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ECOLOGICAL NICHE MODELLING FOR CONSERVATION OF *HABENARIA SUAVEOLENS* DALZELL, AN ENDANGERED ORCHID SPECIES ENDEMIC TO WESTERN GHATS: A CASE STUDY

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Abstract

Habenaria suaveolens Dalzell is an endangered orchid species, confined to Western Ghats. The aim of the study is to test a maximum entropy approach to predict suitable areas for *in situ* conservation of this species. Maxent modelling software has been used for predicting potential suitable habitats combining environmental variables and species occurrence data. A total of twenty six occurrence records were used for modelling, of which 75% records were used as training data. The remaining 25% were used as test data. The output of the model was evaluated using the area under the receiver-operating characteristic curve (AUC). The threshold values training (0.985) and test (0.968) were close to 1, thereby showing the accuracy of the model.

Introduction

IN THE last decade, there has been remarkable development in use of species distribution models (SDMs), the approaches based on correlation between known occurrences of species and features of the ecological and environmental landscape. The aim of such models is to reconstruct empirically derived 'environmental profile' which can be used to estimate the ecological space of species or predict geographical distribution of species (Peterson, 2006). These models are not only just to understand the ecological requirements of species, but also to understand species prediction of known populations, identify potential sites for reintroductions and planning for conservation area (Guisan and Zimmermann, 2000; Peterson, 2006). Most species distribution modeling methods are sensitive to sample size (Wisz *et al*., 2008) and may not accurately predict habitat distribution patterns for threatened and endangered species. Among such models, Maxent (maximum entropy algorithm modeling programme), is a machine-learning algorithm based on principles of maximum entropy (Jaynes, 1957), and has been widely used in recent studies (Elith *et al*., 2006; Merow *et al*., 2013; Philips *et al*., 2006).

The Western Ghats encompasses a wide range of ecological conditions. The 1,60,000 km^2 mountainous range of the Western Ghats, is one of the 34 global biodiversity hotspots (Myers *et al*., 2000). Nearly 123 endemic orchid species occur in Western Ghats (Jalal and Jayanthi, 2012), of these many are rare and restricted to certain specialized niches. In this study, we have analyzed the relationships between the occurrence of *Habenaria suaveolens* Dalzell, an endemic and endangered terrestrial orchid species of Western Ghats (Jalal and Singh, 2015; Mishra and Singh, 2001), and environmental variables. This terrestrial orchid species is strictly confined to the Western Ghats of Maharashtra, Goa and Karnataka states. This species was described by Dalzell in 1850 based on collections from the Konkan region of Maharashtra and Bababudan hills of Karnataka. It is a highly variable species with regard to the size of plant and shape of lip (Jalal and Jayanthi, 2013; Santapau and Kapadia, 1966). Majority of the terrestrial orchids are threatened globally (IUCN, 2001) with specialized habitat requirements, making them particularly susceptible to habitat fragmentation and modification (Pillon and Chase, 2007). Orchid seeds are microscopic, and generally require symbiotic contact with an appropriate mycorrhizal fungus, and germination rates in the wild are surprisingly low as compared to many other plants (Rasmussen, 1995). Due to high extinction risk to this group, there has been a major conservation concern for many environmental groups (Cribb *et al*., 2003; Swarts and Dixon, 2009).

Given the conservation concern and narrow range of distribution, we have developed a species distribution model for effective conservation of *H. suaveolens.* The objectives of the study were: i) to predict the suitable habitat distribution using small number of occurrence, and ii) to identify the environmental factors which associated with its distribution.

Materials and Methods

Study Area and Occurrence Records

The major portion of the study area falls under Northern Western Ghats and some extent to central Western

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Ghats towards Karnataka. The area lies towards the western edge of Deccan plateau and separates the plateau from the narrow coastal zone of the Arabian Sea. The elevation ranges from sea level to 1892 m (Kudremukh, Karnataka). The average annual rainfall varies from 2000 to 7000 mm. Vegetation is mainly tropical evergreen forest, tropical semi-evergreen forest and tropical moist deciduous forest.

Field surveys were conducted in different localities during 2012–2016 and their geographical coordinates were recorded using Garmin etrex 12 channel GPS handset. Apart from field survey, details on a few localities were collected from herbarium records and published literature. Geographic coordinates of the localities which were not indicated by the plant collector(s) were assigned based on the data about the collection place. The Google Earth (v. 7.1.7.2606, Google Inc.) application was used to validate all gathered information. In total, 26 localities were included in the database (Table 1).

