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# Optimization of Ensemble Modeling Approach for Studying Climatic Niche and Conservation Status Assessment for Endemic Taxa

**Rajasri Ray*** and **T.V. Ramachandra**

Centre for Ecological Sciences, Indian institute of Science, Bangalore-560012, India
Phone: 91-080-22933504 (extn. 116),
E-Mail: rajasri.ces@gmail.com (Rajasri Ray)
cestvr@ces.iisc.ernet.in (T.V. Ramachandra)

* corresponding author

## ABSTRACT

*Modeling ecological niche of rare endemic species is an understated issue especially for data-deficient endangered taxa. Syzygium travancoricum Gamble. a critically endangered plant in southern Western Ghats of India was considered to examine the role of pseudo-absence and modeling algorithms in endemic species niche formulation. This aided in reassessing IUCN status emphasizing on geographical distribution.*

*Seven different modeling algorithms were attempted considering different sets of pseudo-absence points through BIOMOD2 program in R and MaxEnt. The outputs were compared with the extent of occurrence (EOO) and area of occupancy (AOO), as done in conservation status assessment exercise by IUCN.*

*Modeling algorithm and pseudo-absence points play an important role in model development. Ensemble methods displayed wider variations in outputs despite having good statistical performance thus emphasizing on importance of multiple algorithm trials for data deficient taxa. Both model and topology based methods have shown much higher values for EOO and AOO which contradict it's critically endangered status; thus, suggesting re-evaluation of the threat status with comprehensive field investigation.*

**Keywords :** BIOMOD2, conservation status, endemism, ensemble modeling, IUCN, Western Ghats
**Mathematics Subject Classification:** 92FXX

## 1. INTRODUCTION

Endemic species, one of the qualitative parameters for biodiversity, are one of the key determinants for prioritising conservation program in a region (Bonn et al. 2002; Burlakova et al. 2011). Management of any endemic species requires an in-depth knowledge of its distribution, biogeographic history, ecology and environmental attributes. Ecological Niche Modeling (ENM) of rare, endangered and endemic members can be implicated in multiple aspects, ranging from prioritising conservation measures to understand the evolution-environmental interactions (Loiselle et al. 2003; Ortega-Huerta and Peterson 2004; Engler et al. 2011; Mercer et al. 2013; Yannic et al. 2014). However, the paucity of occurrence data, sampling bias and absence of geographic co-ordinates in historical accounts of distribution (Araujo and Guisan 2006; Hernandez et al. 2008) are the persistent problems for ENM of rare and endemic organisms. Inadequate occurrence data and insufficient coverage of ecological niches often impedes the development of robust models, sensitivity analysis and statistical validation (Duputie et al. 2013; Platts et al. 2014). Although combining various algorithms and data specific validation procedures (eg. Jack-knife leave one out) aid in minimizing the uncertainties, but the need for sufficient occurrence data continues to be a vital component in ENM.

Pertinently, ensemble techniques tend to outperform single algorithm due to multiple trials with different algorithms as well as considerable reduction in modeling uncertainty (Marimon et al. 2009; Buisson et al. 2010). Previously, ensemble modeling on endemics has been applied at macroscale (Thuiller et al. 2006; Li et al. 2013) as well as in species based studies (Lomba et al. 2010; Porfirio et al. 2014; Sousa-Silva et al. 2014) but attempts towards its optimisation for rare/endemic members is scanty till date.

Apart from ensemble modeling approach, absence or pseudo-absence information has significant role in correlative model building strategy. Although presence-only methods (e.g. BIOCLIM, Mahalanobis distance and others) are in use, but are outnumbered in recent times by presence-absence techniques. The absence data helps in the development of discriminative rules which can help to rank habitat suitability based on presence or absence information, thus, restricting over-prediction to some extent. Absence data can be contingent (environmentally suitable but biologically unsuitable), environmental (climatically unsuitable), and methodological (sampling error) depending on the study organism (Lobo et al. 2010). In essence, the collection of reliable absence data is a time and resources demanding task in ecological research. Pseudo-absence (pa) strategy is an alternative to true-absence points that can select multiple points from background and consider them as absence points; however, this could influence considerably the output (Brotons et al. 2004; Lobo et al. 2010; Massin et al. 2012).

