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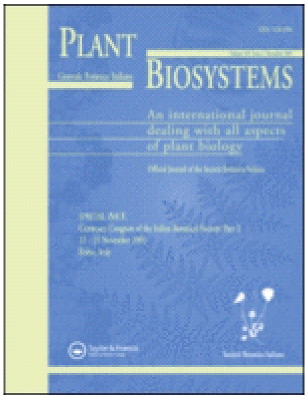
Original
Predicting the suitable habitats of Elwendia persica in the Indian Himalayan Region (IHR) / Thakur, S., Rai, I.D., Singh, B., Dutt, H.C., Musarella, C.M.. - In: PLANT BIOSYSTEMS. - ISSN 1126-3504. - 157:4(2023), pp. 769-778. [10.1080/11263504.2023.2204090]

Published
DOI: http://doi.org/10.1080/11263504.2023.2204090

The final published version is available online at:https://www.tandfonline.com/doi/full/10.1080/11263504.



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Journal:	*Plant Biosystems*
Manuscript ID	TPLB-2021-0331.R3
Manuscript Type:	Original Article
Date Submitted by the Author:	13-Mar-2023
Complete List of Authors:	Thakur, Sajan; University of Jammu, Ecological Engineering Laboratory, Department of Botany Rai , Ishwari ; Indian Institute of Remote Sensing Singh, Bikarma; CSIR-National Botanical Research Institute, Botanic Garden Division Dutt, Harish; Department of Botany, University of Jammu, Musarella, Carmelo Maria; Università "Mediterranea" di Reggio Calabria, Agraria
Keywords:	Ecological niche modelling, Climate change, Climatic scenarios, MaxENT, NW Himalaya, Asia, <i>Bunium persicum</i>

Predicting the suitable habitats of *Elwendia persica* in the Indian Himalayan Region (IHR)

Sajan Thakur[a], Ishwari Datt Rai[b], Bikarma Singh[c], Harish Chander Dutt[a]* and Carmelo Maria Musarella[d]

[a]Ecological Engineering Laboratory, Department of Botany, University of Jammu, Jammu-180006 (India); [b]Forest and Ecology Department, Indian Institute of Remote Sensing-ISRO, Dehradun -248 001 (India); [c]Botanic Garden Division, CSIR-National Botanical Research Institute, Lucknow -226001 (India); [d]Department of Agraria, Mediterranean University of Reggio Calabria, 89122 Reggio Calabria (Italy)

* Ecological Engineering Laboratory, Department of Botany, University of Jammu, Jammu-180006 (India)

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Rare, Endemic and Threatened (RET) species with naturally small populations are always at high risk of extinction, especially during the climate change process. Climate change phenomena are also identified as a strong driver in the habitat shift of many medicinal and aromatic plants (MAPs). The expected consequences of climate change are so dangerous that some key species can move to extinction. Therefore, the quest for suitable habitats of such species is taken as a challenge by various ecologists and conservationists. This study aims to predict the suitable habitats of *Elwendia persica* (Boiss.) Pimenov & Kljuykov, a threatened species for current and future climatic scenarios in the Indian Himalayan Region (IHR). The assessments for current and future climatic scenarios are accessed on the optimistic Representative Concentration Pathway 4.5 (RCP 4.5). The MaxENT algorithm has helped to predict the suitable habitat of the species in the study area. The model has predicted 1.12%, 2.37%, and 0.98% of the total study area as highly suitable habitats in current (2000) and future (2050 and 2070) climatic scenarios. South-eastern slopes are considered as the most suitable areas for the species in the Indian Himalayan Region. Our results show that suitable habitats of the species may increase upto 2050, and subsequently decrease.

Keywords: Ecological niche modelling; climate change; climatic scenarios; *Bunium persicum;* MaxENT; NW Himalaya; Asia

1. Introduction

Ecological Niche Models (ENMs) are experimental tools that have proven beneficial in conservation biology, ecology, biogeography, and predicting potential habitats (Feng et al. 2019; Méndez-Encina et al. 2021; Raghavan et al. 2021). ENM studies are based on the existing or predicted environmental variables and occurrence records. Therefore, these models are quantitative, empirical models of species-environment relationships, which are developed using species location information like abundance and/or occurrence and environmental variables. ENMs used to understand the prioritized areas of conservation have helped in the preparation of effective conservation and management strategies (Barbosa et al. 2012). Therefore, such studies can prioritize conservation plans of targeted species in future climatic scenarios (Silva et al. 2017; Edalat et al. 2019; Willcock et al. 2018; Zhang et al. 2019).

Studies have revealed that climate change poses a severe threat to many species and is likely to impact the organizational levels of vulnerable ecosystems (Cahill et al. 2012; del Río et al. 2021). In a very precise manner, climate change studies have reported a range shift of the species toward higher latitudes and altitudes throughout the world (Chen et al. 2011; Hamid et al. 2018; Sousa-Guedes et al. 2020). Many biological species in the communities are responding differently to climate change. Morphological plasticity, adaptation, change in growth strategy, and extended range of distribution are some of the common responses of plant species towards changing climatic conditions (Bonamour et al. 2019; Garzón et al. 2019; Musarella et al. 2020). Under specific circumstances, mountain plants respond to a climatic change by switching to persistent behaviour in the modified climate, migrating to more suitable climates, and/or facing extinction (Guisan et al. 1995). Habitat fragmentation and degradation are some more visible consequences of climate change (Spampinato et al. 2018).

Climate change has also shown its impacts in the form of a range shift of many species and communities on Himalayan tracts (e.g., treeline vegetation) to higher altitudes (Hamid et al. 2018; Singh et al. 2021). As a result, ecologists and conservationists are frequently trying to predict suitable habitats and/or estimate the spatial distribution of Rare, Endemic and Threatened (RET) as well as Medicinal and Aromatic Plant (MAP) species in different climate scenarios using machine learning techniques and models like GARP, DOMAIN, GAM, MaxENT, etc. (Stalin et al. 2015; Felix Ribeiro et al. 2021). MaxENT modelling is one of the most robust and trusted choices for species modelling using presence data (Yackulic et al, 2013). The machine-learning software MaxENT capable of creating suitable maps is generally used for ENM. The advantage of creating such maps is that these maps are useful in developing new strategies for species conservation. Such models are also helpful to work out conservation strategies even for poorly explored species (Fois et al. 2018).

Elwendia persica (Boiss.) Pimenov & Kljuykov, an economically valued species of the Apiaceae family measuring *ca.* 15-70 cm tall, is a branched perennial herb with underground bulbs (*ca.* 1-2 cm). According to “Plants of the World Online” (www.plantsoftheworldonline.org), the species has as synonym *Bunium persicum* (Boiss.) B. Fedtsch., and is native to the mountainous areas of Iran, especially Khorasan, Kerman, Fars, Hamadan, Tehran, Mazandaran, and Semnan provinces. Seeds are sold as a well-known spice in the international market.

The aqueous and alcoholic extracts of the seeds are reported to have diuretic, antioxidant, antibacterial, antifungal, anti-toxoplasmosic, hypoglycemic, hypolipidemic, antiapoptotic, anti-carcinogenic, anti-mutagenic, bronchodilatory, anticholinergic, antihistaminic, antinociceptive, hypolipidemic, anticonvulsant, and anti-fertility activities (Shahsavari et al. 2008; Talei et al. 2009). Seeds are used by local people to cure back pain, liver problems, and gastrointestinal disorders (Thakur et al. 2020). According to Mardani et al. (2015), demand for seeds of *E. persica* is rapidly increasing while its habitat is shrinking across the country because of overheating of the atmosphere. Therefore, the principal aim of this work is to predict the potential habitats of *E. persica*, an important MAP species for current and future climatic scenarios in the Indian Himalayan Region (IHR).

