Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

Population Assessment and Ecological Niche Modelling of Threatened Medicinal Plant Species (*Ephedra Gerardiana* Wall. Ex Stapf) in Cold Desert Biosphere Reserve, Trans Himalaya - An Approach for Conservation and Reintroduction

Deepti Negi, Harish Chandra Joshi
Uttarakhand Open University (UOU), Teenpani, Haldwani-263139, Nainital, Uttarakhand, India

Sher Singh Samant
Uttarakhand State Council for Science and Technology (UCOST), Manaskhand Science Centre,
Almora-263601, Uttarakhand, India

Abstract - The high altitude cold desert regions are the richest store house of many high value medicinal plants. *Ephedra gerardiana* Wall. ex Stapf is one of the oldest xerophytic shrub found in arid and semi arid regions of Cold Desert Biosphere Reserve (CDBR), Trans Himalaya. *Ephedra* is a good source of essential phytochemicals and traditionally being used to treat various diseases. Therefore, present study is an attempt to make effective conservation strategies on the basis of population assessment and niche modelling approach for its successful reintroduction in the BR. We found 34 natural populations of *E. gerardiana* across entire BR; the density was ranged between 5-245 individual/25m^2. Maximum density was observed in dry alpine slope, scree and bouldary habitats. Maximum entropy distribution modelling output reveals that only 6.9% area of the whole BR is highly suitable for its growth and development. Strong correlation exists between species occurrence and bioclimatic variables. Precipitation seasonality and precipitation of the coldest quarter are the most influential variables. Low density population of *E. gerardiana* (modelling result) can be taken under consideration for monitoring and reintroduction. Thus, population assessment and niche modelling together provide useful recommendations for restoration and designing short and long term conservation planning.

Keywords: Ecological niche modelling, Cold Desert Biosphere Reserve, Bioclimatic Variables, MaxEnt, *Ephedra gerardiana*.

1. INTRODUCTION

Biodiversity is the necessity for survival of humans and all other species on earth, without it ecosystems would be more vulnerable to climate change and natural calamities. After the 1992 Earth Summit, the consequences of biodiversity loss and its importance in regulating ecosystem functioning is taken into consideration. Himalaya the youngest mountain range of the world is one of the richest stores house of biodiversity and famous for its wide landscape and diverse ecosystems with incredible floral and faunal diversity. Beyond the Himalaya, there is a typical cold desert region, characterized by harsh climatic condition, limited growing season, sparsely distributed vegetation, fast blowing wind, high altitude, glacier-fed rivers, snow covered mountains etc. The cold desert region of Lahaul and Spiti district of Himachal Pradesh is designated as Cold Desert Biosphere Reserve (CDBR) by the Government of India (28th August, 2009; File No. 9/9/2005-CS/BR). CDBR is the sixteenth Biosphere Reserve of India. The unique climatic conditions of arid and semi-arid regions of CDBR favours growth of very high value medicinal plants having huge source of photochemical, due to their potential to grow under such situation. A total of 332 medicinal plants belonging to 176 genera in 58 families were recorded from the CDBR, which were utilised by native communities for curing diseases of different body parts. The *Ephedra* genus, belongs to the family Ephedraceae of Gymnosperm is one of the oldest medicinal plants known to humankind and consists of 69 species mainly distributed in semi-arid environments throughout both the Palearctic and Nearctic realms, although some species are distributed through few Neotropical countries (Hollander et al. 2010). *E. gerardiana* is endemic to the Himalayan regions and according to "International Union for Conservation of Nature" it is listed as vulnerable. However, its regional status varies across regions. According to a comprehensive inventory it is listed as vulnerable in Himachal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

Pradesh and Sikkim and endangered in Jammu Kashmir and Uttarakhand. It is considered as a critically endangered medicinal plant of trans-himalayan region (Rinchen et al. 2021).

E. gerardiana is an evergreen, perennial xerophytic shrub, with densely clustered slender, branches arising from the woody base. Indigenous to the temperate and sub-tropical regions of Asia, Europe, North and Central America (Ratsch 2005). Genus *Ephedra* consisting of about 42 species, of these 6 species are reported from India, found in dry alpine and temperate Himalaya spreading from Kashmir to Sikkim (Rungsung et al. 2015). It is locally known as "Somlata, Chesna and Chapa" (figure 1).

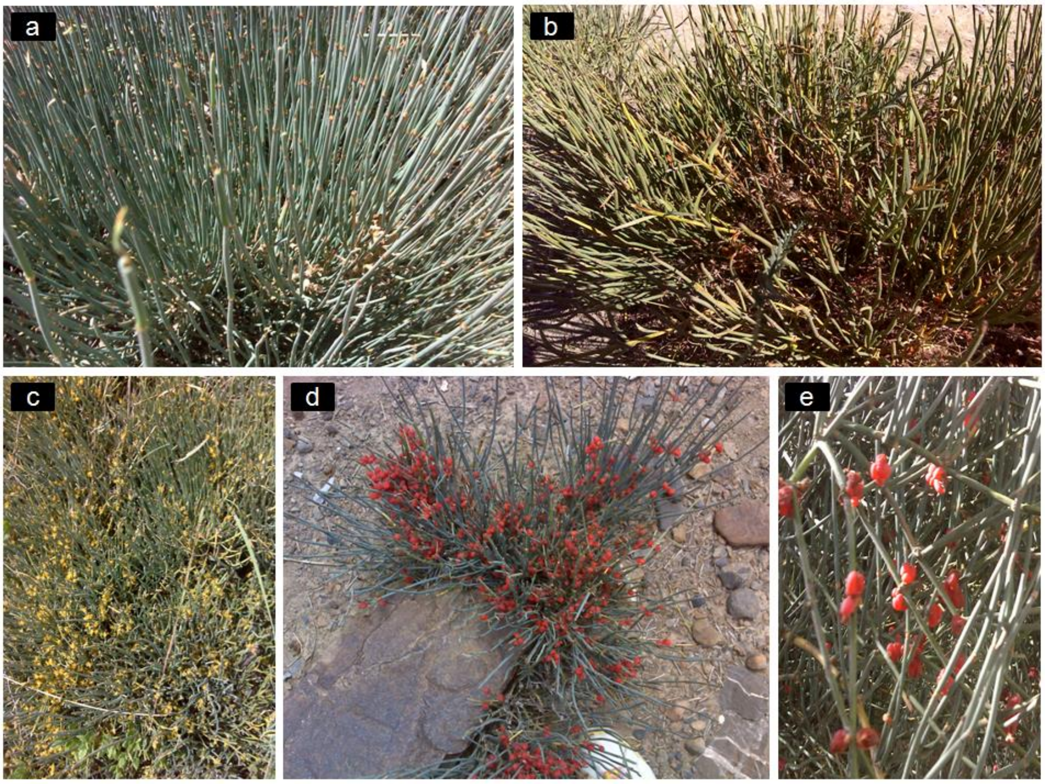

Figure 1: *Ephedra gerardiana* (a) young plant, (b) mature plant, (c) male plant, (d) female plant, and (e) enlarged view of female plant

Its pharmacological importance started with the isolation of secondary metabolite such as antioxidant, antimicrobial and alkaloids. Recently, Negi and Samant worked on the antioxidant potential of *E. gerardiana* of CDBR and found it possess high amount of phenolic and flavonoid contents with excellent free radical scavenging properties (Negi and Samant 2020). The dried twig has been used traditionally for the treatment of hay fever, asthma and allergic reaction. Its young branches used as fodder for yaks and goats, which attract nomadic graziers from lower altitudinal regions. Additionally, *Ephedra* species play significant role in controlling desertification and improving deteriorating habitats due to their strong ecological characteristics, which include cold resistance, drought resistance, windproof and sand-fixing characteristics (Li et al. 2024). But, severe climatic conditions and over exploitation by tribal communities, nomadic graziers and drug industries exert pressure on this multipurpose medicinal plant. For improving and maintaining the status of depleted species populations and degraded habitats, species re-introduction is successful ecological engineering techniques (Adhikari et al. 2012; Samant and Lal 2015). In recent years, growing numbers of scientists are estimating distributional areas by calculating environmental, or ecological, niches. This concept of ecological niche is associated mostly with Joseph Grinnell, who first introduced the term. Ecological niche modelling (ENM) is a modern tool which uses computer algorithms to generate predictive maps of species distributions. These maps are very efficient in describing basic phenomena behind species distribution pattern, verification of presence record, understanding biogeography, assessment of impacts of environmental changes on species distribution and conservation planning.