In this study, ensemble niche modeling technique is attempted with pseudo-absence points for *Syzygium travancoricum Gamble. a* critically endangered woody endemic tree in southern Western Ghats of India with the objectives to evaluate 1) the performance of ensemble modeling 2) importance of pseudo-absence points in modeling and 3) applications in conservation status assessment.

## 2. METHODS

### 2.1 Study species

*Syzygium travancoricum* Gamble. is endemic to the southern Western Ghats of peninsular India, one of the global hotspots of biodiversity (Myers et al. 2000). The tree is hygrophilous, prefers swampy conditions, and found mostly in (especially in Kerala) *Myristica* swamp areas (Gamble 1935; Sasidharan 1997). The species is considered critically endangered and the conversion of low lying swamp areas to paddy fields is the major reason for its habitat degradation (IUCN 2015). In addition, other forms of disturbance e.g. urbanization, developmental pressures and conversion of forest lands for other land use purposes also magnify the potential threat (Chandran et al. 2008; Roby et al. 2013).

A recent study from *Myristica* swamps of Kerala, located in the extreme southern part of peninsular India, has reported its habitat preference as well as recommended reconsideration of IUCN status (Roby et al. 2013). However, except a few, the information on distribution of natural population is still scattered and taxonomic disputes among closely related members aggravate the problem thus limiting the conservation and management planning.

## 2.2 Syzygium travancoricum distribution

*Syzygium travancoricum* Gamble. was first reported from *Myristica* swamps of southern Western Ghats, Kerala, India (Bourdilion 1908; Gamble 1935). Myristica swamps are shallow water logged areas dominated by tree members of Myristicaceae family. Later on, few more reports on *S. travancoricum*'s occurrence were published from the nearby areas indicating water logged / moist habitat preference of the species. The species geographical distribution was later extended up to central Western Ghats region after its discovery from swampy areas / forest patches of Uttrara Kannada district of Karnataka and Goa (Chandran et al. 2008, Prabhugaonkar et al. 2014). The species is categorized as critically endangered by IUCN based on earlier published data on its distribution limited to southern Western Ghats (IUCN 2015). Additionally, identification of *S. travancoricum* is a complex issue because of its morphological similarity with another *Syzygium* species i.e. *S. stoksii*, therefore, proper taxonomic identification is essential for any new occurrence record. Hence, research has been undertaken to authenticate the species identity through type specimens at herbarium and molecular techniques apart from distributional data and taxonomic accounts.

**Figure 1.** Study area and occurrence points (Western Ghats = gray coloured area, as per the boundary shown by Conservation International)

### 2.3 Study area

The study was conducted in the Western Ghats and costal region of peninsular India. The Western Ghats are flanked by the Arabian Sea in the west, Deccan Plateau in the east, The Vindyan Range in the north, and Kanyakumari plain in the south. The mountain chain covers an area of 160 000 km$^2$ spanning through six Indian states (south of Gujarat, Maharashtra, Goa, Karnataka, Kerala and west of Tamil Nadu). Annual rainfall varies from 2350 mm in the north to 7450 mm in the south. The mean temperature also has distinct gradients from sea level (25$^0$ C) to higher altitudes at 2400m (11$^0$ C) in coldest month. This temperature and rainfall gradients along with varied topography, have resulted in a diverse vegetation mosaic from tropical wet evergreen forest, semi-evergreen, moist deciduous forest, dry deciduous forest, scrub jungles, savannahs, peat bogs, and *Myristica* swamps. It is a global biodiversity hotspot, with numerous rare, endangered, and endemic taxa, which also make it one of the global and national priority areas of conservation concern (Pascal and Ramesh 1997; Myres et al. 2000; Bawa et al. 2007)

### 2.4 Occurrence data

32 occurrence records of *S. travancoricum* have been collected through field surveys and literature review (Pascal and Ramesh 1997; Sasidharan 1997; Chandran et al. 2008, 2010; Ray et al. 2012, 2014; Roby et al. 2013). A total of 21 points have been selected finally for model development that is at least 10 km apart to avoid the bias among clustered occurrence records (Fig1). By this step, it has been assumed that, data points are sufficiently separated as to be spatially independent.

