Ecological Processes

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Evolution of seasonal land surface temperature trend in pond-breeding newt (*Neurergus derjugini*) in western Iran and eastern Iraq

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Abstract

Background Temperature, as one of the effective environmental stimuli in many aspects of species life and ecosystems, can affect amphibians in many ways. Knowing and predicting temperature change and its possible effects on the habitat suitability and movements of amphibians have led many researchers to use climate change scenarios and species distribution models (SDMs). One of the important remote-sensing products that received less attention of conservation biologists is the land surface temperature (LST). Due to the small difference between LST and air temperature, this component can be used to investigate and monitor the daily and seasonal changes of habitats. This study aims to investigate the seasonal trend of LST in the habitat suitability and connectivity of the critically endangered newt (*Neurergus derjugini*) in its small distribution range, using the MODIS LST time series (2003 to 2021) and with the help of SDMs, Mann–Kendall (MK) and Pettitt non-parametric tests.

Results In the last decade, the increasing trend of LST versus its decreasing trends is obvious. Based on MK and Pettitt tests, in the winter and spring, with the decrease in latitude of 35.45° and increase in longitude of 46.14°, the core populations which are located in the southeast have experienced an increase in temperature. Considering the period time of breeding and overwintering, the continuity of winter and spring can be effective on the survival of adult newts as well as larvae in the microclimate. Linkages with the highest current flow between core populations in the winter and summer are the most likely to be vulnerable. At the level of habitat, the increase in LST is proportional to the trend of thermal landscape changes, and all seasons have had an increase in LST, but in winter and summer, the largest area of the habitat has been involved. By continuing the current trend, many high-altitude southern habitats in Iran will be endangered, and the species will be at risk of local extinction.

Conclusion The increasing trend of temperature in all seasons such as winter will affect many adaptations of the species and these effects are mostly evident in the southern parts of its distribution range therefore, captive breeding and reintroduction are recommended for the populations of these areas.

Keywords Seasonal change, Local extinction, Climate refuge, Amphibian

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Introduction

Temperature and its changes are one of the current climate challenges. Underestanding the effects of the environment on species and communities is a topic of utmost importance in ecology (Esparza-Orozco et al. 2020). Rising temperature acts as a stimulus for the decline, loss, and fragmentation of wildlife habitats. In dealing with rapid climate change, ecologists are increasingly challenged to understand the severity and frequency of weather events (Osland et al. 2021). Estimates show that arid and semi-arid regions in middle latitudes in North Africa, Middle East, and Central Asia will undergo the greatest impact in terms of intensity and fluctuation of climatic parameters (Li et al. 2013).

Amphibian physiology and also life history makes them sensitive to climate parameters (Stuart et al. 2004) and habitat loss (Sauer et al.2022). According to the IUCN, more than 40% of amphibians are at risk of extinction, and 128 species are listed in the "possibly extinct" category (IUCN 2017). Due to being biphasic, many amphibians need aquatic (for breeding and growth) and terrestrial (for feeding) habitats to complete their life cycle. They exchange water, electrolytes, and other environmental compounds through their moist skin (Hillman et al. 1992). Ample empirical evidence suggests that high temperatures lead to a male-biased sex ratio, while growth at low temperatures may increase the number of females after metamorphosis (Ruiz-García et al. 2021). Rising temperature can affect amphibian growth and size and leads to larger individuals feeding on smaller ones (Polis 1981).

Understanding how climate change affects biogeographic patterns helps to predict the possible effects on ecological goods and services resulting from changes in functional and phylogenetic diversity and evolutionary processes (Lourenço-de-Moraes et al. 2019). Today, SDMs, which are increasingly used to manage wildlife species, natural habitats, and landscapes for different purposes, are one of the most common tools for assessing and quantifying changes in species distribution (Bellard et al. 2012). Habitat connectivity is an essential feature of the landscape (Taylor et al. 1993), which, if lost, could endanger biodiversity. The main threat to amphibians that have recently undergone a significant decline worldwide is connectivity changes in their habitats (Stuart et al. 2004; Cushman 2006). Preserving and restoring landscape connectivity is a top priority for wildlife protection and an adaptation strategy to protect biodiversity against climate change (Heller and Zavaleta 2009; Lawler 2009). In their corridors, amphibians are dependent on the contexts that contain components such as moisture and water in their structure. Therefore, any change in temperature trend can be considered as a threat to connectivity of species communication.

Nowadays analyzing time-series data is a powerful way to conduct impact assessment in ecology (Wauchope et al. 2021). Time-series analysis describes the dynamic behavior of observations and links them to provide clues about their origin (Lange 2001). The data that can be processed in time series make it possible to analyze the trend and direction of spatial changes, overcome the limitations of information retrieval, and assess the relationship between species and the periodic fluctuations from time point of view (i.e., seasonally, monthly, and annually) and from spatial point of view (i.e., in habitats, home range). In general, time-series analysis includes the investigation of trends and seasonality in the data (Dimri et al. 2020).

Seasonality is a prevalent environmental particular in diverse ecological systems that is driven by periodic climatic conditions (Holt 2008). Although ecologists consider the seasonality of changes very important, in many cases the seasonality of phenomena is ignored. The use of seasonal data faces two problems, one is that the data must be collected throughout the year and for several years (Power et al. 2008) and the other one is that some advanced mathematical relationships are needed to analyze these complexities (White and Hastings 2020). Contrary to the difficulties in seasonal analysis, many ecological questions are answered in the context of seasonality (White and Hastings 2020). But there are space–time limitations for using time-series variables that are recorded as points. Point observations need interpolation and many interpolation methods are useful for gentle terrains (Ossa-Moreno et al. 2019), but it is difficult to measure temperature in high-elevation regions due to the high ruggedness. Many meteorological stations that collect the weather parameters as points are located within valleys, which increases the risk of using obtained data from these areas (Liu and Yan 2017). Moreover, the efficiency of interpolation methods remains a challenge (Steinacker et al. 2006).

The need for real-time access to spatial information and also new meteorological data have increased scientific interest in finding new satellite approaches to fill existing climate gaps (Espín Sánchez et al. 2022). Using big data in the form of time-series with remote-sensing is also possible (Wauchope et al. 2021). Satellite data, in theory, can overcome the information gap in highlands. Rapid data collection, frequent and intermittent data capture, and broad coverage make it possible to extract much information from satellite images, including LST which is the earth's surface temperature (Chehbouni et al. 1996), measured at 1.5 m above the ground level by radiation-shielded ventilated sensors (Mildrexler et al. 2011). LST is a key dynamic surface parameter that helps to grow the knowelege about energy balance, impact on regional climate, surface/ground water, vegetation phenology, human health, location of hotspots, land use/land cover features (Rani and Mal 2022), and estimation of some atmospheric parameters (Hereher 2019; Prakash et al. 2019; Singh et al. 2020) in mountainous regions where we face data shortage (Kuenzer and Dech 2013). In summary, LST is a critical variable for retrieving main climate parameters (e.g., air temperature and tropospheric vapor) (Hulley et al. 2019).

