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Research article

Predicting habitat suitability of *Selaginella adunca* A.Br. ex Hieron., an endangered and endemic fern-allies of Western Himalaya

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Abstract: *Selaginella adunca* is a quite distinct and rare species of *Selaginella* found in Western Himalaya. This species is reported only from few populations occurring in India and Nepal. Since most of its reported habitats are under anthropogenic pressure, therefore for proper conservation of this species it is necessary to mark the suitable habitat for its conservation and reintroduction. The present study was aimed to find out the suitable habitat of this species through ecological niche modelling (ENM) technique using Maxent model. This will also help in relocating the species in other preferred habitat type and its reintroduction as well.
Keywords: Selaginellaceae - Modelling - Pteridophyte - Threatened - Maxent.

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INTRODUCTION

Most of the threatened plants are generally habitat specific and prefers to grow in their specific niche only. For the successful conservation of these species it is necessary to have a better knowledge of their preferred habitat for the purpose of their reinforcement and reintroduction. *Selaginella adunca* A. Br. ex Hieron (Selaginellaceae) is a member of fern allies, endemic to North-West Himalayan range of India and Nepal. The species is found mostly on exposed, dry, barren rocks and hill slopes at an altitude range of 800–2200 m. In India, this species is reported only from few localities of the lower Shiwaliks and outer Himalayan range of Himachal Pradesh and Uttarakhand state.

As per the earlier workers, the species is facing threat mainly due to loss of its specific habitat (Dixit 1990). Due to the low distribution range and fragile nature of its habitat the species is considered as Endangered (IUCN 1998). However further extensive field surveys are required in suitable habitat regions to update the current status of this species as per the recent IUCN guidelines. Therefore to predict the suitable habitat for the occurrence of this species we conducted niche modeling.

MATERIAL AND METHODS

The Maxent model works on presence only data therefore field data points were collected from the field. For running the model both field data and online available datasets is required which were collected in following ways:

Survey and collection

Selaginella adunca is a rare and sporadically distributed species found in Western Himalaya. Field surveys were conducted to different localities of Indian Western Himalaya in 2015–2018 on the basis of secondary data obtained from literature and herbarium specimens to locate the species in natural condition. During the surveys, the habitat characteristics of the species were also noted along with the occurrence data points (Fig. 1).

Identification

The collected material was identified with the help of herbarium specimens and literature. Since the species is closely allied to *Selaginella jacquemontii* Spring. therefore, the collected specimens were also identified under microscope to ascertain the identity.

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Figure 1. *Selaginella adunca* A. Br. ex Hieron: **A**, Growth habit; **B**, Habitat characteristics.

Species occurrence data

Primary distributional records of the species were collected from different localities of Uttarakhand and Himachal Pradesh, India. The species occurrence geo-coordinates were recorded to an accuracy of 5–10 m using Garmin GPS e-Trex 10. These geo-coordinates were converted to decimal degrees for use in modeling software. The spatial errors were cleaned using Diva-GIS and duplicate records were discarded using MS Excel (Broennimann & Guisan 2008).

Software and spatial data

The modelling software, Maxent (version 3.3.3e) used in this study was downloaded from the link: http://www.cs.princeton.edu/~schapire/maxent/. Different bioclimatic and environmental variables were used for running the model and habitat suitability prediction which include: (i) bioclimatic variables with 1 km resolution were downloaded from http://www.worldclim.org/, (ii) topographic variables viz., elevation, slope, aspect and terrain roughness index and (iii) forest canopy height (Simard *et al.* 2011). The topographic variables i.e., slope, aspect and terrain roughness index were derived from the digital elevation model (DEM) of the study area. Of the 24 variables used in the first run, only 10 variables having higher prediction values were selected to run the final model (Table 1). SRTM 90 m digital elevation data was downloaded from Consortium for Spatial Information (http://srtm.csi.cgiar.org, Jarvis *et al.* 2008).

Table 1. Variables used in the present study.

S.N.	Variable used	Description of variable
1.	bio_17	Precipitation of Driest Quarter
2.	bio_6	Min Temperature of Coldest Month
3.	bio_14	Precipitation of Driest Month
4.	bio_13	Precipitation of Wettest Month
5.	bio_11	Mean Temperature of Coldest Quarter
6.	canopy_ht	Canopy height
7.	h_dem	Altitude (m)
8.	h_topoind	Topographic index
9.	bio_15	Precipitation Seasonality (Coefficient of Variation)
10.	h_aspect	Slope aspect

Validation of model

The grid cell pixel dimension was taken as 250 m × 250 m for running the model using maximum entropy modelling (MaxEnt version 3.3.3e, Philips *et al.* 2006). To validate the model robustness, 20 replicated model runs were executed for the species applying the threshold rule of 10 percentile training presence. Since the sample size was low we employed bootstrap technique in the replicated runs. The quality of model was evaluated on the basis of Area Under Curve (AUC) value and the model was graded as poor (AUC<0.8), fair (0.8<AUC<0.9), good (0.9<AUC<0.95) and very good (0.95<AUC<1.0) (Thuriller *et al.* 2006).

