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Predictive distribution modeling for rare Himalayan medicinal plant *Berberis aristata* DC

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Abstract

Predictive distribution modelling of *Berberis aristata* DC, a rare threatened plant with high medicinal values has been done with an aim to understand its potential distribution zones in Indian Himalayan region. Bioclimatic and topographic variables were used to develop the distribution model with the help of three different algorithms *viz.* Genetic Algorithm for Rule-set Production (GARP), Bioclim and Maximum entropy (MaxEnt). Maximum entropy has predicted wider potential distribution (10.36%) compared to GARP (4.63%) and Bioclim (2.44%). Validation confirms that these outputs are comparable to the present distribution pattern of the *B. aristata*. This exercise highlights that this species favours Western Himalaya. However, GARP and MaxEnt's prediction of Eastern Himalayan states (*i.e.* Arunachal Pradesh, Nagaland and Manipur) are also identified as potential occurrence places require further exploration.

Key words

Berberis aristata, Bioclim and Maximum entropy, Distribution modeling, GARP, Indian Himalayan region

Introduction

The Indian Himalayan Region (IHR) harbours a wide spectrum of biodiversity which is reflected in diverse groups of flora, fauna and microorganisms. It supports about 8000 species of angiosperms of which 40% are endemics and the region is aptly considered as "hotspot" of Indian flora as well as part of the recently announced Himalaya "hotspot" (Nayar, 1996; Conservation International, 2007). The presence of rich biodiversity is mainly attributed to diverse habitat types influenced by wide altitudinal range (300 – 8000 m), varied rainfall and precipitation, temperature regime and complex topographical features (Samant *et al.*, 1998).

The vast number of medicinal plants present in the region is an integral part of the livelihood of local communities. Apart from their medicinal usage, many plants are used as edible items, source for oil, fodder, fuel and timber which has been documented for a long time (Singh *et al.*, 1984; Olsen and Larsen, 2003). However, the exponential increment of natural resource utilization, booming market demand and environmental changes nowadays put the medicinal plant resources under serious threat of existence (Ved *et al.*, 2003). The growing list of rare, threatened and endangered plants of the region is a direct outcome of these consequences.

The raising awareness towards the importance of Himalayan biodiversity and alarming rate at which they are being exploited from natural habitats leads to initiate various conservation actions to mitigate such uncontrolled resource exploitation and its management (Arunachalam *et al.*, 2004; Rana and Samant, 2010). As a part of the conservation and management programme, species distribution and its ecological characteristic features must be taken into consideration for species protection / restoration activities (Hirzel *et al.*, 2004; Sanchez-Cordero *et al.*, 2005; Martinez-Meyer *et al.*, 2006). Himalayan region requires special attention in this regard, as frequent environmental changes take place because of its mountainous nature. The enormous variation in the altitude, latitude and longitude of the Himalayas has added to the multiplicity of habitats and provides diverse microclimates and ecological niches for all the living beings (Karan, 1989; Carpenter, 2005; Anonymous, 2006).

Although information on plant distribution and their environmental association in IHR are available to some extent, there is a gap in understanding species ecological amplitude and its application in systematic management of resources.

Berberis aristata, a well known medicinal plant in IHR and its occurrence is reported from middle altitude areas (1800-3000 m) of the state of Uttarakhand and Himachal Pradesh (Samant *et al.*, 1998; Chauhan, 1999). It is a spinescent shrub, 3-6 m in height with obovate to elliptic, toothed leaves, yellow flowers in corymbose racemes and oblong-ovoid, bright red berries. The extract from root-barks, roots and lower stem-wood, (known as Rasanjana or Rasaut or Rasavanti) is used as stomachic, laxative, hepato-protective, antipyretic and in other ailments (Wang *et al.*, 2004; Shahid *et al.*, 2009; Semwal *et al.*, 2009). It is useful in eye diseases particularly in conjunctivitis, indolent ulcers and in hemorrhoids (Rashmi *et al.*, 2008). The plant is mostly collected from wild areas, and its agro-technique, cultivation is poorly known. Therefore, high demand for local usage as well as for pharmaceuticals creates a serious pressure on the natural resource which already categorized the plant as endangered (Srivastava *et al.*, 2006; Ali *et al.*, 2008). As a remedial measure, exploration of new resource, conservation of the existing resources and establishment of cultivation are of prime importance for what systematic planning and management is essential and where distribution modeling can play a key role.