2. Materials and Methods

2.1 *Data collection and threat assessment:*

Elwendia persica grows in forests, grassy slopes, and to some extent in low alpine pastoral lands between 1850 to 3100 m above mean sea level. The species is also reported from Afghanistan, Pakistan, China, Kyrgyzstan, Tajikistan, Uzbekistan, and Turkmenistan. In India, the species is reported from the high altitudes of Jammu and Kashmir (JK), Ladakh (LA), and Himachal Pradesh (HP). The fruits are black-brown, oblong, slightly curved, 3-4 mm long with prominent ridges and flat stylopodium; styles are reflexed; furrows 1-vittate; commissure 2-vittate; vittae large (Nasir and Ali 2005). Because of seed colour, this plant species is commonly called ‘Black Caraway’, ‘Black Cumin’, or ‘Kala Zeera’. *E. persica* is believed to be originated in the area between Central Asia and northern India (Sofi et al. 2009). The seeds are used as spice wherein the flavour of the seeds is due to the presence of γ-terpinene and p-cymene (Chizzola et al. 2014).

Individuals of *E. persica* were collected from sandy calcareous and clayey soils of grassy slopes and mounds of agricultural fields in Padder valley of JK. The collected specimens were identified using taxonomic keys published in various floras (Nasir and Ali 2005; Hooker 1975-97; Sharma and Kachroo 1993) and deposited to the herbarium of the Department of Botany, University of Jammu (HBJU). The species was collected from six locations in JK and the rest of the presence data was obtained from GBIF as well as already preserved specimens.

To understand completely the distribution of *E. persica* in NW Himalaya, we used three data sources to generate ENM. First, field data from JK collected and recorded six populations (occurrence records) of the species. Additional data on seven occurrence records were obtained from the Global Biodiversity Information Facility (https://www.gbif.org accessed on July 16, 2019) and the third dataset was generated from already preserved specimens in two regional herbaria namely Janaki Ammal Herbarium (acronym: RRLH) and Herbarium of Department of Botany, University of Jammu (acronym: HBJU). Initially, the obtained data were cleaned up by plotting occurrence records on the open-source facility Google EarthPro after which R-4.0 software was used for data thinning through the *spThin*- package (Aiello-Lammens et al., 2015). After cleaning, 26 occurrence records for JK, LA and LA were used to generate the ENM for the species in IHR.

As the species is an economically important herb, people were interviewed in the field to understand the status of anthropogenic threats on the species. GeoCAT minimum convex polygon method was used to assess the threat status of the species in JK, LA, and HP. The refined data on occurrence records were used to measure the area of occupancy (AOO) and extent of occurrence (EEO) at the spatial scale of 10^2 km in the study area.

2.2 *Environmental variables*:

We used 10 environmental variables, out of which seven were obtained from the WorldClim (version 1.4) database at the resolution of 1 km^2, two topographical variables (elevation and mountain aspect) were generated through SRTM-DEM data downloaded from a dedicated website of the United States Geological Survey (https://earthexplorer.usgs.gov) using open-source software QGIS version 3.16.1 and one environmental variable, i.e., human pressure, was obtained from open-source (https://sedac.ciesin.columbia.edu/data/set/wildareas-v3-2009-human-footprint/data-download). The selection of environmental variables was based on the regional climatic conditions at different occurrence points (Table 1). As topographical variables are fixed and did not change over the period of time, the same data was used for current and future projections, whereas the multicollinearity problem was removed using R-4.0 software. Important climatic variables were selected through VIF correlation in the *usdm*-package. A total of 12 variables (bio1, bio3, bio5, bio6, bio7, bio9, bio11, bio12, bio13, bio16, bio17, bio18) from the 19 input variables have collinearity problem. After excluding the collinear variables, the linear correlation coefficients ranging between minimum 0.01517605 (bio10 ~ bio4) to maximum 0.9012836 (bio14 ~ bio10) were used for ENM (Table 1).

Table 1: List of different environmental variables used in ecological niche modelling after multi-collinearity test.

S.No.	**Variables and their description**	**Variance inflation factors (VIFs)**	**Temporal scale**
1.	bio2 – Mean diurnal range (Mean of monthly (max temp - min temp))	1.850742	Variation
2.	bio4 – Temperature seasonality (Standard deviation*100)	2.443821	Variation
3.	bio8 – Mean temperature of wettest quarter	2.785470	Quarter
4.	bio10 – Mean temperature of warmest quarter	8.984852	Quarter
5.	bio14 – Precipitation of driest month	8.724363	Month
6.	bio15 – Precipitation seasonality (Coefficient of Variation)	2.161488	Variation
7.	bio19 – Precipitation of coldest quarter	8.308532	Quarter
8.	SRTM-DEM	NA	Continuous
9.	Mountain aspect	NA	Variation
10.	Human footprint	NA	Variation

2.3 *Model tuning and procedure*:

MaxENT (version 3.4.1) is a java-based-machine learning software that operates on the Maximum Entropy theory (Jaynes 1957). It estimates the probability of distribution of a species based on environmental variables, therefore, requires presence data with background points and environmental data. It is an efficient tool that projects current climatic and environmental data to future climate scenarios (Phillips et al. 2006). Geographical coordinates of the study sites were converted into degree decimal form (.csv format) to use as input data in MaxENT. Further, the screened environmental data transformed to ASCII using QGIS version 3.16.1 was also used as input data. Thus, point distribution data as dependent variables and spatial data on environmental variables as environmental layers were used to run the model. MaxENT interface was set at 30% data random test and 70% training data.

2.4 *Model validation and suitability analysis*:

The models were made to run on 10 replicates (subsample) to obtain Receiver Operating Curves (ROC), Area Under Curve (AUC), pictures of predictions, and Jackknife simulations (Phillips et al., 2006). Values of AUC above 0.7 indicate good performance of the model and are supposed to be efficient predictors of habitat suitability (Swets, 1988; Elith et al., 2011). Therefore, to measure the model performance, the average AUC for the replicate run was utilized as suggested by Swets (1988). Variable value was determined by Jackknife simulation. Suitability maps generated were processed for presentation in QGIS version 3.16.1.

3. Results

3.1 *Threat status*

Interview with local people in the study area revealed that unscientific collection of ripened speeds and consumption of young plantlets by domesticated grazers are serious local threats to the species. Padder valley in NW Himalaya is the summer destination for nomadic tribals (Dutt et al, 2015). Consumption of raw tubers of *E. persica* by the nomads is another unseen threat to the survival of the species. GeoCAT minimum convex polygon method has also demonstrated the EOO of the species as being 20,977.363 km^2 and AOO 1800 km^2 at 10-km^2 grid size, which reveals the narrow distribution range and the vulnerable status of the species in NW Himalaya of the IHR (Figure 1). The narrow distribution range and vulnerable status has driven the predictive suitability modelling of the species. Despite several cultivation trials, mass cultivation of the species is still under experimentation. The reason may be the selection of non-suitable or low potential agro-climatic regions for the cultivation of the species.

3.2 *Model performance and Jackknife test*

According to Swets (1988), an AUC above 0.9 is excellent model performance and acceptable for the given training and testing data (Supplementary file 1). Jackknife test of regularized training data revealed that the environmental variable with the highest gain, when used in isolation, is bio19, which therefore appears to have the most useful information by itself, whereas environmental variables bio08 and bio04 appear to have the most information that is not present in the other variables (Supplementary file 2).