Selecting Environmental Variables

The 19 bioclimatic variables (Hijmans *et al.*, 2005) were obtained from World Climate Website (http://www.worldclim.org): annual mean temperature (BIO1), mean diurnal range (BIO2), isothermality (BIO3), temperature seasonality (BIO4), maximum temperature of warmest month (BIO5), minimum temperature of coldest month (BIO6), temperature annual range (BIO7), mean temperature of wettest quarter (BIO8), mean temperature of driest quarter (BIO9), mean temperature of warmest quarter (BIO10), mean temperature of coldest

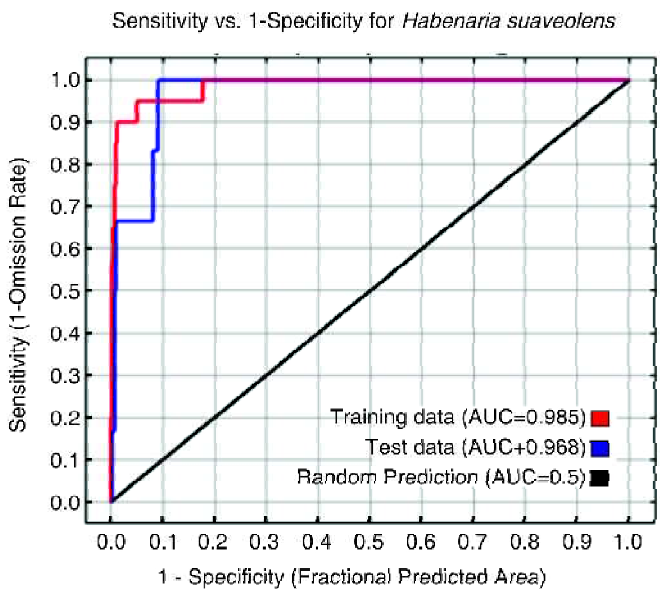

Fig. 1. Receiver operating characteristic curve with area under curve (AUC).

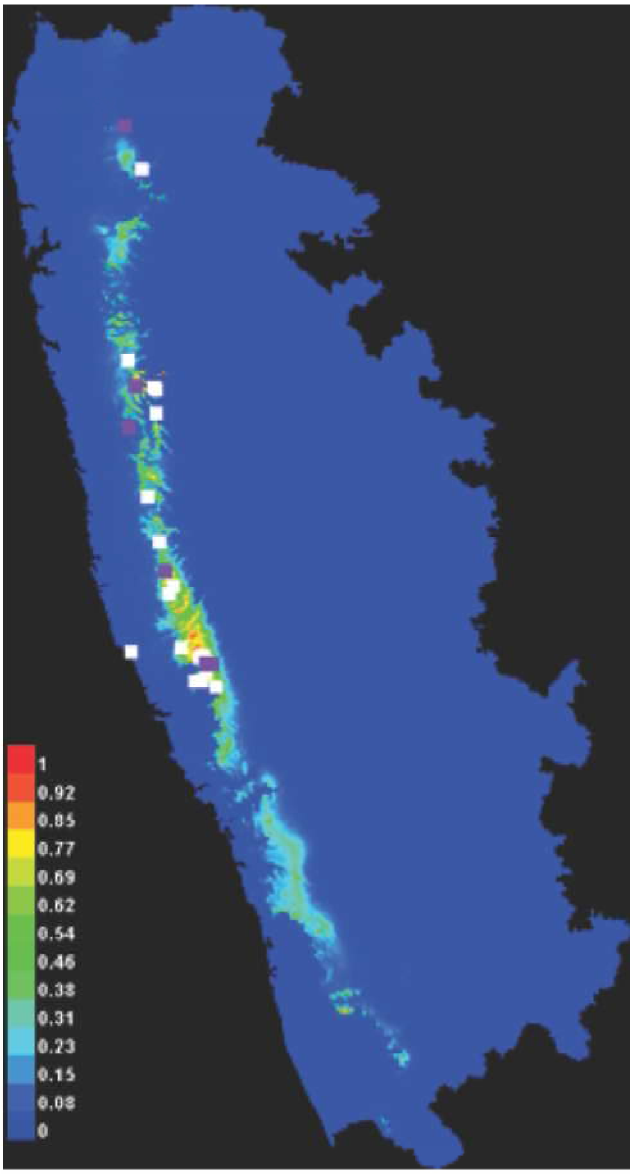

Fig. 2. Model output showing the presence locations used for training (in white) and the test locations (in violet).