### 2.5 Environmental data

We selected 20 potential environmental predictor variables for model training based on published literatures on *S. travancoricum* and other studies on species distribution modeling (Anonymous 2007; Irfan Ullah et al. 2007; Nair et al.2007; Zhu et al. 2007; Chandran et al. 2008; Yates et al. 2010). These variables included precipitation, temperature (19 bioclimatic layers from the WorldClim dataset (Hijmans et al. 2005) and soil moisture (Willmott and Matsuura 2001). Correlation analysis and PCA were conducted considering 19 bioclimatic variables to minimise redundancy. First, correlated variables (≥ 0.7) were grouped and from this group, the variable with highest loading on principle axes was selected (Slender et al. 2013). All the layers were geo-referenced to the same projection, grid cell size, and resampled to the resolution of 1km$^2$ with the help of DIVA-GIS (version 7.1.6) and GRASS (version 6.2, http://ces.iisc/ernet.in/grass). These layers were finally cropped corresponding to the study region (i.e. Western parts of peninsular India).

### 2.6 Modeling procedure

The recent development of various model building tools based on diverse algorithm, data availability and inherent statistical interpretation provide a wide range of choices to test their applicability to real ecological problems. On the other hand, selection of optimum/perfect procedure often turns to be a difficult task because of considerable variance in modeling output. Seven modeling techniques were attempted to reduce uncertainty and optimize the modeling output. Among these, six are available in BIOMOD2 package in R: three regression methods (GLM, GAM and MARS), two machine-learning methods (ANN and RF), one classification method (CTA) (Thuiller et al. 2013) and Maxent is a standalone program (MaxEnt, version 3.3.3; http://www.cs.princeton.edu/~schapire/maxent/). The ensemble approach was divided into three parts based on pseudo-absence point requirement: MARS, CTA-RF and GLM-GAM-ANN.

Pseudo-absence (pa) strategy in BIOMOD2 package was considered due to lack of real absence data. Multiple numbers of pseudo-absence points were selected based on study conducted by Massin et al. (2012). For CTA and RF we considered 21 pa (similar to occurrence no.), for MARS, it was 100 pa and for GLM-GAM-ANN, 10,000 pa. To optimise the model performance, a total of 6 pa sets were chosen in modeling. Both random as well as geographical exclusion principles were considered for trial as pa selection strategy has important role in modeling outcome. For geographical exclusion, 5 km buffer area was selected based on field experience and comprehensive review of earlier modeling experiments (Lobo et al. 2010).

Majority of the default parameters were considered for BIOMOD2. The dataset was split into 80:20 ratios for model development and evaluation respectively. Each model was iterated for 10 times and the final run used 100% of data in case of all models (Fig 2).