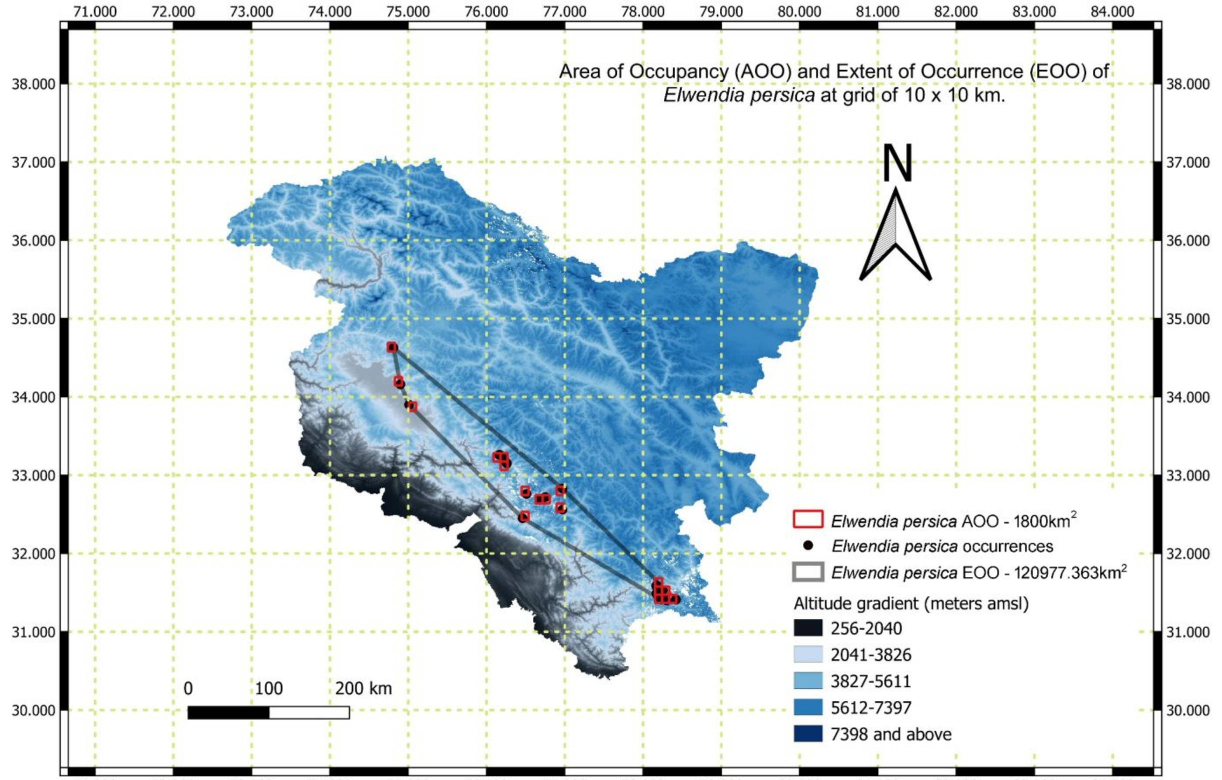


Figure 1: Extent of occurrence (EOO) and Area of occupancy (AOO) of *Elwendia persica* (Boiss.) Pimenov & Kljuykov in the Indian Himalayan Region (IHR).

3.3 *Response curves and environmental variables:*

According to the response curve, increasing elevation in the study area has no significant role in deciding the suitable habitat of the species whereas the south eastern aspects of the mountains are predicated as suitable slopes for habitat extension. The human footprint is also predicted as a significant factor in the extension the suitable habitat of the species in the study area (Figure 2). Further, habitat suitability will increase with the increase in “mean diurnal range” (bio2) in both the current and future climatic scenarios, whereas “temperature seasonality” (bio4) will play a negative role in the habitat suitability of *E. persica* and the same prediction is for the “mean temperature of the wettest quarter” (bio8). Mean temperature of the warmest quarter (bio10) has no major role to play in the extension of shrinking of the habitat of the species, however, “precipitation of the driest month (bio14)” and “precipitation seasonality (bio15)” will negativity influence the habitat of the species in IHR. Response curves also suggest that “precipitation of coldest quarter (bio19)” is a significant climatic factor in increasing the habitat suitability of the species in current and future climatic scenarios (Figure 3).

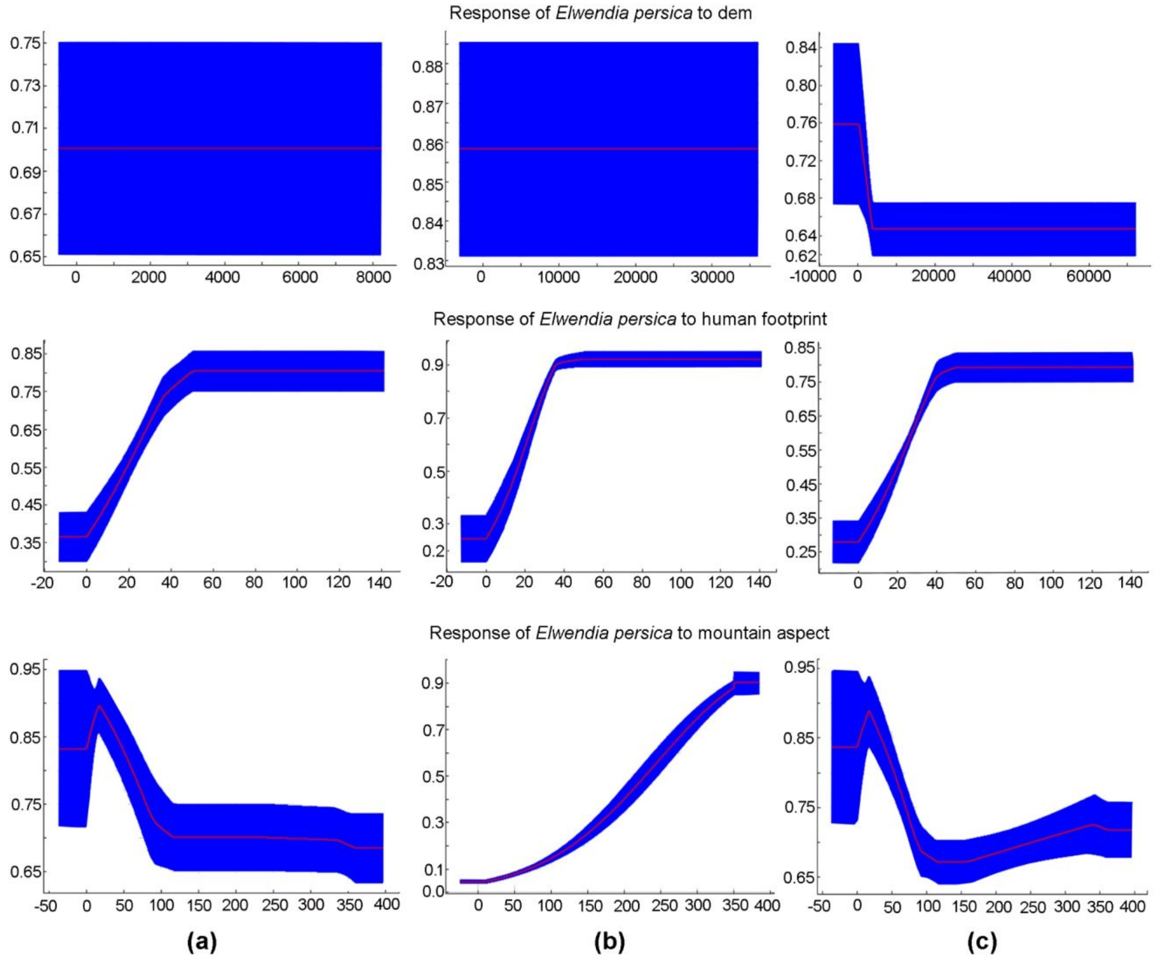
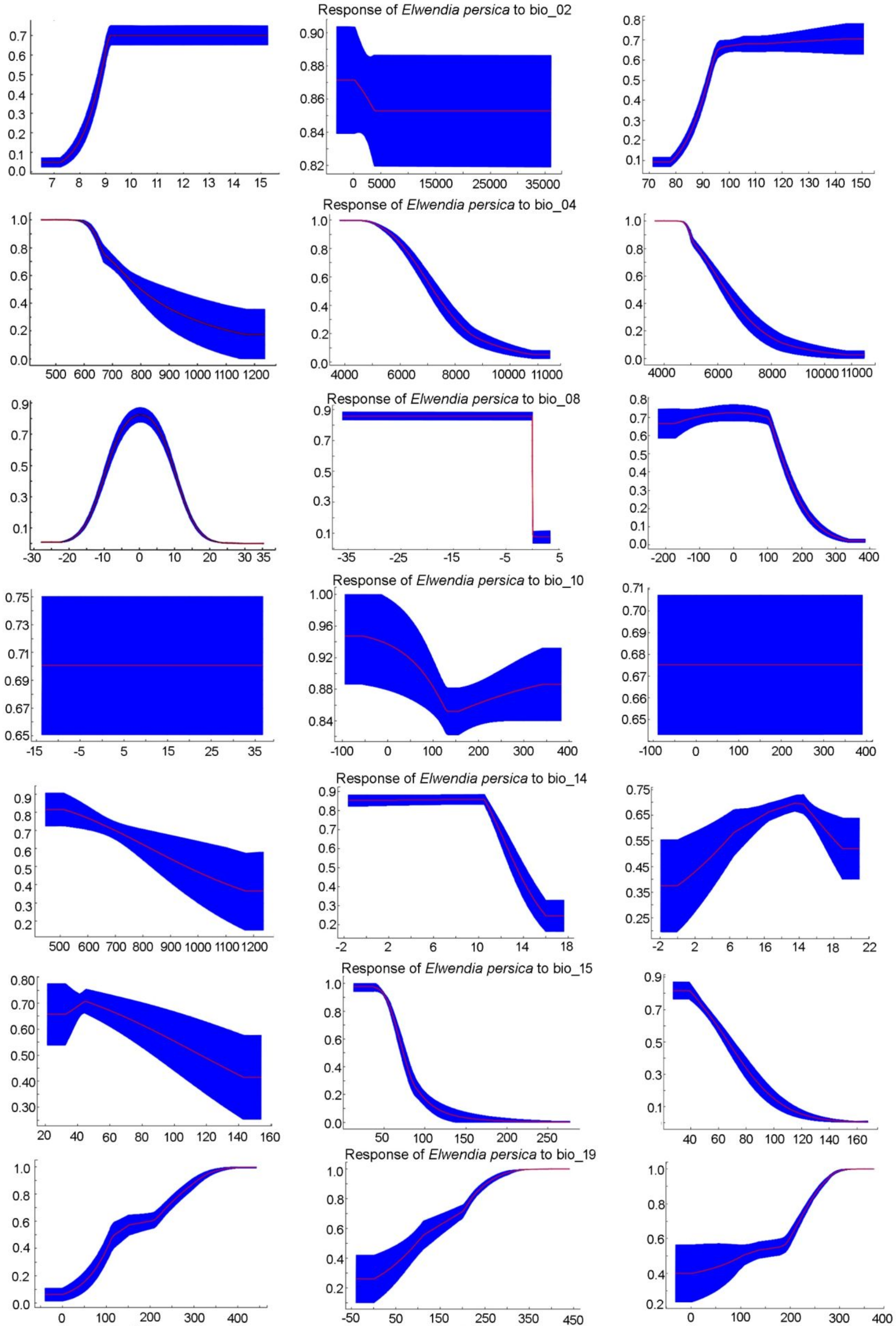