Maximum entropy algorithm modelling programme (MaxEnt) is a species distribution model originated from statistical mechanisms has been described as especially efficient, because it requires a set of known occurrences together with predictor variable such as topography, climate, soil, biogeography, etc. (Yang et al. 2013) and recognize the area where a given species has a high probability of occurrence. In general, many scientist worked on ecological niche modelling at global level (Gong et al. 2020; Xian et al. 2023 etc.) and studies especially focused on habitat suitability of plants based on MaxEnt model (Kumar and

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

Stohlgren 2009; Gao et al. 2021 etc.). However, few studies on predictive models have been carried out at **national** level (Barik and Adhikari 2012; Sen et al. 2016; Kumar et al. 2020; Mathur et al. 2023; Mathur and Mathur 2024) and in **Indian Himalayan Region** (Shankhwar et al. 2019; Lal et al. 2020; Chandra et al. 2021; Dhyani et al. 2021; Rawat et al. 2022**,** etc.). Porwal and other workers have been worked on mapping and stratification of *E. gerardiana* in Poh village of Lahaul and Spiti district (Porwal et al. 2003). But such studies especially in respect of threatened plants of cold desert of India are not available. However, few studies are available on indigenous uses of medicinal plants diversity in CDBR. While, available literature not shows any study especially in respect to population assessment and ecological niche modelling of *E. gerardiana* in CDBR.

Therefore, we aimed at assessing the population status and identifying the key factors responsible for the current and future distribution of spatial patterns of the selected threatened medicinal plant species (MPs), in order to prepare short and long term conservation strategies. Thus, present attempt has been made to provide detailed information on population status, geographical distribution, ecological elements and conservation implications of *E. gerardiana* in CDBR, Trans Himalaya.

2. STUDY AREA

Present study has been conducted in Cold Desert Biosphere Reserve (CDBR), located in Lahaul and Spiti district of Himachal Pradesh, India. The location map of CDBR is illustrated in figure 2. It covers an area about 7770 sq km, lies between Latitudes 31°44’ to 32°59’N and Longitudes 77°21’ to 78°34’ E. It includes whole Spiti Forest Division and a few parts of the Lahaul Forest Division *i.e.*, Baralacha Pass, Bharatpur and Sarchu areas (Samant et al. 2012). Temperature ranges between -30° to 3°C in the winter, and between 1° to 28°C in summer (Rana et al. 2011). The region faces fast blowing winds 40 to 60 km hr^{-1} mainly in the afternoon hours. The annual average precipitation of CDBR is 170 mm. Soil moisture remains frozen during winter season and holds less humidity in summer season. Vegetation is typically unique, quite sparse and has been broadly classed as ‘alpine scrub’ (Champion 1968). The CDBR represents less but highly endemic vegetation.

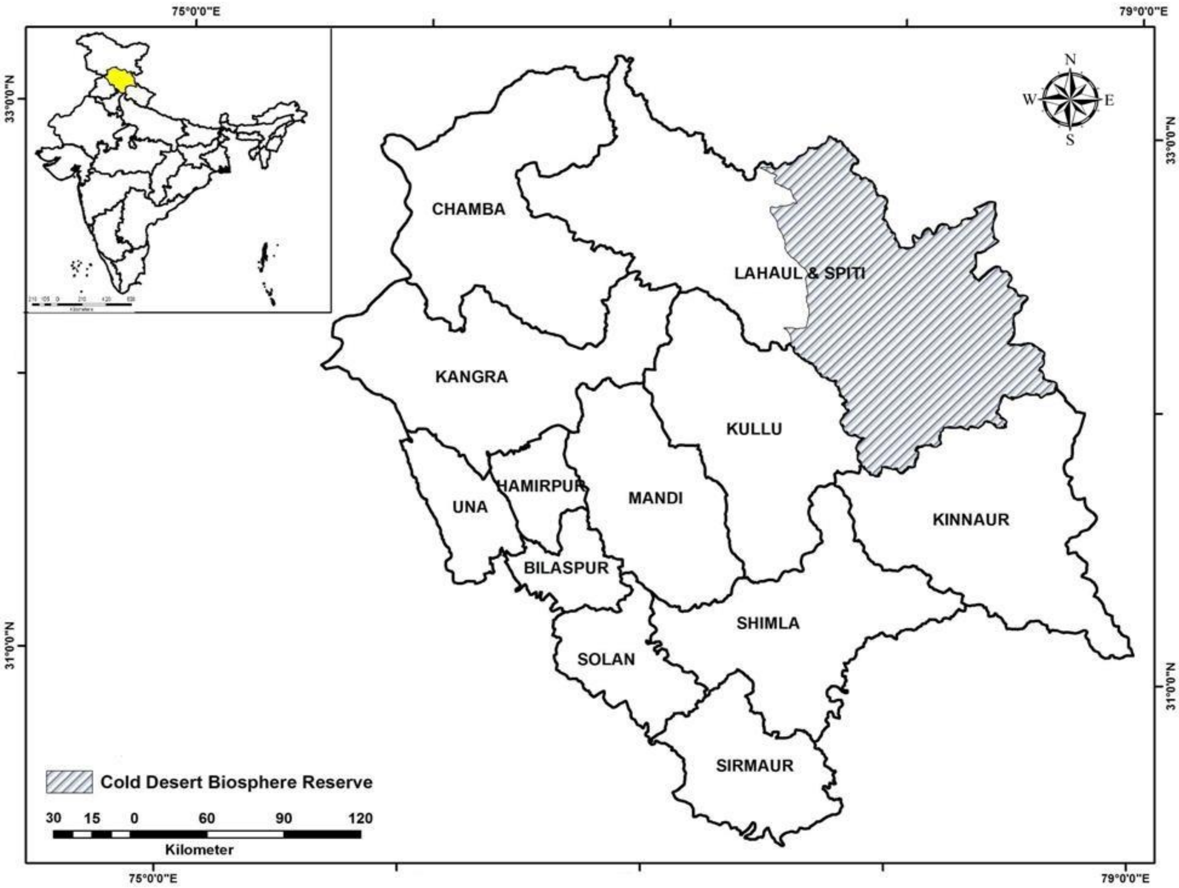

Figure 2: Location map of the Cold Desert Biosphere Reserve

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

3. MATERIALS AND METHODS

3.1. Population assessment

The cold desert region of Himachal Pradesh remains snow covered more than six months in a year therefore; extensive field surveys were conducted in the month of July, August and September from the year 2021 to 2023, when flower starts blooming and proper identification of plants is possible. All the assessable aspects between 3088-4500m amsl of CDBR were surveyed. The sites representing the populations of *E. gerardiana* were randomly sampled. For each site, information on altitude, latitude, longitude, aspect, slope, habitat type and associate species were recorded. Habitats were identified based on physical features and dominance of the vegetation (Samant et al. 2002; Rana et al. 2011). Longitudes, latitudes and altitudes of all natural populations were recorded using Global Positioning System (GPS, Garmin) and aspects with the help of compass. Slope was measured with the help of Abney's Level.

For quantitative assessment of *E. gerardiana* populations a plot of 20×20m was marked in each population, for shrubs 10 quadrats of 5×5m and for herbs 20 quadrates of 1×1m were laid randomly within the plot. The individuals of all the species were recorded in each quadrat and fresh samples brought to the Institute for identification. The species were identified with the help of local and regional flora (Chowdhery and Wadhwa 1984; Aswal and Mehrotra 1994; Singh and Rawat 2000; Murti 2001). For data collection and analysis of various ecological parameters, standard ecological methods (Simpson 1949; Shannon and Weaver 1949; Singh and Singh 1992; Samant et al. 2002; Samant and Joshi 2004) were followed. Species diversity was determined by Shannon Wiener's information statistic (H') (Shannon and Weaver 1949) and Concentration of Dominance by Simpson's Index (Simpson 1949). Soil samples were collected from centre and four corners of each plot, up to 20 cm depth. These samples were mixed together and a composite sample measuring 200g was stored in airtight polythene bags and brought to the laboratory for the analysis of chemical properties (Tandon 2005).