Assessment of suitable habitat

The habitat suitability regions predicted by the model were superimposed on Google Earth Ver. 6 (www.google.com/earth). For this, the predicted suitability map was exported in KMZ format using Diva GIS ver. 7.3 (www. diva-gis.org). The exported KMZ files were overlaid on satellite images in Google Earth to ascertain the actual habitat condition prevailing in the areas of occurrence (Adhikari *et al.* 2012).

RESULTS

Model calibration

To predict potential habitat for reintroduction and relocation of *Selaginella adunca*, the model calibration test for *Selaginella adunca* through MaxEnt model yielded satisfactory results (AUC_{train} = 0.998± 0.000). The average values of relative contributions of the environmental variables in the form of percent contribution and permutation importance over replicate runs are mentioned in Table 2.

To determine the first estimate, in each iteration of the training algorithm, the increase in regularized gain was added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative. For the second estimate, for each environmental variable in turn, the values of that variable on training presence and background data were randomly permuted (Elith *et al.* 2011). The model was revaluated on the permuted data, and the resulting drop in training AUC was normalized to percentages. The Jack knife results showed the test of variable importance.

The variable bio_17 has maximum percent contribution and it also showed maximum permutation importance in the model for *Selaginella adunca*. The average training AUC for the replicate runs is 0.998, and the standard deviation is 0.000 (Fig. 2). The test of variable importance is shown in the Jackknife, which also shows that the bio_17 variable is having the highest gain when used in isolation and is having the most useful information by itself to explain the model. It also decreases the gain the most when it is omitted and is, therefore, appears to have the most information that is not present in the other variables. However, h_dem (elevation) also revealed significantly higher gain as compared with the other NDVI and bioclimatic variables (Fig. 3).

Table 2. Analysis of variable contributions to the model for *Selaginella adunca* A. Br. ex Hieron.

S.N.	Variable used	Percent contribution	Permutation importance
1.	bio_17	35.9	59
2.	bio_6	23.7	12.3
3.	bio_14	12.6	18.4
4.	bio_13	11.2	0
5.	bio_11	4	0.2
6.	canopy_ht	3.7	0.2
7.	h_dem	3.1	9.5
8.	h_topoind	2.7	0.3
9.	bio_15	2.7	0.1
10.	h_aspect	0.4	0

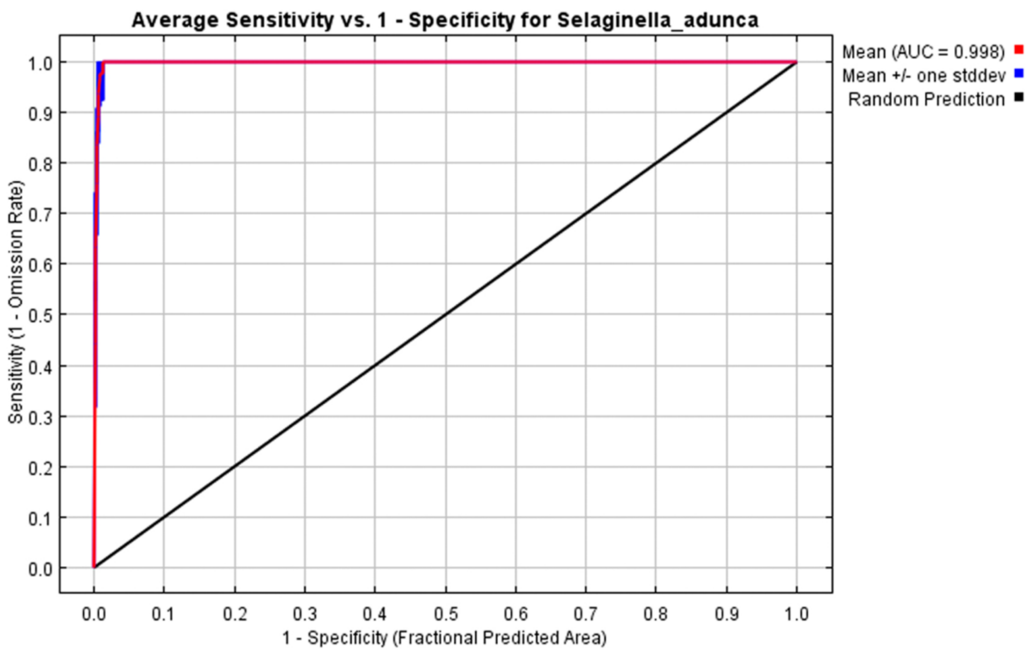

Figure 2. Receiver operating characteristic (ROC) curve for *Selaginella adunca* A. Br. ex Hieron.

