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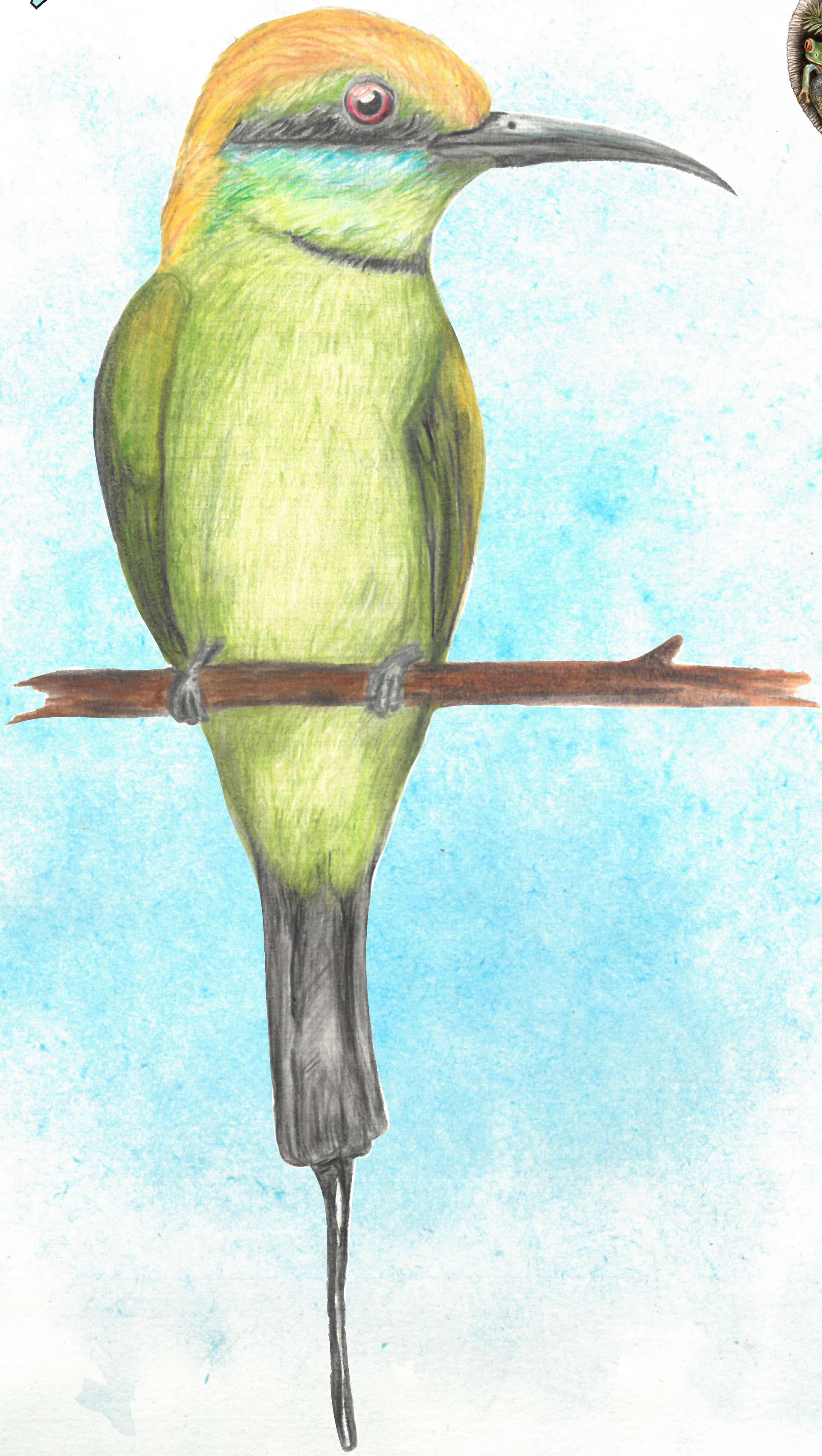

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Cover: Green Bee-eater with colour pencils and watercolor wash by Elakshi Mahika Molur.

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COMMUNICATION

Ecological niche modeling to find potential habitats of *Vanda thwaitesii*, a notified endangered orchid of Western Ghats, India