3.2. Ecological niche modelling

Ecological niche modeling of *E. gerardiana* was done in four major parts, the first part deals with the CDBR boundary delineation using topographical maps in GIS environment (ERDAS imagine 2020 and ArcGIS 10.8).

The second part includes collection of species occurrence points, which were collected from two sources, a) primary sources: extensive ground truthing in order to record occurrence point (longitudes and latitudes) to an accuracy of 10-30m. (b) Secondary sources: Global Biodiversity Information Facility (GBIF, http://data.gbif.org) was chosen. A total of 68 geo coordinates obtained through primary and secondary sources, out of which 34 unbiased and non-overlapped geo coordinate were used to run the model.

Third part deals with the preparation of generating bioclimatic raster layers. These layers were downloaded from worldClim website (http://www.worldclim.org). It provides high resolution (*i.e.*, nearly 1 km) data, which is derived from historical records from a number of weather stations across the globe over the 50 years period from 1950 to 2000 (Hijmans et al. 2005; Roy et al. 2005). Digital Elevation Model (DEM) data were also obtained from WorldClim dataset and further used to calculate slope (in degrees) and aspect using the Spatial Analyst functionality of the ArcGIS 10.8. Overall, 22 highly relevant environmental raster layers were used including nineteen bioclimatic variables (monthly temperature and precipitation, including annual and seasonal aspects of temperature and precipitation) along with altitude, slope and aspect. ERDAS Imagine 2020 and Arc GIS 10.8 software were used for digital image processing and spatial database handling.

Finally fourth part involves model run and evaluation of the modelling results. We used MaxEnt downloaded from http://www.cs.princeton.edu/~schapire/maxent/ (Phillips et al. 2006). All environmental rasters including bio1_19, altitude, slope and aspect were clipped down according to the CDBR area in order to set all layers in the same extent, cell size, and coordinate system and converted to ASCII format (a requirement of MaxEnt). The model was run using linear feature and other basic, advanced and experimental settings done in MaxEnt.

3.3. Validation of model robustness

Testing and validation are needed to evaluate the predictive performance of the model thus, occurrence point data were divided into 75% training and 25% test sets (Fielding and Bell 1997; Guisan and Hofer 2003; Kumar and Stohlgren 2009). We also did a jackknife (also called 'leave-one-out') procedure, in which model performance was assessed to get alternate estimates of variable importance. Each variable was excluded in turn, and a model created with the remaining variables (Pearson et al. 2007). MaxEnt allows the ability to run a model multiple times (15 replicates) and then the final potential habitat map was generated as an

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

average result from all models created. Model performance was evaluated by Area Under Curve (AUC) of Receiver Operating Characteristic (ROC) plot. The AUC is a threshold-independent measure of model performance that ranges from 0 to 1. According to AUC value, models can be classified into the following 5 groups *i.e.*, Excellent (AUC>0.9), Good (AUC 0.8-0.9), Acceptable (AUC 0.7-0.8), Bad (AUC 0.6-0.7), Invalid (AUC 0.5-0.6) (Hoffman 2008).

4. RESULTS AND DISCUSSION

4.1. Biophysical characteristics of *E. gerardiana* populations in CDBR

Thirty four natural populations of *E. gerardiana* assessed across 3290 to 4313m amsl with altitudinal range lies between 32°02.265′ N to 32°27.048′ N latitudes and 77°36.463′ E to 78°01.36′ E longitudes and slope varies between 2˚ to 60˚. Most of the populations (13) were studied in dry alpine slope followed by scree (5); bouldary and riverine (4 each); dry alpine pasture (3); moist alpine pasture and rocky (2 each) and river bed (1), and 8 aspects viz., north-east (7); south (6); north (5); north-west and south-west (4 each); south-east and west (3 each) and east (1) (Table 1). Similar to previous studies maximum species density was reported from dry and boundary habitat (Rinchen et al. 2021). The habitat wise distribution of *E. gerardiana* in CDBR is presented in figure 3.

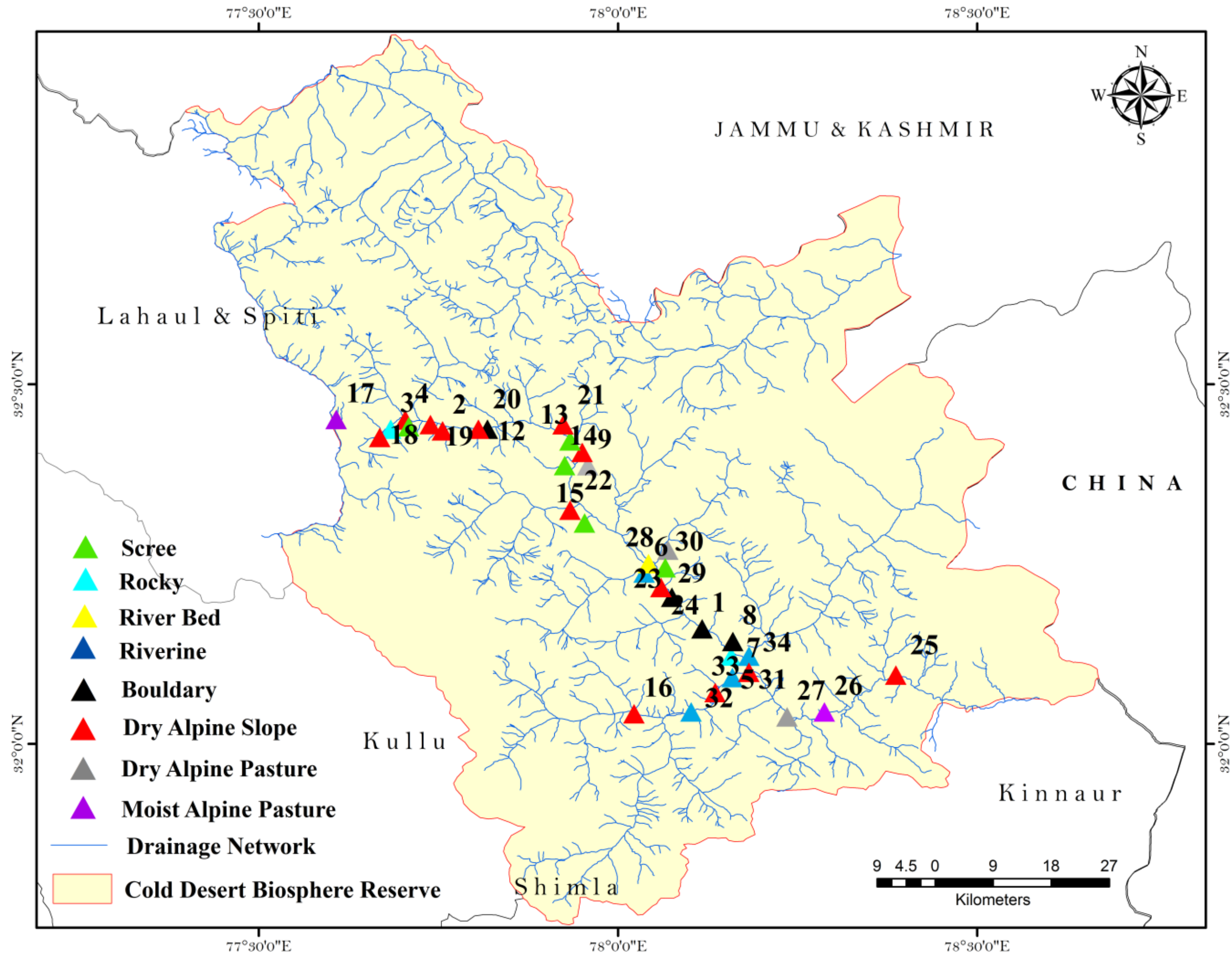

Figure 3: Map showing habitat wise distribution of *Ephedra gerardiana* populations in the Cold Desert Biosphere Reserve of Trans-Himalaya

Overall, species richness ranged from 6 to 26, richness of shrubs ranged from 1 to 6 and herbs 4 to 24, maximum shrubs were reported in P_{10} (6 spp.), followed by P_5, P_7, P_{23}, P_{28}, P_{32} (5 spp., each) and rest of the populations had < 5 shrub species (Table 2). The herb density ranged from 45-994 individual/m^2 and shrub density 8 to 245 individual/25m^2. Maximum shrub density 245

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

individual/25m^2 was found in P_{19}, represented by DAS of Lossar. Species diversity for herbs ranged from 0.84 to 3.06 and concentration of dominance 0.05 to 0.58 and for shrubs, species diversity 0.03 to 1.34 and concentration of dominance 0.04 to 1 (Table 2). Among the populations, pH ranged from 6.26-8.01; total nitrogen ranged from 0.05-0.89%; total organic matter ranged from 0.07-10.29%; C/N ratio ranged from 0.14-51.81% and total potassium ranged from 0.2-0.5%.