The yellow-spotted mountain newt (*Neurergus derjugini*) also known as Kurdistan newt is critically endangered based on IUCN red list. The presence of this species has so far been confirmed in western Iran and eastern Iraq. Their life cycle includes migrations that occur seasonally between aquatic and terrestrial habitats. For many newts, migration between spring and autumn habitats for reproduction and hibernation is an essential cycle of vital activities (Dervo et al. 2016). Many studies on the impact of climate change on the Kurdistan newt (Khwarahm et al. 2021; Malekoutian et al. 2021; Karamiani 2021) and habitat modeling are available (Vaissi 2021; Barabanov and Litvinchuk 2015). However, no study has so far focused on quantifying the possible effects of seasonality trend of LST on the suitable habitat and connectivity of *N. derjugini* core populations, therefore this study aims to use LST time series to determine the temporal–spatial effectiveness of the habitat and linkages between the core populations by different seasons of the year and identify vulnerable populations in relation to the increase in temperature.

Materials and methods

Study area and localities

The boundary of this study with an area equal to 97,233.76 km^2 is jointly located between Iran and Iraq. The minimum and maximum height in this area is 12 and 3580 m a.s.l., respectively. In order to collect presence points, during the years 2019–2021, field visits to the species habitats in Kermanshah, Kurdistan and west Azerbaijan provinces in the west of Iran were made in April, May, June and July. Most of the presence points were inside canals, streams and springs. Presence points in Iraq were collected using previously conducted studies (Afroosheh et al. 2016). In addition to these visits, the present data from the Department of Environment of Kermanshah and Kurdistan Provinces of Iran were also used. A total of 72 locations, which almost covered most of the habitats of the species in Iran and Iraq, were collected (Fig. 1). In terms of altitude, the distribution range of the species can be divided into two parts: cold and humid in the heights of Zagros and hot and dry at low altitudes shared by Iran and Iraq (Sharifi and Vaissi 2014). The Zagros Mountains in the west of the Iranian plateau, including the vast mountain ranges, after various geological periods, glacial eras, and profound climate change, now have rich fauna and flora. Many of its species are exclusive to Iran, and some are found only in this mountain range (Ghahremaninejad et al. 2021). Since basins with two factors of water and altitude can play a decisive role in forming movement contexts for amphibians and thus their connectivity, this study used basins to analyze habitat conditions and linkages within localities. The basins were analyzed using the Digital Elevation Model (DEM) and a set of commands in the Hydrological toolbox of the Spatial Analysis in ArcGIS 10.4.1 (Fig. 1).

LST product

Remote-sensing offers valuable tools and relevant information for studying biodiversity and the environment associated with biological communities (Esparza-Orozco et al. 2020). Considering the data shortage due to inadequate and uneven distributions, MYD11A1 (Daily LST from Aqua) was used with a spatial resolution of 1 km in the time period of 2003–2021. Due to its daily global coverage and high temporal frequency, MODIS LST is widely used for local and global studies (Bai et al. 2019; Minacapilli et al. 2016). Since LST (MODIS) is calculated only based on clear sky observations, so its bias is toward cloudless days (Benz et al. 2017). To apply the bias correction, the average (Benz et al. 2017) quarterly LST was calculated in the Google Earth Engine (GEE) with a scale factor of 0.02 in Kelvin (Gorelick et al. 2017). The use of mean data is also recommended to keep the temporal resolution (Zhao et al. 2022) and abnormal weather (Morovati et al. 2020) consistent with the habitat condition and therefore, for each season, LST was calculated as the average daily LST of that season.

Distribution modeling

The species' distribution was determined using bioclimatic, topographic, anthropogenic, vegetation index, and landform variables. The bioclimatic variables were prepared with a spatial resolution of 30 s from WorldClim (Version 2). DEM was also prepared with the same spatial resolution from the mentioned database. The vegetation index was prepared in GEE from NDVI on an annual average (2021 to 2022) using the 16-day MODIS product "MODIS/006/MOD13Q1". Due to the presence of the species at high elevation, the density of mountain tops was used. A 10-class landform variable was first prepared from DEM in SAGA-GIS. Then, using the reclassify, all classes except mountain tops (coded 1) were given a zero code. The density map was then calculated using the FocalStatistics in ArcGIS 10.4.1. Distance

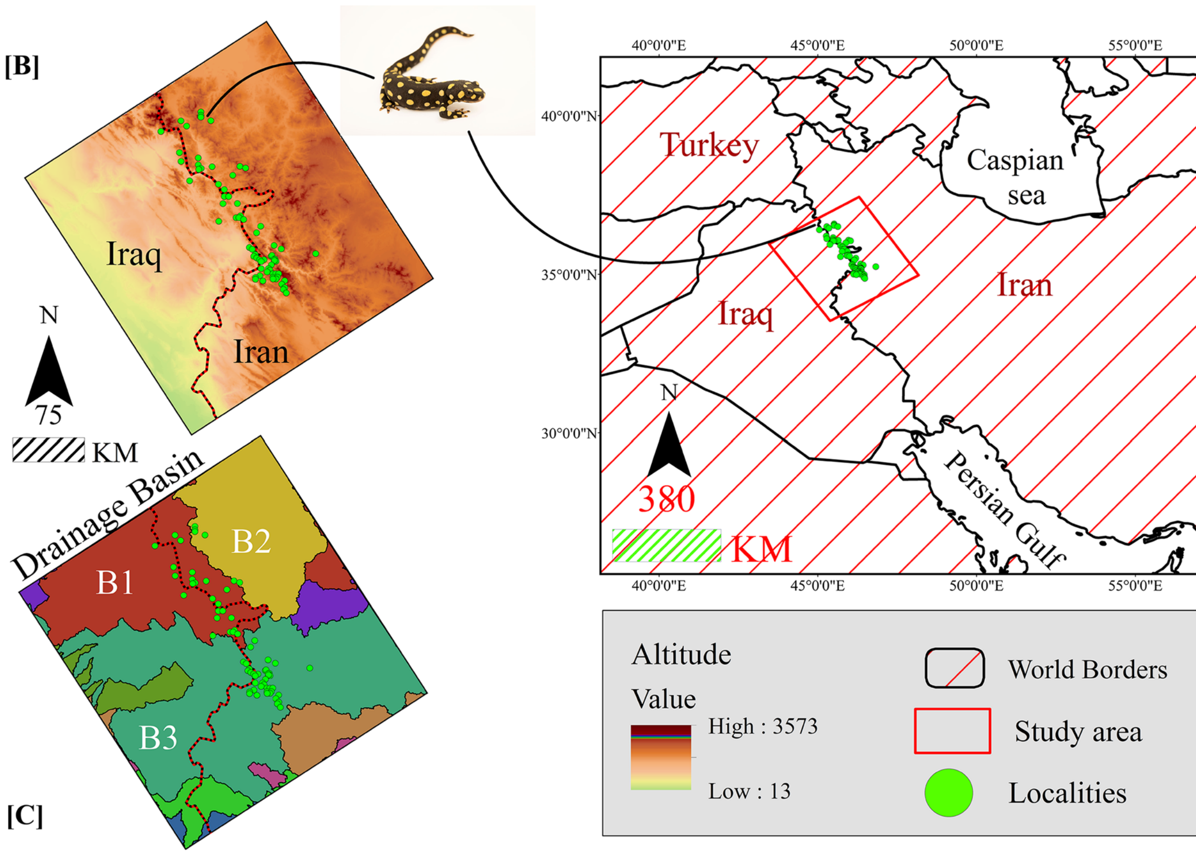

Fig. 1 **A** location of the study area in Iran and Iraq; **B** elevation of study area; and **C** drainage basins (B1, B2, and B3) of the study area