Predictive distribution models aid in forecasting the spatial occurrence of species, especially, habitat suitability or realized niche based on the data from traditional field work in conjunction with climatic and topographic factors (such as slope, elevation, and precipitation) (Pearson, 2007). This habitat suitability or niche prediction is done through various algorithms or principles which usually integrate the species occurrence information and environmental data to find out the possible favourable places. A number of algorithms are available nowadays for performing the task and each unique to their data requirement, statistical methods and ease of use.

We selected Genetic Algorithm for Rule-set Production (GARP), Bioclim and Maximum entropy (MaxEnt) methods for our study because of their predictive abilities and wide usage.

Precise prediction of the distribution of endemic and endangered species is useful for decision makers, especially for those whose conservation and management activities involve large areas but constrained by resources to carry out detail exploration / investigation. Potential distribution of species prioritises the favourable biogeographic areas to lead the conservation / management activity in a more focused way. The advantages of distribution modeling is manifold like, explaining basic ecological phenomenon behind species distribution, understanding biogeography and dispersal barriers, verification of the earlier presence records, explored the yet uncovered regions, assessment of impacts of environmental changes over species distribution, conservation planning and reserve system design (Peterson, 2006; Guisan and Thuiller, 2005; Johnson, 2005). Considering the extent of plant distribution and diversity in India, available data related to ecology and environmental preference still represents a small fraction of this vast field especially distribution modelling (Ganeshaiah *et al.*, 2003; Irfan Ullah *et al.*, 2007; Giriraj *et al.*, 2008).

In our study, we developed predictive distribution models of *Berberis aristata* using three different modeling techniques, GARP,

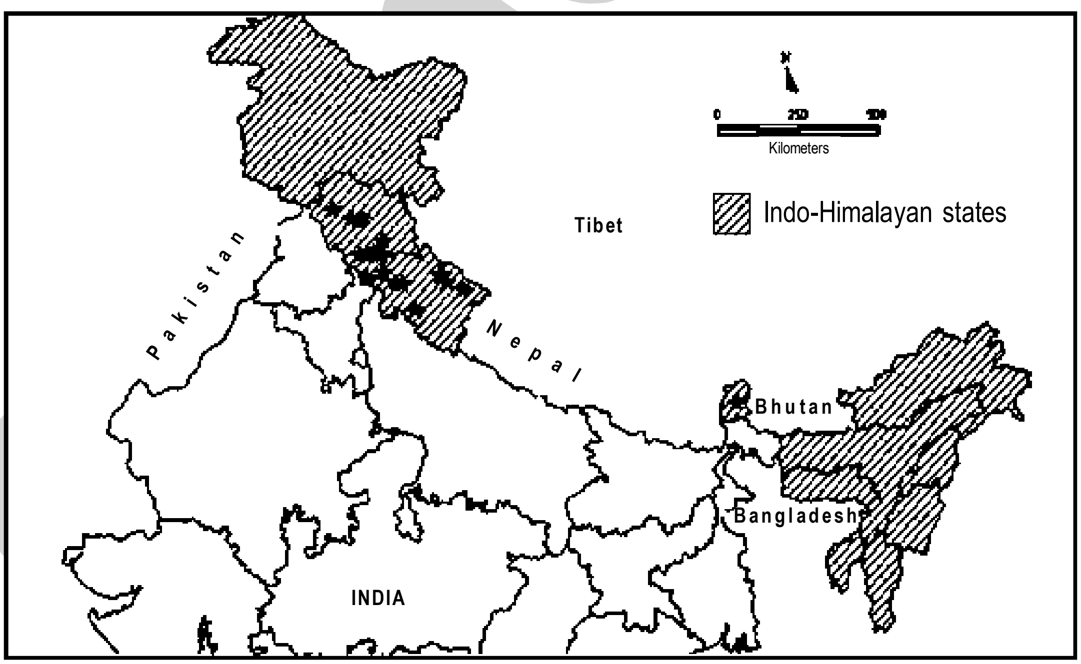

Fig. 1: Study area : Indo – Himalayan region (★ = occurrence points for *B.aristata*)

Bioclim and MaxEnt to know its potential distribution in Indo-Himalayan region.