quarter (BIO11), annual precipitation (BIO12), precipitation of wettest month (BIO13), precipitation of driest month (BIO14), precipitation seasonality (BIO15), precipitation of wettest quarter (BIO16), precipitation of driest quarter (BIO17), precipitation of warmest quarter (BIO18), and precipitation of coldest quarter (BIO19). All variables were reduced to a grid resolution of 30 arc-seconds or 0.008333° (ca. 1km^2) for the analysis. These bioclimatic variables represent annual trends and seasonality, derived from monthly temperatures and rainfall recorded worldwide. The native format of these files is ‘BIL’. In order to be compatible with Maxent, these files were converted to ‘ASCII’ using ArcGIS 10.5 (Scheldeman and van Zonneveld, 2010). Highly inter-correlated variables (r >0.9) excluded by using principal

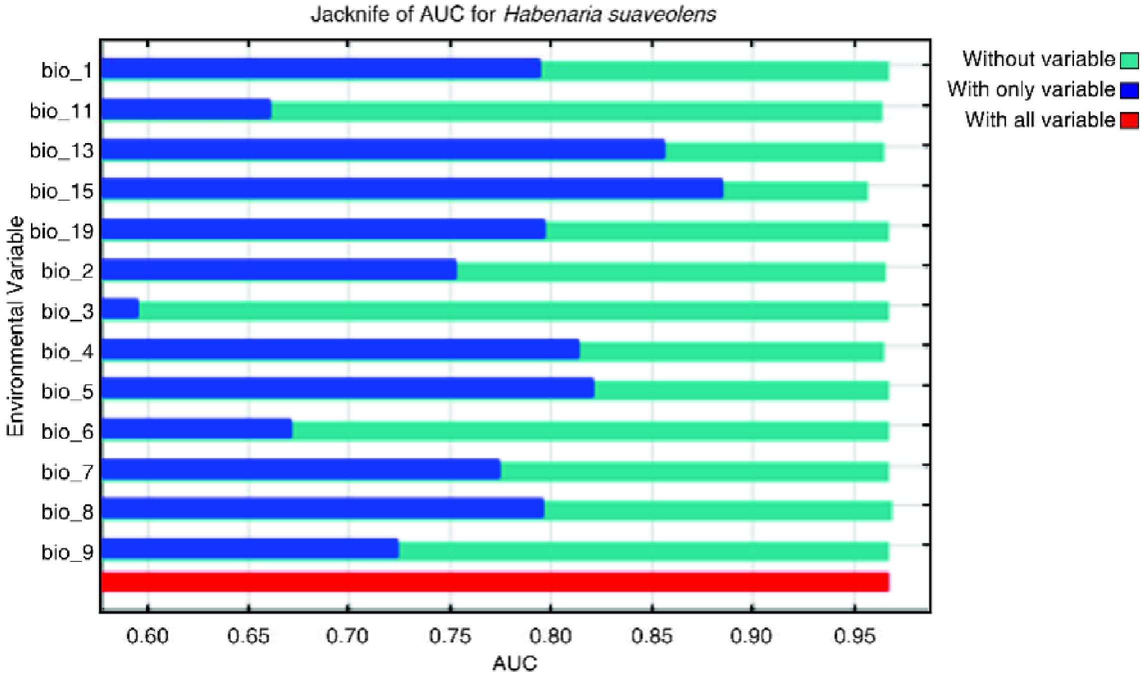

Fig. 3. Jackknife plot for AUC.

component analysis (Table 2) because multi-collinearity may violate statistical assumptions and may alter model predictions (Heikkinen and Luoto, 2006). Thus, the number of predictor variables (here bioclimatic variables) was reduced to eleven.

