

Mapping the potential distribution of *Rhododendron arboreum* Sm. ssp. *nilagiricum* (Zenker) Tagg (Ericaceae), an endemic plant using ecological niche modelling

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Rhododendron arboreum Sm. ssp. *nilagiricum* (Zenker) Tagg, a tree species endemic to the southern Western Ghats of peninsular India, is restricted to a narrow topographic and bioclimatic niche. Since information on ecological and geographic extent of the species is lacking, we used Genetic Algorithm for Rule-set Prediction (GARP), an ecological niche modelling (ENM) method to model its spatial distribution. The model is developed based on its occurrence in the Western Ghats, in relation to topographic and environmental variables. Prediction of *R. arboreum* ssp. *nilagiricum* in the Western Ghats is strongly related to local climatic conditions in terms of annual temperature, precipitation and diurnal temperature ranges and not so much dependent on altitudinal variations. The numerous bioclimatic, topographic and anthropogenic factors have led to the formation of islands of species distribution, restricted to the Nilgiri, Anamalai, Palni and Meghamalai hills of the Western Ghats. Predictions allow identification of key areas for *in situ* conservation of the species and prioritize areas falling in the ecological extent of the species for conservation.

Keywords: Niche modelling, protected area, rhododendron, species distribution.

MODELLING species distribution using environmental surrogates of known locations can provide a range of its potential distribution for conservation planning, when primary information is lacking¹⁻³. Association of a particular species with specific environmental conditions has long been documented^{4,5}, but quantitative analyses have been possible only recently⁶ with the advent of new tools, as well as availability of continuous spatial data on various environmental parameters⁷. Ideally, for modelling potential distribution of species, environmental data at an appropriate

scale (i.e. rainfall and temperature) and precise geocoordinates are required. Inferential procedures that provide robust and reliable predictions of geographic distribution and ecological conditions of species are thus critical for biodiversity conservation⁸. This approach has recently been explored under the rubric of ‘ecological niche modelling’ (ENM)⁸, and refers to reconstruction of ecological requirements of species that are analogous to the Grinnellian ecological niche⁹.

Rhododendron is an important genus occurring in the high altitudes of the Western Ghats (above 1500 m), having ecological significance and economic importance in addition to its graceful flowers. The term ‘Rhododendron’ comes from the Greek words ‘rhodo’ meaning rose and ‘dendron’ meaning ‘tree’; in combination ‘rosetree’¹⁰. A total of 72 species, 20 subspecies and 19 varieties have been listed from India¹¹. Among all Indian rhododendron species, *Rhododendron arboreum* is widely distributed, occurring from the western to eastern Himalayan region and other neighbouring countries. One subspecies (*R. arboreum* ssp. *nilagiricum*) is found in the South Indian hilltops – Nilgiri, Palni and Anamalai, Western Ghats¹¹⁻¹³. This species is apparently confined to the forest type, the stunted southern montane wet temperate forest and grasslands (Figure 1 a), locally called shola grassland ecosystem¹⁴. This slow-growing and fire-resistant montane species has canopy usually not exceeding 10–15 m and foliage clustered towards the ends of the branches¹². Therefore, biological reasons (slow growth) as well as direct or indirect anthropogenic pressures (fire) explain the extent of its distribution in the montane grasslands. The species is phytogeographically significant because all other members of the genus in India are confined to the Himalayas. Three hypotheses have been postulated regarding the occurrence of the species in the Western Ghats. (i) Some studies¹⁵⁻¹⁷ support the Pleistocene glaciation theory for the occurrence of temperate species such as

