migrants and will make amphibians even more vulnerable to climate change. So, it is necessary to protect amphibians' habitats from fragmentation and avoid synergetic effects of habitat fragmentation and climate change (Mantyka-Pringle et al., 2012). It is necessary to improve the conservation of newts within their distribution range by designing new protected areas in places that are currently suitable and which may not change much. In addition, there should be new reserves in areas that will become suitable in the future. Increasing the level of conservation in some currently protected areas can be very helpful. In Iran, for example, amphibians are not a priority for conservation so even in protected areas they suffer illegal collecting. Generally, reducing one type of threat (e.g., illegal collection) might compensate, at least partially, for losses due to climate changed-induced reductions in habitat suitability.

The results presented in this study show that the Anatolian Crested Newt and Balkan Crested Newt will be affected by the future climatic changes and will lose suitable habitat even within protected areas (where there is no land use change). We are aware that apart from climate change other factors such as habitat destruction and environmental pollution, or changes in environmental factors such as vegetation cover, and introduction of disease (Winter et al., 2016) could also play important role on the future distribution of crested newts. For example, Hyrcanian forests are rapidly being converted to agriculture and human settlements in Iran (Mahmoudi et al., 2016; Ashoori et al., 2018). As a consequence, the Southern Crested Newt is experiencing local extirpations in some parts of it distribution range in Northern Iran (A. Kafash personal observations). The Balkan Crested Newt and Anatolian Crested Newt currently meet at a hybrid zone that has been inferred to be moving (Wielstra et al., 2013c; Wielstra and Arntzen, 2016). Predicted changes in habitat suitability of the two species shown in this study are likely to influence which species outcompetes which and where.

5. Conclusions

We highlight the mixed effects of future climatic change on crested newts in mountain forests of the Near East and southeastern Europe. Our result also showed that some species will lose a substantial proportion of suitable habitat in the future, thus it is necessary to take into account the impacts of climate change on species for implementing more effective conservation strategies (Araújo et al., 2004; Hole et al., 2009). Since habitats with higher suitability scores may support higher population size of newts (Unglaub et al., 2018) we believe that those habitats projected to remain highly suitable for the three species under the future climate changes would play a critical role in species survival. Unfortunately, these habitats may be seriously at risk by future land use developments (Edgar and Bird, 2006), so they need strict protection. We also suggest that those habitats projected to become suitable for the Southern Crested Newt are considered and incorporated into the future conservation plans.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gecco.2018.e00471.

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