from sparse vegetation (tree, shrub, and herbaceous cover) and shrubland were prepared from the land use/land cover map at the Copernicus Climate Change Service database. The soil organic carbon was used to apply soil quality in the model. The soil organic carbon map at 0–30 cm depth with ton ha^{-1} unit of measurement was downloaded from FAO to a spatial resolution of 1 km (http://54.229.242.119/GSOCmap/). The human modification was used to assess the impact of human communities on the species' habitats, which can be downloaded under the title "Global Human Modification of Terrestrial Systems" at https://earthdata.nasa.gov. All variables with a spatial resolution of 1 km were entered into the modeling. A correlation test was run within all variables, and those variables with a correlation coefficient greater than 0.80 were excluded from the modeling process. In order to reduce the spatial autocorrelation, the spatial resolution of 1 km for habitat variables was considered, and all presence points with a less distance were not included in the modeling process. This was done using SDM Toolbox v2.5 (Brown et al. 2017).

The species distribution modeling was performed with the integrated approach of profile and presence/pseudo-absence models. Presence-only or profile models include One-Class SVM, Domain, and Bioclim. Since pseudo-absence is required to run the presence/pseudo-absence models, this study used the output of presence-only models to create pseudo-absence points (Piri Sahragard et al. 2021). After validation by Area Under the Curve (AUC), the outputs of the profile models were combined to prepare the presence-only ensemble binary model. The suitable habitat (Class 1) was excluded, and in the remaining unsuitable habitat (code 0), pseudo-absence points were created with the same number, 3 times and 5 times the number of presence points (Liu et al. 2019) as well as 1000 random points in QGIS 3.16.3. Then, using the presence and pseudo-absence points, the presence/pseudo-absence models, including BP-ANN, MaxEnt, MaxLik, CART, Rough Set, and Two-class SVM, were run. As the models used in this study are of classifier type, the criteria related to the classifier models including sensitivity, specificity, overall accuracy and Kappa index, were used to validate the models (Piri Sahragard et al. 2021; Karami and Tavakoli 2022). After validation, all the mentioned models were combined to prepare the ensemble presence/pseudo-absence model. Finally, the presence-only and the presence/pseudo-absence ensemble models were combined, and the final ensemble model (probability) was obtained. In all used models, 70% of the data were allocated for training and 30% for testing. All models were implemented in ModEco (Guo and Liu 2010). Then, to identify the affectability range of the suitable habitats from the LST trend and mean LST at the habitat level, the lowest presence threshold (LPT) was applied on the final ensemble model.

Habitat connectivity

Integration of electrical circuit theory and least cost path (LCP) models in the Linkage Mapper toolbox was used to investigate the species' connectivity. In the electrical circuit theory, electrical nodes are the same as cells in a landscape connected to the neighboring cells by resistors. Resistance values are determined by the resistance/conductivity values of the cells in the landscape. The presence points were introduced as the nodes (or cores), and the inverse of the probability distribution map was used as the resistance for the connection (Ahmadi et al. 2017). After importing the input files (core habitat and resistance), the Linkage Mapper was run to prepare Least Cost Corridors (LCCs) and LCPs between each pair of core populations. By detecting neighboring core habitats based on distance and adjacency data, the Linkage Mapper establishes a network of core habitats and produces LCCs by calculating cost-weighted distance (CWD) and LCP. It also integrates the single corridors to obtain the normalized composite map of corridors (Dutta et al. 2016). Various metrics are determined by models to judge the linkage quality, among which this study used Current_Flow_Centrality. The metric helps estimate the importance of a connection in preserving the connectivity in the entire landscape (McRae 2012), which measures the current flowing between the corridors in amperes. Linkages that have a high current facilitate the connection path between the nodes.

Trend exploration

MK is a non-linear trend test to detect monotonous up- and downtrends over a specific period and check the similarity between two ranking sets assigned by the same dataset (Neeti and Eastman 2011). This study ran the MK test considering two aspects to evaluate the impact of LST on habitat suitability/connectivity and also detect the changing trend of LST with decreasing latitude in the species' areas of presence. In the first analysis, seasonal LSTs were entered into TerrSet software from 2003 to 2021, then grouped into raster time series, and the MK test was performed by seasons. The primary assumption of trend analysis using the MK test is the lack of correlation between input data; therefore, prewhitening is used to eliminate the influence of serial correlation on the Mann–Kendall test of trends. The standardized MK test statistic (Zmk) test was used to determine the significant levels of the changes. The positive Zmk value shows an uptrend and vice versa. Zmk fluctuations were reported by Kandya et al. (2021). To better evaluate and judge the decreasing and increasing trends, significance levels of 0.01 and 0.05 were considered. After identifying the level of changes by crossing these findings with the habitat suitability (derived from LPT), the areas that underwent the increasing/decreasing trends were estimated. The second MK test was performed to assess the changing trend of LST that may occur with decreasing latitude. First, the presence points were sorted in descending order of latitude and LST values were assigned to localities for each year using the Extract Values to Points command in ArcGIS. Finally, using MK and Sen's slope test, the trend in the data was analyzed separately in 76 runs at a significance level of 95%. It is should be noted that in each run Hamed and Rao's (1988) test was performed in XLSTAT for the autocorrelation analysis.

Homogeneity test

One of the objectives of this study is to identify the affectability threshold of the species' presence areas against the LST trends. After calculating the MK test at the level of localities, it is necessary to determine the breakpoint in the LST value occurred at the location of each site from which, the LST changes have become "increasing" or "decreasing". Therefore, the Pettitt test which is non-parametric test for determining break points introduced in 1979 was used to detect homogeneity and break point in the LST data. It divides a time series into two separate homogeneous groups and examines the significance of this separation. The Pettitt test is widely used in climate and hydrological studies (Mezger et al. 2022). In this test, the H_0 hypothesis refers to the homogeneity of data, and the H1 hypothesis shows the presence of an ascending/descending trend, which its selection was subject to the implementation of the MK test at the level of the locality. After performing the MK test and determining the trend in XLSTAT, the H1 hypothesis in the Pettitt test was adopted to check any increasing or decreasing trend. If a breakpoint is observed, the localities will be divided into two groups by the Minimum Bounding Geometry in ArcGIS 10.4.1.