Cousinia thomsonii, *Polygonum tubulosum*, *Heteropappus holohermaphrodites*, *Lindelofia longiflora*, *Scorzonera virgata*, *Arnebia euchroma*, *Nepeta laevigata*, *Selinum elatum*, *Agrostis pilosula*, *Poa lahulensis*, *Youngia glauca*, *Nepeta eriostachya*, *Thymus linearis*, *Astragalus rhizanthus*, *Carddus thomsonii*, *Cynoglossum lanceolatum*, *Eritrichium nanum* and *Polygonum plebium* are the major associated herb species and *Rosa webbiana*, *Astragalus strobiliferus*, *Caragana vesicolor*, *H. rhamnoides* ssp. *turkestanica*, *Cotoneaster gilgitensis* and *Myricaria germanica* were the dominant associated shrub species.

4.2. Population status of *E. gerardiana* in CDBR

Total 34 natural populations consisted of about 2010 individuals (6.8 km^2 sampled area) with 163 (145 herbs and 18 shrubs) associated species were recorded. *Causinia thomsonii* and *Polygonum tubulosum* were the major associated herb species and *Rosa webbiana* is the major associated shrub species in *E. gerardiana* populations. Density of *E. gerardiana* was ranged from 5 to 245 individual/25m^2 with 59.2±53.3 individual/25m^2 mean density. Maximum density was found in dry alpine slope of Losar *i.e.,* P_{19} (245 individual/25m^2), followed by P_{18} (174 individual/25m^2) scree, P_{22} (164 individual/25m^2) DAS and P_{23} (116 individual/25m^2) bouldry habitats. Relative density of *E. gerardiana* was ranged from 4.35 to 100%, maximum relative density (100 %) was reported in 5 populations *i.e.,* P_3, P_{18}, P_{19}, P_{22} and P_{30}, which represents rocky, scree and dry alpine slope habitats (Table 2). Rich population in rocky, scree and dry alpine slope habitats indicates that the geophysical attributes of CDBR provides perfect natural niche for its growth and reproduction. Regression analysis showed a positive and negative significant correlations of *E. gerardiana* density with Shannon diversity (r= -0.52; p<0.01 (2-tailed); n=34), species richness (r= -0.44; p<0.01; n= 34), altitude (r = 0.62; p<0.01; n= 34) and concentration of dominance (r= 0.59; p<0.01; n= 34) (figure 4). Species diversity gradually declined with increasing altitude. Population assessment results indicated that *E. gerardiana* showed distribution range between 3290-4313m amsl. Similar studies conducted in cold desert region of Ladakh, confirm that the species has very low density (individual/m^2) in the region (Rinchen et al. 2021).

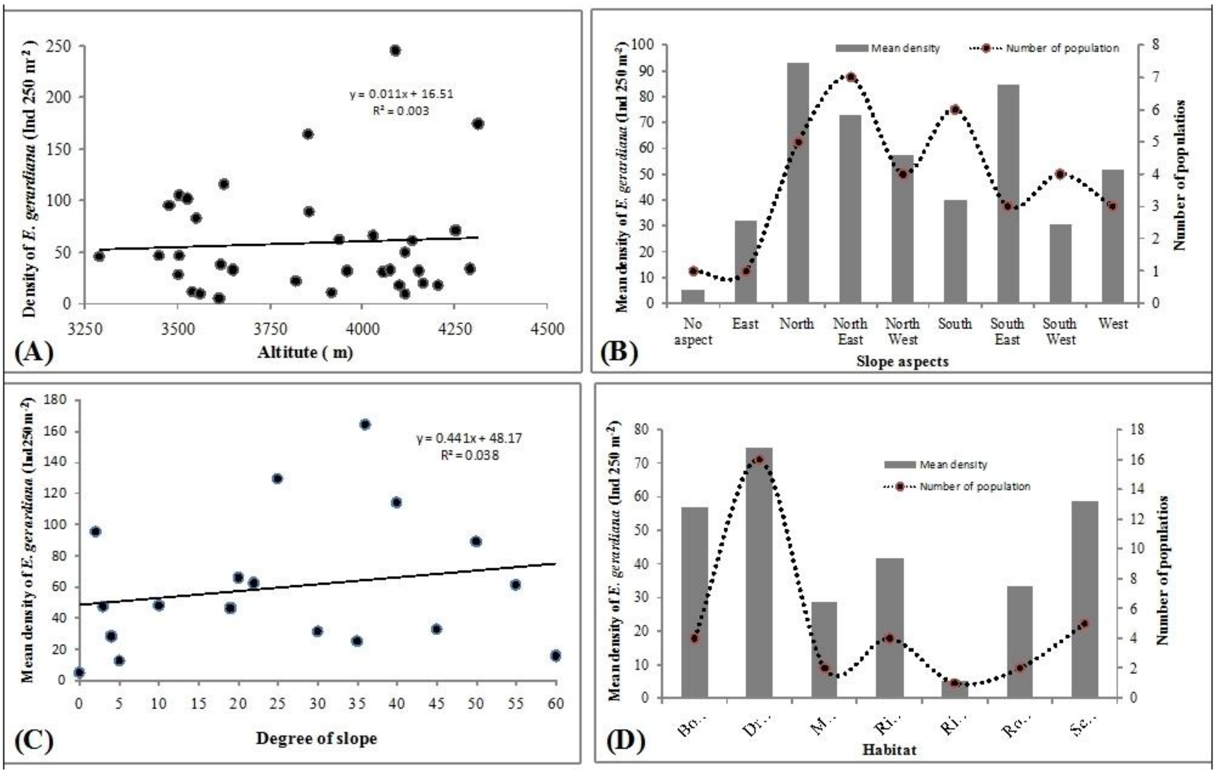

Figure 4: Correlation between A) density and altitute; B) mean density and number of populations in slope aspects; C) density and number of populations along slope gradient and D) mean density and number of populations in different habitat types.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

4.3. Species distribution maps

The model accuracy and prediction success was assessed by threshold independent measure i.e., AUC. The AUC for *E. gerardiana* is 0.953, over the replicate runs, indicating very high accuracy and comes in the category of excellent performance (AUC>0.9) (Hoffman 2008). MaxEnt generated habitat suitability map for *E. gerardiana* was reclassified into different suitability classes as illustrated in figure 5.