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Abstract: Conservation planning of a threatened species essentially requires information on its present population and extent of distribution. Ecological niche modeling (ENM) is a suitable machine learning technique to predict potential distribution of a species enabling to identify suitable habitat for conservation action. The present study undertook distribution modeling of *Vanda thwaitesii*, a notified endangered orchid species of the Indian Western Ghats and Sri Lanka using maxent software. Geographical coordinates of 54 occurrence points at 1 km resolutions gathered during the study were utilized for modeling. A total of 37 variables including bioclimatic, topographical, and seasonal climate subjected to principal component analysis extracted into three components based on temperature and precipitation. Four representative variables from each component in all possible combinations resulted consistent output showing distribution of the species extending from Gavi in Periyar Tiger Reserve of Kerala to Chikkamagalur of Karnataka. Habitat suitability was confined to the cooler regions receiving an average 3,400 mm annual mean precipitation, 22.7^{0}C annual mean temperature, and 290 mm summer precipitation. A total of 2,557 km^2 in Kerala and Karnataka mostly outside protected forests demonstrated as the highly suitable habitats. Silent Valley National Park, Idukki Wildlife Sanctuary, Periyar Tiger Reserve, and Brahmagiri Wildlife Sanctuary in addition to a few reserve forests hold sufficient area for reinforcement of diversity of *V. thwaitesii* from vulnerable locations. The present study revealed niche modeling as a useful tool to find suitable habitats for *V. thwaitesii* in the Western Ghats.

Keywords: Bioclimatic variables, co-linearity, conservation, endangered species, jack knife test, maxent modeling, Orchidaceae, QGis, summer precipitation, Wayanad.

Malayalam: വംശനാശ ഭീഷണി നേരിടുന്ന സസ്യങ്ങളുടെ സംരക്ഷണ ആസൂത്രണത്തിന് അവയുടെ വിതരണപരിധിയും എണ്ണവും നിർബന്ധമായും അറിയേണ്ടതായിട്ടുണ്ട്. സസ്യ ജാതികളുടെ സാദ്ധ്യമായ വിതരണ പരിധി പ്രവചിക്കുവാനും സംരക്ഷണ പ്രവർത്തനങ്ങൾക്ക് അനുയോജ്യമായ വാസസ്ഥലങ്ങൾ തിരിച്ചറിയുവാനും യാന്ത്രിക പഠനവിദ്യയായ എക്കോളജിക്കൽ നിഷ് മോഡലിങ് പ്രാപ്തമാക്കുന്നു. ഭാരതത്തിലെ കേന്ദ്ര പരിസ്ഥിതി വനം മന്ത്രാലയം, വംശനാഷ ഭീഷണി നേരിടുന്ന സ്പീഷീസായി വിജ്ഞാപനം ചെയ്തിട്ടുള്ള, പശ്ചിമഘട്ടത്തിലും ശ്രീലങ്കയിലും മാത്രം കണ്ടെത്തിയി-ട്ടുള്ള, വാണ്ട ത്വയ്റ്റീസി എന്ന ഓർക്കിഡിൽ മാക്സെൻറ് എന്ന സോഫ്റ്റ്വെയർ ഉപയോഗിച്ച് ഇവിടെ പഠനവിധേയമാക്കി. വിപുലമായ പഠന യാത്രകളിലൂടെ ശേഖരിച്ച, 54 വാസസ്ഥാനങ്ങളുടെ ജോഗ്രഫിക്കൽ കോർഡിനേറ്റർ ഉപയോഗിച്ച് വിതരണ മാതൃക തയാറാക്കി. ബയോക്ലൈമറ്റ്, ടോപോഗ്രഫി, സീസണൽ ക്ലൈമറ്റ് എന്നിവയിൽപ്പെടുന്ന 37 വേരിയബിൾസ് പ്രിൻസിപ്പൽ കമ്പോണൻറ് അപഗ്രഥനത്തിലൂടെ താപനില, മഴ ഇവയെ അടിസ്ഥാനമാക്കി 3 ഘടകങ്ങളായി ചുരുക്കി. എല്ലാ ഘടകങ്ങളെയും പ്രതിനിധീകരിച്ചുള്ള 4 വേരിയബിൾസ് സാധ്യമായ എല്ലാ കോമ്പിനേഷനിലും അപഗ്രഥിച്ചപ്പോൾ, സ്ഥിരതയുള്ള വിതരണ മാതൃക ലഭിച്ചു. മാതൃക പ്രകാരം, കേരളത്തിലെ പെരിയാർ കടുവാ സങ്കേതത്തിൽ ഉൾപ്പെട്ട ഗവി മുതൽ കർണാടകയിലെ ചിക്കമഗല്ലൂർ വരെ വിതരണസാദ്ധ്യതയുള്ളതായി തെളിഞ്ഞു. പൊതുവെ തണുത്ത കാലാവസ്ഥയിൽ, ശരാശരി 3400 മി.മി. വാർഷിക വൃഷ്ടിയും 22.7°C വാർഷിക താപനിലയും, 290 മി.മി. വേനൽ മഴയും ലഭിക്കുന്ന സ്ഥലങ്ങൾ വാണ്ട തൃയ്റ്റീസിയുടെ വളർച്ചക്കും നിലനില്പിനും വളരെ ഉചിതമെന്നു കണ്ടെത്തി. കേരളത്തിലും കർണാടകയിലുമായി ആകെ 2557 ച.കി.മി. പ്രദേശം വളരെ അനുയോജ്യമെന്ന് സമർത്ഥിക്കുവാൻ കഴിഞ്ഞു. സുരക്ഷിതമല്ലാത്ത പ്രദേശങ്ങളിൽനിന്നും വാണ്ട തൃയ്റ്റീസിയുടെ ജനിതകവൈവിദ്യം പുനരധിവസിപ്പിക്കുവാൻ സൈലൻറ് വാലി, ഇടുക്കി വന്യജീവി സങ്കേതം, പെരിയാർ കടുവ സങ്കേതം, ബ്രഹ്മഗിരി വന്യജീവിസങ്കേതം കൂടാതെ ഏതാനും സംരക്ഷിത വനങ്ങൾ അനുയോജ്യമായ വാസസ്ഥലങ്ങൾ ഉൾക്കൊള്ളുന്നതായി തെളിയിക്കുവാൻ നിഷ് മോഡലിങ്ങിന് കഴിഞ്ഞു.