Model Building and Evaluation

Maxent algorithm (version 3.3.3k) was used for modeling (Phillips *et al*., 2006), which generates an estimate of probability of presence of the species that varies from 0 to 1, where 0 being the lowest and 1 the highest probability. A total of 26 occurrence records and 13 environmental variables were used to model potential habitat distribution for *H. suaveolens*. Runs were conducted with the default variable responses settings, and a logistic output format. Additionally, to know the relative influence of each of the predictor variables selected for Jackknife test (Phillips, 2006). For every model to check the predictive performance testing or validation is must. Here, we have divided the occurrence dataset into two sets, training or test sets. Seventy-five percent of the data points were randomly selected as training points and used in model building. The remaining 25% of the records were test points and used in model validation. The output results generated by Maxent predict habitat suitability of the species ranging from 0 to 1 per grid cell, where in the average observation should be close to 0.5 (Elith *et al*., 2011). Lowest suitability areas are represented by 0, while 1 represents areas with highest suitability (Jaryan *et al*., 2013). In order to apply a threshold value to produce suitable occurrence map, the output ASCII file imported in ArcGIS 10.5. We have used 10 percentile training presence logistic thresholds to create a distribution map (threshold 0.491) for a better ecologically significant result. It is necessary to transform the probability map in presence/absence data. Furthermore, for the sake of easy understanding and conceptualization the logistic probability distribution we have classified the areas into high, low and medium probability areas. The area under the receiver operating characteristic (ROC) curve (AUC) is used for evaluation (Fig. 1). This provides a summary measure of the model's discrimination ability, that is, its ability to differentiate suitable from unsuitable habitats (Phillips *et al*., 2006). An AUC value of 0.5 shows that model predictions are not better than random; < 0.5 are worse than random; 0.5–0.7 indicates poor performance; 0.7–0.9 reasonable/moderate performance; and > 0.9, high performance (Peterson *et al*., 2011).

Results

The output of the model has been shown in Figure 2, which represents the logistic output of Maxent model. It is easiest to conceptualize and interpret (Jaryan *et al*., 2013; Kumar, 2012) and gives an estimate between 0 and 1 of probability of presence. Warmer colors show areas with better predicted conditions; red indicating high probability of suitable conditions for the species, green indicating conditions typical of those where the species is found, and lighter shades of blue indicating low predicted probability of suitable conditions. White