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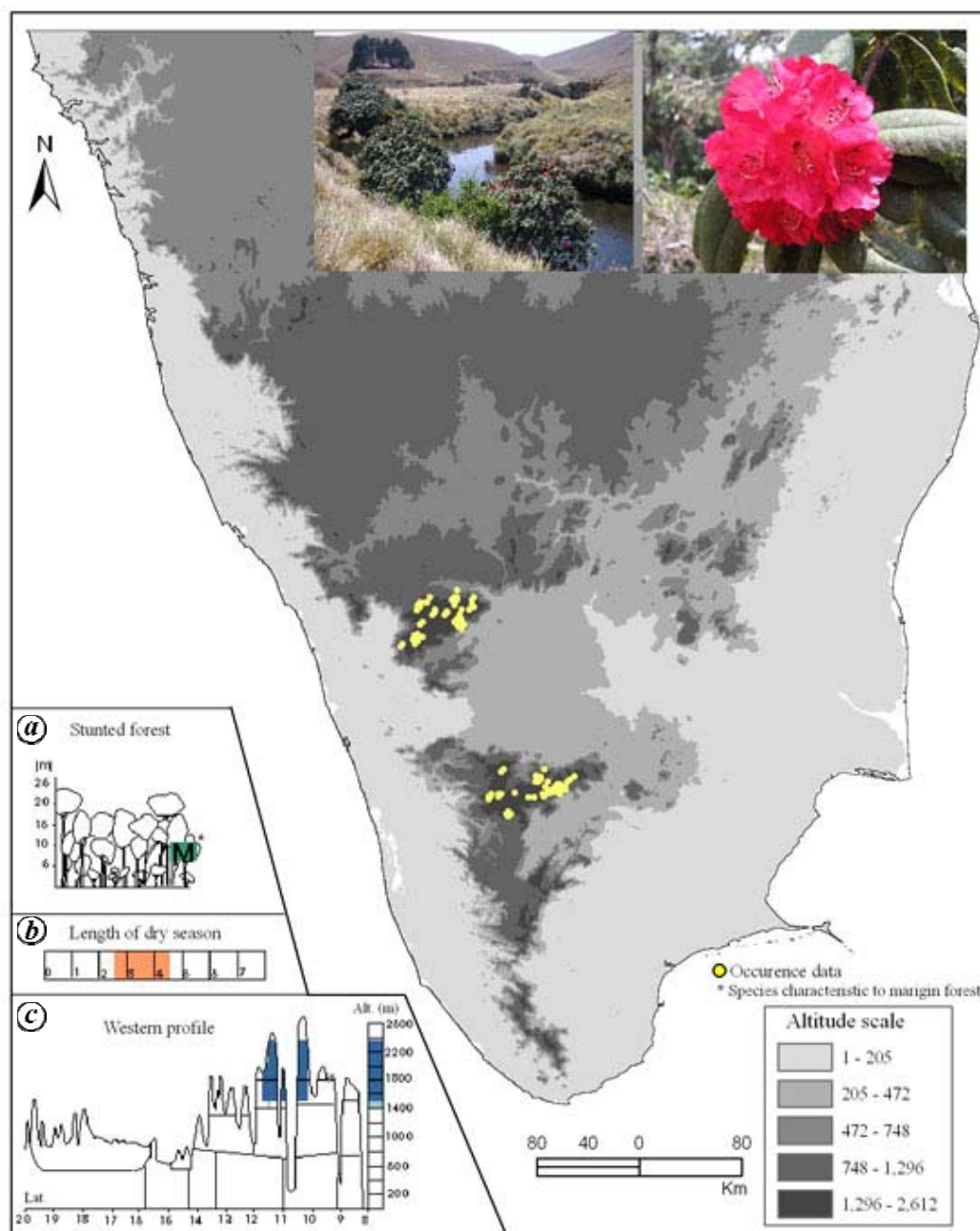


Figure 1. Species occurrence and ecological amplitude of *Rhododendron nilagiricum* Zenk. (Ericaceae) in the southern Western Ghats, India.

Rhododendron in the Western Ghats, where the species migrates southwards in view of the large thermic fluctuations less than 100,000 years ago. (ii) Hedberg¹⁸ postulated the terrestrial migration of species from East Africa. (iii) Blasco¹⁹ put forward the theory of animal dispersal, especially in the case of *Rhododendron* and *Mahonia* from temperate to tropical areas.

Many species that need conservation are known from only a few localities, as in the case of *Rhododendron*.