Results

Habitat suitability

Table 1 lists the validation of each model. Most of the used models have good validity. Kappa index for MaxLik and CART models was higher than other models; however, the sensitivity value for the Rough set model

Table 1 Validation results of the profile and presence/pseudo-absence models based on threshold-dependent criteria

Model	Overall accuracy	Kappa	Sensitivity	Specificity
Bioclim	0.87	0.75	0.75	1.00
Domain	0.94	0.88	0.88	1.00
One-class SVM	0.93	0.87	0.87	1.00
BPANN	0.95	0.91	1.00	0.97
MaxEnt	0.97	0.92	1.00	0.95
MaxLlk	0.97	0.94	0.98	0.95
CART	0.97	0.94	0.95	0.98
Rough set	0.84	0.68	0.69	0.98
Two-class SVM	0.95	0.91	1.00	0.91

Overall accuracy: overall accuracy is the rate of correctly classified cells; Kappa: normalizes the overall accuracy by the accuracy that might have occurred by chance alone; sensitivity: the probability that the model will correctly classify a presence; specificity: specificity is the probability that the model will correctly classify pseudo-absence

was calculated to be 69%, which is low compared to the other models used in this study. Overall, the models had good accuracy, and all were used to create the ensemble model.

Figure 2 depicts the newts' habitat suitability for the presence-only and presence/pseudo-absence SDMs. There are differences between the models in identifying the suitable habitat of the species. One-class SVM, two-class SVM, and ANN models predicted the southern parts of the study area as suitable. The suitable habitat is shared between Iran and Iraq; and it seems that compared to the modeling boundary, the majority of the area of suitable habitats belongs to Iran. The suitable habitat of the Kurdistan newt has a small area and is confined to the highlands with a mountainous landscape covered by oak forests.

Figure 3 shows the average LST in the suitable habitat from 2003 to 2021. The mean LST in the suitable habitat is the highest in summer. Winter has the lowest average LST with an evident increasing trend of changes. This upward trend is also observed for spring. Spring and autumn are most similar in terms of average LST in 2006, 2008, 2014, 2015, and 2016. The average LST in the suitable habitat increased from 318.09° K in the summer of 2003 to 321.18° K in 2021. From 2003 to 2021, the average LST in the suitable habitat changed from 276.87° K to 284.28° K and from 298.84° K to 303.66° K for the winter and spring, respectively.

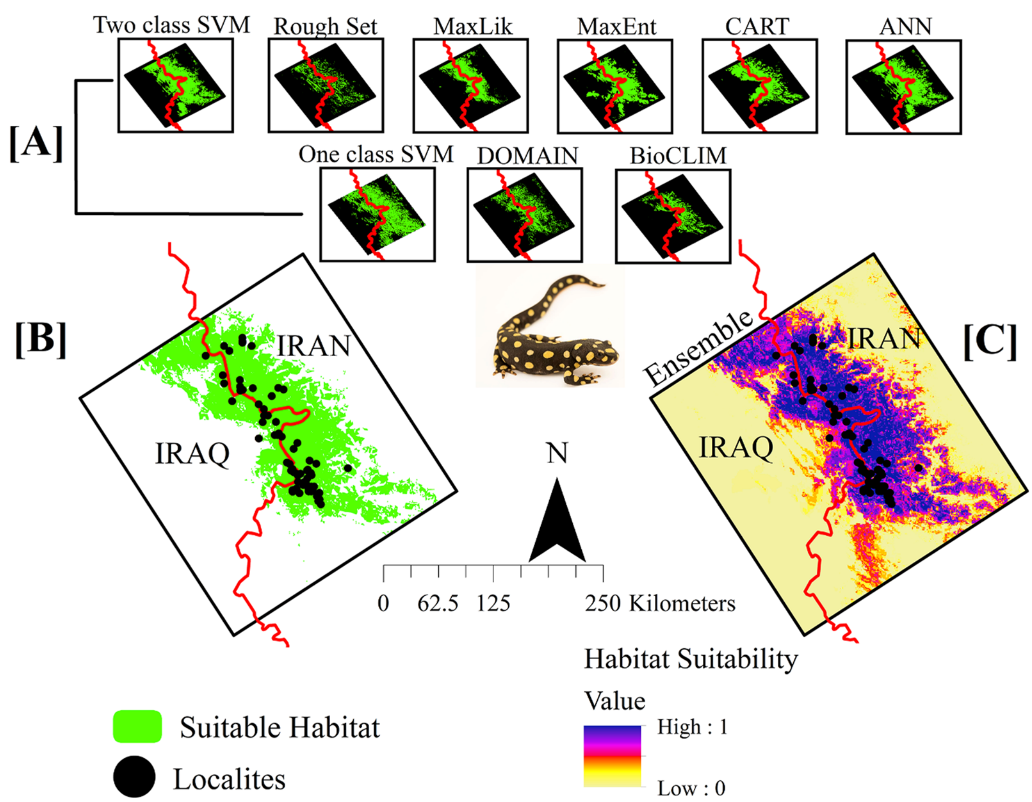

Fig. 2 Result of SDMs models: **A** suitable/unsuitable habitat based on Profile models, **B** suitable habitat based on LPT threshold and **C** ensemble habitat suitability