Colored

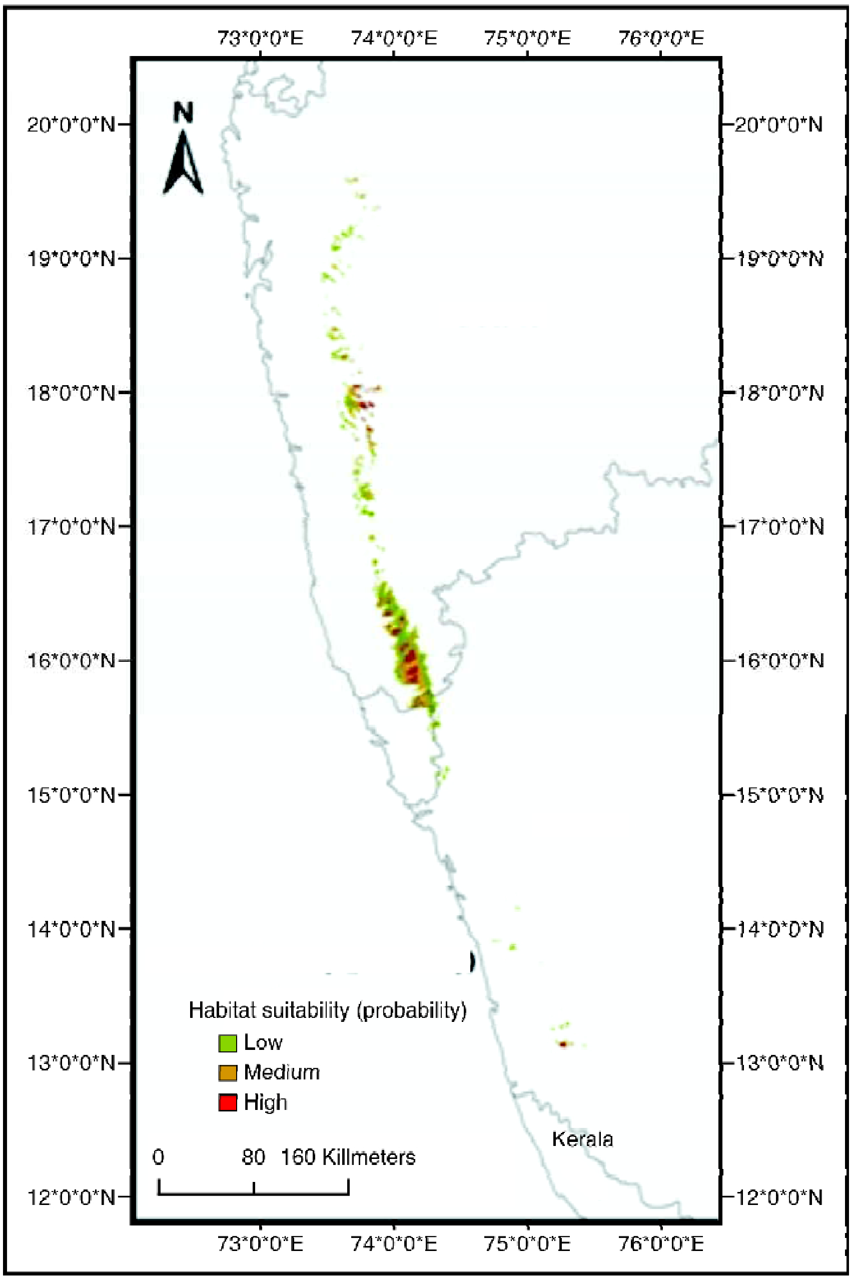

Fig. 4. Predicted potential suitable habitat for *Habenaria suaveolens* in Western Ghats.

dots show the presence locations used for training, while violet dots show test locations. Statistical evaluation of the Maxent output indicated that the model provided useful prediction. The threshold value training (0.985) and test (0.968) was close to 1, thereby showing the accuracy of the model (Fig.1). The Maxent internal Jackknife test (another method of testing the importance of each variable) showed that Bio13 and Bio15 (precipitation of wettest month and Precipitation Seasonality) were the two most important predictors of *H. suaveolens's* habitat distribution (Fig. 3). Their individual contribution was 42% and 20.3%, respectively. The potential habitat suitability of *H. suaveolens* in Western Ghats is shown in Fig.4. The areas in red depict localities that have high probability (189 km^2) of *H. suaveolens,* while those in yellow represent medium probability (615 km^2). Low probability (1668 km^2) areas are shown in green. Commonly used threshold of 0.5 (Jimenez-Valverde and Lobo, 2007) was taken in consideration to calculate extent of occurrence (EOO, as defined by IUCN, 2001). The total predicted area was estimated 2,472 km^2. The state-wise prediction shows that Maharashtra state has maximum predicted area 2,184 km^2, which contributes 88 % of total predicted area. Less predicted states are Karnataka and Goa, 230 Km^2 and 58 km^2, respectively.

Discussion

The distribution of *H. suaveolens* is fragmented and limited to elevations between 700 and 1500 m. Apparently, it is confined to the lateritic plateaus in the higher elevations of Western Ghats. These unique plateaus have a narrow range in the Western Ghats and providing unique micro-environments to support the growth and regeneration. These plateaus are isolated summits and are often referred to as terrestrial islands (Lekhak and Yadav, 2012). The soil cover is very thin on the plateaus and appears almost barren during winter and summer seasons. The early phase of monsoon starts in June when the vegetative growth of this plant starts (Jalal and Jayanthi, 2013). Field surveys and modelled outputs indicate that elevation zone between 700 and 1300 m provides the suitable environment for its distribution. The southern part of Kolhapur district particularly Chand had taluka, which is connected to Karnataka state indicates the highly suitable area followed by Mahabaleshwar and Kas plateau. Furthermore, the model has predicted a new area in Karnataka state that is Kudremukh (1500 m). Ground survey and model output show its maximum abundance outside the limit of Protected Areas, which could lead higher vulnerability in near future.

Table 1. Occurrence records of *Habenaria suaveolens*.

Population (sub-population)	Latitude (E)	Longitude(N)	Locality	State	Elevation (m)
1.	17.616	73.616	Thoseghar plateau	Maharashtra	850
2.	17.082	73.754	Gothane plateau	Maharashtra	881
3.	16.514	73.891	Morjai plateau	Maharashtra	962
4.	17.935	73.665	Mahableshwar	Maharashtra	1300
5..	17.925	73.806	Panchgani	Maharashtra	1331
6.	17.911	73.820	Panchgani	Maharashtra	1312
7.	18.138	73.608	Varandha Ghat	Maharashtra	600
8.	16.400	73.955	Radhanagari	Maharashtra	570
9.	16.744	73.848	Barki plateau	Maharashtra	950
10.	16.341	73.919	Shelap plateau	Maharashtra	1010
11.	17.727	73.820	Kaas Plateau	Maharashtra	1194
12.	19.602	73.711	Kalsubai	Maharashtra	1500
13.	15.930	74.013	Kegad_Amboli	Maharashtra	700
14.	19.936	73.578	Anjaneri	Maharashtra	1200
15.	15.855	74.158	Gavalivada (Chandgad)	Maharashtra	750
16.	15.856	74.185	Pargad Road	Maharashtra	726
17.	15.805	74.205	Tilari (Chandgad)	Maharashtra	800
18.	15.802	74.255	Satav (Chandgad)	Maharashtra	750
19.	15.815	74.209	Satav (Chandgad)	Maharashtra	750
20.	15.892	73.630	Malvan	Maharashtra	89
21.	15.864	74.182	Pargad Road	Maharashtra	718
22.	15.864	74.172	Pargad Road	Maharashtra	710
23.	15.665	74.166	Surlasada	Goa	830
24.	15.739	74.205	Chigul (Belgaum)	Karnataka	800
25.	15.671	74.119	Kankumbi (Belgaum)	Karnataka	830
26.	15.630	74.277	Amgaon (Belgaum)	Karnataka	800