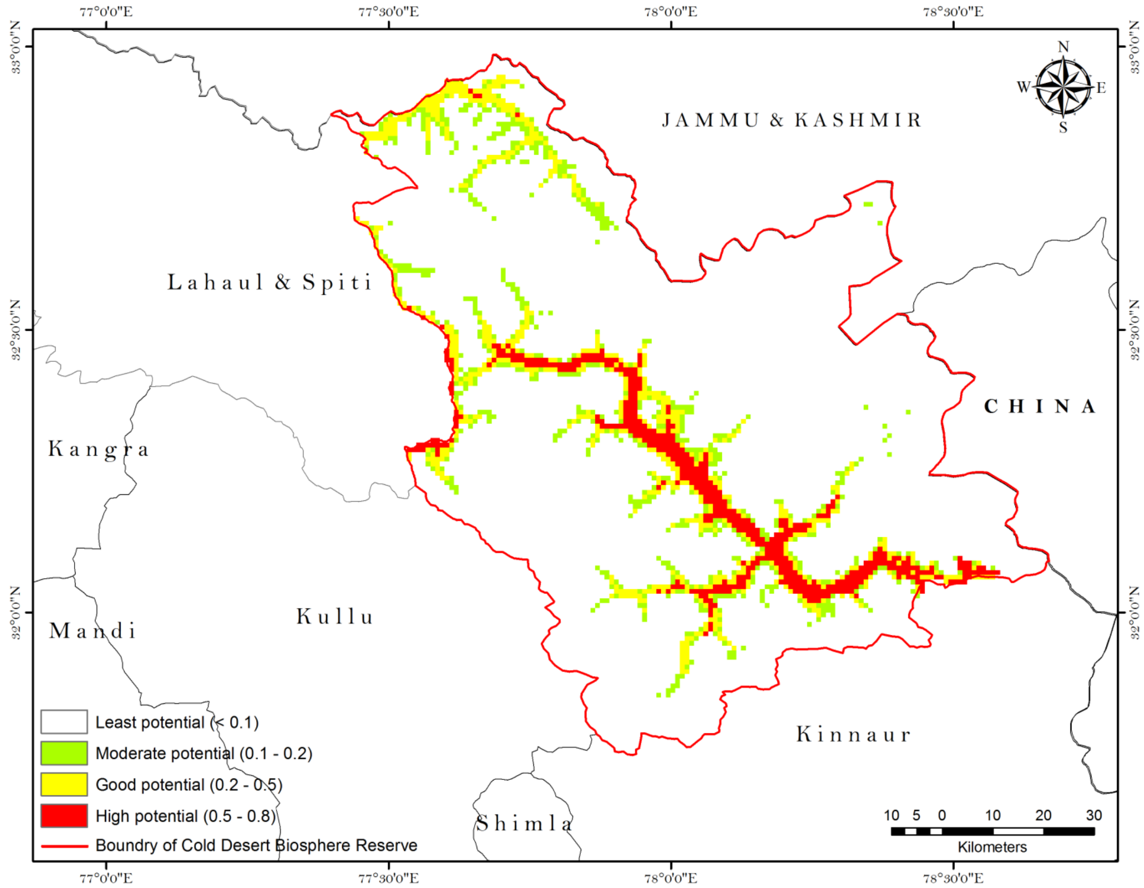

Figure 5: MaxEnt representation of predicted *Ephedra gerardiana* distribution in Cold Desert Biosphere Reserve

About, 531 km^2 (6.9%) of the entire BR is highly suitable for its growth, where altitude ranged between 3260-4399 m amsl; good potential area was about 692 km^2 (8.9%) extends in wider altitudinal range from 3150-4809 m amsl and 610 km^2 (7.9%) area was moderately suitable found in the high altitude areas from 3866-5063 m amsl. Overall, 1833 km^2 (23.7%) area was suitable and rest of the area *i.e.,* 5937 km^2 (76.3%) was least suitable or unsuitable for its growth and development in CDBR (Table 3). MaxEnt generated map reveals that the areas along the rivers and their adjacent mountains are suitable for its growth, while largest portion of land is unsuitable.

4.4. Key input bioclimatic variable

Among the 22 environmental variables (Table 4), relatively unimportant variables were removed in order to strengthen the model and only twelve key environmental factors were chosen. The model output indicates that the geographical distribution of medicinal plants was mostly dependent on bioclimatic variables then the topographical factors. According to the result of modeling process by jackknife test the twelve contributing key variables of model were: Bio 1 (Annual Mean Temperature), Bio 5 (Max. Temperature of Warmest Month), Bio 6 (Min. Temperature of Coldest Month), Bio7 (Temperature Annual Range), Bio8 (Mean Temperature of Wettest Quarter), Bio9 (Mean Temperature of Driest Quarter), Bio10 (Mean Temperature of Warmest Quarter), Bio14 (Precipitation of Driest Period), Bio15 (Precipitation Seasonality), Bio17 (Precipitation of Driest Quarter), Bio18 (Precipitation of Warmest Quarter), Bio19 (Precipitation of Coldest Quarter) and Altitude

The value of relative contributions of selected environmental variables to the MaxEnt model is given in **table 5**. Among the twelve input variables, precipitation seasonality (bio15, 41.8%), was the most influential variable followed by precipitation of coldest quarter (bio19, 32%) for predicting the habitat suitability. Out of twelve, seven temperature, four precipitation and one

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

physiography related variable i.e., altitude predicting the potential distribution of *E. gerardiana* in the cold desert biosphere reserve region.

Previous studies showed that average annual temperature was the main driving force effecting the distribution of *E. gerardiana* in cold desert regions (Rather et al. 2021) and other studies also indicates that temperature, elevation and precipitation were important drivers (Guo et al. 2023).

Present analysis clearly indicates that temperature and precipitation highly influenced the growth and distribution of studied medicinal plant species. Similar to previous findings our study showed that precipitation seasonality is one of the most influential variable influencing the distribution of *E. gerardiana* (Sourabh et al. 2018, Anand and Garg 2024; Li et al. 2024) followed by Precipitation of Coldest Quarter. Therefore, the species is best suited in colder temperature -17 °C to -5 °C for its propagation and can tolerate drought event (Anand and Garg 2024).

The MaxEnt also allows performing an internal Jackknife to quantify the importance of each input variable in influencing the distribution of model species. The Jackknife evaluation result in figure 6 indicated bio10 (mean temperature of warmest quarter) as main factors influencing *E. gerardiana* distribution when used in isolation. The environmental variable that decreases the gain the most when it is omitted was also bio15 (Precipitation Seasonality).

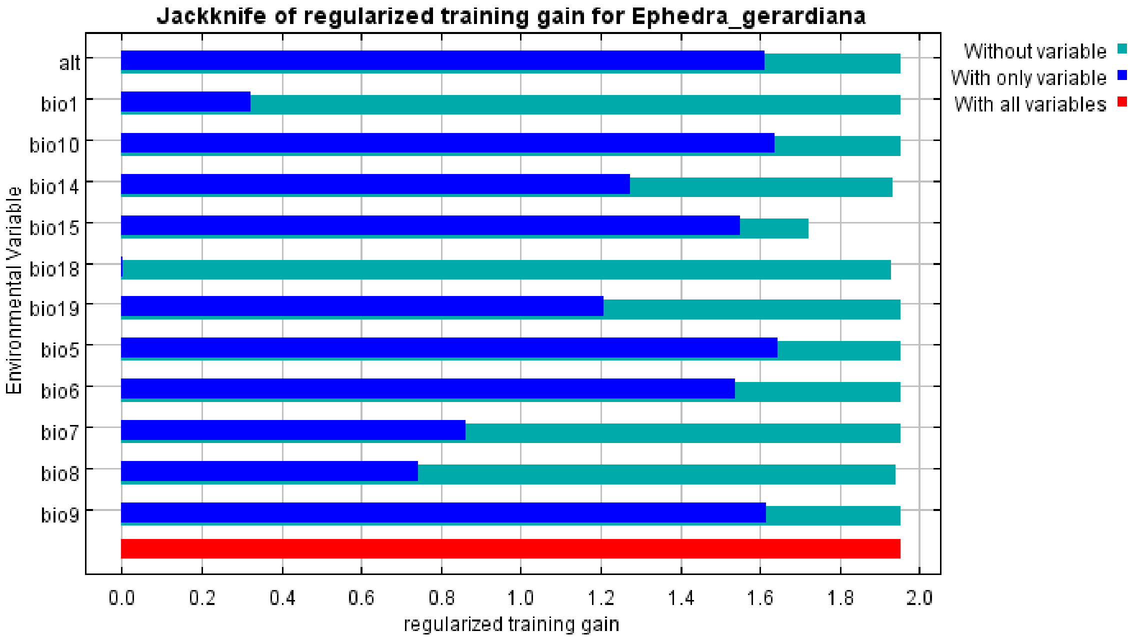

Figure 6: Results of Jackknife evaluations indicating the relative importance of each environmental variable for *Ephedra gerardiana* spatial distribution

5. CONCLUSION

The Indian Trans Himalaya is considered ‘the most important biological hotspots and ecologically fragile biogeographic zones in India’ (Singh et al. 2012). The CDBR being a part of Indian Trans Himalaya is a natural home of many high altitude medicinal plants, but largest area of land is rocky and barren *i.e.,* about 76.96%, with highly sensitive climatic conditions, so these medicinal plants are limited in number. Instead of this, they are facing high depletion rate, due to lack of awareness of the local inhabitants, limited natural resources, unemployment among the inhabitants, inadequate medical and transport facilities, limited land for agriculture and animals raring, etc. Such conditions cause overall dependence of locals on wild plants to fulfil their basic requirements.