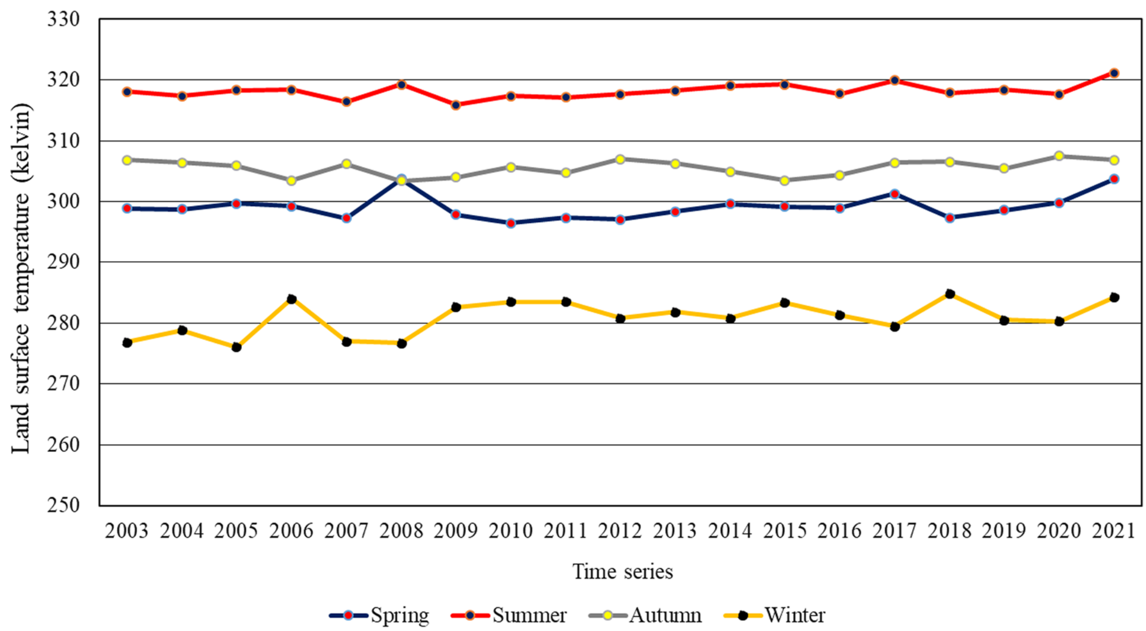

Fig. 3 Time series of average LST based on Kelvin in the suitable habitat by spring, summer, autumn and winter in the years 2003 to 2021

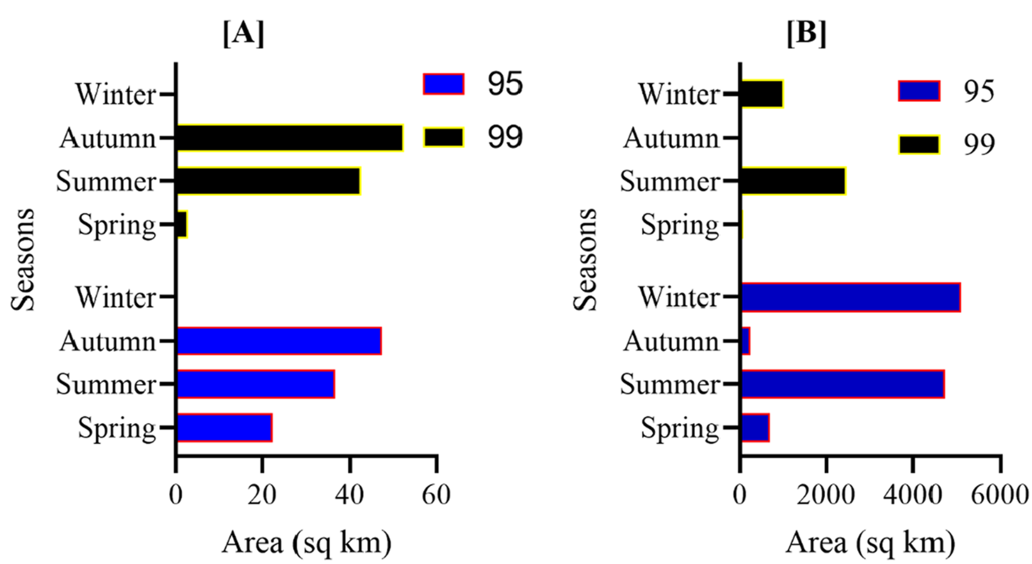

Fig. 4 The results of the overlap analysis of LST trend with the suitable habitat. **A** The area of the habitat involved in the decreasing trend of LST by seasons at different significance levels. **B** The area of the habitat involved in the increasing trend of LST by the seasons at different significance levels

Figure 4 shows the area of suitable habitat underwent increasing and decreasing trends at the significance levels of 99% and 95%. The comparison of areas shows that the area of the increasing trend is much larger than the decreasing trend. Also, the seasonal pattern of increasing and decreasing LST trends is different. No decreasing trend of LST was observed in the suitable habitat in winter. In all seasons except winter, the habitat experienced both increasing and decreasing trends in LST, even to a small extent. In decreasing trends at the significance levels of 95% and 99%, summer and autumn have the largest decrease in LST with areas of 36.50, 47.44, 42.57, and 52.56 km^2, respectively. The spring season has the lowest decreasing trend of LST at the 99% significance level with an area of 2.84 km^2. In increasing trends, winter and summer have the

Table 2 The results of the analysis of the trend of LST changes in population centers based on the decrease of latitude by different seasons

Season	Year	*P* value	Sen's slope	Kendall's tau
Spring	2011	0.017	0.043	0.270
	2015	0.002	0.082	0.420
	2018	0.007	0.057	0.303
	2020	0.020	0.038	0.198
	2021	0.047	0.054	0.223
Summer	–	–	–	–
Autumn	–	–	–	–
Winter	2014	0.033	0.108	0.254
	2015	0.029	0.074	0.270
	2016	0.042	0.108	0.281
	2017	0.029	0.128	0.322
	2021	0.034	0.083	0.266

highest increase in LST at the significance levels of 95% and 99%.

Trend analysis based on latitude

Table 2 shows the results of the MK test at the level of sites. In the spring of 2011, 2015, 2018, 2020, and 2021, the increasing trend of LST showed a significant relationship with increasing latitude. However, according to Sen's slope, the intensity of these changes was higher in 2015 than the previous years. In summer and autumn, no significant trend was observed with decreasing latitude. In winter, the results showed that the changes in LST were increasing, and Sen's slope also confirmed that the increase in LST in this season occurred more strongly in the areas of the species' presence points.

Sen's slope: this slope corresponds to the median of all the slopes calculated between each pair of points in the series. Kendall's tau measures the monotony of the slope. Kendall's tau varies between − 1 and 1; it is positive when the trend increases and negative when the trend decreases.

Among the years, 2020 was selected as an example to plot LST changes based on latitude and longitude. Figure 5 shows the results of LST distribution in spring and winter, respectively. As it turns out, LST is lower in high latitudes and eastern latitudes. As latitude decreases and longitude increases, LST will increase in both seasons.

Breakpoint analysis

After the trend analysis test and Sen's slope (Table 2), based on the presence of an increasing trend in the data, the H1 was considered, and the Pettitt test was performed. The results show a significant jump in the years mentioned in the table 2 (*P*-value < 0.05). This breakpoint is shown in Fig. 6, taking into account the spatial position of the localities separately for the significant years in Table 2. The observations were grouped based on the results of the Pettitt test. Considering the breakpoint, the groups are displayed in blue and yellow. According to the findings, a large part of the separations occurred at the latitude 35.45° and the longitude 46.14°.

Effects on linkages

The electrical circuit theory established 192 linkages between the localities with minimum 900 m and maximum 125,073 m distance. At the significance level of 99%, the corridors in the southern parts were surrounded by incremental LST changes in both summer and winter (Fig. 7). At a significance level of 95%, these two seasons also had the highest impact on the linkages. Compared to the upward trend, the downward trend in LST did not occur within the linkages (Fig. 8).