Materials and Methods

Study area: Indian Himalayan Region (IHR) ranges from Jammu and Kashmir to Arunachal Pradesh including Himachal Pradesh, Uttarakhand, Sikkim, Darjeeling district of West Bengal. North - East states (*i.e.* Assam, Meghalaya, Manipur, Nagaland, Mizoram and Tripura) are also included as part of Eastern Himalaya as per available literature (Samant *et al.*, 1998; WWF-US, 2005) (Fig 1.).

Species occurrence data: Twenty one occurrence points of *Berberis aristata* were shortlisted from a collection of field survey done at Moolbari watershed area of Himachal Pradesh, India and secondary data available from published literatures (Uniyal, 2002; Chhetri *et al.*, 2005; Anonymous, 2007-2008) (Fig 1.). Moolbari watershed is situated in Shimla district, Himachal Pradesh, India and encompasses an area of 13.41 km^2 from 31.07-31.17°N and 77.05-77.15°E. Field study was conducted by following standard ecological methods and the species was identified with the help of keys (published flora) in addition to the consultation of herbarium samples and discussion with the Himalayan flora experts.

Environmental data: For environmental information, 19 bioclimatic variables derived from globally interpolated datasets (source: http://www.worldclim.org) representing annual trends, seasonality and extreme or limiting environmental factors, were used for the modelling study which are presumed to be maximum relevant to plant existence (Pearson and Dawson, 2003; Irfan Ullah *et al.*, 2007). The WorldClim climate layers were created by interpolating observed climate from climate stations around the world, using a thin-plate smoothing spline set to a resolution of approximately 1 km, over the 50-year period from 1950 to 2000 (Hijmans *et al.*, 2005). Additioinally, we used aspect, slope, altitude (http://edc.usgs.gov/products/elevation/gtopo30/hydro/asia.html and http://www.worldclim.org) and landcover (GLC, 2000), in the model development (Table 1). All analyses were conducted at the 1 x 1 km pixels spatial resolution of the environmental data sets since, bioclimatic variables with finer than 1 km resolution is not available at this moment. All environmental data layers were finally cropped for the study area (Indian Himalayan Region) to perform the modeling experiment.

Model development: We followed three different modeling techniques for our study. The open Modeller desktop version 1.0.9 was used for GARP (GARP with best subsets – Desktop GARP implementation) and Bioclim techniques. Maxent 3.3.1 used for performing Maxent algorithm (downloaded from http://www.cs.princeton.edu/~schapire/maxent/). A brief description of the techniques is mentioned below.

GARP is a genetic algorithm that creates ecological niche models for species. The models describe environmental conditions under which the species should be able to maintain populations. For input, GARP uses a set of point localities where the species is known to occur and a set of geographic layers representing the environmental parameters that might limit the species' capabilities to survive. Details of the modeling algorithm can be found in Stockwell and Peters, 1999. In our study, we assigned 50% of the occurrence points as training data for developing the model while rest of the data has been used as intrinsic test data. For other parameters, we used default values available in open Modeler *i.e.* commission threshold = 50% of distribution models, omission threshold = 20% of the models with least omission error and resample value = 2,500.

Bioclim is one of the earlier modeling techniques, tallying species occurrence points for each environmental variable including 95% of the distribution (*i.e.* excluding extreme 5% of the distribution) along each ecological dimension. Details of the algorithm can be obtained from Busby (1991).

The maximum entropy (MaxEnt) approach estimates a species' environmental niche by finding a probability distribution that is based on a distribution of maximum entropy (with reference to a set of environmental variables) (Phillips *et al.*, 2006). Default values of different parameters, maximum iterations = 500, convergence threshold = 0.00001 and 50% of data points were used as random test percentage in our study.

Model validation: Prediction accuracy of all three model outputs was measured through receiver operating characteristics (ROC) analysis because of its wider application in the modeling studies despite some recent arguments (Lobo *et al.*, 2008; Boubli and Lima, 2009; VanDerWal *et al.*, 2009; Yates *et al.*, 2010). A ROC plot can be generated by putting the sensitivity values, the true positive fraction against the false positive fraction for all available probability thresholds. A curve which maximizes sensitivity against low false positive fraction values is considered as good model and is quantified by calculating the area under the curve (AUC). An AUC statistic closer to1.0 indicates total agreement between the model and test data and considered as good model. An AUC with value closer to 0.5 considered to be no better than random.