Figure 2: Response curves showing effect of topographic variables and human footprint on habitat suitability of *Elwendia persica* (Boiss.) Pimenov & Kljuykov in current (a) 2000 and future (b) 2050 (b) 2070 climatic scenarios.


Response of *Elwendia persica* to bio_02

Response of *Elwendia persica* to bio_04

Response of *Elwendia persica* to bio_08

Response of *Elwendia persica* to bio_10

Response of *Elwendia persica* to bio_14

Response of *Elwendia persica* to bio_15

Response of *Elwendia persica* to bio_19

(a) (b) (c)

Figure 3: Response curves showing effect of different bioclimatic variables on habitat suitability of *Elwendia persica* (Boiss.) Pimenov & Kljuykov in current (a) 2000 and future (b) 2050 (b) 2070 climatic scenarios.

3.4 *Predicting habitat suitability*:

The geographical areas of JK, LA, and HP in northwest Himalaya of IHR cover 2,77,909 km^2. According to the model, *ca*. 3132.7 km^2 (1.1%) is the most highly suitable habitat for *E. persica* in the current (2000) climatic scenario. The model predicts *ca*. 2.03% increase in highly suitable area (6613.3 km^2) for the species in 2050 future climatic scenario in the NW Himalaya, whereas in the 2070 future climatic scenario the suitable habitat for the species is likely to get shrunk to 0.9% (*ca*. 2737.3 km^2). The habitat suitability maps of *E. persica* under present and future climatic scenarios indicate that the habitat of the species will increase slightly by 2050 and then decrease by 2070 (Figure 4-6; Table 2).

Table 2: Suitable habitat of *Elwendia persica* (Boiss.) Pimenov & Kljuykov (area in km^2)

Suitability category	2000 Scenario	2050 Scenario	2070 Scenario
Not suitable	250652.7 (90.1%)	231758.02 (83.3%)	248813.6 (89.5%)
Less suitable	15407.4 (5.5%)	21291.9 (7.6%)	17012.8 (6.1%)
Marginally suitable	6135.6 (2.2%)	10270.5 (3.6%)	6482.9 (2.3%)
Moderately suitable	2580.2 (0.9%)	7974.7 (2.8%)	2862.3 (1.0%)
Highly suitable	3132.7 (1.1%)	6613.8 (2.3%)	2737.3 (0.9%)

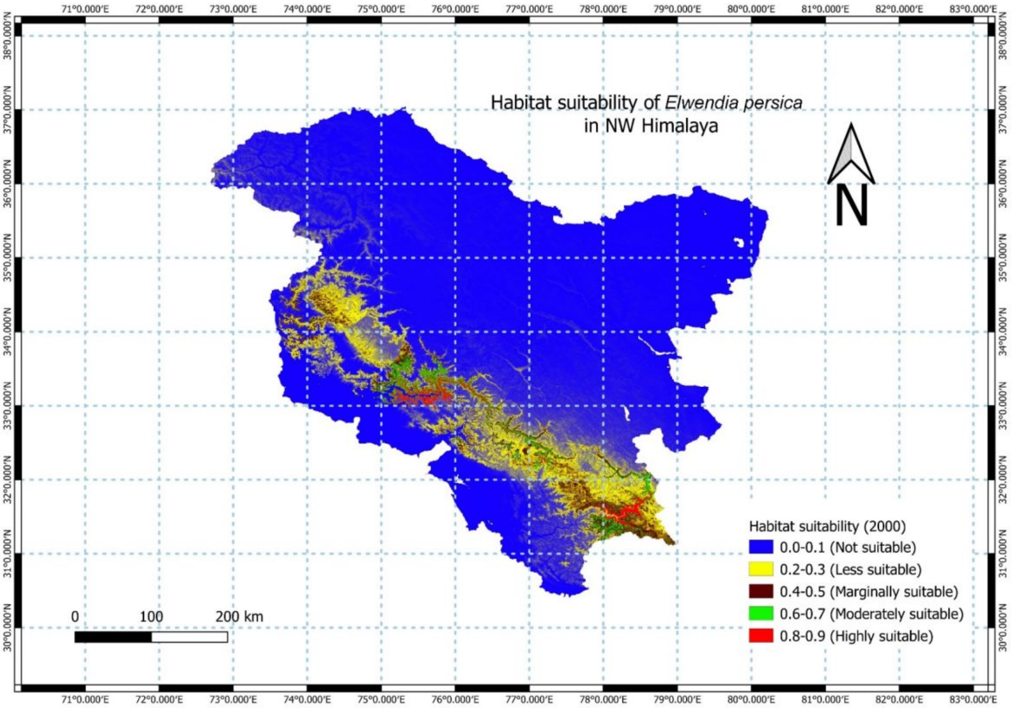


Figure 4: Habitat suitability map of *Elwendia persica* (Boiss.) Pimenov & Kljuykov in the northwestern IHR for the current (2000) climatic scenario.

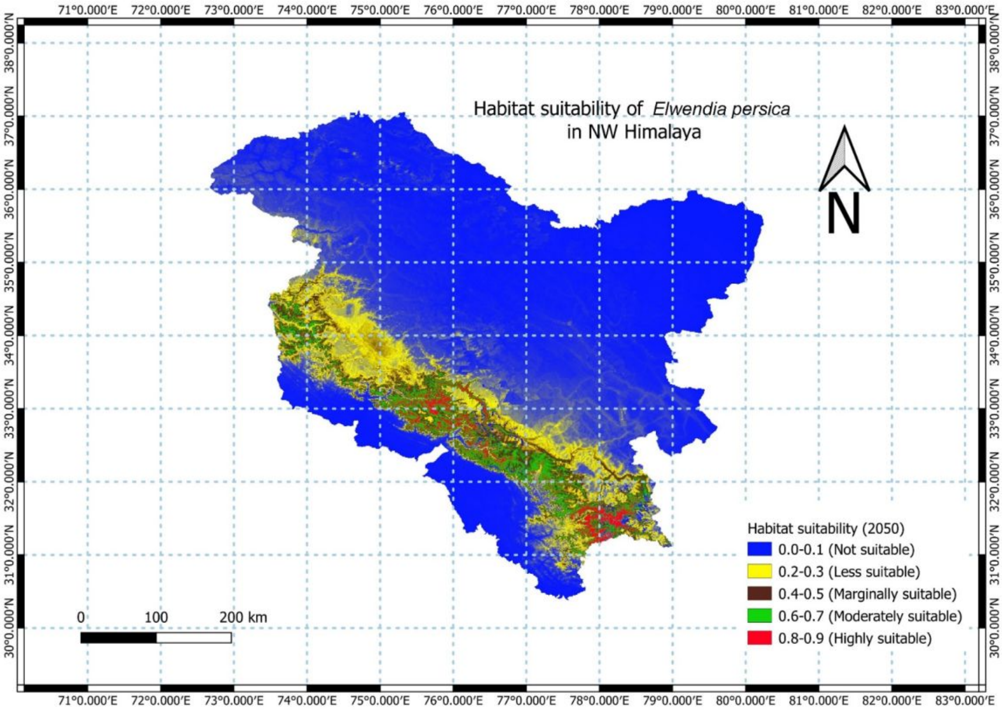


Figure 5: Habitat suitability map of *Elwendia persica* (Boiss.) Pimenov & Kljuykov in the northwestern IHR for the 2050 climatic scenario.