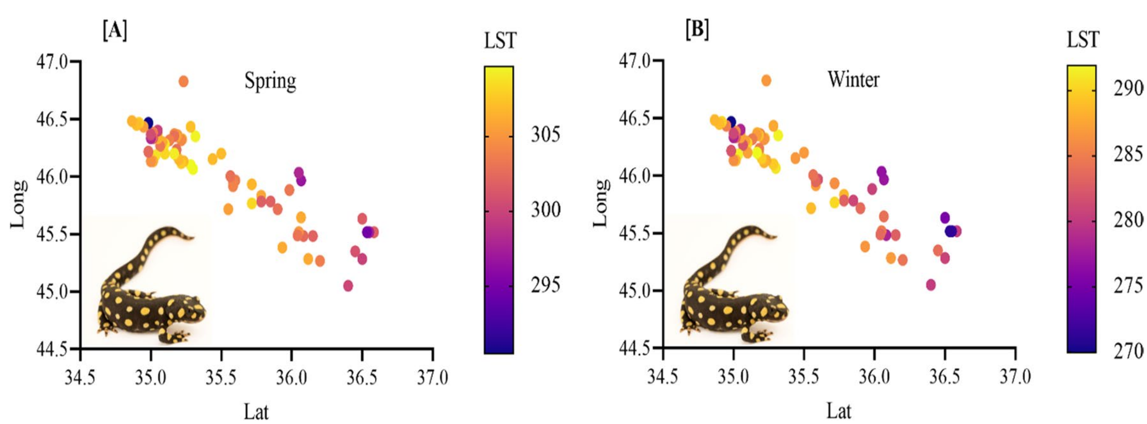

Fig. 5 Fluctuation of LST in localities based on latitude and longitude. **A** Spring and **B** winter in 2020. Yellow colors show higher LST and blue colors the lower LST

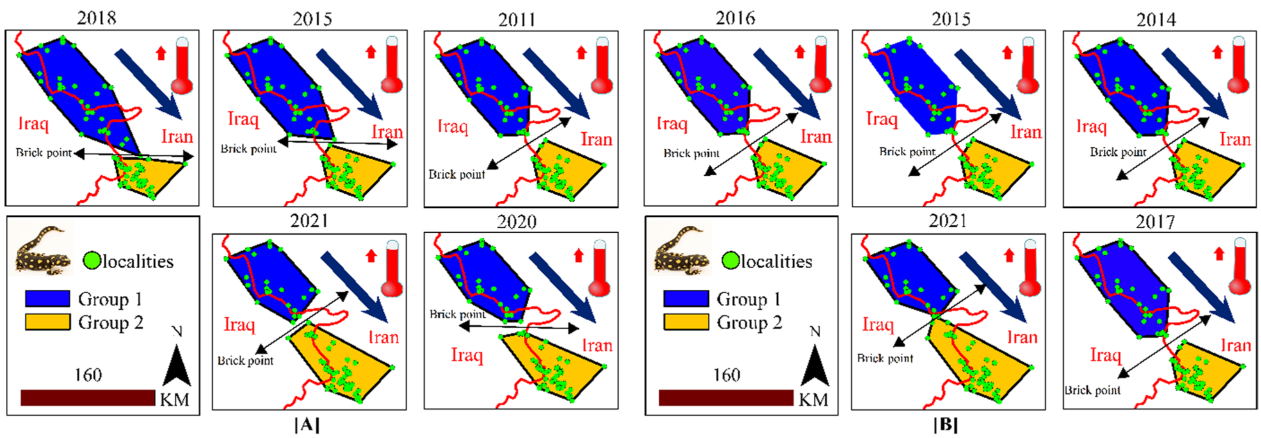

Fig. 6 Breakpoint in LST of localities for the seasons with significant changes. **A** Spring (left plot) and **B** winter (right plot). Blue arrow indicates the decrease in latitude, and the black arrow shows the line distinguishing localities based on the start of LST rise

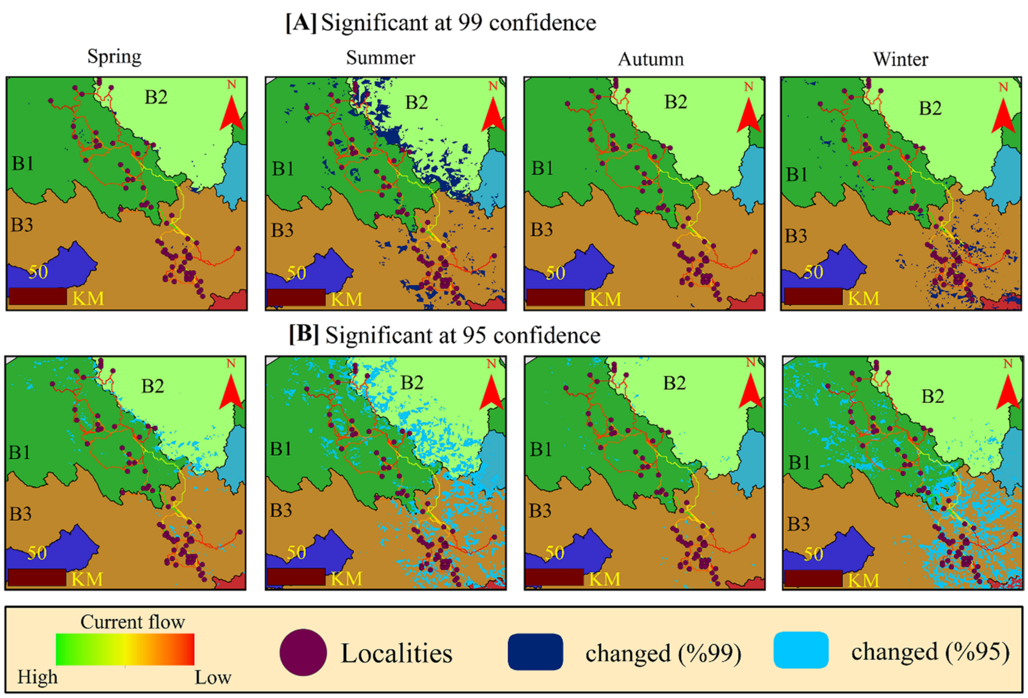

Fig. 7 The areas of suitable habitat with increasing LST trends. **A** Significance levels of 99% (dark navy) and **B** 95% (big sky blue) from 2003 to 2021, separated by different seasons. The linkages between the core populations and the current flow passing through them are also displayed

Discussion

To predict the possible effects of temperature changes on distribution range and habitat suitability, researchers usually use databases such as WorldClim and CHELSA besides SDMs, but using data from different climatic databases in SDMs leads to differences in results (Datta et al. 2020) and their efficiency. In a study by Bobrowski et al. (2021) comparing the two databases, it was concluded that the CHELSA database performed better than the WorldClim database. These differences can occur, especially in areas with high orographic heterogeneity that are also highly sensitive to the prediction errors of plant species (Hanspach et al. 2011). This study is the first research on trends of LST in the distribution ranges and Linkages of newts. It was conducted to detect the trend of seasonal LST changes in the habitat of yellow-spotted mountain newt over the period of 2003 to 2021. LST was calculated using the MODIS product, the efficiency of which has already been confirmed for different purposes (Ermida et al. 2014; Guillevic et al. 2014). LST is different