Results and Discussion

Predictions of the potential distribution of *Berberis aristata* in Indo-Himalayan region are comparable based on its current distribution in the region. Model outputs are varied according to the modeling techniques (Fig. 2 A, B and C).

Both the GARP and MaxEnt models showed distribution spread in Western and Eastern Himalayan states of India. On the contrary, Bioclim output is restricted in Western Himalayan region *i.e.*, Himachal Pradesh and Uttarakhand. . All three models showed higher accuracy and AUC value near 1.0 with low omission error (Table 2).

Modelling outputs reveal that, MaxEnt predicted largest area (10.36% of Indo-Himalayan region) under potential distribution in comparison to GARP (4.63%) and Bioclim (2.44%). However, Bioclim had higher high probability regions (100%) than GARP

Table - 1: Environmental variables used in the model development

Variables	Details
BIO1	Annual mean temperature
BIO2	Mean diurnal temperature range [mean of monthly (max temp–min temp)]
BIO3	Isothermality (P2/P7) (×100)
BIO4	Temperature seasonality (standard deviation×100)
BIO5	Max temperature of warmest month
BIO6	Min temperature of coldest month
BIO7	Temperature annual range (P5–P6)
BIO8	Mean temperature of wettest quarter
BIO9	Mean temperature of driest quarter
BIO10	Mean temperature of warmest quarter
BIO11	Mean temperature of coldest quarter
BIO12	Annual precipitation
BIO13	Precipitation of wettest month
BIO14	Precipitation of driest month
BIO15	Precipitation seasonality (coefficient of variation)
BIO16	Precipitation of wettest quarter
BIO17	Precipitation of driest quarter
BIO18	Precipitation of warmest quarter
BIO19	Precipitation of coldest quarter
Slope	Slope value from digital elevation model (http://edc.usgs.gov)
Aspect	Aspect value from digital elevation model (http://edc.usgs.gov)
Altitude	Elevation above sea level (m)
Landcover	Global landcover map

Table - 2: Comparative details of the modeling outputs

Parameters	Modelling techniques		
	GARP	Bioclim	MaxEnt
Accuracy	86.66	100	-
AUC value	1.0	1.0	0.969 (training set) 0.947 (test set)
Omission error	0.142	0	-
Total distribution (% of total area)	4.63	2.44	10.36
High probability area (% of total distribution)	29.65	100	6.27

and MaxEnt (*i.e.* 29.65 and 6.27%, respectively). Both GARP and MaxEnt showed a wider range of distribution from low to high probability in Himachal Pradesh, Uttarakhand, Jammu-Kashmir, Arunachal Pradesh, Nagaland and Manipur whereas, Bioclim distribution was restricted as high probability areas in Himachal Pradesh and Uttarakhand.

The jackknife test of variable importance in MaxEnt has identified the precipitation of driest quarter (bioclimatic variable 17) as the most important environmental variable in model development. This variable has highest predictive value or gain when used in isolation. Other variables like precipitation of coldest quarter (bioclimatic variable 19), temperature seasonality (bioclimatic variable 4), mean temperature of coldest quarter (bioclimatic variable 11) and minimum temperature of coldest month (bioclimatic variable 6) also have considerable predictive value with regard to distribution of *Berberis aristata.*