Furthermore, recent taxonomic revision providing confirmed, georeferenced occurrence records are rare, though highly desirable. Accurate distributional information thus becomes crucial for management and conservation efforts. Most often, management decisions for conservation are based on known occurrence, sites associated with field observations or specimens in museums and herbaria. Such records are generally used in constructing crude range maps: vaguely extrapolated polygons that enclose

known occurrences, based on subjective interpolations. These maps are often highly biased towards accessible or well-sampled areas, and rarely can be extended to remote and poorly known locations. Detailed, fine-scale, validated maps, however, can be developed based on known occurrences and are essential in designing conservation strategies. Moreover, specific requirements of species regarding favourable environmental conditions can educate these decisions enormously.

Data gathered through field surveys and other ancillary input were combined with climatic data to provide invaluable resources for addressing questions such as: What is the distribution of *R. arboreum* ssp. *nilagiricum* species in the Western Ghats? What are the ecological limiting factors for the species to occur? Are these 'hotspots' protected? This article attempts to answer these questions.

Methods

Study area

Field survey was conducted in the high altitudes of southern Western Ghats, i.e. Nilgiri, Anamalai, Meghamalai and Palni hills of peninsular India. The targeted area approximately covers 3094 km², in which the rhododendron habitat²⁰ (shola grassland ecosystem) represents about 1000 km². The area lies between 9°30'–11°39' lat. and 76°22'–77°45' long. (Figure 1 c) and biogeographically²¹ falls under Western Ghats Mountains-5B. The vegetation and species assemblages of these regions are influenced by gradients in rainfall (east to west and north to south), length of dry season (south to north), temperature (south to north) and topography (Figure 1).

Input data

We collected 120 spatially unique point locations in all for *R. arboreum* ssp. *nilagiricum*. Records of the current distribution of the species were gathered from ground surveys using GPS during the regional biodiversity inventory of the Western Ghats²². To include historical occurrences, herbarium specimen data were gathered from the French Institute of Pondicherry²³ and Botanical Survey of India (BSI)²⁴. All records were geocoded via reference to large-scale (1 : 50,000 scale) topographic maps. Data on ecological amplitude of the species were collected from the endemic atlas²³ (Figure 1).

We used 19 'bioclimatic' variables derived from globally interpolated datasets of monthly temperature and precipitation available²⁵, including annual and seasonal aspects of temperature and precipitation that are presumed to be maximally relevant to plant survival and reproduction. We also included elevation, slope and aspect from the USGS Hydro-1K dataset²⁶. All analyses were conducted at the native 30" (~1 × 1 km pixels) spatial resolution of the environmental datasets.

Ecological niche modeling

ENM has been used in numerous applications and subjected to various tests, based on diverse analytical approaches^{27–31}. The particular approach to model ecological niche of species and prediction of geographic distributions is described in detail elsewhere^{32–34}. Previous tests regarding the predictive power of this modelling technique for diverse phenomena in various regions have been published^{3,8,32,35–37}.

The ecological niche of a species can be defined as the set of ecological conditions within which it is able to maintain populations without immigration^{9,38}. Several approaches have been used to approximate ecological niches of these species^{39–42}. One that has seen considerable testing is the Genetic Algorithm for Rule-set Prediction (GARP), which includes several inferential approaches in an iterative, evolutionary computing environment³³. All modelling in this study was carried out on a desktop implementation of GARP, now available publicly for downloading (<http://www.lifemapper.org/desktopgarp/>).

For GARP analyses, we initially divided (randomly) the available occurrence points as follows: (i) 19 training datapoints (for rule generation), (ii) 19 intrinsic testing datapoints (for model optimization and refinement), (iii) 39 extrinsic testing datapoints (for choosing best subsets models), and (iv) 43 independent validation datapoints (for final model validation); this procedure was repeated four times based on different random subsets of available data⁴². After validation trials were completed, to maximize occurrence data available to the algorithm, we eliminated the validation step and thus provided 29 training points, 29 intrinsic testing points, and 62 extrinsic testing points to the algorithm.

GARP is designed to work based on presence-only data; absence information is included in the modelling via sampling of pseudo-absence points from the set of pixels where the species has not been detected³³. GARP works in an iterative process of rule selection, evaluation, testing, and incorporation or rejection: first, a method is chosen from a set of possibilities (e.g. logistic regression, bioclimatic rules), and then is applied to the training data and a rule developed; rules may evolve by a number of means (e.g. truncation, point changes, crossing-over among rules) to maximize predictivity. Predictive accuracy is then evaluated based on 1250 points resampled with replacement from the intrinsic testing data and 1250 points sampled randomly from the study region as a whole, to represent pseudoabsences. The change in predictive accuracy from one iteration to the next is used to evaluate whether a particular rule should be incorporated into the model, and the algorithm runs either 1000 iterations or until convergence.