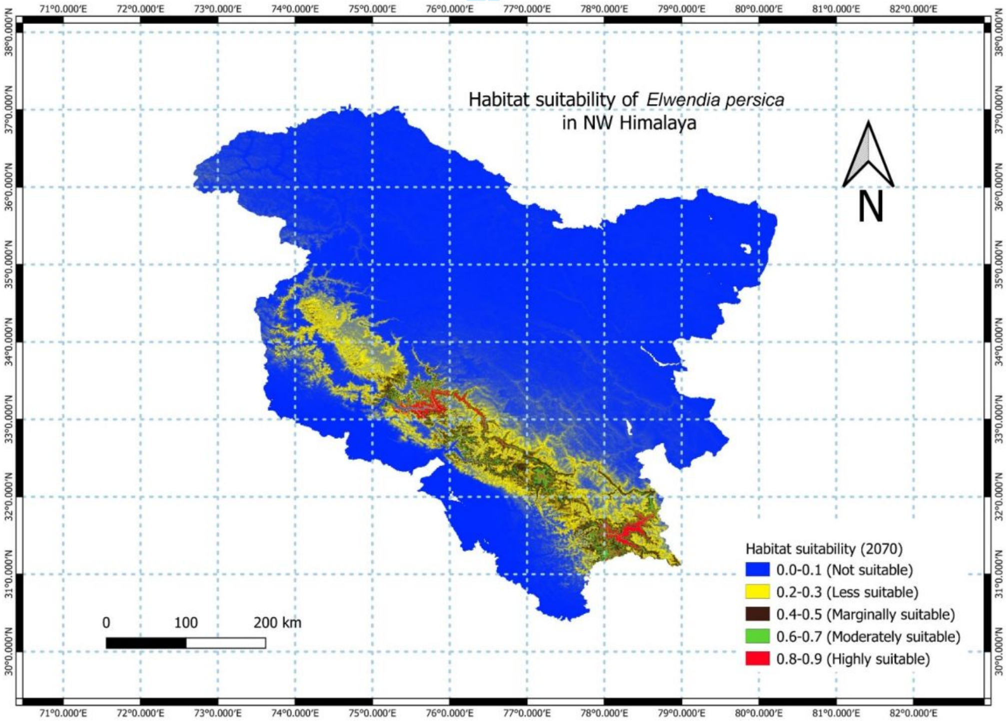


Figure 6: Habitat suitability map of *Elwendia persica* (Boiss.) Pimenov & Kljuykov in the northwestern IHR for the 2070 climatic scenario.

4. Discussion

Species distribution depends on biotic and abiotic factors (Cano et al. 2017) and alterations in any of these factors may be fatal for the habitat suitability of a given species (Perrino et al. 2021). However, this may not always be true, as some climatic or biotic alterations may increase the suitability of some species and decrease for others (Cano Ortiz et al. 2015; Motti et al.

2021). Habitats may experience degradation and move to unsuitability even when a small, indirect changes act as a source of chain events causing many other sequential alterations (Musarella et al. 2020). In such cases, species neither show resilience nor resistance and move to the next IUCN threat status category (Orsenigo et al. 2017). Therefore, before a change of the status category, detailed field studies using recent appropriate tools should be carried out to assess the threat category of rare taxa (Mendoza-Fernández et al. 2015; Orsenigo et al. 2020). The current study reveals that *E. persica*, besides anthropogenic pressure like unscientific collection and overgrazing, also faces an unseen threat of consumption of tubers by nomads. The species is an important bioresource as its seeds are commercially important spices in developing as well as developed countries. Medicinally the species is of immense importance and generally used as carminative by the local people. Because of its worldwide importance and imposed threat, its conservation becomes a thrust area particularly in changing climatic conditions. The species grows naturally in specific areas of the world, therefore for effective conservation suitable potential habitats for the species must be identified.

Ecological Niche Modelling is widely used in spatial prioritization for the selection of conservation areas (Ishihama et al. 2019). The main advantage of this technique is that it reduces fieldwork efforts. Climate change is considered a strong driving force for triggering alterations in many ecological factors as a result of which vulnerable species become extinct (del Río et al. 2018). The MaxENT algorithm is an appropriate modelling technique that (i) requires presence data only, (ii) is efficient for running continuous and categorical data together, (iii) is more reliable on small sample size, (iv) directly produces habitat suitability maps, (v) produces Jackknife outputs to evaluate the role of the single environmental variable, and (vi) directly provide of response curves for each environmental variable determining habitat suitability (Fois et al. 2018; Phillips et al. 2006; Boogar et al. 2019).

Anthropogenic activities like unscientific collection of seeds, overgrazing and consumption of tubers are some unseen threats for *E. persica*. The species grow in well-drained, slightly acidic soils in the northwestern part of the IHR. The AOO of the species in NW Himalaya indicates that *E. persica* is a vulnerable (V) herb in IHR (Figure 1). Many such threatened species, like *Homonoia riparia* Lour., *Ilex khasiana* Purk., *Justicia adhatoda* L., *Fallopia japonica* (Houtt.) Ronse Decr. (Synonym of *Reynoutria japonica* Houtt.), and *Juniperus* spp. are subjected to ecological niche modelling, so that appropriate conservation approaches can be established (Cano Ortiz et al. 2015; Boogar et al. 2019; Beerling et al. 2009; MacLaren et al. 2016). In our study, the model has given dramatic outputs estimating the highly suitable habitat of *E. persica* (Figure 4-6; Table 2). Therefore, the obtained map suggests that the maximum suitable habitat of *E. persica* will be in the year 2050 which is likely to decline by the year 2070. The habitat suitability of the species will depend upon environmental variables that are directly linked to climate change.

The environmental variables which will influence positively towards the habitat suitability of *E. persica* in IHR are human footprint, mountain aspect, temperature seasonality and precipitation of the coldest quarter. The probable reason for the positive influence of human footprint on the habitat suitability of the species is indicated by the fact that humans being the major consumers of the species and may help in seed dispersal in future scenarios. South-eastern aspect of the mountain due to maximum exposure to sun radiations figures less moisture in the soil which is a promising environmental condition for geophytic or cryptophytic species like *E. persica*. It is also understood that the seeds of the species remain in dormant state during winter and germinate once snow in the field gets melted down. Therefore, a chilling treatment of 3-5 ^{O}C is recommended for the maximum germination of species from seeds (Thakur and Dutt 2019). Subsequently, adequate temperature seasonality (bio02) and prolonged precipitation of the coldest quarter (bio19) may trigger the breaking of seed and bud dormancy of the species.

5. Conclusions

In the IHR, *E. persica* has a narrow distribution range as it naturally grows in few regions like LA, JK and HP in the northwestern part of the region. It is enormously exploited for its seeds, which are used as spice throughout the world. In addition, the seeds, considered as medicinally important parts of the plant, are also used for treating various disease and ailments. Overexploitation of the species is responsible for the shifting of *E. persica* to the list of vulnerable plants therefore, its suitable habitats for three climatic scenarios 2000, 2050 and 2070 were predicted through MaxENT models. AUC suggested that the model is acceptable for the given training and testing data. According to the model, the maximum gain in suitable habitat for the species will be during 2050 climatic scenario. Further, the model has also predicted the dependency of habitat suitability on environmental variables like human footprint, mountain aspect, temperature seasonality and precipitation of the coldest quarter. It can be concluded that the changing climatic conditions will act moderately on the different habitat of the species in IHR.