This species was almost vanished from its type locality, Malvan. After its first report it was not collected by any field botanists in the last 166 years. It was once abundant in the Panchgani plateau has now become almost a rare sighting due to immense pressure and disturbance caused by tourism. Similar threats were also noticed in Mahabaleshwar around Venna Lake area. In some localities like Kas plateau, a Natural World Heritage Site declared by UNESCO (2012), the population is under protection. The high abundance area of *H. suaveolens* is Chandgadtaluka, where the population is threatened due to trampling by cattle and quarrying activities. Most of the population is on roadsides and between human settlements so they are also facing direct and indirect anthropogenic threats. Besides population at easily accessible plateaus namely Chaukul (Amboli), Morjai, Surlasada (Goa), Chigul and Kankumbi (Karnataka) are threatened by large number of tourists during monsoon season. The present ecological niche modeling study has achieved its main objectives of predicting the suitable habitats and environmental factors that influence and limit the distribution of the species under consideration. This study provides the first predicted potential habitat

Table 2. Correlation between different bioclimatic variables.

Variable	BIO2	BIO3	BIO4	BIO5	BIO6	BIO7	BIO8	BIO9	BIO10	BIO11	BIO12	BIO13	BIO14	BIO15	BIO16	BIO17	BIO18	BIO19
BIO1	-0.846	0.364	0.721	0.255	0.566	-0.054	0.450	0.360	-0.820	0.748	-0.778	-0.461	0.496	0.025	0.907	0.586	0.531	-0.010
BIO2	1.000	0.043	0.294	-0.489	-0.742	-0.016	-0.524	-0.456	0.988	-0.790	0.959	0.863	-0.017	0.475	-0.596	-0.764	-0.731	-0.060
BIO3		1.000	0.608	0.122	0.118	-0.467	0.351	-0.166	0.003	-0.118	0.210	0.416	0.948	0.850	0.621	0.090	0.075	-0.235
BIO4			1.000	-0.146	0.103	-0.152	0.093	0.127	-0.249	0.426	-0.255	0.194	0.784	0.545	0.857	0.114	0.061	-0.149
BIO5				1.000	0.849	-0.305	0.583	0.257	-0.557	0.163	-0.385	-0.572	-0.005	-0.255	0.187	0.821	0.873	-0.105
BIO6					1.000	-0.151	0.666	0.562	-0.774	0.515	-0.657	-0.699	0.088	-0.295	0.453	0.997	0.995	-0.005
BIO7						1.000	-0.273	0.257	0.015	0.125	-0.081	-0.078	-0.353	-0.296	-0.196	-0.098	-0.141	0.702
BIO8							1.000	0.060	-0.584	0.202	-0.395	-0.446	0.248	-0.046	0.383	0.650	0.641	-0.015
BIO9								1.000	-0.433	0.538	-0.441	-0.417	-0.072	-0.274	0.235	0.598	0.544	0.193
BIO10									1.000	-0.695	0.915	0.867	-0.025	0.456	-0.562	-0.790	-0.764	-0.069
BIO11										1.000	-0.859	-0.606	0.053	-0.360	0.620	0.552	0.489	0.046
BIO12											1.000	0.860	0.112	0.583	-0.541	-0.685	-0.654	-0.041
BIO13												1.000	0.442	0.814	-0.132	-0.716	-0.714	-0.110
BIO14													1.000	0.866	0.761	0.073	0.037	-0.204
BIO15														1.000	0.363	-0.318	-0.336	-0.186
BIO16															1.000	0.463	0.409	-0.143
BIO17																1.000	0.991	0.028
BIO18																	1.000	-0.004

distribution map for an endemic terrestrial orchid species in Western Ghats as well as in India.

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