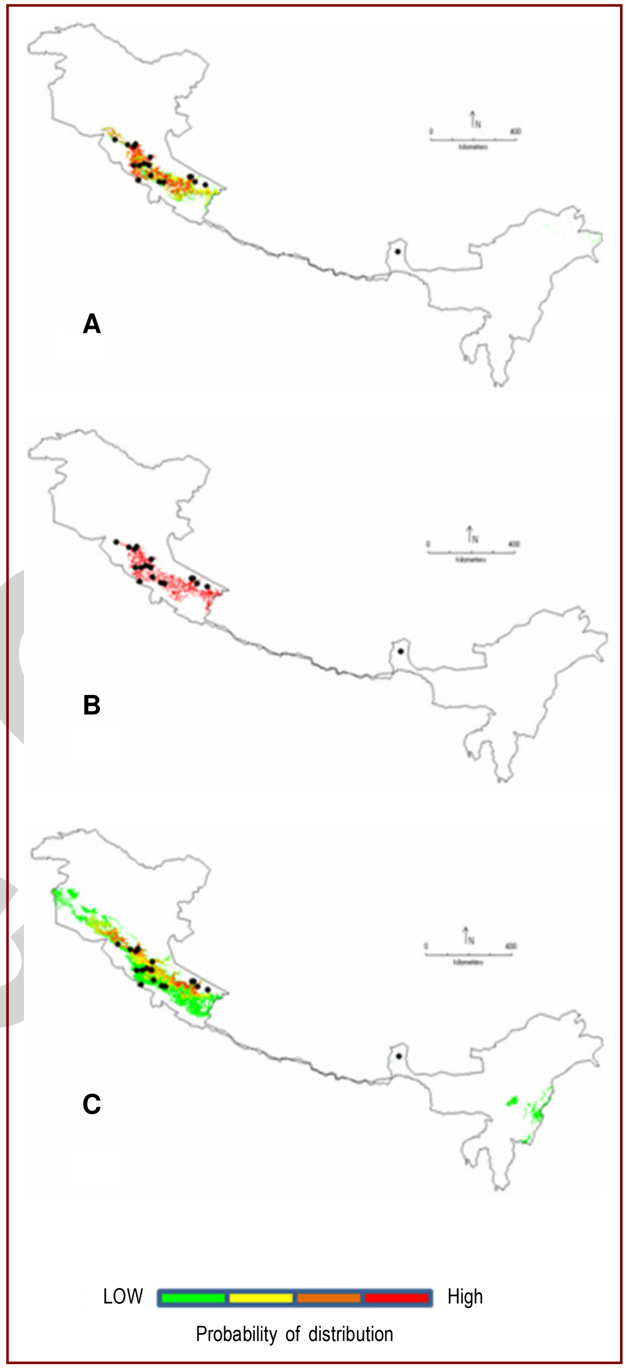

Fig. 2: Modelling outputs from three different algorithms A = GARP, B = Bioclim, C = MaxEnt

Potential distribution maps show various possibilities for conservation and management of this valuable plant species. Clustering of high probability areas in the northwestern states around the occurrence points indicate the suitability of the region for further exploration as well as reintroduction / conservation program as it satisfies fundamental niche requirement of the species. Considering the mountainous inhospitable nature of the Himalayan region, targeting high probability regions for future exploration could increase the probability of success in the venture. Earlier endevours involving field surveys / exploration based on model outputs had helped in discovering new populations as well as allied species (Raxworthy *et al.*, 2003; Siqueira *et al.*, 2009). This prior information on species probable distribution in the area certainly helps in judicious utilization of resources and time. On the other hand, new areas like Eastern Himalayan states have come out as potential occurrence sites for the species as evidenced through GARP and MaxEnt outputs. At present we have only one occurrence record from this site (*i.e.* Sikkim) but further studies may improve the candidature of the region as favorable site for the *Berberis aristata*. This idea gets support from available literature on *Berberis* spp. distribution in India, where several other species of *Berberis viz.*, *B. asiatica var asiatica*, *B. parisepala, B. macrosepala var macrosepala, B. insignis, B. dasyclada* etc. have been reported from Northeastern Himalayan states (Sharma *et al.,* 1993). The presence of other species in the region may open up the possibilities for *B. aristata* as several studies have indicated niche conservatism among the closely related species (Peterson, 1999). However, this could only be verified after field exploration and collection of information.

This exercise could be useful for comparing natural resource distribution pattern and conservation / management strategies to protect them. Application of species distribution modeling in conservation area planning and management is widely used nowadays (Araujo and Williams, 2000; Ortega-Huerta and Peterson, 2004; Pearson, 2007). By knowing the potential distribution region, especially the high probability areas (here it is part of Uttarakhand and Himachal Pradesh), it is possible to design conservation priority zone / resource management zone with an emphasis on species ecological boundary. This approach from ecological viewpoint makes species survival and management easier and more efficient than other practices.

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