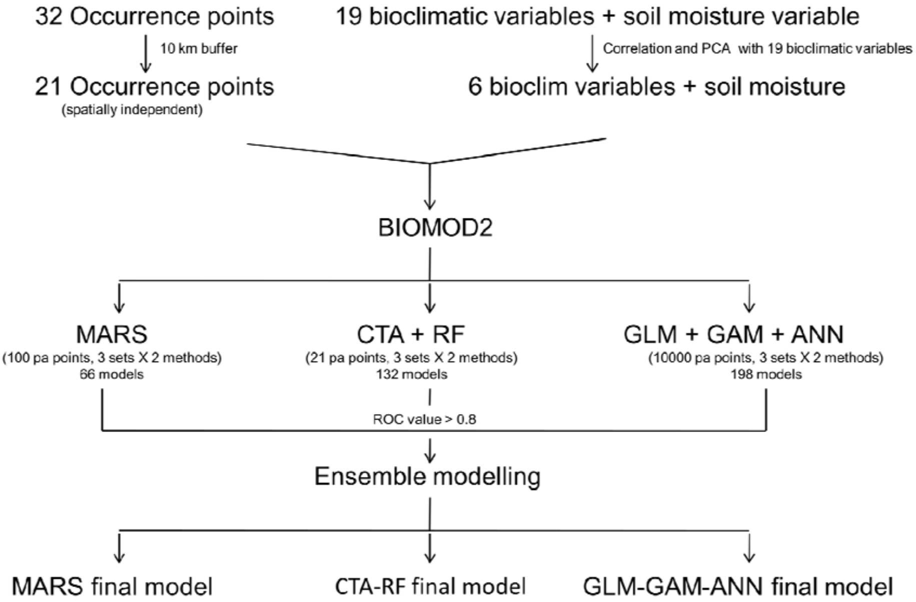


**Figure 2**. Modelling framework in BIOMOD2

Best performing models were chosen based on i) the area under the relative operating characteristic curve (AUC), ii) Cohen's *kappa* iii) the true skill statistic (TSS) and iv) sensitivity. In each set, a final model was developed by ensemble forecast of the best performing models from all respective algorithms. The projected distributions were calculated with the weighted mean approach using the pre-evaluation of the predictive performance of the single models. Binary transformation of the modeling output was done by applying ROC value from ensemble weighted mean models. The randomization technique as described in BIOMOD2 was used to find out the respective variable importance in models. This model independent approach helps in making direct comparison of variable importance across models. In addition, evaluation strips were used to determine the response curves of the four most influential variables.

In MaxEnt, the default parameters with few modifications were used for the modeling experiment. Only linear, quadratic and hinge features were used due to the paucity of occurrence data and 25% of the data was kept aside for random testing purpose. Jackknife test of variable importance was conducted to get the details of variable contribution. The performance of the model was tested through the AUC value.

### 2.7 Conservation status assessment

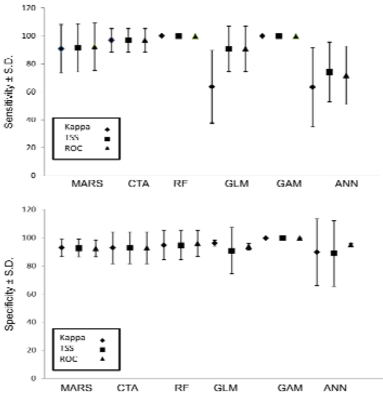
The IUCN Red List categories and Criteria (Anonymous 2010) were used to assess the conservation status of the plant in the Western Ghats. Extent of Occurrence (EOO) and Area of Occupancy (AOO) of two Red list parameters under Criteria B were measured. EOO was measured by two methods based on the established protocols (Moat 2007; Franklin and Preece 2014) and for AOO, a grid of 2 X 2 km was superimposed on occurrence points and cumulative area of cells occupied by the species was calculated (Moat 2007). All measurements were done in ArcGIS 9.3.1 and Q-GIS (1.6.0).

## 3. RESULTS

### 3.1 Modeling performance and output

Ensemble modeling approach has shown good performance in our study. MARS, CTA, RF and GAM showed consistently better value for specificity (0.75-1.0) in comparison to GLM and ANN (0.4-0.9) (i.e. AUC, TSS and kappa values), whereas, there is not much difference in sensitivity (Fig 3). Similarly, selection of multiple sets of pseudo-absence points for different sets of algorithms notably improved model performance (Fig 4) although absence point selection strategy has not shown much difference. The role of variables depends on the chosen algorithm and the results indicate that bioclim 7 (annual temperature range), bioclim 10 (mean temperature for warmest quarter), bioclim 16 (precipitation of wettest quarter) and soil moisture played a pivotal role in the model.

3.