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Author details: Dr. S. William Decruse is Principal Scientist and HOD, Biotechnology and Bioinformatics Division, KSCSTE-JNTBGRI, Thiruvananthapuram. Dr. Decruse is working on conservation of RET orchids of Western Ghats India through micropropagation and restoration since 1991. As a prerequisite for restoration, worked on population study and niche modeling of a few orchid species.

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INTRODUCTION

Orchids are a group of plants belonging to Orchidaceae with 29,335 accepted species worldwide (POWO 2021). They have wide climatic preferences ranging from tropical to alpine habitats. However, due to habitat loss, habitat fragmentation, over-exploitation, and unrestrained illegal activities, many orchids have limited distribution range and population strength as other threatened plant species (Agustini et al. 2016; Warghat et al. 2016; Bachman et al. 2019; Lughadha et al. 2020). The existence of biodiversity have prime importance for the stability of an ecosystem and thus developing effective strategies for their conservation is the serious concern of conservation biologists (Singh et al. 2017). Besides, conservation planning of a threatened species essentially requires information on its present population and extent of distribution (Radosavljevic & Anderson 2014; Štípková et al. 2020). Mapping the identified geographical locations and predicting potential distribution of a species out of that is known to be useful in identifying critical regions that may need conservation action (Warren & Seifert 2011).

Vanda thwaitesii Hook.f. is one among the 81 species of *Vanda* reported worldwide (POWO 2021). It is endemic to the southern Western Ghats and Sri Lanka and is endangered mainly due to habitat loss and fragmentation. It was first collected by Thwaites from Sri Lanka in 1898 and remained elusive for over a century which forced to declare the species as extinct in 1981 (Sathishkumar & Sureshkumar 1998). During the period from 1982 to 1997, the species was collected from Silent Valley and Wayanad, Kerala thus confirming its presence in India (Sathishkumar & Sureshkumar 1998). The latter authors could also locate reference sample of *V. thwaitesii* collected in 1885 from Mananthavady in Wayanad District of Kerala. As per reports, the species have distribution in seven localities in Kerala. The species is distributed in narrow pockets with restricted numbers and later under section 38 of the Biological Diversity Act 2002, the Central Government notified that *V. thwaitesii* is on the verge of extinction and prohibited/regulated collection (MOEF 2009). The ministry also called for studies on all aspects of the notified species for holistic understanding and propagation of the species for the purpose of in situ and ex situ conservation and rehabilitation.

Plant distribution modeling/ ecological niche modeling (ENM) is recognized as an efficient tool to understand potential distribution of a plant/animal species and maximum entropy method (MEM; Phillips et al. 2006) is widely used for the purpose (Elith et al. 2011; Peterson et al. 2011). These models establish relationships between occurrences of species and biophysical and environmental conditions in the study area thus predicting suitable habitat for survival and existence of a species. This technique was successfully applied to find potential distribution and identify environmental niches for several plant species including orchids *Vanda wightii* (Decruse 2014), *V. bicolor* (Deb et al. 2017), *Paphiopedilum javanicum* (Romadlon et al. 2021), and *Habenaria suaveolens* (Jalal & Singh 2017). Based on the current understanding and the requirement of devising conservation action, the present study is framed to understand the habitat suitability of the species in localities other than that described earlier and the reported localities in Western Ghats region of Kerala, Tamil Nadu, and Karnataka states in India.