Acknowledgments

Authors are thankful to the Head, Department of Botany, University of Jammu, Jammu as well as Co-ordinator (University Grant Commission-Special Assistance Programme-DRS-II), Department of Botany, University of Jammu, Jammu for all the necessary facilities provided for completing this study. Authors are also obliged to Director of ISRO-IIRS, Dehradun, India, and Head, Forest, and Ecology Development ISRO-IIRS, Dehradun, India for providing the training with respect to ecological modelling. Dr. Puspinder Jamwal is also acknowledged for his technical help during the execution of the modelling program.

Funding

No funding was received for this study

Conflicts of Interest

The authors declare no conflict of interest.

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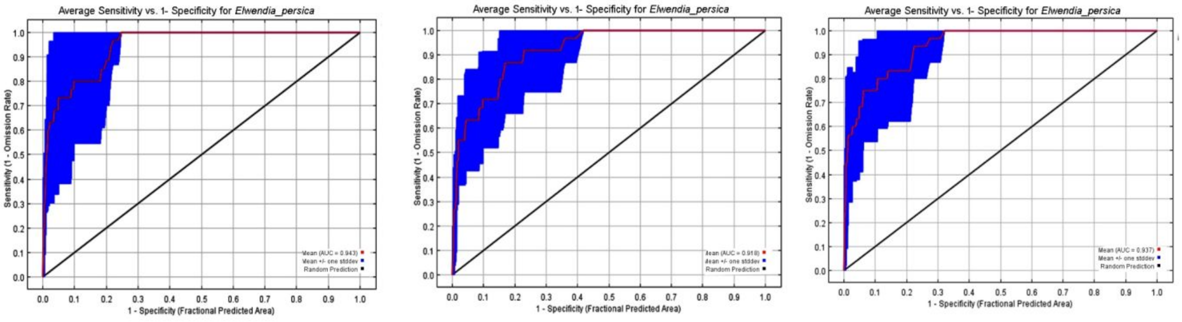
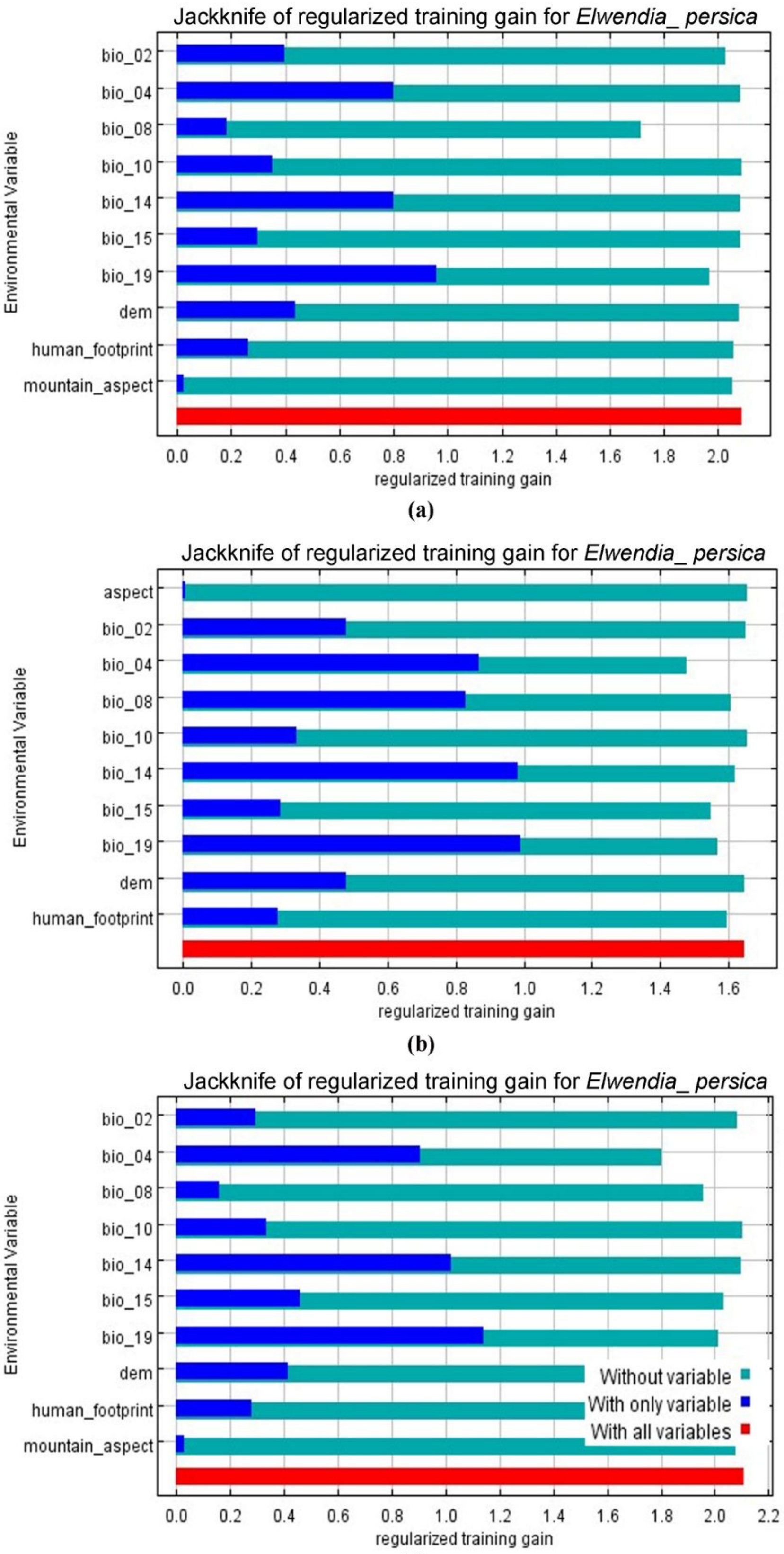
Supplementary files



(a) (b) (c)

Supplementary file 1: AUC curves for current (a) 2000 and future (b) 2050 and (c) 2070 climate scenarios for *Elwendia persica* (Boiss.) Pimenov & Kljuykov. Blue area is the average deviation for average testing data on AUC-area under receiver operating curve (ROC) (red line) for the replicate run.



(a)

(b)

(c)

Supplementary file 2: The result of the Jackknife test of environmental variable's relative contribution of environmental variables in modelling of *Elwendia persica* (Boiss.) Pimenov & Kljuykov habitat suitability in three climatic scenarios (a) 2000 (b) 2050 and (c) 2070.

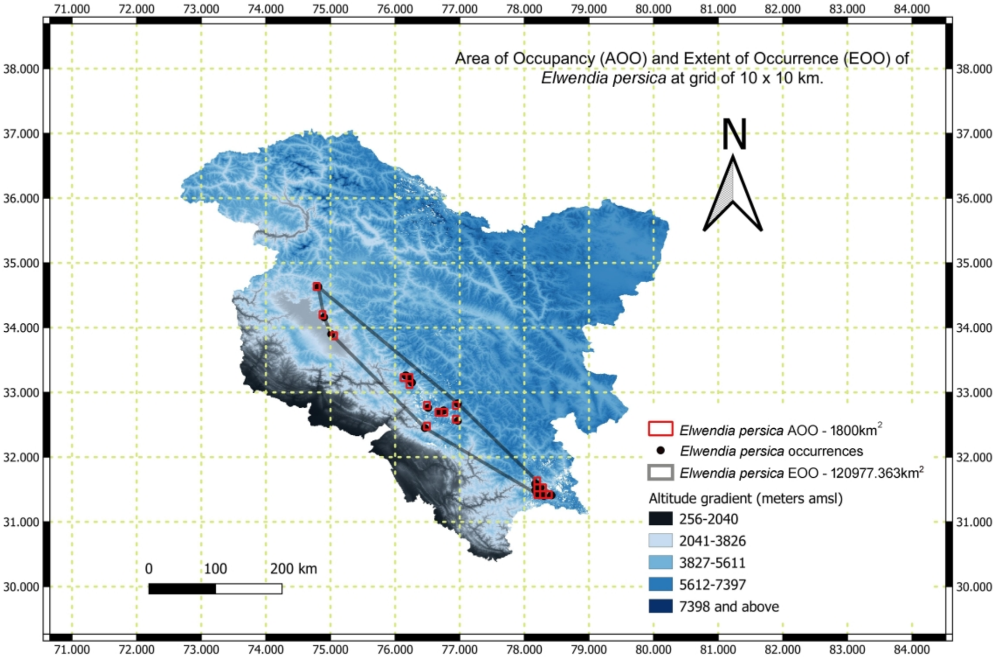


Figure 1: Extent of occurrence (EOO) and Area of occupancy (AOO) of *Elwendia persica* (Boiss.) Pimenov & Kljuykov in the Indian Himalayan Region (IHR).