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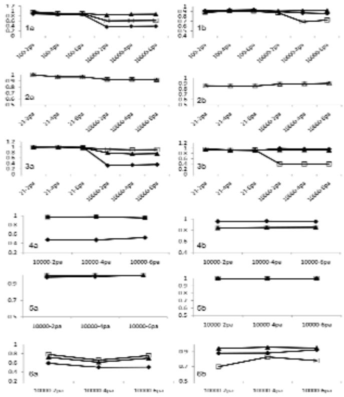

**Figure 3**. Modelling performance in terms of sensitivity and specificity (BIOMOD2)

**Figure 4**. Performance of pseudoabsence points in modeling experiment in BIOMOD2 (a= sensitivity, b=specificity; 1=MARS, 2=CTA, 3=RF, 4=GLM, 5=GAM and 6=ANN)

MaxEnt has shown a better output in comparison to some of the BIOMOD2 based algorithms. AUC values for training and test data were ≥ 0.95. Similar to BIOMOD2 soil moisture, bioclim 16 (precipitation of wettest quarter), bioclim 10 (mean temperature for warmest quarter) and bioclim 11 (mean temperature of coldest quarter) have shown significant role in the model (Table 1).

The usual approach of getting a final ensembled map has not been followed here due to methodological differences (eg. 3 different sets of pseudoabsense points, 2 different selection strategies etc.) applied in BIOMOD2. The result obtained from each set (i.e. 3 from BIOMOD2 + 1 from MaxEnt = total 4 outputs) has been presented for comparative assessment.

| | Models (%) | | | |
|---|---|---|---|---|
| Variables | MARS | CTA-RF | GLM-GAM-ANN | MaxEnt |
| Bioclim7 | 5.4 | 7.4 | 47.2 | 0 |
| Bioclim10 | 3.2 | 0.4 | **60.1** | 8.2 |
| Bioclim11 | 2.7 | 0.2 | 44 | 2.8 |
| Bioclim14 | 3.0 | 0 | 32.6 | 0 |
| Bioclim16 | 32.1 | 0.7 | 51.8 | 11.3 |
| Bioclim17 | 0.8 | 0 | 34.2 | 2.6 |
| Soil moisture | **42** | **34.9** | 33.2 | **75.1** |

**Table 1**. Importance of variables in model development (highest contributor under each model is in bold format)

Potential distribution maps generated from these modelling exercises have shown diverse areas ranging from 5,000 – 79,000 km$^2$ (Figure 5 and Table 2). Both MARS and MaxEnt results have projected near realistic distribution pattern (26,689 and 55,962 km$^2$ respectively) in contrast to CTA-RF and GLM-GAM-ANN ensemble sets (79,985 and 5,144 km$^2$).

### 3.2 Conservation status assessment

Potential distribution area for the species based on the extent of occurrence (EOO) is about ~ 47,700 km$^2$ while, area of occupancy (AOO) done by grid method indicate of 116 km$^2$ as currently occupied area (Table 2).

| Study species | AOO (km$^2$) (2 x 2 km grid) | | EOO (km$^2$) |
|---|---|---|---|
| *Syzygium travancoricum* Gamble. | 116 | quickhull (Moat 2007) | 48,317.8 |
| | | (Franklin and Preece 2014) | 47,138 |
| | | modeling output | |
| | | MARS | 26,689 |
| | | CTA-RF ensemble output | 79,985 |
| | | GLM-GAM-ANN ensemble output | 5,144 |
| | | MaxEnt | 55,962 |

**Table 2**. Results of EOO and AOO measurements based on different methods.

## 4. DISCUSSION

Ecological niche modeling of rare, endangered, and endemic species poses serious challenge to researchers (Engler et al. 2004; Pearson et al. 2007; Lomba et al. 2010) due to absence of appropriate occurrence data. Recent studies, indicate that species with restricted range distribution or narrow biological niches perform better as their specific requirement is easy to define in a multivariate setting (Segurado et al. 2004; Luoto et al. 2005; Coetzee et al. 2009; Marimon et al. 2009). The current work tried to build up a robust niche model with 21 spatially independent points distributed across Western Ghats and adjoining areas. The attempt aimed at few key parameters for information deficient endemic taxa to develop baseline distribution map for future inventory and conservation plan (Engler et al. 2004; Siqueira et al 2009; Marini et al 2010).