We developed 100 replicate model runs for *Rhododendron*, and filtered out suboptimal models based on characteristics in terms of omission (leaving areas of known presence out of predictions) and commission (including

areas not actually inhabited) error statistics³⁵. Best models were selected in DesktopGARP using a 0% extrinsic hard omission threshold and 50% commission threshold. Throughout the analysis, we included only the southern Western Ghats region.

To permit visualization of patterns of *R. arboreum* ssp. *nilagiricum* ecological niche variation, we combined the input environmental grids with the final ENM to create a new grid with a distinct value for each unique combination of environment. We exported the attributes table associated with this grid in ASCII format for exploration in a graphic program.

The coincidence between the independent points and model prediction was used as a measure of model predictive ability. Binomial tests (based on the proportional area predicted present and the number of independent test points successfully predicted) were used to compare observed predictive success with that expected under random (null) models of no association between predictions and test points. As model results are in the form of a 'ramp' of model agreement from 0 to 10, we repeated the binomial tests across all thresholds of model agreement (prediction levels 1 to 10).

Results and discussion

Predictions of the distribution of *R. arboreum* ssp. *Nilagiricum* were good, given current knowledge of the species. To date, this species has been reported only from the

montane ecosystems of the southern Western Ghats, particularly in the Nilgiri, Anamalai, Palni and Meghamalai hills. The species has never been documented from other sectors of the Western Ghats. The preliminary models for rhododendrons correctly predicted most sites in the test dataset. Among the 100 models, ten best subsets were chosen for modelling the species distribution and significance was found to be $P < 0.0001$, one-tailed binomial.

R. arboreum ssp. *nilagiricum*, as predicted by all ten best-subsets models in this analysis (Figure 2) occupies 7708 km² out of the 260,962 km² area that constitutes the entire Western Ghats, or ~3% of the total. Accuracy between known locations and the predicted areas of the final model is best fitted. Potential areas were intersected with protected areas using GIS, and were found to be two in Tamil Nadu and five in Kerala. Species prediction in the Tamil Nadu is ~26% (1037 km²), while the remaining ~41% (1388 km²) falls under Kerala.

Much of the predicted *R. arboreum* ssp. *nilagiricum* regions do not fall under the protected areas (PAs), since 89% (6882 km²) of the area falls under non-PA and the remaining 11% (826 km²) is under PA (Table 1). The two PAs of Tamil Nadu are Indira Gandhi Wildlife Sanctuary (WLS), covering 25% of the predicted area (958.59 km²) and Mukurthi National Park (NP) covering 47% (78.46 km²) of the area. The five PAs of Kerala include Eravikulam NP covering 94% (97 km²), Chinnar WLS covering 62% (90.44 km²), Periyar WLS/NP covering 22% (777 km²), Silent Valley NP covering 95% (89.52 km²) and Parabi-