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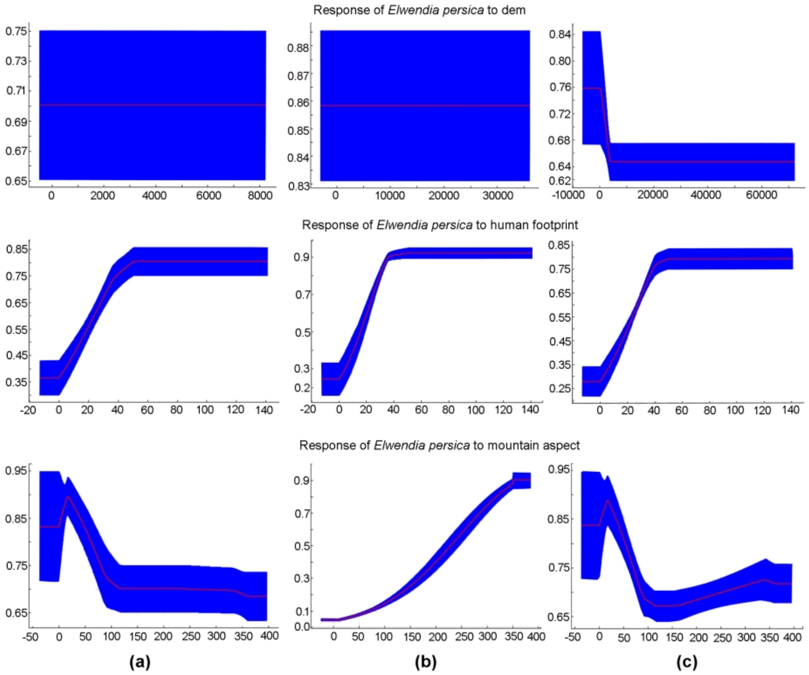

Figure 2: Response curves showing effect of topographic variables and human footprint on habitat suitability of *Elwendia persica* (Boiss.) Pimenov & Kljuykov in current (a) 2000 and future (b) 2050 (b) 2070 climatic scenarios.

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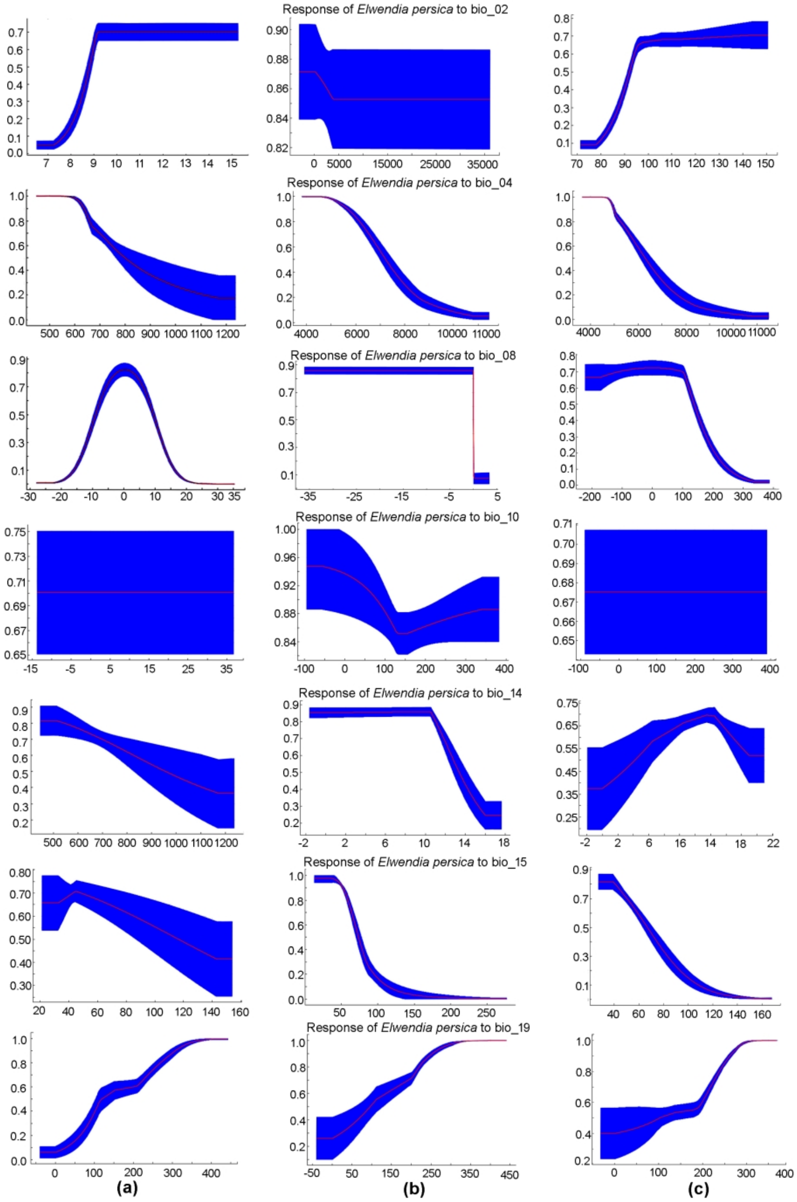

Figure 3: Response curves showing effect of different bioclimatic variables on habitat suitability of *Elwendia persica* (Boiss.) Pimenov & Kljuykov in current (a) 2000 and future (b) 2050 (b) 2070 climatic scenarios.

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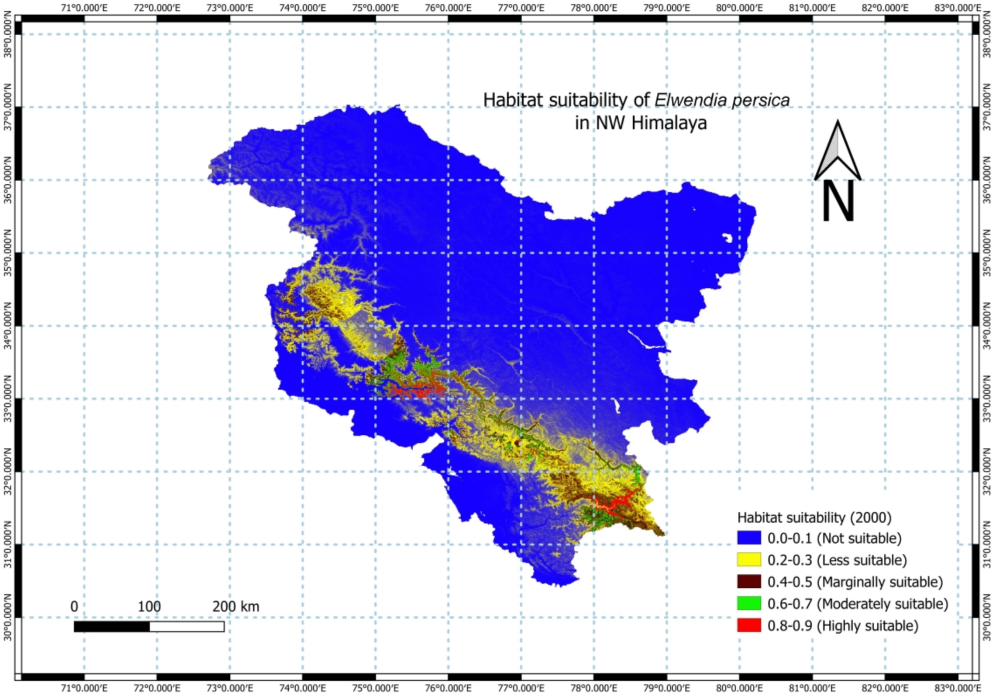

Figure 4: Habitat suitability map of *Elwendia persica* (Boiss.) Pimenov & Kljuykov in the northwestern IHR for the current (2000) climatic scenario.