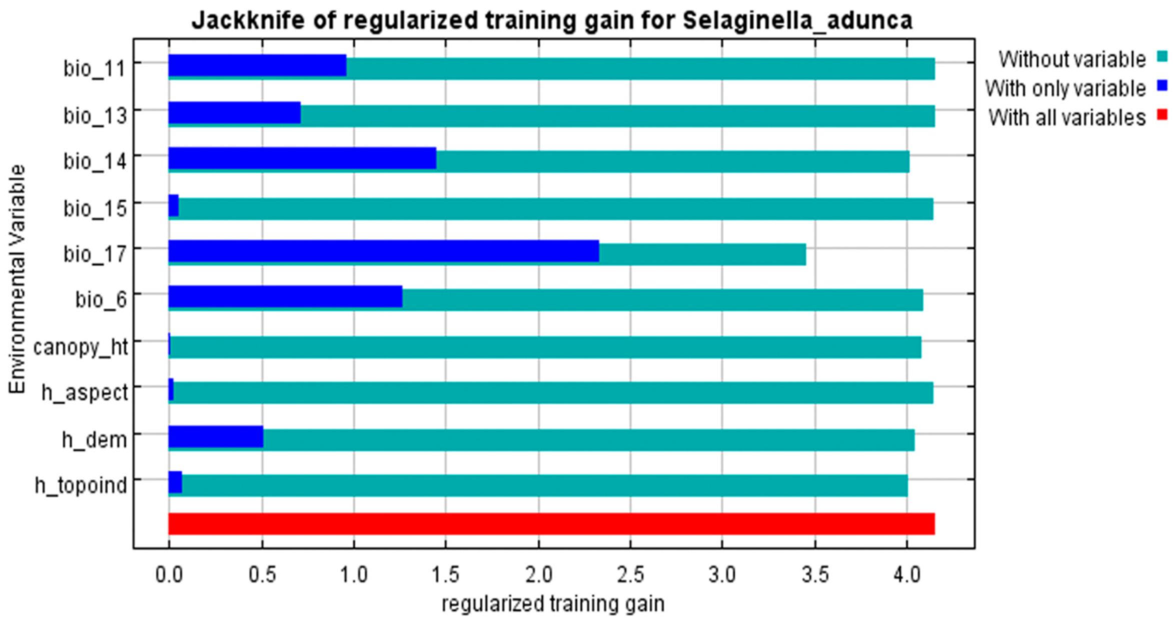

Figure 3. Jackknife test of variable importance for *Selaginella adunca* A. Br. ex Hieron: individual variable contribution (blue bar), contribution when a given variable is excluded (green bar), whole set of variables (red bar).

Habitat assessment and identification

Suitable habitats for reinforcement of *Selaginella adunca* in the predicted potential areas revealed different sites in Indian Western Himalaya and adjoining areas which could be identified as suitable environment for persistence of the species. The predicted potential habitats were superimposed on Google Earth to get a mosaic of different suitability regions. Since the species is habitat specific and grows mainly on exposed locality, the areas with higher habitat suitability form continuous patches in some of the temperate regions of Uttarakhand, Himachal Pradesh and the adjoining regions of Jammu & Kashmir. Though mosaics of high suitable areas also occur in fragmented forms along the distribution range of the species. These identified areas would act as in situ conservation area for the species and could also be used for reintroduction of the species (Fig. 4).