Present study provides quantitative details on population density, relative density, diversity, distribution, richness and associated species of *E. gerardiana* of CDBR along with its habitat suitability via ENM. The AUC value *i.e.,* 0.953, suggest an excellent and accurate prediction. The area occupied by *E. gerardiana* in the MaxEnt predicted maps were similar to the field observation, which is found in nearby existing population of Shego, Chichong, Takcha, Atargu, Rongtong, Guling, Demul, Chicham, Hansa, Pangmo, Moorang, Ka, Chandertal, Losar, Kholaksa, Hull, Choling, Kaza, Tabo, Poh, Mane, Rangrik, Langza, Hikkim, Lingti, Tangti and Atargu villages. This emphasized manifold the effectiveness of MaxEnt model prediction.

Result indicated strong correlation between variables and spatial distribution of species. Contribution of bioclimatic variables

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

clearly indicates that only few variables were affecting its growth and development in CDBR. These most suitable habitats and altitudinal zone will makes the actual platform for designing effective conservation strategies for threatened medicinal plants, including establishment of Medicinal Plants Conservation Areas (MPCAs), reintroduction in the highly suitable areas and their short and long term monitoring. It also helps us to prepare database for the target species, provides new localities where natural habitats can be protected and restored in order to promote natural regeneration, which further can be used to monitor population status, thereby, useful in minimizing threats as well as creating awareness. Hence, ecological niche modelling prediction makes species survival approach more effective than other practices.

Conservation implications

The natural habitats of *Ephedra* species in Himalayan region of India are being diverted to agriculture land for cash crop cultivation, construction of houses, roads and development of infrastructural facilities. In addition to this grazing by large herds of cattle, ruthless exploitation and uprooting of rootstocks for fuel by local inhabitants will cause immediate threats to the existing populations (personal observation). This day by day increasing tremendous pressure exert strong need for the maintenance of available genetic diversity of this endangered, endemic, highly medicinal and industrially valuable plant resource. Although, many of the natural habitats of *Ephedra* species, including *E. gerardiana* fall under in-situ protected areas (Gangotri National Park, Nanda Devi National Park, Pin valley National Park, Dachigam Wildlife Sanctuary, etc.) in the western Himalayas, even, existing in-situ conservation methods need to be further supplemented with an appropriate ex-situ conservation strategies for sustainable utilization of this important plant genetic resources in the entire Himalayan region.

ACKNOWLEDGEMENTS

All the lab facilities provided by the Co-ordinator, Department of Forestry and Environmental Science is highly acknowledged. The completion of this research paper would not have been possible without the support and guidance of Director, School of Earth and Environmental Science and Vice chancellor, Uttarakhand Open University for their support and encouragement.

Funding

The authors did not receive support from any organization for the submitted work.

Data availability

Topographical map were downloaded from Survey of India (SOI), Dehradun website (https://onlinemaps.surveyofindia.gov.in/). Some species occurrence points were collected from the website, Global Biodiversity Information Facility (GBIF, http://data.gbif.org). Bioclimatic raster layers and Digital Elevation Model (DEM) were downloaded from worldClim website (http://www.worldclim.org).

Declarations

Author contributions statement: Both authors contributed equally in the current study.
Consent to Publish declaration: Not applicable.
Consent to Participate declaration: Not applicable.
Ethics Declaration: Not applicable.
Competing interests: The authors declare no competing interests.

REFERENCES

[1] Hollander JL, Vander Wall SB, Baguley JG (2010) Evolution of seed dispersal in North American *Ephedra.* Evol Ecol 24:333-345.
[2] Rinchen T, Gurmet P, Dolker P, Stobgais T (2021) Cultivation and population status of *Ephedra* (*Ephedra gerardiana* Wall. Ex Stapf) critically endangered medicinal plant for the conservation in cold desert of Ladakh, India. Res Square. https://doi.org/10.21203/rs.3.rs-246584/v1.
[3] Ratsch C (2005) The encyclopedia of psychoactive plants: ethnopharmacology and its applications. Simon and Schuster.
[4] Rungsung W, Dutta S, Ratha KK, Mondal DN, and Hazra J, (2015) Pharmacognostical and phytochemical study on the stem of *Ephedra gerardiana*. J Int Res Med Pharm Sci 2:80-85.
[5] Negi D, Samant SS (2020) Quantitative estimation of total phenols, total flavonoids, and antioxidant activity of methanolic extracts of *Ephedra gerardiana* Wall. ex Stapf across different habitats of cold desert biosphere reserve, trans Himalaya, India. Med Plants-Int J Phytomedicines Relat Ind 12:598-608.
[6] Li Y, Wang Y, Zhao C, Du X, He P, Meng F (2024) Predicting the spatial distribution of three *Ephedra* species under climate change using the MaxEnt model. Heliyon. https://api.semanticscholar.org/CorpusID:270344958.
[7] Adhikari D, Barik SK, Upadhaya K (2012) Habitat distribution modelling for reintroduction of *Ilex khasiana* Purk., a critically endangered tree species of northeastern India. Ecol Eng. https://doi.org/10.1016/j.ecoleng.2011.12.004
[8] Samant SS, Lal M (2015) Diversity, distribution, ecological niche modeling and economic importance of Bamboo species in North Western and Western Himalaya. Hill Bamboos An important Resour. Improv. Rural livelihoods. Himal. For. Res. Institute, Shimla. pp1-20.
[9] Yang XQ, Kushwaha SPS, Saran S, Xu J, Roy PS (2013) Maxent modeling for predicting the potential distribution of medicinal plant, *Justicia adhatoda* L. in Lesser Himalayan foothills. Ecol Eng 51:83-87.
[10] Gong X, Chen Y, Wang T, Jiang X, Hu X, Feng J (2020) Double-edged effects of climate change on plant invasions: Ecological niche modeling global distributions of two invasive alien plants. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.139933

