Water-Energy dynamics derives the plant species richness patterns in the major bio-geographic zones of India

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Abstract

Regional differences in climate variable affect patterns of plant species by modifying their niches. Thus, more robust research on plant species richness (SR) in response to various drivers is must for formalising suitable conservation measures. We have modelled the plant SR pattern of two major biogeographic zones i.e. Deccan Peninsula (DP) and Arid and Semi-arid (ASA) zone of India by testing various statistical models including generalised linear model (GLM), Random forest (RF), Generalised boosted model (GBM) and Support vector machine (SVM) to predict the SR of the zones using climatic variables. Water variables (combination of minimum and maximum precipitation) played dominant role in deriving SR in DP zone explaining significantly 15% to 51% of correlation respectively. In contrast, ASA zone showed an influence of energy (temperature; bio7) and water variables (average precipitation; bio 13 and bio 14) explaining correlation of 54% to 80% respectively in combination. The dominant role of water over energy variables in warmer climates at lower latitudes supports the climate tolerance hypothesis (CTH) resulting the high species richness of Eastern Ghats in DP zone. However, low species richness in the ASA zone was attributed to the lower ranges of precipitation and higher ranges of temperature variables showing significant correlation with species richness.

Keywords: Species Richness, Biogeographic zone, India, modeling

1. Introduction

Climate has gained topical recognition as a determinant of species patterns along various spatial and temporal scales (Kreft & Jetz, 2007). Studies have shown that high species richness is associated to greater water-energy availability (Clarke, 2007; Currie, 2007). Water plays an indispensible role in plant photosynthesis for nutrient transport and their metabolism (Nobel, 2009). Energy on the other hand in the form of temperature, radiation and productivity also determines species richness (Hawkins *et al*., 2003; Moser *et al*., 2005). In general, 50 to 70% of variations explained by climatic variables are self-explanatory in interpreting the role of climate in determining species richness patterns among bio-geographical zones (O'Brien, 1998). As a consequence of changing climate, the changes in plant species richness might take place in three axes: spatial, temporal and self (Bellard *et al*, 2012). Therefore, it is critically needed to assess biodiversity w.r.t. climate variables by modelling to provide inputs to management planning for biodiversity conservation. Species modelling can be done following two different ways (i) Assemble first, predict later, corresponds to the modelling of species directly through statistical model to a set of predictors and (ii) predict first, assemble later corresponds to the modelling of individual species and then assembling them to recompose. Wide ranges of statistical models have been used to predict the distribution of plant species where non-parametric algorithms such as generalised linear model (GLM), generalised additive model (GAM), Random forest (RF), support vector machine (SVM) and generalised boosted model (GBM) have gained considerable attention. These models are flexible and free from presumption of any given probability distribution and the fact that the observations are assumed to be independent of each other therefore, describe non-linear dependencies (Sironen *et al*., 2010). In the present study we have modelled the plant species richness of two biogeographic zones of India given by Rodgers and Panwar (1988) using different statistical models i.e GLM, RF, GBM, SVM. The main objective of our study was to test the water and energy influence on species richness patterns of the two zones.

2. Materials and Methods

2.1 Study area

India, a large country with a total geographical area of nearly 329 million hectares, lies to the north of the equator, between latitudes 6˚ E 44΄ N and 35˚ E 30΄ N and longitudes 68˚E 70΄ E and 97˚E 25΄E. The present work was carried out for two major biogeographic zones of India i.e. Deccan Peninsula and Arid & Semi-Arid Zone. Deccan peninsula zone is the most extensive zone with an area of c.a. 1400000 km2 in the country with deciduous vegetation type and have greater biological species richness in the hill ranges of Eastern Ghats. Arid and Semi-arid zones together contribute to an overall area of c.a. 7,50000 km2 and are characterized by dry climatic conditions owing to low rainfall (400- 1000 mm) and have dry deciduous and thorn forests as major vegetation types.