MATERIALS AND METHODS

Study site and field survey

As per the cited literature, Wayanad, Silent Valley, and Periyar Tiger Reserve in Kerala are the reported localities of *V. thwaitesii* in India (Agustine 1995; Sathishkumar & Sureshkumar 1998). The species have distribution at altitudes 500–1,060 m in moist deciduous to evergreen forests. Therefore, similar habitats in Idukki District of Kerala to Coorg District of Karnataka were surveyed to record geographical coordinates of occurrence points and score population status. Periyar Tiger Reserve, Idukki WS, Thirunelli, and Silent Valley are the protected forests surveyed. The inhabited land mainly covered is along roadways in North and South Forest Division of Wayanadu and adjoining places in Coorg District of Karnataka and Nilgiri District of Tamil Nadu. The surveys were conducted during 2011–2014 periods. The presence of *V. thwaitesii* was confirmed through close observation of the morphological feature (Image 1) of the species including fruit and flowers with the help of binoculars. Geographical co-ordinates of the presence location were recorded using Garmin GPSMap 60CSx.

Distribution modeling

A total of 37 environmental variables including 19 bioclimatic, six topographic, 11 seasonal climatic, and one vegetation variable (Table 1) influencing survival of a plant species were analyzed for their importance in modeling studies. As peninsular India receive monsoon in four distinct season, i.e., January–February (Dry period),

Image 1. Habit of *Vanda thwaitesii* Hook.f. © S. William Decruse

March–May (Summer precipitation), June–September (South-west monsoon), and October–December (North-east monsoon) the monthly precipitation data obtained from world climate (https://www.worldclim.org) was reconstructed to obtain seasonal precipitation variables of the region. All extraction, clipping, and recalculation were undertaken using QGIS software version 3.10

The climatic variables are derived from temperature and precipitation data and thus multi co-linearity always exists among different variables. Therefore, principal component analysis (PCA) is often recommended (Junior & Nóbrega 2018) to control the negative effects of co-linearity and as a more objective solution for the problem of variable selection. The data points of all the 37 variables corresponding to the geo-reference points of *V. thwaitesii* occurrence in 1-km spatial resolution were extracted using point sampling tool in QGIS and PCA analysis undertaken in SPSS 16 software to sort out the variables having significant contribution to the model. Accordingly, three major components were extracted (Table 2) and one important variable representing each component and all those with VIF less than 10 (Naimi et al. 2014) in each component were selected. Thus the variables Bio_1, Bio_9, Bio_12 and summer precipitation (PMM) were included in the final model.

The reported localities are confined to southern Indian peninsula and Sri Lanka and thus the region falling under longitudes (E) 67.5 & 89 and latitudes (N) 5.5 & 24.5 was extracted from the world climate to prepare distribution model for peninsular India and Sri Lanka. Maxent software version 3.40 (Philips et al. 2006) was used to build a habitat suitability model. In this modeling, 75% of the encounter data was used for the training set and the rest for the test set. The modeling used auto features with 500 iterations and other default values. For validating model robustness, 10 replicated model runs was executed with a threshold rule of 10 percentile training presence and employed bootstrapping method for dividing the samples into replicate folds. The output of the Maxent software predicts habitat suitability in the range 0 (not suitable) to 1 (appropriate) (Phillips & Dudik 2008). For selection of most important environmental variable, Jack knife test was performed. The output was

Table 1. Climatic and topography variables utilized for analysis of their contributions in plant distribution modeling.

Bioclimatic Variables[a]	Topography [b]	Specific Climate (Western Ghats)	Vegetation[c]
Bio_1–19	Elevation Slope Topical wetness index Vertical distance from channel network Convexity Aspect	*Precipitation[e]:* Jan–Feb Mar–May (PMM, Summer) Jun–Sep (SW monsoon) Oct–Dec (NE monsoon) Precipitation humid months (PHM, Apr–Nov) Precipitation dry months (Dec–Mar) *Evapotraspiration[d]:* Annual (aieto) Humid months (Apr–Nov) Dry months (Dec–Mar) *Temperature[e]* Average humid months (THM) Average dry months	Normalized digital vegetation index (NDVI)

[a] https://www.worldclim.org/data/worldclim21.html.
[b] Digital Elevation Model (DEM) data downloaded from http://www.earthexplorer.usgs.gov/ and derived the topographic variables in QGIS 3.10.7
[c] Buchhorn et al. (2020) Copernicus Global land Service, http://www.land.copernicus.eu/g;pbal/products/ndvi
[d] CGIAR, FAO, http://www. cgiar-csi.org. Monthly data downloaded and computed the seasonal value in in QGIS 3.10.7
e https://www.worldclim.org/data/worldclim21.html). Monthly data downloaded and computed the seasonal data in QGIS 3.10.7

imported to QGIS and a distribution map was created and prediction area calculated.

RESULTS

Field Survey

Extensive field surveys revealed the distribution of *V. thwaitesii* altitudes from 489 m to 1,168 m mostly on evergreen trees exposed to sunlight. A total of 93 occurrence points were recorded in Kerala, Tamil Nadu, and Karnataka. The surveys in Periyar Tiger Reserve (PTR), Idukki Wildlife Sanctuary, and Wayanad revealed inhabited land in Wayanad Plateau as the dominant distribution area and their population near forest segments is meager. Therefore, it is clear that the dominant population in the most ideal habitat was lost due to habitat loss and extension of their population was withheld due to habitat fragmentation.