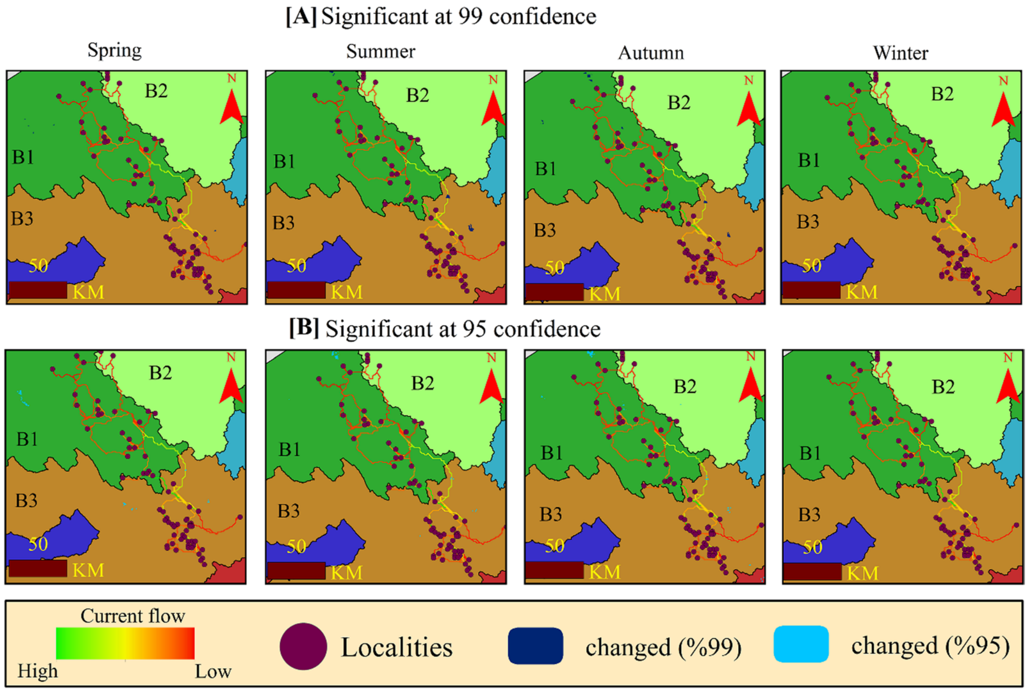

Fig. 8 The areas of suitable habitat with decreasing LST trends. **A** Significance levels of 99% (dark navy) and **B** 95% (big sky blue) from 2003 to 2021, separated by different seasons. The linkages between the core populations and the current flow passing through them are also displayed

from air temperature and is strongly influenced by land covers such as forests, ice cover, lakes, and bare soil. Air temperature is more than a regional average and shows lower spatial and temporal gradients than LST. However, studies show that the trend of LST changes is similar to the air temperature changes (Li et al. 2016). In some cases, its difference with the air temperature is ± 1 K (Duan et al. 2018; Wan 2014). Therefore, despite some weaknesses, it can provide credible results. The use of cloud computing platform such as GEE has made it possible to process large data on different types of satellites at different time-spatial scales, therefore the use of this system and some prepared products such as LST in combination with the findings of SDMs can be useful for the conservation of endangered species.

At a significance level of 95%, an increasing trend of LST was observed in all seasons during the study period. Most of the incremental changes were in summer and winter. In a study by Jamali et al. (2022) on the relationship between LST and environmental variables in Iran, it was reported that most changes occurred in summer and winter. In summer, there has been an increasing trend in the northern and eastern parts of the suitable habitat. In winter, these changes have been in the southern and middle parts of the suitable habitat in Iran (within Kermanshah Province). As the current trend continues, the south and central parts of the distribution range (Fig. 2) will be highly affected and more threatened by the rising LST trends. However, in a study by Vaissi (2021) these areas were reported as habitats with constant suitability under different climate change scenarios, which contradicts this study's findings, showing the species' current distribution range will be affected by LST changes. Some studies suggest that the movement of amphibians to heights can be a solution to cope with rising temperatures (Barrett et al. 2014; Cemal Varol et al. 2016). For example, in a study by Shin et al. (2021) on *Onychodactylus koreanus*, the results showed that due to rising temperatures under climate change scenarios, the species' distribution range would tend to higher latitudes and altitudes. A study by Lourenço-de-Moraes et al. (2019) on amphibians' climate refuges yielded similar results. However, the upward trend of LST changes (at 99% and 95% significance levels) has occurred in many southern parts of the current distribution range (e.g., Shahuo, Bouzin and Markheil heights), which are also elevated. As the current trend continues, the effectiveness of this strategy will be challenged in these regions. The increasing LST trend in winter (at 95% significance level) involved suitable habitat areas with a minimum altitude of 470 m to a maximum height of 3439 m, which indicates that high altitudes in the region are not immune to rising temperatures. Elevated temperatures were also reported in a study by Knapp et al. (2011) as a barrier to creating suitable conditions for *Batrachochytrium dendrobatidis*. Notably, no decreasing trend of LST was observed in winter (Fig. 4), and LST in the suitable habitat was unchanged or increased in winter. It is supposed the daily temperature rise in winter affects the rainfall and snowline (Pepin et al. 2019). Rising temperature and decreasing rainfall causes increasing droughts and water loss. Water loss is inversely proportional to temperature, especially for wet-skinned species such as frogs and salamanders (Khwarahm et al. 2021), which require moist skin to breathe (Lertzman-Lepofsky et al. 2020). In that case, the adaptations between "hibernation", "leaving the shelter", and "the presence of water resources" may be disturbed for the Kurdistan newts. These possible events are significant because *N. derjugini* is highly dependent on seasonal streams and aquatic ecosystems during the breeding and resting seasons.

The overlapping of the distribution range of the species with the Zagros forests can have negative and positive effects on the population. Small parts of the Zagros forests are still suitable and have not experienced any significant increase in LST (at 95% and 99% significance levels). The vegetation cover inside streams and groves of the distribution range, such as open oak woodland and deciduous dwarf, amygdale, and cushion scrublands (Henareh Khalyani et al. 2013), are some types of riparian ecosystem the canopy cover of which can moderate the temperature increase and block direct sunlight (Moore et al. 2005). But Zagros forests are mixed with bare soil in the distribution range of Kurdistan salamander, and this will lead to temperature heterogeneity in the region because bare soil and straw have a higher LST value than the forest (Sayão et al. 2020). This is why some southern localities in bare soil are subject to temperature increase. But one of the negative effects of temperature increase in Zagros forests, especially in summer, is the increase in the probability of wildfire, which has been observed repeatedly in the past few years in Kermanshah province (range of distribution of the species in basin 3). The importance of the effect of wildfire depends on the biophysical context and severity of the fire, the response of some streams is negligible and some heating dramatically (Isaak el al. 2010). Studies have shown that the loss of riparian canopies due to forest wildfire will increase the temperature between 0.8 and 15 °C (Warren et al. 2022). Therefore, managing mass forest areas with an emphasis on preventing the development of agricultural lands, deforestation, improper wood harvesting, and livestock grazing can effectively control temperature fluctuations in these areas.