In data deficient studies, ensemble method provides opportunity to assess performance of multiple algorithms in a common limiting condition. In this study, statistical performances of the ensemble sets are quite satisfactory, but projected distributions have shown much variation than expected. The binary maps created from ROC value of ensemble weighted mean models varied considerably across algorithms. Both over prediction and over-fitting are observed in CTA-RF, GLM-GAM-ANN techniques due to the limitations of the algorithms and predictor variables to deal with the limited occurrence points. However, validation in consultation with the regional domain experts indicate that ensemble output from MARS has shown near realistic distribution pattern. In addition, MaxEnt generated relatively better realistic map than ensemble method confirming to earlier findings on its appropriateness (Pearson et al. 2007; Graham et al. 2008; Wisz et al. 2008; Mateo et al. 2010).

It is due to inadequate distribution data, defining confirmed absence points have been a problem; paving the way for pseudo-absence (pa) strategy. Multiple options such as number of pa points, sets of pa to be included, and pa selection strategies were examined. Algorithm specific pseudo-absence point sets performed better than uniform pseudo-absence points (i.e. 10,000 points for all algorithms) (Fig 4). On the contrary, model performance has not differed much when pseudo-absence selection strategy was evaluated i.e. geographical exclusion (5km buffer) vs. random selection. Final run with three pa sets has been selected after initial trials with different sets have not shown much change in performance (in terms of TSS, Kappa and ROC values beyond three sets).

### 4.1 Ecological implications of the models

Out of seven selected variables, temperature (bioclim 7, 10 and 16) and wetness (i.e. soil moisture) have profound influence on species distribution. The result corroborates the general understanding of the species' preferential distribution in perennial or seasonally wet regions (Sasidharan 1997; Chandran et al. 2008; Roby et al. 2013). Its clustered presence near southern Western Ghats is perhaps related to high wetness with the longer period (8-10 months) of rainy days and higher quantum of rainfall (Prasad et al. 2008; Anu et al. 2009). Higher number of rainy days influences seasonality and isothermality while keeping temperature differences minimal. The scattered distribution of suitable areas in central and northern Western Ghats may be due to a decline in species habitat (with suitable microclimate), variations in rainfall (there is a gradual northward decline of rainfall from south both in terms of duration and quantity), and large scale forest fragmentation in addition to inadequate exploration.

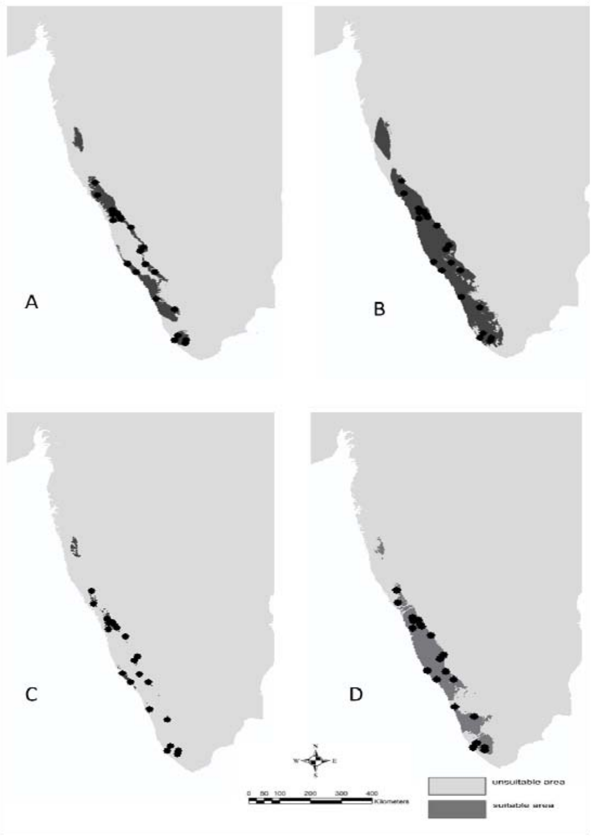

**Figure 5**. Potential distribution map of *S.travancoricum* Gamble. (a = MARS ensemble output, b = CTA and RF ensemble output, c = GLM,GAM and ANN ensemble output and d= MaxEnt output )