Modeling studies

Out of the 93 occurrence points recorded during our field surveys, 54 geo-reference points were at 1-km spatial resolution (Table 3). Hunnasgiria in Sri Lanka the reported type locality retrieved from Google Earth was also included for modeling. Thus 55 occurrence points were available for modeling. The 37 variables (19 bioclimatic, six topography, 11 seasonal, and one vegetation) subjected to principal component analysis, extracted into three components explaining 96.5% variance (Table 2). The final model based on the four selected variables revealed summer precipitation in the months of March to May (PMM), annual precipitation (Bio_12), and annual mean temperature (Bio_1), have significant contribution to the model (Table 4). Jack Knife test (Figure 2) revealed PMM as the environmental variable with highest gain and significant drop when it is omitted. The species flowers during April–May when receives summer showers, after a dry period and thus precipitation during March–May may be critical for the survival and spread of the species. In the distribution model generated (Figure 3), one occurrence point at 489 m altitude in Kannur District was in the least probable region. This is the only one occurrence record below 700 m still establishing a solitary colony with 15 individuals with the incidence of fruit set and new recruit. However, 41% of the points fall in high probable (0.8–1) region and 32.6% in the 0.6–0.8 region (Figure 4). The whole peninsular India was modeled where only 0.59% area (11,561 km^2; Figure 4) confined to the Western Ghats region of Kerala, Karnataka, and Tamil Nadu emerged as suitable habitats for *V. thwaitesii*. Out of the total area (2,557 km^2) in the high probable region (0.6–1.0), Wayanad District of Kerala and Coorg District of Karnataka together constitute 1,461 km^2 (57%). Idukki District (353), Nelliyampathy (195), and Sholayar (137) of Kerala are the other regions having habitat suitability of 0.6–1.0 class. Suitable habitats extend from cooler regions in Thirunelveli districts of Tamil Nadu to Chikkamagalur district of Karnataka (Figure 3) covering protected forests as Idukki Wildlife Sanctuary, Silent Valley National Park, Periyar Tiger Reserve, and Brahmagiri Wildlife Sanctuary. In addition, a small area in Central Province of Sri Lanka also has habitat suitability.

Different variables extracted in the two principal components have equal variance of temperature and precipitation in the occurrence localities and thus the distribution models appeared very similar; *V. thawaitesii* inhabits cooler regions receiving annual mean temperature in the range 19.75–24.3 ^{o}C. Similarly, annual precipitation in the occurrence points are in the range 2020–4794 (Table 5). The occurrence points also

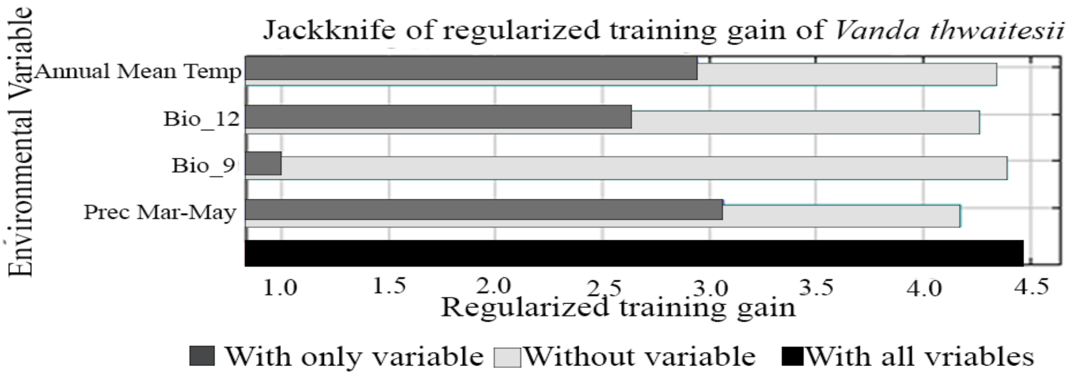

Figure 2. Jackknife of regularized training gain of *Vanda thwaitesii*.

Table 2. Output of principal component analysis (PCA) and variance inflation factor (VIF) among the variables.

Total variance explained and component variables			Principal components and VIF against one variable taken as constant				
Component	PCA output		PC1		PC2		PC3
	Eigen values	% of Variance	Variables	VIF	Variables	VIF	Variable
1	7.14	59.5	Bio_1		Bio_12		PMM
2	3.62	30.3	Bio_8	17.7	Bio_13	199.0	
3	0.8	06.7	Bio_9	5.4	Bio_16	443.9	
Total		96.5	Bio_11	57.3	PHM	61.6	
			THM	32.0	aieto	52.2	

Table 3. Geo-reference points (~1 km spatial data) of Vanda thwaitesii occurrence in Kerala, Tamil Nadu, and Karnataka used for distribution modeling.