2.2 Species data

The species richness data collected through the project 'Indian National-Level Biodiversity Characterization at

Landscape Level' (Roy *et al.*, 2012a) was used. In this project, 15,565 nested quadrats of area 0.04 ha (20×20 m) were laid in 100 vegetation types across the length and breadth of the country, wherein 7642 and 2728 unique quadrats fall in the Deccan Peninsula and arid & Semi-arid zone respectively. The sites were selected on the basis of stratified random sampling (Roy *et al.*, 2012a; Fig. 1). Quadrat level data were aggregated at 1˚ grids to assess sampling sufficiency by Tripathi *et al.*, (2017). We used only the sufficiently sampled grids in species richness modelling.

2.3 Climate data

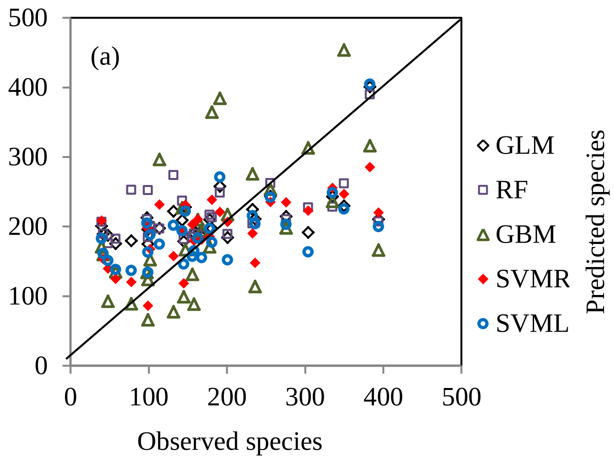
Bioclim climate data including all the 19 explanatory variables was downloaded from http://www.worldclim.org/bioclim site. Prior to modelling a collinearity analysis was carried out in R version 3.1.2 using Corrplot package. We considered two variables to be collinear when they are strongly correlated (r > 0.7), and excluded one of them from the regression analyses. Model accuracy was evaluated by splitting the data into 70% and 30% to be used in training and validating the models respectively.

3. Results

The efficacy of the models was assessed by plotting modeled species richness against observed distributions of species richness for each model (Fig. 1). Results showed a good predictive ability for observed distribution for the two zones. All the possible combinations of variables were tried in the two zones and significant results (high correlation and low RMSE) only are displayed in table. An influence of water and energy variable was dominant in both the zones showing a good agreement with the observed data. Individual performance of variables and model between the zones did vary. SVM model came out as a best model in predicting species richness at Deccan Peninsula zone while GBM performed better over other models at Arid & Semi-Arid zone leading to high correlation and low RMSE.The zone wise statistical results for validation are briefly discussed below.

3.1 Deccan Peninsula

A total of 92 grids were observed to be sufficiently sampled in the zone (Tripathi *et al.*, 2017). Out of which 64 grids were used for training and 28 for validation purpose.



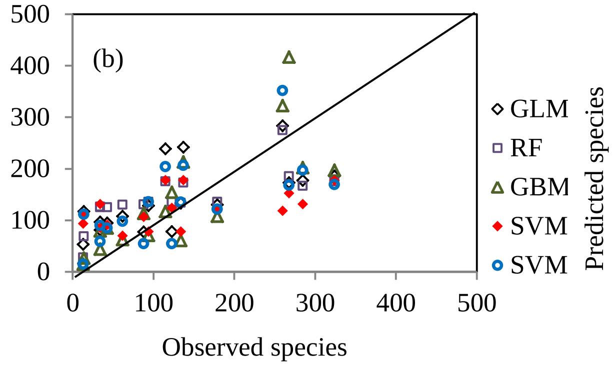


Fig.1. 1:1 line plot between observed and modeled species richness for different models (a) Deccan Peninsula (bio10+bio14+bio19) (b) Arid & Semi-Arid zone (bio 7+ bio 13+ bio 14)

Deccan Peninsula showed a dominant impact of water variables (bio14 and bio 19) showing a combined correlation coefficient (r) of 0.15 for GBM to 0.51 for SVML for observed vs. simulated species. Among water variables precipitation of driest month (bio14) and precipitation of coldest quarter (bio19) played significant role. No temperature variable could explain more than 25% of agreement individually. However, Mean Temperature of Warmest Quarter (b10) in combination with other variables enhanced the correlation showing significant influence. Water and energy (bio14, bio19 and bio 10) as a whole could explain an agreement of 0.37 to 0.53 for RF and SVMR respectively. This correlation was enhanced to 0.59 to 0.66 for GLM and GBM respectively with an addition of heterogeneity (TRI) and disturbance (HII) variable, showing a significant decrease in RMSE (table).