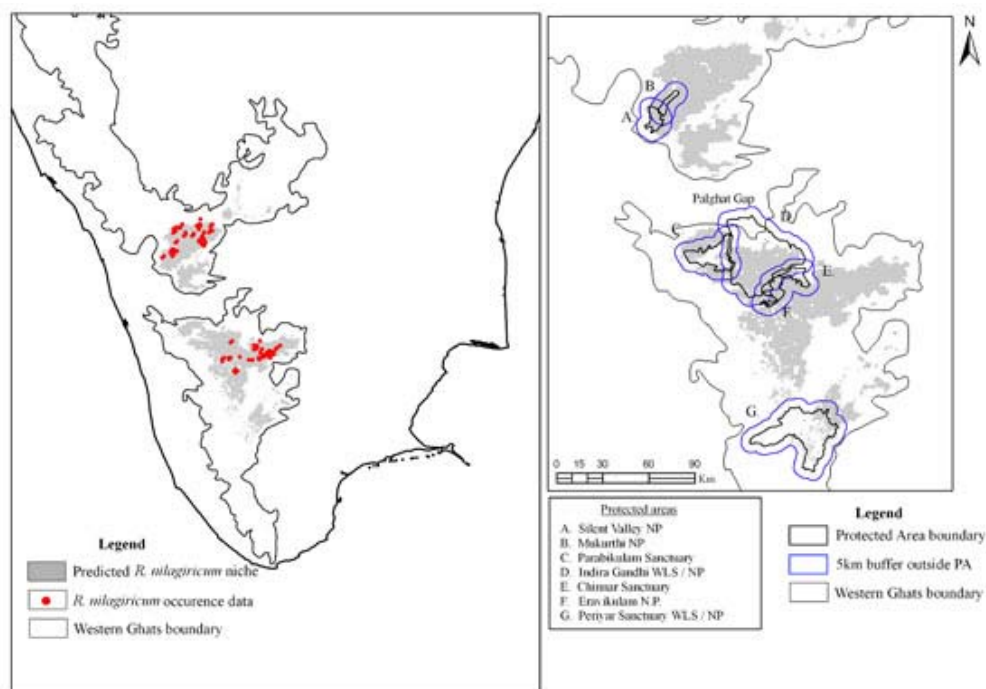


Figure 2. Coarse- and fine-scale views of known and predicted distribution of *Rhododendron nilagiricum*.

Table 1. Predicted area of *Rhododendron arboreum* ssp. *nilagiricum* in relation to protected areas in the Western Ghats region

Protected area	State	Area (km ²)	Predicted areas
Chinnar Sanctuary	Kerala	90.44	55.89 (62)
Eravikulam NP	Kerala	97.00	90.89 (94)
Parabikulam Sanctuary	Kerala	285.00	150.49 (53)
Periyar Sanctuary WLS/NP	Kerala	777.00	170.3 (22)
Silent Valley NP	Kerala	89.52	85.37 (95)
Indira Gandhi WLS/NP	Tamil Nadu	958.59	236.32 (25)
Mukurthi NP	Tamil Nadu	78.46	37.2 (47)
Total		2376.01	826.46

*Figures in brackets indicate percentage of predicted area.
NP, National Park; WLS, Wildlife Sanctuary.

Table 2. Comparison of environmental variables in actual and predicted niche of *R. arboreum* ssp. *nilagiricum*

Variable	Actual range	Predicted range	P value
Annual mean temperature*	13.4–24.9	13.6–24.4	0.0001
Mean diurnal range*	7.5–10.1	7.5–10.1	0.0001
Isothermality*	5.6–6.3	5.6–6.4	0.0001
Temperature seasonality*	10.67–16.82	10.72–17.85	0.0001
Temperature annual range*	12.5–16.6	11.9–17.2	0.0001
Mean temperature of wettest quarter (mm)	13.1–24.3	13.1–24.8	0.0001
Precipitation of driest month	0.8–4.7	0.8–4.7	0.0001
Precipitation seasonality (mm)	4.9–9.6	4.9–9.9	0.0001
Precipitation of wettest quarter (mm)	38–167.7	37.5–161.1	0.0001
Precipitation of driest quarter (mm)	3.2–15.5	3.4–15.2	0.0001
Annual precipitation (mm)	1047–2880	1010–2792	0.0001
Elevation (m)	1074–2461	1008–2427	0.0001

*Values in °C.

kulam WLS covering 53% (285 m²). An augmentation of 5 km along the western boundary of the protected areas would cover an additional 24% of the species distribution, bringing the total to 91% of the total species distribution.

Predicted areas of *R. arboreum* ssp. *nilagiricum* niche were spatially correlated with the ecological surrogates for the entire Western Ghats, which revealed four parameters as the most influential: (i) mean diurnal temperature ranging from 7.5 to 10°C, (ii) number of driest months ranging between 1 and 3, (iii) elevation above 1000 to 2500 m, and (iv) annual precipitation above 1000 to 2800 mm (Figure 3 and Table 2). Availability of niche is narrow with the existence of microclimatic conditions prevailing in Nilgiri, Anamalai, Palni and Meghamalai hills. We observed inverted 'V'-shaped pattern of the niche distribution between mean temperature of the wettest quarter and annual temperature range. Rhododendrons require specialized habitat conditions and specific plant associations to survive. The results presented in this study suggest that the reliability of potential species distributions depends strongly on the modelling procedures being used in relation to bioclimatic variables. This was observed in the modelled distribution of the species, which limits three main ecological limiting factors.