Population	Latitude	Longitude	Altitude (m)	Location	District
1	9.4826166	77.144733	910	PTR	Idukki
2	9.46885	77.142266	931	PTR	Idukki
3	9.4653	77.143766	931	PTR	Idukki
4	9.4552	77.1426	1004	PTR	Idukki
5	11.098583	76.442203	920	Silent Valley	Palakkad
6	11.105	76.421345	1149	Silent Valley	Palakkad
7	11.079016	76.441608	1168	Silent Valley	Palakkad
8	11.46208	76.413495	839	Nadugani	Nilagiri
9	9.7479333	76.9709	986	Idukki WLS	Idukki
10	9.83825	76.92895	830	Kulamavu	Idukki
11	9.79245	76.8809	788	Kulamavu	Idukki
12	11.735766	75.9297	990	Vellamunda	Wayanad
13	11.71355	75.919216	991	Vellamunda	Wayanad
14	11.721683	75.935333	751	Pulinjal	Wayanad
15	11.9098	75.989583	793	Thirunelli	Wayanad
16	11.911316	75.98155	787	Thirunelli	Wayanad
17	11.827433	76.03125	774	Onedayangadi	Wayanad
18	11.83295	75.853733	727	Periya	Wayanad
19	11.835716	75.834616	772	Periya	Wayanad
20	11.838516	75.8295	727	Periya	Wayanad
21	11.8385	75.880516	772	Peria Peak	Wayanad
22	11.839583	75.891266	741	Varayal	Wayanad
23	11.84	75.902283	721	Varayal	Wayanad
24	11.838866	75.912816	781	Boys town	Wayanad
25	11.842583	75.868833	781	Peria Peak	Wayanad
26	11.802316	75.865283	754	Aalattil	Wayanad
27	11.76565	75.8666	721	Kunhome	Wayanad
28	11.7638	75.855216	727	Kunhome	Wayanad
29	11.753316	75.855716	720	Kunhome	Wayanad
30	11.7401	75.8398	720	Niravilpuzha	Wayanad
31	11.5139	76.019233	739	Lakkidi	Wayanad
32	11.526066	76.023116	739	Lakkidi	Wayanad
33	11.541	76.037516	735	Vythiri	Wayanad
34	11.83995	75.849278	735	Periya	Wayanad
35	11.839071	75.8535	735	Periya	Wayanad
36	12.154783	75.569166	489	Paithalmala	Kannur
37	12.35375	75.6586	925	Karugunda	Coorg
38	12.3545	75.652566	925	Karugunda	Coorg
39	12.3554	75.649316	925	Karugunda	Coorg
40	12.370266	75.621983	957	Cherambane	Coorg
41	12.376433	75.569266	901	Chettimani	Coorg
42	11.595216	76.01625	727	Achooranam	Wayanad
43	11.619966	76.001316	770	Edathara	Wayanad
44	11.62865	75.989016	817	Thariode	Wayanad
45	11.718533	75.92335	918	Mangalas-sery mala	Wayanad
46	11.69515	75.9385	863	Valaram-kunnu	Wayanad
47	11.712516	75.94255	772	Pulinjal	Wayanad
48	11.63262	76.01695	756	Thariode	Wayanad
49	11.54169	76.22731	898	Vaduvanchal	Wayanad
50	11.53397	76.24425	869	Vaduvanchal	Wayanad
51	11.49433	76.33644	992	Pandallur	Nilagiri
52	11.84624	76.02874	776	Thrissileri	Wayanad
53	7.294328	80.85475	880	Hunnasgiria	Srilanka
54	11.6621	75.94205	764	Kuttiyam-vayal	Wayanad
55	11.676533	75.935517	914	Meenmutty	Wayanad