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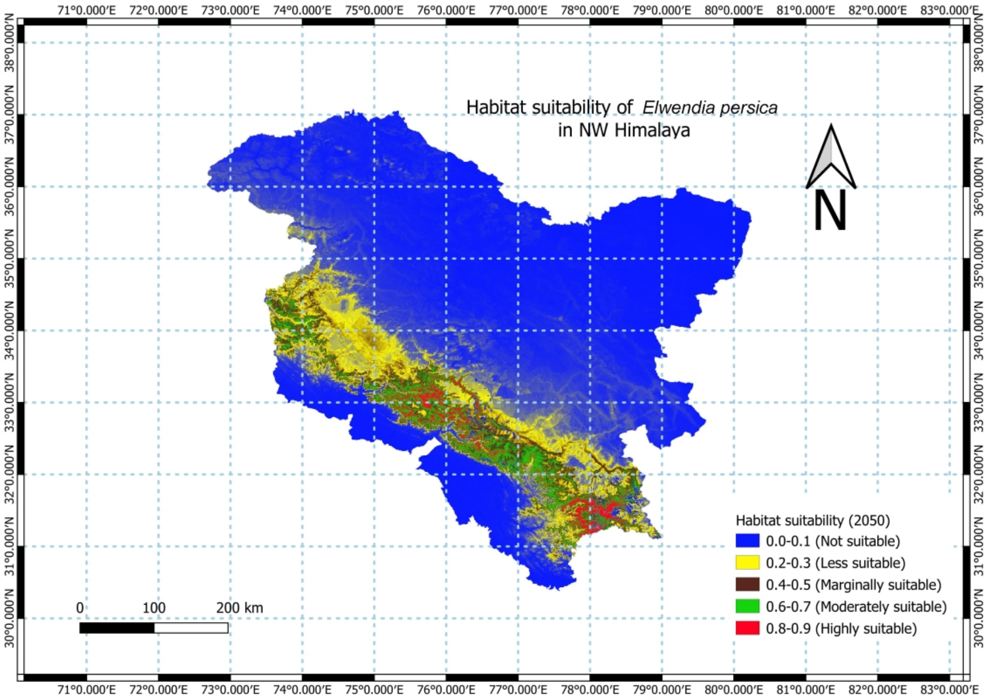

Figure 5: Habitat suitability map of *Elwendia persica* (Boiss.) Pimenov & Kljuykov in the northwestern IHR for the 2050 climatic scenario.

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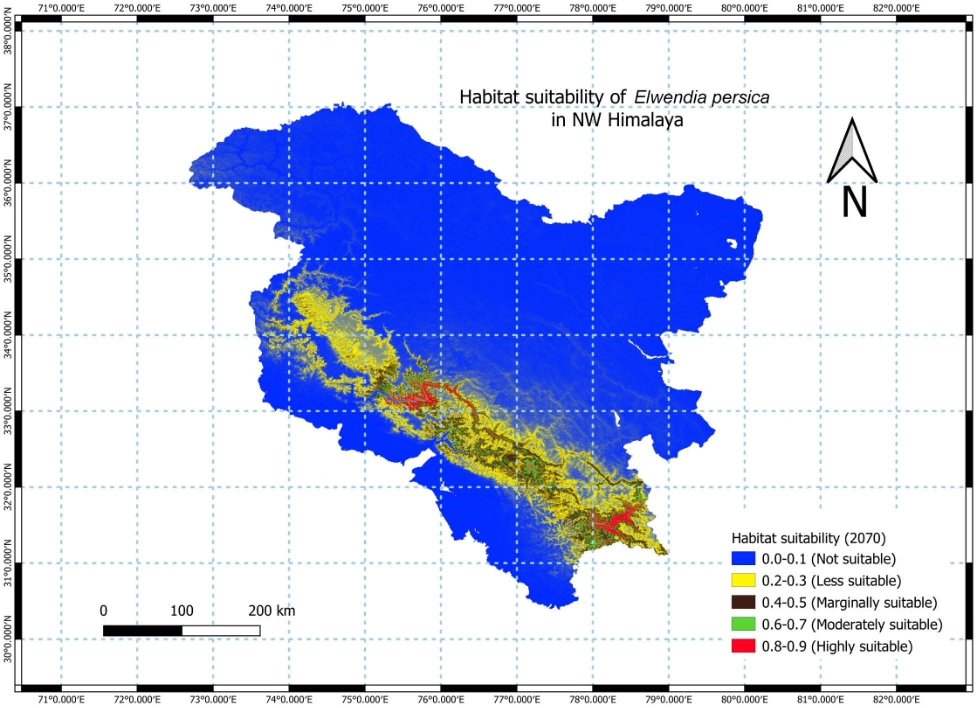

Figure 6: Habitat suitability map of *Elwendia persica* (Boiss.) Pimenov & Kljuykov in the northwestern IHR for the 2070 climatic scenario.

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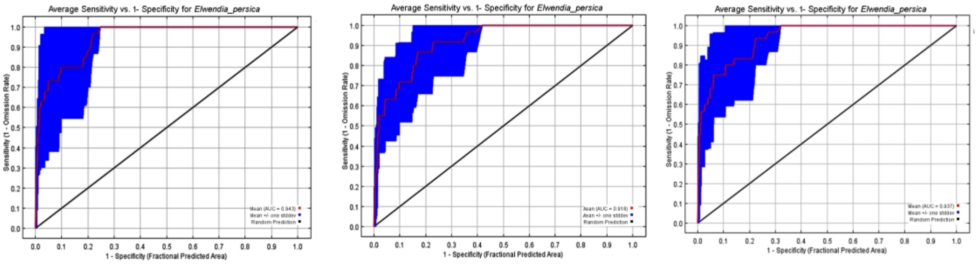

(a) (b) (c)

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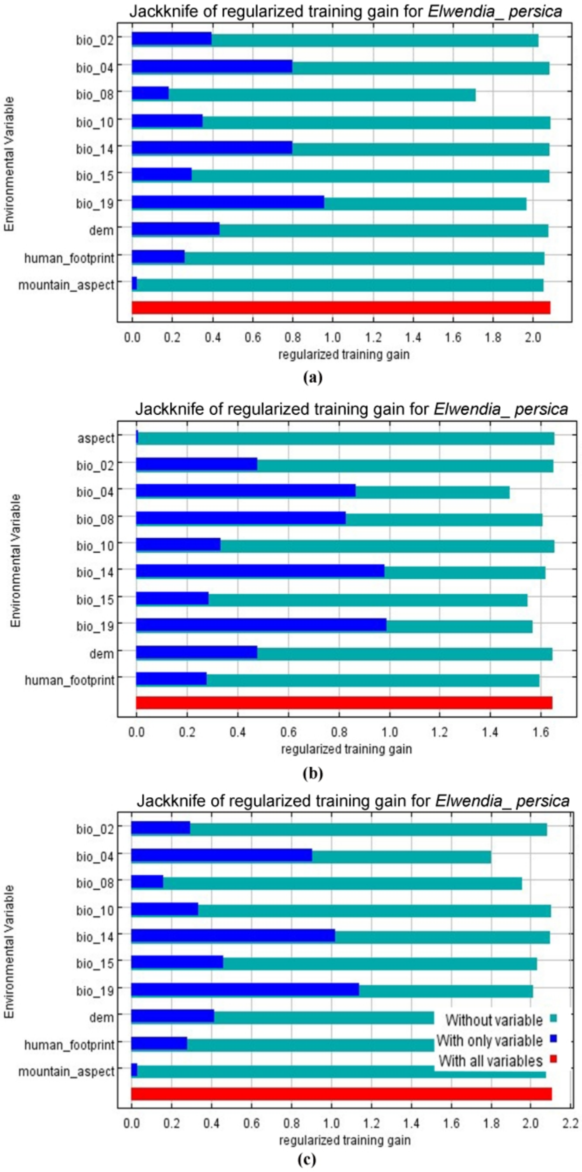

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