[11] Xian X, Zhao H, Humair L, Yang N, Li J, Weyl P, Liu WX (2023) Niche shifts undermine the prediction performance of species distribution models: estimating potentially suitable areas for *Myriophyllum aquaticum* at the global scale. Glob Ecol Conserv 48:e02764.
[12] Kumar S, Stohlgren TJ (2009) Maxent modeling for predicting suitable habitat for threatened and endangered tree *Canacomyrica monticola* in New Caledonia. J Ecol Nat Environ 1:94–98.
[13] Gao T, Xu Q, Liu Y, Zhao J, Shi J (2021) Predicting the potential geographic distribution of *Sirex nitobei* in China under climate change using maximum entropy model. Forests 12:151.
[14] Barik SK, Adhikari D (2012) Predicting the geographical distribution of an invasive species (*Chromolaena odorata* L. (King) & HE Robins) in the Indian subcontinent under climate change scenarios. In: Invasive alien plants: an ecological appraisal for the Indian subcontinent, CABI Wallingford, UK, pp 77-88.
[15] Sen S, Gode A, Ramanujam S, Ravikanth G, Aravind NA (2016) Modeling the impact of climate change on wild *Piper nigrum* (Black Pepper) in Western Ghats, India using ecological niche models. J Plant Res 129:1033–1040.
[16] Kumar A, Kumar A, Adhikari D, Gudasalamani R, Saikia P, Khan ML (2020) Ecological niche modeling for assessing potential distribution of *Pterocarpus marsupium* Roxb. In Ranchi, eastern India. Ecol Res 35:1095-1105.
[17] Mathur M, Mathur P, Purohit H (2023) Ecological niche modelling of a critically endangered species *Commiphora wightii* (Arn.) Bhandari using bioclimatic and non-bioclimatic variables. Ecol Process 12(1):8.
[18] Mathur M, Mathur P (2024) Ecological niche modelling of *Indigofera oblongifolia* (Forssk.): a global machine learning assessment using climatic and non-climatic predictors. Discov Environ 2(1):9.
[19] Shankhwar R, Bhandari MS, Meena RK, Shekhar C, Pande, VV, Saxena J, Kant R, Barthwal S, Naithani HB, Pandey S, Pandey A (2019) Potential eco-distribution mapping of *Myrica esculenta* in northwestern Himalayas. Ecol Eng 128:98-111.
[20] Lal M, Samant SS, Kumar R, Sharma L, Paul S, Dutt S, Negi D, Devi K (2020) Population ecology and niche modelling of endangered *Arnebia euchroma* in Himachal Pradesh, India-An approach for conservation. Med. Plants-International J Phytomedicines Relat Ind 12:90–104.
[21] Chandra A, Singh G, Lingwal S, Bisht MPS, Tiwari LM (2021) Population assessment and habitat distribution modelling of the threatened medicinal plant *Picrorhiza kurroa* Royle ex Benth. in the Kumaun Himalaya, India. J Threat Taxa 13:18868–18877.
[22] Dhyani A, Kadaverugu R, Nautiyal BP, Nautiyal MC (2021) Predicting the potential distribution of a critically endangered medicinal plant *Lilium polyphyllum* in Indian Western Himalayan Region. Reg. Environ. Chang 21(2): 30.
[23] Rawat N, Purohit S, Painuly V, Negi GS, Bisht MPS (2022) Habitat distribution modeling of endangered medicinal plant *Picrorhiza kurroa* (Royle ex Benth) under climate change scenarios in Uttarakhand Himalaya, India. Ecol Inform. 68:101550.
[24] Porwal MC, Sharma L, Roy PS (2003) Stratification and mapping of *Ephedra gerardiana* Wall. in Poh (Lahul and Spiti) using remote sensing and GIS. Curr Sci. pp208-212.
[25] Samant SS, Palni LMS, Pandey S (2012) Cold Desert Biosphere Reserve-Trans Himalaya, India," Compend. Indian Biosph. Reserv. Progress. Dur. two Decad. Conserv. (eds. LMS Palni, RS Rawal, RK Rai SV Reddy). Minist. Environ. For. New Delhi GBPIHED, Kosi-Katarmal, Almora. pp. 169-177.
[26] Rana MS, Lal M, Samant SS (2011) Status and regeneration of Himalayan maple in the Himachal Pradesh: Honing Red List of plants. J Sustain For 30(8):775–789.
[27] Champion HG (1968) A revised survey of the forest types of India. Gov. India Publ, Dehli.
[28] Samant SS, Joshi HC, Arya SC, Pant S (2002) Studies on the structure, composition and changes of the vegetation in Nanda Devi Biosphere Reserve of West Himalaya." Biosphere Reserves in India and their Management. New Delhi, Kerala Forest Research Institute and Ministry of Environment and Forests. pp133-139.
[29] Chowdhery HJ, Wadhwa BM (1984) Flora of Himachal Pradesh, Botanical Survey of India.
[30] Aswal BS, Mehrotra BN (1994) Flora of Lahaul-Spiti (A cold desert in north west Himalaya). Bishen Singh Mahendra Pal Singh.
[31] Singh SK, Rawat GS (2002) Flora of great Himalayan national park, Himachal Pradesh.
[32] Murti SK (2001) Flora of cold deserts of western Himalaya, Botanical survey of India. Vol 2.
[33] Simpson EH (1949) Measurement of Diversity, Nature. vol 163.
[34] Shannon CE, Weaver W (1949) The mathematical theory of communication, Urbana Univ. Illinois Press. pp117.
[35] Singh JS, Singh SP (1992) Forest of Himalaya. Gyanodaya Prakashan, Nainital.
[36] Samant SS, Joshi HC (2004) Floristic Diversity, Community Patterns and Changes of Vegetation in Nanda Devi National Park. Biodiversity Monitoring Expedition, Nanda Devi, Shiva Offset Press, Dehra Dun.
[37] Tandon HLS (2005) Methods of analysis of soils, plants, waters, fertilisers & organic manures, Fertiliser Development and Consultation Organisation, New Delhi, India.
[38] Hijmans RJ, Cameron SE, Parra JL, Jones PG, A. Jarvis (2005) Very high resolution interpolated climate surfaces for global land areas. Int J Climatol: A J of the Royal Meteorol Soc 25(15):1965-1978.
[39] Roy PS, Padalia H, Chauhan N, Porwal MC, Gupta S, Biswas S, Jagdale R (2005) Validation of geospatial model for biodiversity characterization at landscape level-A study in Andaman & Nicobar Islands, India. Ecol Modell 185(2-4): 349-369.
[40] Phillips SJ, Anderson RP, Schapire RE (2006) Maximum entropy modeling of species geographic distributions. Ecol Modell 190(3-4):231-259.
[41] Fielding AH, Bell JF (1997) A review of methods for the assessment of prediction errors in conservation presence/absence models. Environ Conserv 24(1):38-49.
[42] Guisan A, Hofer U (2003) Predicting reptile distributions at the mesoscale: relation to climate and topography. J Biogeogr 30(8):1233–1243.
[43] Pearson RG, Raxworthy CJ, Nakamura M, Townsend Peterson A (2007) Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. J Biogeogr 34(1):102-117.
[44] Hoffman D (2008) Evaluation and application of predictive habitat modeling in ecology, The University of Nebraska-Lincoln.
[45] Rather ZA, Ahmad R, Dar AR, Dar TUH, Khuroo AA (2021) Predicting shifts in distribution range and niche breadth of plant species in contrasting arid environments under climate change. Environ Monit Assess. https://doi.org/10.1007/s10661-021-09160-5
[46] Guo L, Gao Y, He P, He Y, Meng F (2023) Modeling for predicting the potential geographical distribution of three *Ephedra* herbs in China. Plants. https://doi.org/10.3390/plants12040787
[47] Sourabh P, Thakur J, Sharma P, Uniyal PL, Pandey AK (2018) Habitat distribution modelling for reintroduction of endangered medicinal plants-*Ephedra gerardiana*, *Lilium polyphyllum*, *Crepidium acuminatum*, *Pittosporum eriocarpum* and *Skimmia anquetilia* in India. Int J Ecol Environ Sci 44(2): 207-216.
[48] Anand A, Garg VK (2023) Assessment of the Spatiotemporal Distribution of *Ephedra gerardiana* in the Himalayan Region under the Influence of Different Climate Change Scenarios. Available at SSRN: https://ssrn.com/abstract=4543680 or http://dx.doi.org/10.2139/ssrn.4543680

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

[49] Li Y, Wang Y, Zhao C, Du X, He P, Meng F (2024) Predicting the spatial distribution of three *Ephedra* species under climate change using the MaxEnt model. Heliyon. https://doi.org/10.1016/j.heliyon.2024.e32696.

[50] Singh KN, Lal B, Chand G, Todaria NP (2012) Ecological features and conservation of *Arnebia euchroma* a critically endangered medicinal plant in western Himalaya. Int J Con Sci 3(3):189-198.

Table 1: Physical characteristics and habitat suitability thresholds of *Ephedra gerardiana* populations in CDBR

Population ID	Location	Altitude (m)	Latitude	Longitude	Habitat (s)	Aspect	Slope (°)	Habitat suitability thresholds
P_1	Shego	3540	32°09.59′ N	78°07.02′ E	BO	S	30	High
P_2	Chichong	4100	32°26.10′ N	77°45.35′ E	DAS	NW	35	High
P_3	Takcha	4165	32°26.21′ N	77°41.01′ E	RO	NW	60	Good
P_4	Takcha	4115	32°27.00′ N	77°42.25′ E	DAS	N	30	High
P_5	Atargu	3505	32°07.30′ N	78°09.46′ E	RO	SW	20	High
P_6	Rongtong	3651	32°14.24′ N	78°02.19′ E	R	NE	10	High
P_7	Guling	3503	32°05.55′ N	78°09.56′ E	R	NE	4	High
P_8	Demul	4291	32°08.53′ N	78°09.59′ E	BO	W	20	Good
P_9	Chicham	4252	32°23.18′ N	77°57.48′ E	DAP	N	10	Good
P_{10}	Chicham	4153	32°24.30′ N	77°57.03′ E	SC	W	45	Good
P_{11}	Takcha	4136	32°26.44′ N	77°42.52′ E	DAS	N	55	Good
P_{12}	Hansa	4030	32°26.24′ N	77°49.11′ E	BO	S	40	High
P_{13}	Chicham	3857	32°25.26′ N	77°56.00′ E	DAS	W	50	High
P_{14}	Pangmo	3959	32°23.19′ N	77°55.54′ E	SC	E	35	High
P_{15}	Moorang	3821	32°18.41′ N	77°57.23′ E	SC	NE	10	High
P_{16}	Ka	3917	32°02.49′ N	78°01.36′ E	DAS	SW	60	High
P_{17}	Chandertal	4116	32°27.048′ N	77°36.463′ E	MAP	S	5	High
P_{18}	Takcha	4313	32°25.538′ N	77°40.099′ E	SC	NW	40	High
P_{19}	Losar	4090	32°26.647′ N	77°44.351′ E	DAS	N	25	High
P_{20}	Kholaksa	4057	32°26.257′ N	77°48.344′ E	DAS	SW	10	High
P_{21}	Pangmo	3937	32°26.607′ N	77°55.416′ E	DAS	NE	22	Least
P_{22}	Hull	3854	32°19.495′ N	77°56.015′ E	DAS	NE	36	High
P_{23}	Choling	3626	32°12.244′ N	78°04.512′ E	BO	NE	20	High
P_{24}	Kaza	3618	32°13.020′ N	78°03.592′ E	DAS	N	25	High
P_{25}	Tabo	3290	32°05.752′ N	78°23.205′ E	DAS	S	19	Good
P_{26}	Poh	3450	32°02.647′ N	78°17.259′ E	MAP	SE	3	High
P_{27}	Mane	3551	32°02.265′ N	78°14.132′ E	DAP	NE	10	High
P_{28}	Rangrik	3613	32°15.036′ N	78°02.549′ E	RB	-	-	High
P_{29}	Langza	4205	32°16.149′ N	78°04.164′ E	DAP	NW	5	Good
P_{30}	Hikkim	4076	32°14.663′ N	78°03.950′ E	SC	SW	45	High
P_{31}	Lingti	3478	32°07.415′ N	78°09.996′ E	R	S	2	High
P_{32}	Tangti	3562	32°02.683′ N	78°06.098′ E	R	S	5	High
P_{33}	Atargu	3527	32°04.275′ N	78°08.117′ E	DAS	SE	40	High
P_{34}	Atargu	3505	32°05.950′ N	78°10.937′ E	DAS	SE	25	High