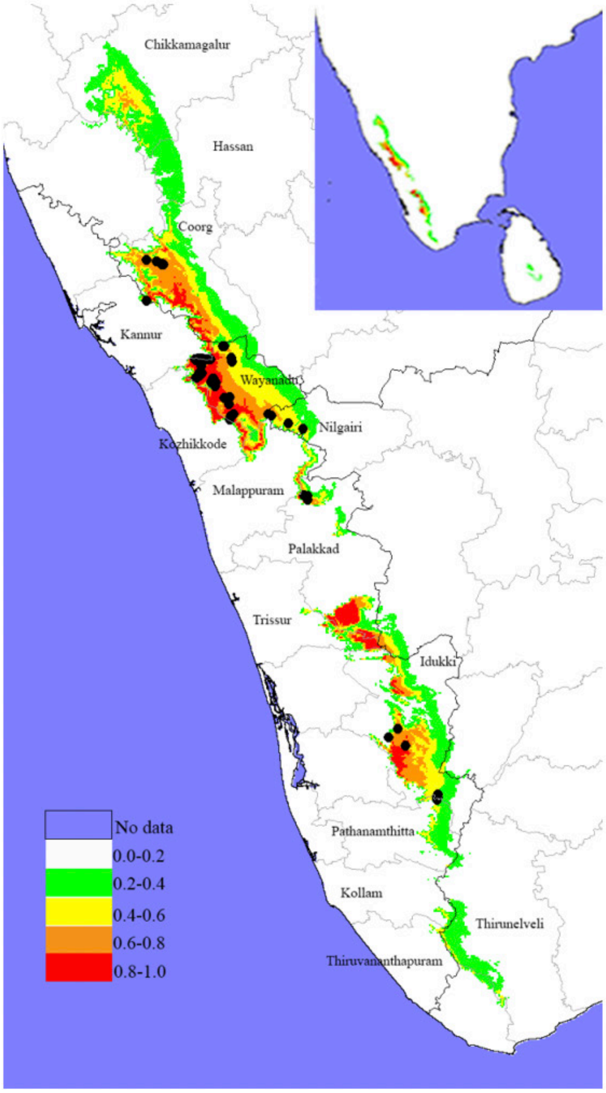

Figure 3. Habitat suitability model of *Vanda thwaitesii* in peninsular India.

received 293.5±28.4 mm rain fall (233–461 mm) during the summer months (March–May). Both annual mean temperature and summer precipitation are contributing significantly to the model as revealed in the model output (Table 4) and jackknife test (Figure 2).

DISCUSSION

Conservation assessment essentially requires sufficient field surveys and gathering of primary data on the distribution of species and their population attributes. This is an exhaustive process requiring substantial effort and investment of human and financial resources which has not been taken seriously in India and therefore the availability of primary data is limited. Conservation planning, action monitoring and evaluation of a species initially require prioritization through threat assessment (Mace & Lande 1991; Master 1991; Moran & Kanemoto 2017). *Vanda thwaitesii* is an epiphytic orchid endemic to Indian peninsula and Sri Lanka hitherto unknown for over 100 years until 1998 when a few populations were discovered from Kerala (Sathishkumar & Sureshkumar 1998). Based on the information on herbarium data, the Government of India notified the species as endangered and invited studies on all aspects of the notified species for propagation and conservation. Based on the extensive field surveys, we found significant populations of the species outside protected forests and the present habitats are highly fragmented. Thus conservation through rehabilitation or translocation into safer localities appeared very essential, preventing further loss before their economic value is deciphered. In spite of its unique aromatic and exquisite flowers it is underutilized in breeding as it is lesser known to orchid breeders. The present study delivers a habitat suitability model for conservation of the species prepared as part of a sponsored project supported by DBT, Government of India during 2010–16.

Table 4. Contributions of variables in the model.

Bioclim as variables	Percent contribution	Permutation importance
Annual mean temperature (Bio 1)	30.6	34.8
Annual precipitation (Bio 12)	18.6	5.1
Precipitation Mar–May (PMM)	48.4	52.7
Mean temperature of driest quarter (Bio 9)	2.4	7.4

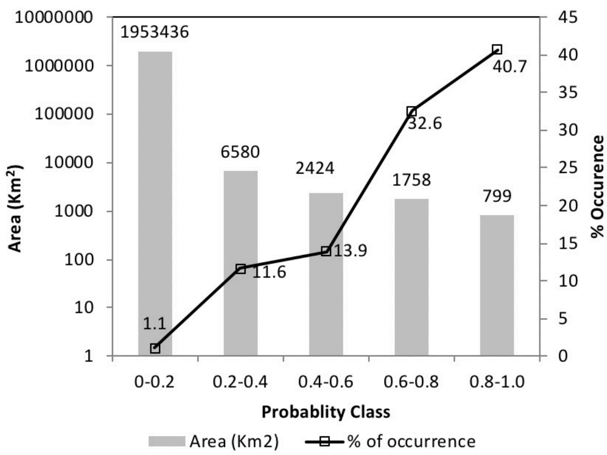

Figure 4. Area of prediction and percentage of occurrence in the habitat model.

Table 5. Temperature and precipitation data at occurrence points of *V. thwaitesii*. The data were retrieved from world climatic data using point sampling tool in QGis.