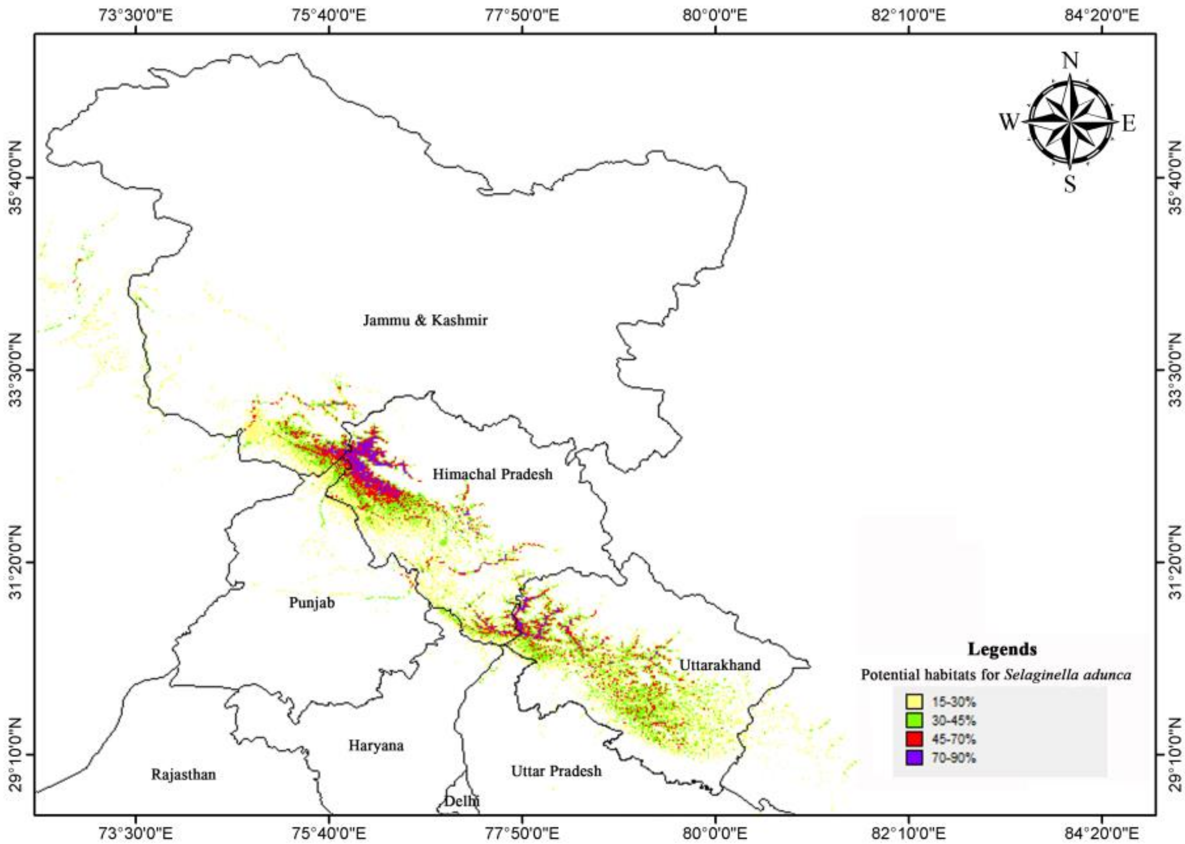

Figure 4. Map showing habitat suitability regions of *Selaginella adunca* A. Br. ex Hieron marked through Maxent.

DISCUSSION

Selaginella adunca is botanically unique in having tripartite veins which shows an advanced characteristic of this group (Mukherjee & Sen 1981, Wagner *et al.* 1982). This character makes it important for studying the evolutionary trend and phylogeny of the group. Therefore, improvement of conservation status is urgently needed for this unique and interesting pteridophyte species. Though occurrence of this species in Kumaon region of Uttarakhand is mentioned in some of the earlier records (Punetha & Kholia 1989, Punetha *et al.* 2013) but during the field surveys in those localities the species could not be traced out. Also the habitat suitability of model shows westward distribution of this species. Extensive field surveys are required in the areas under high suitability range to locate new population of this species in those regions. This will also help in redefining the conservation status of this species in future.

The model prediction in the present study has showed good overall performance along the distribution range of this species. However it has also predicted habitat suitability regions outside the known distributional range of *Selaginella adunca* which indicates possible occurrence of this species in these regions or suitable areas for its reintroduction and conservation. The high AUC values (>90) for training indicate that the model has a good prediction and well differentiated between presence and absence areas for this species. Moreover, it has successfully predicted most of the validation points in the Indian subcontinent, showing its fair transferability. On the basis of these results it can be said that the species has conserved its original niche properties in the Western Himalayan region of Indian subcontinent. However, the lower degree of prediction probability for some of the validation points hints at the possibility of a niche shift for the species, which has to be studied further.

CONCLUSION

The natural populations of *Selaginella adunca* are facing various anthropogenic threats due to mining, road broadening, forest fire, quarrying etc. resulting in deplete of its population. The propagation of this species through spores requires specific conditions which are difficult to maintain in the garden. Though the species proliferates easily through vegetative means with the help of its subterranean stem and can be propagated by dividing the clumps but the very existence of it lies in conservation of its specific habitat type. Though the present study has marked suitable habitat for this species but it requires further ground validation. The present study demonstrated that habitat distribution modelling could be of great help in predicting the potential habitats of threatened species for reintroduction as well as reinforcement.

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