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

Abbreviations Used: DAS= Dry Alpine Slope; MAS= Moist Alpine Slope; DAP=Dry Alpine Pasture; MAP=Moist Alpine Pasture; BO= Bouldary; SC=Scree; RO=Rocky; R=Riverine; AF= Agriculture field; RB= River bed; NS= Near Settlement; NE= North-East; NW= North-West; S= South; N= North; SW= South-West; W= West; SE= South East; and E= East.

Table 2: Population wise total density, species richness, diversity and concentration of dominance of herb and shrub species

Population	Location	SD	Herbs				Shurbs			
			Den*	SR	H'	Cd	Den	SR	H'	CD
P_1	Shego	12	266	4	0.84	0.58	40	4	1.34	0.28
P_2	Chichong	18	406	16	2.25	0.16	134	3	0.47	0.74
P_3	Takcha	20	770	13	2.24	0.13	20	1	0.00	1.00
P_4	Takcha	50	488	10	2.03	0.16	59	2	0.43	0.74
P_5	Atargu	47	366	7	1.78	0.20	126	5	1.25	0.34
P_6	Rongtong	33	356	11	2.27	0.11	108	4	1.29	0.29
P_7	Guling	28	419	7	1.43	0.33	116	5	1.24	0.36
P_8	Demul	34	776	16	2.43	0.12	156	4	1.23	0.33
P_9	Chicham	71	592	11	2.14	0.14	163	3	0.79	0.48
P_{10}	Chicham	32	212	10	2.16	0.13	43	6	0.94	0.57
P_{11}	Takcha	61	407	12	1.77	0.24	88	4	0.92	0.52
P_{12}	Hansa	66	314	11	2.20	0.13	114	3	0.86	0.47
P_{13}	Chicham	89	286	24	3.06	0.05	95	2	0.24	0.88
P_{14}	Pangmo	32	523	11	1.93	0.19	78	2	0.68	0.52
P_{15}	Morang	22	349	10	1.96	0.18	99	3	0.85	0.51
P_{16}	Ka	11	404	13	2.38	0.10	57	4	1.18	0.37
P_{17}	Chandertal	10	326	9	1.71	0.26	30	4	0.03	0.04
P_{18}	Takcha	174	219	8	1.81	0.20	174	1	0.00	1.00
P_{19}	Lossar	245	232	10	2.20	0.12	245	1	0.00	1.00
P_{20}	Kholaksa	31	322	12	2.28	0.13	35	2	0.36	0.80
P_{21}	Pangmo	62	229	8	1.90	0.17	69	2	0.33	0.82
P_{22}	Hull	164	425	9	1.76	0.24	164	1	0.00	1.00
P_{23}	Choling	116	180	9	2.06	0.15	137	5	0.24	0.72
P_{24}	Kaza	38	147	5	1.23	0.35	49	3	0.69	0.63
P_{25}	Tabo	46	45	4	1.30	0.29	79	2	0.97	0.43
P_{26}	Poh	47	140	7	1.82	0.19	55	2	0.41	0.75
P_{27}	Mane	83	269	8	1.95	0.16	93	3	0.41	0.80
P_{28}	Rangrik	5	994	15	2.26	0.13	115	5	1.09	0.42
P_{29}	Langza	18	652	16	2.23	0.16	57	2	0.62	0.57
P_{30}	Hikkim	33	308	7	1.40	0.37	8	1	0.00	1.00
P_{31}	Lingti	95	68	4	1.28	0.31	18	3	0.72	0.59
P_{32}	Tangti	10	170	9	2.14	0.12	30	5	1.22	0.40
P_{33}	Atargu	102	138	8	1.93	0.17	13	2	0.28	0.85
P_{34}	Atargu	105	232	8	1.95	0.15	18	3	0.67	0.63

Abbreviations used: H'= Species Diversity; Cd= Concentration of Dominance; Den*=Density (Individual per 20 square meters); Den= Density (Individual per 250 square meters); SR=Species Richness; and SD= Species Density (Individual per square meter/250 square meters).

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 12 , December - 2025

Table 3: Habitat suitability classes area of E. gerardiana distribution in CDBR

Area	Square Kilometre (Km^2)	Percent (%)
Least potential (<0.1)	5937	76.3
Moderate potential (0.1-0.2)	610	7.9
Good potential (0.2-0.5)	692	8.9
High potential (>0.5)	531	6.9

Table 4. List of Environmental variables used in the model (Hijmans *et al*., 2005)

S. No.	Code	Environmental variables	Unit	S. No	Code	Environmental variables	Unit
1	Bio1	Annual Mean Temperature	°C	**12**	Bio12	Annual Precipitation	mm
2	Bio2	Mean Diurnal Range (Mean of monthly max. and min. temp))	°C	**13**	Bio13	Precipitation of Wettest Period	mm
3	Bio3	Isothermality ((Bio2/Bio7)*100)	-	**14**	Bio14	Precipitation of Driest Period	Mm
4	Bio4	Temperature Seasonality (standard deviation*100)	C of V	**15**	Bio15	Precipitation Seasonality (Coefficient of Variation)	C of V
5	Bio5	Max. Temperature of Warmest Month	°C	**16**	Bio16	Precipitation of Wettest Quarter	Mm
6	Bio6	Min. Temperature of Coldest Month	°C	**17**	Bio17	Precipitation of Driest Quarter	Mm
7	Bio7	Temperature Annual Range (Bio5-Bio6)	°C	**18**	Bio18	Precipitation of Warmest Quarter	Mm
8	Bio8	Mean Temperature of Wettest Quarter	°C	**19**	Bio19	Precipitation of Coldest Quarter	Mm
9	Bio9	Mean Temperature of Driest Quarter	°C	**20**	Alt	Altitude	M
10	Bio10	Mean Temperature of Warmest Quarter	°C	**21**	Asp	Aspect	
11	Bio11	Mean Temperature of Coldest Quarter	°C	**22**	Slo	Slope	°

Table 5: Selected bioclimatic variables used in the study and their percentage contributions

Variables	Percent Contribution (%)	Permutation Importance (%)	Variables	Percent Contribution (%)	Permutation Importance (%)
Bio1	1.6	0	**Bio12**	-	-
Bio2	-	-	**Bio13**	-	-
Bio3	-	-	**Bio14**	2.8	**19**
Bio4	-	-	**Bio15**	**41.8**	**77**
Bio5	1.5	0	**Bio16**	-	-
Bio6	2.9	0	**Bio17**	-	-
Bio7	0.3	0	**Bio18**	1.3	3.4
Bio8	10.2	0.5	**Bio19**	**32**	0
Bio9	2.1	0	**Altitude**	2.2	0
Bio10	1.2	0.1	**Aspect**	-	-
Bio11	-	-	**Slope**	-	-