Temperature (°C)			Precipitation (mm)		
Variable	Mean±SD	Min–Max in occurrence points	Variable	Mean±SD	Min–Max in occurrence points
Annual mean temperature	22.27±0.68	20.60–24.3	Annual	3398.98 ±608.4	2020–4794
Mean wettest quarter	21.3±0.6	20.20–23.1	Wettest Period	1153.65±325.4	376–1713
Mean driest quarter	22.5±0.86	20.85–22.4	Wettest quarter	2429.37±650.9	873–3680
Mean coldest quarter	21.2±0.69	19.75–23.2	Humid months	3307.67±687.1	1197–4744
Mean humid months	22.27±0.67	20.75–23.2	Summer (Mar–May)	292.67±30.1	218–461

Niche modelling is an economical and effective tool to prepare guide maps for intended plant survey and delineation of conservation areas for selected species (Adhikari et al. 2012) thus improving the availability of primary data on the distribution of species and their population attributes for improved threat assessment and more accurate categorization of endangered species (Adhikari et al. 2018). Georeferenced occurrence points and environmental data pertaining to the distribution area are the two prerequisites for habitat modeling. The 55 occurrence points used are more than sufficient to undertake such study. Environmental variable as 19 bioclimatic variables and digital elevation are observed as biologically meaningful to define ecophysiological tolerances of a species (Graham & Hijimans 2006; Murienne et al. 2009) and generally utilized for modeling studies. Topographic variables are derived from digital elevation model from satellite data and are also known to influence the distribution of plant species (Wang et al. 2014). However, those variables and normalized digital vegetation index, another remote sensing data variable are least influencing the distribution of *V. thwaitesii* as they did not extract as a significant factor in PCA. Nevertheless, the bioclimatic variables and seasonal climatic variables are derived from temperature and precipitation data and thus often expresses multi co-linearity and thus often difficult to select the decisive environmental variables and their contributions. Principal component analysis and regression analysis executed on them reduced the number of factors into three still explaining 96.5% variance. Environmental variables showing VIF less than 10 are also included as the existing co-linearity is less significant (Naimi et al. 2014). In this study, we could extract three components with six, four, and one variable and excluding variables with VIF greater than 10, retained four variables (Table 2) to determine habitat suitability for *V. thwaitesii* in peninsular India.

The distribution map thus obtained showed high resolution with AUC 0.997 and therefore is having high prediction efficiency. The AUC ranges from 0.5–1.0 for models that are no better than random to perfect predictive ability. It is also clear that 73.3% of the occurrence records falls in the high suitability region (0.6–1.0) and only 1% in the least suitable region (0–0.2). Besides, a few occurrence records in Chikkamagallur, Hassan and Nelliyampathy later gathered from online resources and not used for modeling fall in the suitable area predicted. Thus, the presence of *V. thwaitesii* could be confirmed in most of the prediction area proving the robustness of the model.

Elevation and temperature are often the most determining variable in habitat modeling as revealed in the terrestrial orchids as *Dactylorhiza hatagirea* (Wani et al. 2021) and *Oeceoclades maculata* (Kolanowska 2013). Precipitation is also an important variable that influences habitat modeling in some species, such as *Habenaria suaveolens* (Jalal & Singh 2017) and *Zanthoxylum armatum* (Xu et al. 2019). However, it seems that the determining factor in habitat modeling is species-specific and not exclusively confined to any of the variables. Work undertaken in epiphytic orchids as *Vanda wightii* from Western Ghats, India (Decruse 2014) and *Vanda bicolor* from northeastern region of India (Deb et al. 2017) indicate that precipitation warmest quarter (Bio_18) is the most influential factor in the model. While *Polystachya concreta,* a pantropic epiphytic orchid (Kolanowska et al. 2020), is reported to prefer different temperature and precipitation factors as far as Asian, African, and American regions are concerned. As reported, temperature seasonality (Bio_4), isotheramality (Bio_3), and precipitation seasonality (Bio_15) have significant contribution in Asian region while temperature factors alone (Bio_2, 4, 1) in American region and precipitation factors alone (Bio_12, 18, 14) in African region. Therefore, a single factor can't be considered important for global distribution of a particular species. The model output for peninsular India and Sri Lanka in the present study revealed that temperature and precipitation contribute significantly to the distribution of *V. thwaitesii* providing a robust model with high prediction efficiency. Therefore, the predicted areas in protected forests are highly suitable for conservation of *V. thwaitesii*. The generated model is also a guide map to find new populations from locations other than those reported earlier.

CONCLUSION

Vanda thwaitesii can sustain in the regions receiving 3,400 mm average annual precipitation and 290 mm in summer. In addition, they prefer cool climate with an average annual mean temperature 22.27°C. The most ideal climatic conditions (0.6–1.0 class) prevail mostly in Wayanad, Idukki, and Palakkad districts of Kerala in addition to Coorg District of Karnataka. However, most of the modeled area in Western Ghats is outside protected forests. Still, there are sufficient locations in reserve forests in Kerala and Karnataka in addition to the sanctuaries as Silent Valley National Park, Idukki Wildlife Sanctuary, Periyar Tiger Reserve, and Brahmagiri Wildlife Sanctuary for reinforcement of diversity from vulnerable locations as inhabited land, plantations, and wayside trees.

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