3.2 Arid and Semi-Arid Zone

A total of 59 grids were observed to be sufficiently sampled in the zone (Tripathi *et al.*, 2017). Out of which 41 grids were used for training and 18 for validation purpose. A combined influence of water and energy was dominant in the zone. Precipitation of wettest and driest month (bio13&bio14) was significant in explaining an agreement of more than 40%. Temperature annual range (bio7) individually showed more than 20% of agreement for linear models i.e. GLM and SVML however, this agreement was more than 40% for non-linear models i.e. RF, GBM and SVMR. Correlation enhanced to more than 50% for a combination of both the water (precipitation) and energy (temperature) variables for each model which significantly dropped the RMSE (Table 1).

4. Discussion

The dominant role of water variables in warmer climates at lower latitudes supports the climate tolerance hypothesis (CTH) resulting the high species richness of Eastern Ghats of Deccan peninsula (Hawkins *et al.*, 2003). A favourable micro-climate (higher temperature and ample precipitation along with a rugged terrain) allows a wide range of functional strategies in this regions allowing moderate to high species richness. A range of bio14 is higher in Deccan Peninsula zone where already the energy demand (bio10) is ample. In contrast, Arid & Semi-arid zone showed lower ranges of bio14 with very high annual ranges of energy variable (bio7). The stimulus of precipitation variables is

Table 1: Statistical results displaying the performance of different variables

	Deccan Peninsula									
	GLM		**RF**		**GBM**		**SVMR**		**SVML**	
	r	**RMSE**	**r**	**RMSE**	**r**	**RMSE**	**r**	**RMSE**	**r**	**RMSE**
B10	0.10	111.76	0.15	112.82	0.10	151.11	0.26	98.51	0.12	116.18
B14	0.40	101.79	0.08	119.17	0.18	126.95	0.24	99.89	0.42	94.65
B19	0.43	97.61	0.42	97.45	0.25	114.36	0.26	109.81	0.44	95.96
B10+B14+B19	0.48	93.22	0.37	101.62	0.44	111.10	0.53	84.91	0.51	86.25
Arid & Semi-Arid										
B7	0.21	97.21	0.66	77.06	0.53	95.42	0.41	88.95	0.23	96.20
B13	0.52	83.54	0.61	81.58	0.51	84.51	0.52	85.07	0.53	83.13
B14	0.41	102.38	0.52	90.40	0.66	79.00	0.58	79.69	0.46	93.90
B7+B13+B14	0.65	74.94	0.73	70.74	0.80	64.91	0.54	84.63	0.68	72.77

ecologically meaningful since high water and optimum temperature enhances the photosynthesis, leading to higher biological activities and so high species richness and vice versa. Various studies have observed precipitation to be the main driver of tropical plant and tree species (Holmgren & Poorter 2007, Wright 1992). Precipitation of driest month showed its influence in both the zones i.e. Deccan Peninsula and arid & Semi-Arid. This can be understood by the fact that minimum precipitation is a basic requirement for seed germination (Wilson and Witkowski, 1998). The available precipitation at and near soil surface is critical for desert plants and is dependent on the balance between input from precipitation and losses from evapo-transpiration. In addition, large fluctuations in temperature ranges lead the plants to adjust their physiological status within a short time. This exaggerates the effect of climate harshness resulting in lower soil moisture and therefore, lowers species richness in arid and semi-arid zone. This study has emphasized the influence of climate variables especially temperature and precipitation on species richness patterns of two biogeographic zones of India using various statistical models. However, various other environmental and anthropogenic variables need to be integrated to understand climate– species richness relationships better.

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