According to the Linkage Mapper results, the paths connecting the middle and lower latitude-localities in the distribution range have a higher current flow, which is in line with Malekoutian et al. (2020). High mountains and high rainfall in the species distribution range in Iran (Karami 2021), along with snowmelt, facilitate the formation of seasonal streams. These conditions have caused the connectivity between the core populations in this region to establish a higher current flow than in other areas. Considering the movement ability of Kurdistan newt, which is estimated at 49.19 ± 71.75 m (Sharifi and Afroosheh 2014), most of the movements in basin 3 are done at short distances and probably with the help of temporary springs and streams that can play the role of stepping-stones. The role that springs and streams play in the distribution of populations reveals the dependence of amphibians on parameters such as humidity and water as a context for movement. Linkages located in basin 3 are more strongly affected by the increasing trend of LST than the other two basins. In the last few decades, increasing landuse change and development of agricultural lands through clear-cutting, overgrazing, and the presence of nomads have been among the concerns which led to changes in vegetation cover and land uses in the distribution range of the species. According to the study of Olson and Van Horne (2017), no-harvest streamside buffers have a positive effect on maintaining the water temperature inside the stream compared to harvested stands (6 m buffer width) and this distance will be more for sensitive salamanders (> 15 m). With low temperature, metabolic rates will also be low and the need for food will be less. If the temperature rises, it can also affect the fluctuation of water in canals and springs in highlands, which will lead to competition among populations. Findings show that water levels in streams or ponds increase or decrease competition for position and oxygen in the water (Loman 2002). Increasing the temperature reduces water-dissolved oxygen and can also affect swimming and invasion performance during the tadpoles (Bickford et al. 2010). Any changes that affect seasonal streams and springs can affect breeding success and its census and conservation monitoring program (Heydari et al. 2021).

MK test at the level of localities showed that with decreasing latitude, significant changes in LST occurred in spring and winter, and the LST trend in summer was not significant. These findings indicate that the alarm of rising temperatures in the spring has been sounded for areas where the species is present. Sen's slope showed that the trend of LST increase was lower in spring than in winter (Table 2) and the grouping in Fig. 6 shows that these changes are almost evident in the southern localities. As there is no time lag between spring and winter, the species' future seems to face the challenges of severe temperature rise in these habitats, which is expected to exacerbate by summer droughts. Most local and regional extinctions will likely occur in the southern range and basin 3. The physiology and behavior of amphibians are related to temperature and loss of water-related parameters (Kearney and Porter 2009; Pirtle et al. 2019). By affecting water, the temperature can disrupt the survival of larvae (Maciel and Juncá 2009). The effect of temperature on the developmental rates of *N. derjugini* has also been confirmed (Sharifi et al. 2017). The temperature rise is even effective on the rate of cannibalism in the Kurdistan salamanders (Vaissi and Sharifi 2016). By increasing temperature that currently exists in the south of the distribution range, the probability of this cannibalism will increase. With the increasing extinction rates, the number of amphibians entering captive breeding programs is high (Conde et al. 2013). The distribution pattern of the Kurdistan newt, its low dispersion capability, and short movement distances are among the reasons that make the development of conservation programs necessary for the population of this species. These programs can be presented in the form of captive breeding and reintroduction to higher latitudes and the management of suitable habitats. Some of the ancestral taxa of *Neurergus*, scattered throughout Europe and the Mediterranean, moved to the south for better climatic conditions, resulting in a limited population expansion to the Zagros and nearby areas (e.g., Iran, Iraq, and Turkey) (Steinfartz et al. 2000). Therefore, the highlands between Iraq and Turkey may have habitats for reintroduction. In a study by Sharifi and Vaissi (2014) on the experimental release of *N. derjugini*, the results showed that captive-raised *N. derjugini*, released into the wild after metamorphosis, can survive until the second growing season. This finding could provide a life-stage choice for the reintroduction plans. When using SDMs to identify reintroduction sites, it is necessary to include dynamic variables such as temperature, humidity, and vegetation covers in the modeling and consider their changes as a trend in locating and selecting reintroduction sites. Using SDMs predictions based solely on Bioclim variables as a baseline map does not yield reliable results. In a study by Vaissi et al. (2019), those areas exposed to rising temperatures were introduced as suitable sites for reintroduction of *N. derjugini*.

Despite studies on the genetics of the species and its populations (e.g., Afroosheh et al. 2019; Malekoutian et al. 2020), fine-scale research on the ecology of the species at different stages of its life cycle is limited (e.g., Sharifi and Afroosheh 2014; Farasat and Sharifi 2014; Afroosheh et al. 2016). No information is available on temperature fluctuations in springs and streams in the larval stage, fluctuations in water parameters due to seasonal temperature changes, and the trend of land use/land cover change in the species distribution range. The information about the habitat of the Kurdistan salamanders in Iraq is also limited. These factors have led to insufficient knowledge of the species to implement conservation plans in the future. More detailed studies at fine scales are suggested for investigating the habitats of Kurdistan newts. According to the studies, the research findings will be more in line with the ecological characteristics of newts at this scale (Ficetola et al. 2018).

Conclusion

Many environmental factors that can affect the habitat of plant and animal species can dynamically be retrieved from satellite images. It is possible to provide them on fine or coarse scales depending on the type of satellite. This information leads to a complete view of habitat conditions, a finding that may not be detectable using just SDMs due to the frequency and up-to-datedness of this data, especially in the case of amphibians, which are highly sensitive to climate and its changes. The trend analysis tests, examining homogeneity to identify data breakpoints, provide very efficient results that can reveal differences in species distribution range when combined with environmental data. The findings clearly showed the difference between the results of SDMs and the current conditions in terms of the species vulnerability to temperature. The complex relationships between temperature and habitat parameters and different stages of amphibian life reveal the possibility of predicting unsuitable conditions for the species in this study. Kurdistan newt in the southern part of its distribution area, i.e., in Iran, experiences more severe conditions in terms of temperature increase, and this increasing trend in seasons such as winter can lead to the disruption of behavioral adaptations. Relying on the findings of this study and such fine-scale studies about the effect of temperature or other dynamic variables such as humidity and vegetation on different life stages and habitats of newts, the species populations can be managed by captive breeding and reintroduction in areas with no trends.

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