The predicted area is characterized by mean diurnal temperature range (7.5–10°C) and mean temperature (13.4–24.9°C), precipitation of the driest months (0.8–4.7) and topography (1074–2461 m). The existence of such bioclimatic pattern is unique to the region, which leads to the formation of a narrow niche having distinct endemic species. The variation of niche occurrence especially in the case of its distribution is due to the anthropogenic influences (fire, cattle grazing and plantations), leading to the isolation of the rhododendron habitat. The physical and climatic barriers limit species migration or adaptation, and lead to enhanced range contraction and species extinction processes.

These results are fundamental in addressing conservation planning to a narrowly distributed species occurring in the Nilgiri–Anamalai–Palni and Meghamalai regions of the southern Western Ghats. Although the best predicted subsets of the rhododendron niche model explain the potential habitat requirements for the species, they need to be interpreted with caution due to the implications of model accuracy, model assumptions and fundamental vs realized niches. They are informative, but have their limitations and should be used for conservation planning only in combination with targeted field survey.

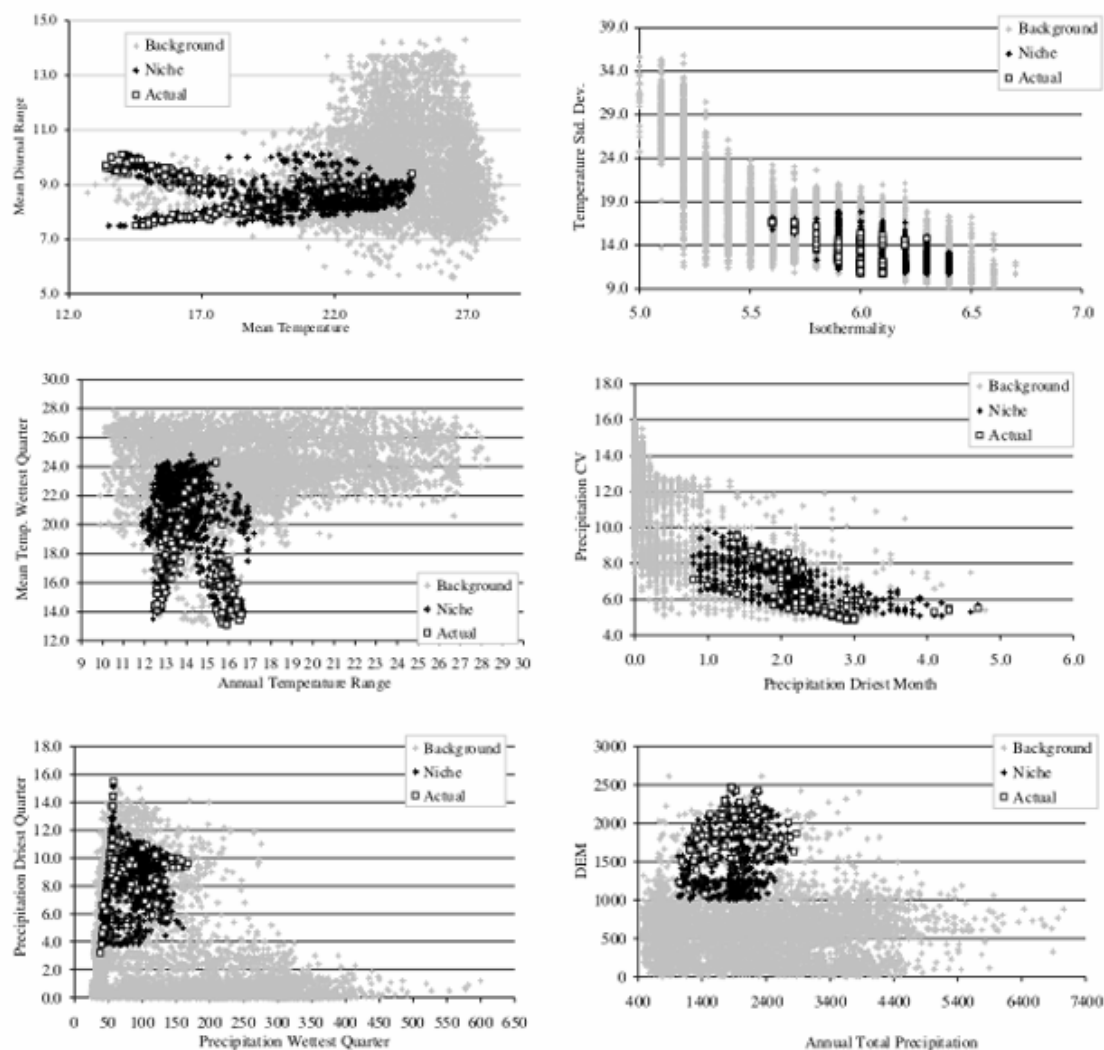


Figure 3. Exploratory visualization of *R. arboreum* ssp. *nilagiricum* niche in environmental space. Grey colour represents conditions available in the southern Western Ghats, black colour represents modelled potential distribution of species, white colour represents occurrence data.

Predicted areas of the rhododendron habitats which were conserved as PAs (Eravikulam NP, Indra Gandhi WLS) need to be monitored and areas which lie outside the PAs (Palni and Meghamalai hills) need to be brought under the PA network for effective conservation.

Numerous bioclimatic variables can be used to predict niche distribution, but it has been observed in ecological science that a few (4–5) variables account for about 95% of the variation in distribution⁴². Furthermore, results derived from the ‘best models’ must be interpreted with caution due to absence of high-resolution spatial climatic data⁴³. Climatic and topographic information, to a certain extent, minimize the potential source of error in prediction^{37,44}. However, with the improvement in technology both spatially and temporally, there could be better availability of data on vegetation, bioclimate and topography