### 4.2 Conservation status assessment

The extent of occurrence was examined through two widely used methods which have demonstrated almost similar estimation for the species. On the contrary, potential distributions obtained from modelling experiments have shown wider variation. The area obtained through MaxEnt was relatively closer to the EOO values estimated through IUCN recommended protocols than the other values (Table 2). The difference between the outputs could be attributed to the applied methods (Sergio et al. 2007); while conventional EOO estimation is based on topological methods, niche models rely on spatial as well as environmental space, but disjunctions are equally considered in both the cases. Similarly, in AOO estimation the scale of the grid is an important factor; however, following IUCN recommended procedure the estimated area of occurrence (i.e. 116 $km^2$) has far exceeded the threshold for critically endangered species of 10 $km^2$.

Application of niche modeling in EOO and AOO estimation had earlier generated diverse responses. Sergio et al. (2007) and Alfaro et al. (2012) have identified ENM based status assessment as ecologically robust and realistic; in contrast, Attorre et al. (2013) and Syfert et al. (2014) have emphasized that the spatial distribution of the species and available information on their distribution play a major role in EOO estimation. In the current investigation, modelling outputs were also varied based on the algorithms, especially for commission and over fitting errors. Moreover, *S. travancoricum* has been reported from Southern Western Ghats swampy areas for a long time (Bourdillon 1908; Gamble 1935), whereas report of central Western Ghats and northward distribution is relatively recent (Chandran et al. 2008, 2010; Prabhugaonkar et al. 2014; Ray et al. 2012, 2014). A close observation on the occurrence points can detect the gap between southern and central Western Ghats, which can be ascribed to the dearth of exploration or to the changes in the rainfall pattern. Both modeling and EOO studies have incorporated this gap area as a possible place for future inventory for finding new populations.

Based on these findings, a reassessment of species' position in IUCN list is essential, as the current EOO estimates are much larger than the < 100 km$^2$ threshold for critically endangered species, putting it under least concern category. Likewise, the magnitude of AOO is also greater than the threshold (< 10km$^2$) according to IUCN guideline, suggesting endangered status of the species. The current results are in conformity with the earlier study (Roby et al., 2013), emphasized the need to consider the species under a changed criterion (from C2a to A1e). Importantly, the current IUCN status of the plant has been assigned based on CAMP workshop study in 1998; thus requiring a thorough recent revision (IUCN 2015). Future exploration in suitable areas to discover new populations may be an integral part for review of the distribution range and population status, threats to the habitats, and other associated parameters (Santos et al. 2006; Papes and Gaubert 2007; Brito et al. 2009).

## 5. CONCLUSION

Modeling of a data deficient endemic taxa is tried with the ensemble approach and pseudo-absence (pa) selection and the results highlight the varied nature of ensemble outputs despite having good statistical performances. Similarly, pa selection also requires attention as it changes with the algorithm, reiteration requirement, and mechanism of selection.

Differences in output based on these parameters emphasize the importance of multiple and/or ensemble modeling approach in species centric conservation planning rather than over-confidence in a single map. Moreover, it is necessary to verify with the local experts on habitat oriented distribution of the species before finalizing the outcome of the model. This findings aid as a baseline information for further inventory/exploration program for fine tuning the modeling outcome apart from further exploration of occurrences . Moreover, the variation in modeling result also influences EOO estimation which requires careful interpretation of the outcome. However, the standard measurements of EOO and AOO focus on the reassessment of its current IUCN status which would not only update the species position but also help to formulate strategy for its management. Apart from species distribution potential, the outcome is important for habitat management too as distribution emphasizes on type or condition of the habitat. A critical evaluation of the habitat status in the distribution area will be more beneficial for longer survival strategy. More importantly, this exercise can further be extended to encompass the other Western Ghats biotic elements to generate precise information on endemic species distribution and their survival status in current scenario.

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