for reliable prediction on the species distribution pattern. We are still in the process of developing an optimal scaling parameter of the bioclimatic variables and drivers for ideal prediction of the spatial variability of the biological system. Furthermore, a collection of the species should be randomly distributed across the region and a precise georeferencing location is necessary to avoid any error in the accuracy of the niche prediction. Modelling algorithm can predict reliably species’ macrodistributions using the present environmental data with the above criteria taken into account.

Conclusion

Modelling the geographic range of a species holds promise in conservation biology as an important improvement

over subjective, broad-stroke, shaded, outline maps. Fine scale resolution of environmental data is always desirable to develop accurate species distribution pattern to address ecological limiting factors. Predictions of potential distribution of the species in this study would help in developing conservation strategies for monitoring and managing the rhododendron species in general, and for the conservation of several relict, endemic floral and faunal species of the South Indian montane ecosystems. Some of the unique species observed are *Elaeocarpus recurvatus*, *Michelia nilagirica*, *Ilex denticulata*, *I. wightiana*, *Turpinia cochinchinensis*, *Mahonia leshenaultii*, *Rhodomyrtus tomentosa*, *Berberis tinctoria*, *Vaccinium neilgherrense*, *Rapanea capillata*, *Strobilanthes* sp., *Impatiens* sp., *Sonerila grandiflora*, Nilgiri tahr, Nilgiri marten and Nilgiri pipit. Hotspot treaty includes Sri Lanka along with the Western Ghats region as one among the 34 hotspots of the world⁴⁵. However Palni hills has not been included in the PA network, and is vulnerable to degradation as a result of increasing tourism, plantation and other anthropogenic activities, resulting in the loss of habitat for unique and endangered ecosystems.

The degradation of rhododendron habitat is due to lack of appropriate policy, and institutional and operational infrastructure. Improved efforts of protection with community participation and *in situ* and *ex situ* conservation methodologies need to be administered in order to conserve the species and ecosystems. In this regard, data on species diversity, population dynamics, location and extent of habitat, its major threats and changes over time need to be understood further to develop a design for proper conservation strategy.

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